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FRAUNHOFER INSTITUTE FOR ELECTRONIC NANO SYSTEMS ENAS

ANNUAL REPORT 2012

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Figure on front page: High-speed image showing a self-sustaining exothermic reaction in integrated reactive and nanoscale material systems used for 150 mm reactive wafer bonding of glass and silicon at room temperature (see page 70).

PREFACE

Dear friends and partners of the Fraunhofer Institute for Electronic Nano Systems,
dear readers,

already Albert Einstein pointed out: “Problems can never be solved applying the same way of thinking, which caused them.” Based on innovative approaches and ideas, on our staff’s commitment and creativity we could solve many industrial and scientific problems in close collaboration with our partners. For that reason we were able to increase our third-party funds as well as the number of projects also in 2012.

Metallization and interconnect systems for micro and nanoelectronics, the development of high-precision sensors and actuators, polymer based sensors, printed functionalities and integration technologies as well as their transfer to industry, material and reliability research for microelectronics as well as microsystem technology and especially smart systems for different applications belong to the topics of Fraunhofer ENAS.

Smart systems are defined as more or less autonomous miniaturized devices that incorporate functions of sensing, actuation, analyses, communication and control. In that sense they are predictive, they have the capability to decide and help to decide as well as to interact with the environment. Examples for such smart systems are devices for monitoring the physical and mental condition of vehicle drivers as well as the autonomous sensor network for power line monitoring which has been developed by Fraunhofer ENAS together with partners from the Chemnitz University of Technology, the Fraunhofer IZM, from industry and the energy provider enviaM.

The institute’s success is rooted in the minds of its employees and their knowledge of details and relationships, products, technologies and processes. In 2012 our first own apprentices finished their vocational training successfully. In cooperation with the Chemnitz University of Technology and the University of Paderborn students and young scientists have successfully defended their thesis. Some of them belong now to our staff.

The building of Fraunhofer ENAS, which had been inaugurated in 2009, has become too small. Together with 3D-Micromac AG we rent offices and laboratories within the neighboring microFLEX-Center in 2012. Together we will work on the development of microtechnologies on flexible substrates.

VORWORT

Liebe Freunde und Partner des Fraunhofer-Instituts für Elektronische Nanosysteme,
sehr geehrte Leserinnen und Leser,

bereits Albert Einstein meinte: „Probleme kann man niemals mit der gleichen Denkweise lösen, durch die sie entstanden sind.“ Dank innovativer Ansätze und Ideen, Kreativität und Leistungsbereitschaft meiner Mitarbeiterinnen und Mitarbeiter ist es uns auch 2012 gelungen, zahlreiche industrielle und wissenschaftliche Fragestellungen konstruktiv und gemeinsam mit unseren Partnern zu lösen. Das widerspiegelt sich sowohl in einem steigenden Ertrag an Drittmitteln im Vergleich zum Vorjahr als auch in der deutlich steigenden Zahl der bearbeiteten Projekte.

Unser Themenspektrum reicht von Arbeiten im Bereich der Metallisierungs- und Interconnectsysteme für die Mikro- und Nanoelektronik, über die Entwicklung von hochpräzisen bzw. polymerbasierten Sensoren, gedruckten Funktionalitäten sowie Integrationstechnologien und deren industriellen Überführung, die Material- und Zuverlässigkeitsforschung für die Mikroelektronik und Mikrosystemtechnik bis hin zu intelligenten Systemen für verschiedene Anwendungen.

Smart Systems sind mehr oder weniger autonome, miniaturisierte Systeme, die sensorische, aktuatorische, analytische, kommunikative und Steuerfunktionen enthalten. In diesem Sinn sind sie vorhersagend und haben die Möglichkeit zu entscheiden, bei der Entscheidungsfindung zu helfen sowie mit der Umwelt zu interagieren. Beispiele für derartige Systeme sind Fahrerüberwachungssysteme oder auch das seitens Fraunhofer ENAS gemeinsam mit dem Fraunhofer IZM, der TU Chemnitz, Industriepartnern und dem Anwender enviaM entwickelte autonome Sensornetzwerk zur Überwachung der Auslastung von Hochspannungsleitungen.

Der Erfolg eines jeden Unternehmens und auch jeder Forschungseinrichtung steckt in den Köpfen der Beschäftigten, ihrem Wissen über Details und Zusammenhänge, Produkte, Technologien und Verfahren. 2012 schlossen unsere ersten Azubis erfolgreich ihre Ausbildung ab. In Kooperation mit der TU Chemnitz und der Universität Paderborn haben Studentinnen und Studenten sowie junge Wissenschaftlerinnen und Wissenschaftler ihre Graduierungsarbeiten erfolgreich verteidigt. Einige von ihnen verstärken jetzt unser Team.

Das 2009 eingeweihte Gebäude von Fraunhofer ENAS in Chemnitz wurde bereits wieder zu klein. Gemeinsam mit der 3D-Micromac AG mieteten wir uns 2012 im benachbarten microFLEX-Center ein und werden die Arbeiten in Richtung Entwicklung von Mikrotechnologien auf flexiblen Substraten vorantreiben.

Also in 2012 the strategic alliance between the Fraunhofer Institute for Electronic Nano Systems and the Center for Microtechnologies of the Chemnitz University of Technology ensured strong synergies in technology and device development.

Fraunhofer ENAS and the Center for Microtechnologies work together within in the excellence clusters „Merge Technologies for Multifunctional Lightweight Structures – MERGE“ of the Chemnitz University of Technology and „Center for Advancing Electronics Dresden – cfAED“ of the TU Dresden. Both clusters have been granted within the excellence initiative of the federation and countries.

Fraunhofer ENAS works international. It cooperates very actively within in the European platform for smart systems integration EPoSS and is a member of groups, networks and alliances. Our representatives in Japan, China and Brazil support our international activities. In September 2012 we could look back on 10 years of successful work of our office in Shanghai.

In 2012 the Fraunhofer Project Center "NEMS / MEMS Devices and Manufacturing Technologies at Tohoku University" had been established at Tohoku University Sendai Japan. It is the first project center of the Fraunhofer-Gesellschaft in Japan. The basic science together with excellent scientists at Tohoku University, the exchange of scientific results and the development of new applications as well as patents belong to the main objectives of the project center.

Today, we look with happiness and pride on what we have achieved. However, it also serves as an incentive to keep up the competent and reliable service for our project partners and customers.

Based on our retrospection to 2012, I want to invite you to reflect and to think ahead. In our capacity as a research institution of Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., research and development for industrial applications belong to our prime and natural concerns also in 2013.

Director of the Fraunhofer Institute for Electronic Nano Systems

Prof. Dr. Thomas Gessner

Auch 2012 sicherte insbesondere die strategische Allianz zwischen dem Fraunhofer-Institut für Elektronische Nanosysteme und dem Zentrum für Mikrotechnologien der Technischen Universität Chemnitz Synergien in der Technologie- und Systementwicklung.

Fraunhofer ENAS und das Zentrum für Mikrotechnologien arbeiten gemeinsam in den 2012 bewilligten Exzellenzclustern „Merge Technologies for Multifunctional Lightweight Structures – MERGE“ der Technischen Universität Chemnitz und „Center for Advancing Electronics Dresden – cfAED“ der Technischen Universität Dresden. Beide Cluster werden im Rahmen der Exzellenzinitiative des Bundes und der Länder gefördert.

Durch die Mitarbeit im Rahmen der Europäischen Plattform für Smart Systems Integration EPoSS, die Mitgliedschaft in Verbünden und Verbänden aber auch Repräsentanten in Japan, China und Brasilien ist das Fraunhofer ENAS international aufgestellt. Im September 2012 konnten wir auf 10 Jahre erfolgreiche Arbeit unseres Büros in Shanghai zurückblicken.

2012 wurde an der Tohoku University in Sendai das Fraunhofer Project Center "NEMS / MEMS Devices and Manufacturing Technologies at Tohoku University" etabliert. Es ist das erste Projektcenter der Fraunhofer-Gesellschaft in Japan. Zu den wesentlichen Zielstellungen gehören neben der Grundlagenforschung zusammen mit exzellenten Forschern der Tohoku Universität, der Austausch von wissenschaftlichen Ergebnissen und die Erarbeitung neuer Anwendungsfelder sowie Patentanmeldungen.

Wir blicken mit Stolz und Freude auf das Erreichte. Es ist uns aber ebenfalls Ansporn, unseren Projektpartnern und Auftraggebern auch in Zukunft kompetent und zuverlässig zur Seite zu stehen.

Mit unserem Jahresrückblick 2012 lade ich Sie zum Nach- und Vorausdenken ein. Als Einrichtung der Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. ist auch 2013 für uns Forschung und Entwicklung für industrielle Anwendungen ein selbstverständliches Anliegen.

Der Leiter des Fraunhofer-Instituts für Elektronische Nanosysteme

Prof. Dr. Thomas Geßner

FRAUNHOFER ENAS

SMART SYSTEMS INTEGRATION BY USING MICRO AND NANO TECHNOLOGIES

FRAUNHOFER-GESELLSCHAFT

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

www.fraunhofer.de

At present, the Fraunhofer-Gesellschaft maintains 66 institutes and independent research units. The majority of the more than 22,000 staff are qualified scientists and engineers, who work with an annual research budget of 1.9 billion euros. Of this sum, more than 1.6 billion euros is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German federal and Länder governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

Affiliated international research centers and representative offices provide contact with the regions of greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

The Fraunhofer-Gesellschaft is a recognized nonprofit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

DIE FRAUNHOFER-GESELLSCHAFT

Forschen für die Praxis ist die zentrale Aufgabe der Fraunhofer-Gesellschaft. Die 1949 gegründete Forschungsorganisation betreibt anwendungsorientierte Forschung zum Nutzen der Wirtschaft und zum Vorteil der Gesellschaft. Vertragspartner und Auftraggeber sind Industrie- und Dienstleistungsunternehmen sowie die öffentliche Hand.

www.fraunhofer.de

Die Fraunhofer-Gesellschaft betreibt in Deutschland derzeit 66 Institute und selbstständige Forschungseinrichtungen. Rund 22 000 Mitarbeiterinnen und Mitarbeiter, überwiegend mit natur- oder ingenieurwissenschaftlicher Ausbildung, erarbeiten das jährliche Forschungsvolumen von 1,9 Milliarden Euro. Davon fallen 1,6 Milliarden Euro auf den Leistungsbereich Vertragsforschung. Über 70 Prozent dieses Leistungsbereichs erwirtschaftet die Fraunhofer-Gesellschaft mit Aufträgen aus der Industrie und mit öffentlich finanzierten Forschungsprojekten. Knapp 30 Prozent werden von Bund und Ländern als Grundfinanzierung beigesteuert, damit die Institute Problemlösungen entwickeln können, die erst in fünf oder zehn Jahren für Wirtschaft und Gesellschaft aktuell werden.

Internationale Niederlassungen sorgen für Kontakt zu den wichtigsten gegenwärtigen und zukünftigen Wissenschafts- und Wirtschaftsräumen.

Mit ihrer klaren Ausrichtung auf die angewandte Forschung und ihrer Fokussierung auf zukunftsrelevante Schlüsseltechnologien spielt die Fraunhofer-Gesellschaft eine zentrale Rolle im Innovationsprozess Deutschlands und Europas. Die Wirkung der angewandten Forschung geht über den direkten Nutzen für die Kunden hinaus: Mit ihrer Forschungs- und Entwicklungsarbeit tragen die Fraunhofer-Institute zur Wettbewerbsfähigkeit der Region, Deutschlands und Europas bei. Sie fördern Innovationen, stärken die technologische Leistungsfähigkeit, verbessern die Akzeptanz moderner Technik und sorgen für Aus- und Weiterbildung des dringend benötigten wissenschaftlich-technischen Nachwuchses.

Ihren Mitarbeiterinnen und Mitarbeitern bietet die Fraunhofer-Gesellschaft die Möglichkeit zur fachlichen und persönlichen Entwicklung für anspruchsvolle Positionen in ihren Instituten, an Hochschulen, in Wirtschaft und Gesellschaft. Studierenden eröffnen sich aufgrund der praxisnahen Ausbildung und Erfahrung an Fraunhofer-Instituten hervorragende Einstiegs- und Entwicklungschancen in Unternehmen.

Namensgeber der als gemeinnützig anerkannten Fraunhofer-Gesellschaft ist der Münchner Gelehrte Joseph von Fraunhofer (1787–1826). Er war als Forscher, Erfinder und Unternehmer gleichermaßen erfolgreich.

FRAUNHOFER GROUP FOR MICROELECTRONICS

Fraunhofer ENAS belongs to the Fraunhofer Group for Microelectronics VµE since its foundation. VµE has been coordinating the activities of Fraunhofer Institutes working in the fields of microelectronics and microintegration since 1996. The Fraunhofer EMFT, ENAS, ESK, FHR, HHI, IAF, IIS, IISB, IMS, IPMS, ISIT, IZM and the guests Fraunhofer FOKUS, IDMT and IZFP-D belong to this Fraunhofer group. Its membership consists of twelve institutes as full members and three as associated members, with a total workforce of around 2900 and a combined budget of roughly 344 million euros.

The purpose of the Fraunhofer VµE is to scout for new trends in microelectronics technologies and applications and to integrate them in the strategic planning of the member institutes. It also engages in joint marketing and public relations work. Further activities of the group concentrate largely on establishing joint focal research groups and projects. In this way, the group is able to provide innovative small and medium-sized enterprises, in particular, with future-oriented research and application-oriented developments that will help them gain a decisive competitive edge.

There are four application-oriented business areas (Ambient Assisted Living & Health, Energy Efficiency, Mobility und Smart Living) and three cross-sectional business areas (Technology – from CMOS to Smart System Integration, Communication Technologies, Safety & Security).

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FRAUNHOFER-VERBUND MIKROELEKTRONIK

Das Fraunhofer ENAS ist seit der Gründung Mitglied im Fraunhofer-Verbund Mikroelektronik VµE. Dieser koordiniert seit 1996 die Aktivitäten der auf den Gebieten Mikroelektronik und Mikrointegration tätigen Fraunhofer-Institute. Zum Verbund gehören Fraunhofer EMFT, ENAS, ESK, FHR, HHI, IAF, IIS, IISB, IMS, IPMS, ISIT, IZM sowie als Gäste Fraunhofer FOKUS, IDMT und IZFP-D. Das sind zwölf Institute (und drei Gastinstitute) mit ca. 2900 Mitarbeiterinnen und Mitarbeitern. Das jährliche Budget beträgt etwa 344 Millionen Euro.

Die Aufgaben des Fraunhofer VµE bestehen im frühzeitigen Erkennen neuer Trends und deren Berücksichtigung bei der strategischen Weiterentwicklung der Verbundinstitute. Dazu kommen das gemeinsame Marketing und die Öffentlichkeitsarbeit. Weitere Arbeitsfelder sind die Entwicklung gemeinsamer Themenschwerpunkte und Projekte. So kann der Verbund insbesondere innovativen mittelständischen Unternehmen rechtzeitig zukunftsweisende Forschung und anwendungsorientierte Entwicklungen anbieten und damit entscheidend zu deren Wettbewerbsfähigkeit beitragen.

Die Kernkompetenzen der Mitgliedsinstitute werden in seinen Geschäftsfeldern gebündelt. Die Aktivitäten der Verbundinstitute unterteilen sich in drei Querschnittsgeschäftsfelder (Technology – from CMOS to Smart System Integration, Communication Technologies, Safety & Security) und vier anwendungsorientierte Geschäftsfelder Ambient Assisted Living & Health, Energy Efficiency, Mobility und Smart Living.

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FRAUNHOFER NANOTECHNOLOGY ALLIANCE

Since 2009 Fraunhofer ENAS belongs to the Fraunhofer Alliance Nanotechnology. There are 20 institutes cooperating in this alliance (Fraunhofer ENAS, IAO, IAP, ICT, IFAM, IFF, IGB, IISB, IKTS, ILT, IPA, ISC, ISE, ISI, ITEM, IVV, IWM, IWS, IZFP, LBF).

The activities of the Nanotechnology Alliance cover the whole R&D value chain starting from application-oriented research until industrial realization. This includes, e.g., multifunctional coatings for use in the optical, automotive and electronics industry, the design of special nanoparticles as fillers (carbon nanotubes, metals, oxides etc), nanocomposites, functional materials, e.g., for biomedical applications and CNT-based structural materials and actuators. The alliance also treats questions regarding toxicology and operational safety when dealing with nanoparticles.

Nanotechnology is a cross-section technology. A nanometer corresponds to a millionth of a millimeter. It is a discipline which offers more potential for innovative applications than any other, as special physical laws apply on the nano level. The optical, electrical or chemical properties of established materials can be altered completely by manipulation of the nano-structure.

The alliance focuses its activities on the following main topics:

- Nano biotechnology,
- Nano materials,
- Technology transfer and consulting,
- Nano processing/handling,
- Nano optics and electronics,
- Measuring methods/techniques .

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FRAUNHOFER-ALLIANZ NANOTECHNOLOGIE

Fraunhofer ENAS ist seit 2009 Mitglied der Fraunhofer-Allianz Nanotechnologie. Zur Allianz gehören 20 Fraunhofer-Institute (Fraunhofer ENAS, IAO, IAP, ICT, IFAM, IFF, IGB, IISB, IKTS, ILT, IPA, ISC, ISE, ISI, ITEM, IVV, IWM, IWS, IZFP, LBF).

Die Arbeiten der Fraunhofer-Allianz Nanotechnologie decken die gesamte Wertschöpfungskette von der anwendungsorientierten Forschung bis zur industriellen Umsetzung ab. Hierbei werden zum Beispiel multifunktionale Schichten für optische Anwendungen, den Automobilbau und die Elektroindustrie entwickelt. Metallische und oxidische Nanopartikel, Kohlenstoff-Nanoröhren und Nanokomposite werden in Aktuatoren, strukturellen Werkstoffen und biomedizinischen Anwendungen eingesetzt. Darüber hinaus beschäftigt sich die Fraunhofer-Allianz Nanotechnologie mit Fragen zur Toxizität und dem sicheren Umgang mit Nanopartikeln.

Nanotechnologie ist eine Querschnittstechnologie. Kaum eine andere Disziplin bietet mehr Potenzial für innovative Anwendungen, denn auf Nanoebene gelten besondere physikalische Gesetze. Durch Manipulation der Nanostruktur lassen sich die optischen, elektrischen oder chemischen Eigenschaften gängiger Materialien völlig verändern.

Die Allianz fokussiert die Aktivitäten auf die nachfolgend formulierten Leitthemen:

- Nanobiotechnologie,
- Nanomaterialien,
- Technologietransfer und Politikberatung,
- Prozesstechnik/Handhabung,
- Nanooptik und -elektronik,
- Messtechnik und -verfahren .

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FRAUNHOFER ENAS

The Fraunhofer Institute for Electronic Nano Systems ENAS is a reliable partner for research and development of innovative solutions. In the focus there are smart systems by using micro and nanotechnologies. Smart systems integrate not only components of different functionality, like sensors, actuators, biochips, batteries, passive and active electronic devices, they are able to capture and identify complex situations. They can decide something, interact with the surrounding, work energy autonomously and cross-linked.

The product and service portfolio of Fraunhofer ENAS covers high-precision sensors for industrial applications, sensor and actuator systems with control units and evaluation electronics, printed functionalities like antennas and batteries as well as material and reliability research for microelectronics and microsystem technology. The development, the design and the test of MEMS/NEMS, methods and technologies for their encapsulation and integration with electronics as well as metallization and interconnect systems for micro and nanoelectronics and 3D integration are especially in the focus of the work. Special attention is paid to security and reliability of components and systems.

The institute offers holistic and continuous research and development services from the idea to tested prototypes. In the case of smart systems single components as well as complete systems have been developed. Multidisciplinary approaches featuring devices for complex solutions and making use of shared and, increasingly, self-organizing resources are among the most ambitious challenges. With the working field smart systems integration Fraunhofer ENAS is able to support strongly the research and development of many small and medium size companies as well as large scale industry By integration smart systems in different applications Fraunhofer ENAS addresses semiconductor industry, medical engineering, mechanical engineering, automotive industry, logistics as well as aeronautics.

In order to focus the activities and to ensure a longterm scientific and economic success Fraunhofer ENAS has defined the three business units "Micro and Nano Systems", "Micro and Nanoelectronics / Back-End of Line" as well as "Green and Wireless Systems". They address different markets, different customers and moreover different stages of the value added chain depending on the required research and development services.

From the organization point of view Fraunhofer ENAS is subdivided into the departments Multi Device Integration, Micro Materials Center, Printed Functionalities, Back-End of Line, System Packaging, Advanced System Engineering and Administration. The headquarter of Fraunhofer ENAS is located in Chemnitz. The department Advanced System Engineering is working in Paderborn. The department Micro Materials Center has a project group working in Berlin-Adlershof.

FRAUNHOFER ENAS

Das Fraunhofer-Institut für Elektronische Nanosysteme ENAS ist ein zuverlässiger Forschungs- und Entwicklungspartner für innovative Lösungen. Im Fokus der Entwicklungen stehen intelligente Systeme, sogenannte Smart Systems, unter Nutzung von Mikro- und Nanotechnologien. Diese intelligenten Systeme integrieren nicht nur Komponenten unterschiedlicher Funktionalität, wie Sensoren, Aktoren, Biochips, Antennen, Batterien, passive und aktive Bauelemente, sondern sind in der Lage, komplexe Situationen zu erfassen und zu erkennen. Sie können Entscheidungen treffen, mit der Umwelt interagieren, arbeiten energieautonom und vernetzt.

Die Produkt- und Dienstleistungspalette reicht von hochgenauen Sensoren für die Industrie, Sensor- und Aktuatorsystemen mit Ansteuer- und Auswerteelektronik, über gedruckte Funktionalitäten (Antennen oder Batterien) bis hin zur Material- und Zuverlässigkeitsforschung für die Mikroelektronik und Mikrosystemtechnik. Im Fokus stehen die Entwicklung, das Design und der Test von MEMS/ NEMS, Methoden und Technologien zur deren Verkappung und zur Systemintegration, Metallisierungs- und Interconnectsysteme für die Mikro- und Nanoelektronik und die 3D-Integration, die Sicherheit und Zuverlässigkeit der Komponenten und Systeme.

Das Institut bietet einen ganzheitlichen und durchgängigen Forschungs- und Entwicklungsservice, von der Idee bis zum getesteten Prototyp. Fachübergreifende Herangehensweisen, die zu Systemen für komplexe Lösungen führen und verteilte sowie in zunehmenden Maße selbstorganisierende Ressourcen nutzen, gehören zu den anspruchsvollsten Herausforderungen. Mit der Ausrichtung auf die Smart Systems Integration ist das Fraunhofer ENAS in der Lage, sowohl KMUs als auch Großunternehmen zu unterstützen. Durch die Integration intelligenter Systeme in die verschiedenartigsten Anwendungen adressiert Fraunhofer ENAS die Halbleiterindustrie, die Luft- und Raumfahrt, den Automobilbau, die Logistik, die Medizin- und Prozesstechnik sowie den Maschinenbau.

Um die Aktivitäten des Fraunhofer ENAS zu fokussieren, wurden die Schwerpunkte im Technologieportfolio und in der Marktbearbeitung auf die drei Geschäftsfelder „Micro and Nano Systems", „Micro and Nanoelectronics / Back-End of Line" sowie „Green and Wireless Systems" gelegt. Jedes Geschäftsfeld verfügt über ein eigenes Kundenprofil, das in Abhängigkeit der benötigten Forschungs- und Entwicklungsleistungen verschiedene Stellen der industriellen Wertschöpfungsketten anspricht.

Organisatorisch ist Fraunhofer ENAS in die Abteilungen Multi Device Integration, Micro Materials Center, Printed Functionalities, Back-End of Line, System Packaging, Advanced System Engineering und Verwaltung gegliedert. Der Hauptstandort des Fraunhofer ENAS ist Chemnitz. Die Abteilung Advanced System Engineering ist in Paderborn angesiedelt. Die Abteilung Micro Materials Center hat eine Projektgruppe in Berlin-Adlershof.

BUSINESS UNITS

MICRO AND NANO SYSTEMS
MICRO AND NANOELECTRONICS / BEOL
GREEN AND WIRELESS SYSTEMS

BUSINESS UNITS OF FRAUNHOFER ENAS

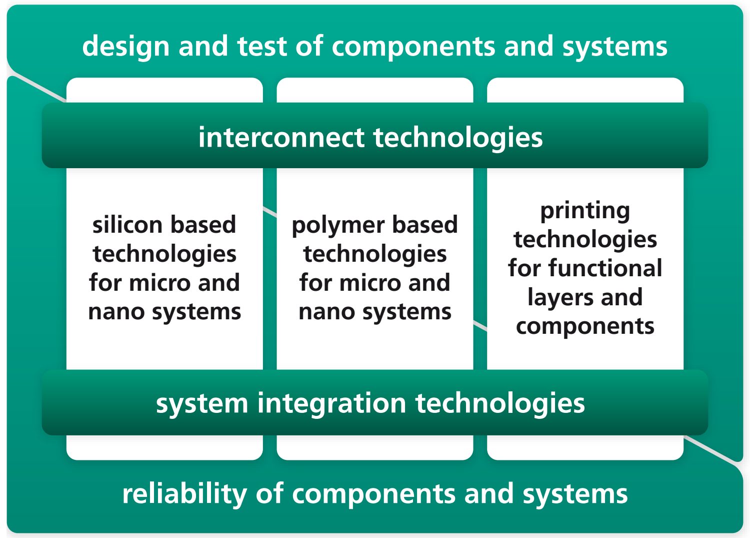
The Fraunhofer-Gesellschaft is one of the leading organizations for applied research in Germany, Europe and worldwide. The main task is to bring research and innovation into products. The successful implementation of research results requires a successful bridging.

The Fraunhofer ENAS works in the field of smart systems integration with the business units "Micro and Nano Systems", "Micro and Nanoelectronics / Back-End of Line" as well as "Green and Wireless Systems" Fraunhofer ENAS addresses different markets and different customers starting from SMEs up to large companies working in different branches. Application areas of the research and development results and/or prototypes of Fraunhofer ENAS are semiconductor industry, medical engineering, mechanical engineering, automotive industry, logistics as well as aeronautics.

Fraunhofer ENAS accesses on a broad variety of technologies and methods for smart systems integration. The core competences are an indicator for the specific technological know-how of the institute. Fraunhofer ENAS has defined seven core competences, which are the inner structure of the technology portfolio of Fraunhofer ENAS. These are:

- Design and Test of Components and Systems,
- Silicon Based Technologies for Micro and Nano Systems,
- Polymer Based Technologies for Micro and Nano Systems,
- Printing Technologies for Functional Layers and Components,
- Interconnect Technologies,
- System Integration Technologies,
- Reliability of Components and Systems.

The core competences "Silicon Based Technologies for Micro and Nano Systems", "Polymer Based Technologies for Micro and Nano Systems" as well as "Printing Technologies for Functional Layers and Components" are the technological basis for the development of components of micro and nano systems. "Interconnect Technologies" and "System Integration Technologies" are so-called cross-sectional technologies. They have a strong interaction with the other core competences via common projects. "Design and Test of Components and Systems" as well as "Reliability of Components and Systems" are supporting fields for the other technologies. They have a lot of interfaces to all other core competences. Moreover they also interact as, e.g., reliability issues have to be considered just in the design phase and vice versa simulations and lifetime predictions need to be supported and calibrated by measured data.



Based on these basic technologies, the cross-sectional technologies and methods for design, test and reliability Fraunhofer ENAS is able to process complete MEMS/NEMS and to integrate them into challenging smart systems. Selected examples are:

- Metamaterial based tunable Fabry-Perot filter,
- 3D integration of smart systems,
- Autonomous sensor network for power line monitoring.

The core competences are based on the know-how of the employees of the departments of Fraunhofer ENAS. It needs to be mentioned that each department contributes to different core competences.
Moreover the core competences are supported by the cooperation with our partners:

- Center for Microtechnologies ZfM of Chemnitz University of Technology,
- Chair Digital Printing and Imaging Technology of the Faculty of Mechanical Engineering of Chemnitz University of Technology,
- Chair Sensor Systems of the Faculty of Electrical Engineering of University Paderborn.

On the following pages the three business units will be described in detail. The description will be supported by the examples.

MICRO AND NANO SYSTEMS

The business unit "Micro and Nano Systems" includes all silicon based and polymer based micro and nano systems. According to markets and customers it is divided into the three parts "High-Performance MEMS/NEMS", "Polymer Based Low-Cost Systems" and "RF MEMS". The business unit bases on the core competences "Design and Test of Components and Systems", "Silicon Based Technologies for Micro and Nano Systems", "Polymer Based Technologies for Micro and Nano Systems", "System Integration Technologies" as well as "Reliability of Components and Systems".

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High-Performance MEMS/NEMS

"High-Performance MEMS/NEMS" includes the development of prototypes and system solutions of high-performance micro electromechanical systems (MEMS) and nano electromechanical systems (NEMS). The focus is on high-performance actuators for optical MEMS as well as on high-precision inertial sensors for industrial applications, navigation and medical application.

Fraunhofer ENAS provides services in:

- MEMS/NEMS design and modeling,
- System design and modeling,
- Technology development,
- Prototypes manufactured by basic and special technologies,
- MEMS/NEMS test,
- System test.

Polymer Based Low-Cost MEMS/NEMS

"Polymer Based Low-Cost MEMS/NEMS" addresses the integration of micro and nano sensor as well as actuator functionalities as integrative components of smart systems. Focus is on nanocomposite based sensors as well as material integrated actuators for polymeric microsystems. Different markets are addressed, such as industrial process monitoring, environmental monitoring, food and beverage analysis as well as human and veterinary diagnostics.

Related to nanocomposite based sensors industrial process monitoring is of strong interest. Thereby the sensors need to fulfill the following requirements:

- Cost-effective, large-area, high sensitive sensors,
- Integration of sensor principles which could not be integrated up to now (integrated condition monitoring),
- Components and systems for precise reliability monitoring,
- Cost reduction based on mass production.

Fraunhofer ENAS provides services in:

- Development of system integrated functionalities based on nanocomposites,
- Customer specific configuration of the nanocomposites for specific applications, e.g., in lightweight structures engineering,
- Condition monitoring based on cost-effective nanocomposite based sensors,
- Development of customer specific fully integrated sensor and actuator solutions,
- Joint developments with SMEs and industry in the field of molecular diagnostics and cell biology (lab-on-a-chip systems).

RF MEMS

"RF MEMS" comprises manufacturing of components for radio frequency applications, which electrical properties may vary based on implementation of micro mechanical components or which functionality is mainly determined by mechanical components. RF MEMS include RF MEMS switches and varactors, which will be able to substitute existing conventional products or enable new applications due to better electrical performance. The market of RF MEMS can be divided into two parts. Aeronautic applications, security and defence applications as well as measuring technique belong to the first category. Therefore components are required with extremely high demands on performance (at the threshold of the physical possibilities). This is the main market.

The second category is communication technique (stationary and mobile). Thereby the improvement of main properties is in the focus. These are power requirements, configuration as well as functionality. RF MEMS can be applied for instance as tunable filters. Using tunable components it is possible to ensure their functionality at different frequencies and standards without constructing parallel signal paths.

The following topics are in the focus:

- Concepts and developments of RF MEMS,
- Development of technologies for manufacturing and integration of RF MEMS,
- Prototypes and small series.

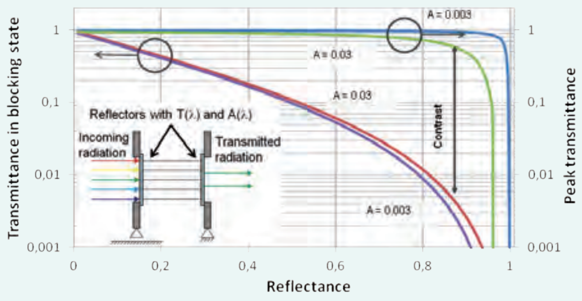

Fig. 1: Transmittance in the blocking state and peak transmittance of a FPI as dependency of reflectance and absorbance of the reflectors. Principle of FPI (inset).

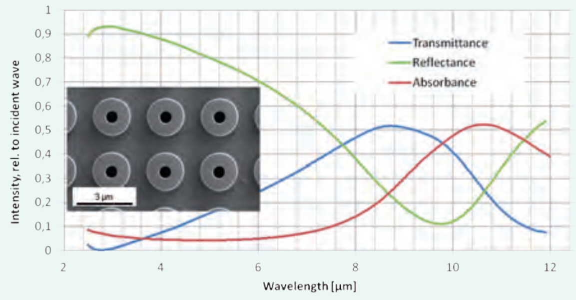

Fig. 2: Transmittance, reflectance and absorbance of an array of ring resonators (simulation result). Al ring resonators forming the reflector (inset).

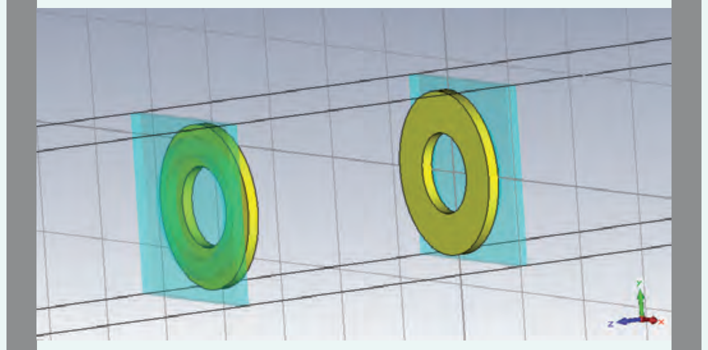

Fig. 3: Schematic view of the model for FDTD simulation.

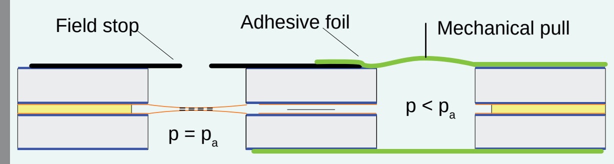

Fig. 4: Cross sectional view of the samples that are prepared for FTIR measurement.

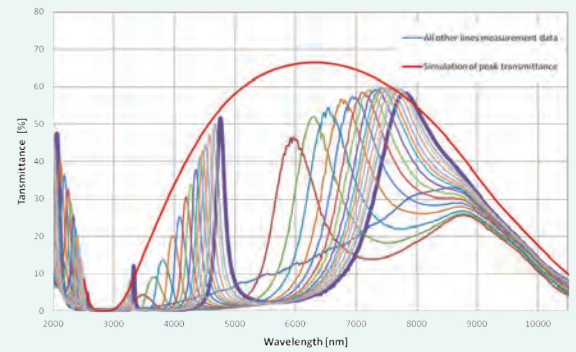

Fig. 5: Results of transmittance measurement and maximum peak transmittance (calculated values).

TOWARDS METAMATERIAL BASED TUNABLE INFRARED FILTERS MADE BY NANOSTRUCTURING

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Introduction

Infrared spectrum analysis of substances and gases by extremely small and lightweight spectrometers is a very time-saving and cost-effective method. Micromachined tunable infrared filters based on the Fabry-Pérot interferometer (FPI) principle are suitable candidates for becoming the key components of such systems. Distributed Bragg Reflectors (DBRs) are applied for the reflectors in most cases. However, they lead to higher complexity of the fabrication procedure. Moreover, the DBR layers cause mechanical stress in the structure that may lead to bending of the reflectors, to temperature dependent variation and to drift of the characteristics when stress relaxation happens. The aim of this work is to avoid the above mentioned difficulties and to evaluate the application of metamaterial based reflectors for tunable infrared filters based on the FPI principle. This report is particularly focusing on the simulation of the characteristic of the FPI in a wide wavelength range including the influence of absorption and on the experimental proof of the theory.

Design and analysis of metamaterial based FPI

A FPI consists of two parallel reflector surfaces with a distance *d* that enclose a cavity, so that an optical resonator is formed in between the reflectors, Fig. 1. The optical resonator gains the field strength of radiation with the wavelength λ that meets the resonance condition. In general, the situation is mathematically described by the Airy function.

$$T(\lambda)=T_{pk}\Big/\left[1+\frac{4R}{(1-R)^2}\sin^2\left(\frac{2\pi n d\cos\theta}{\lambda}-\phi(\lambda)\right)\right] \qquad (1)$$

with the peak transmittance

$$T_{pk}=\left(1-\frac{A}{1-R}\right)^2 \qquad (2)$$

and with the reflectance of the reflectors *R* and its absorbance *A*.

Fig. 1 shows the peak transmittance and the transmittance in the blocking state as a function of reflectance and of absorbance. It is clearly visible that in case of very low absorbance ($A < 0.003$), a FPI with a reflectance in the range of $R = 0.85 \ldots 0.98$ shows very good peak transmittance and blocking. Properly designed dielectric layer reflection stacks show excellent reflectance and low absorbance. In case of the application of subwavelength structures, it is important to consider the absorbance when designing them. Moderate absorbance (e.g., $A = 0.03$) leads to significantly reduced peak transmittance and contrast.

Modeling and simulation by FDTD method

In order to achieve suitable reflectors, the approach of ring resonators is followed because of the relatively broad reflectance spectrum and the insensitivity regarding the polarization angle of the radiation. For the numerical analysis of the optical properties of the structure, the Finite Difference Time Domain (FDTD) method was applied using the CST Microwave Studio software. A tetrahedral mesh and periodic boundary conditions (unit cell) were used in order to periodically virtual repeat the structure in two directions up to infinity using a grid angle of 90°. In a first step, the reflector was analyzed taking into account the specific conductivity of aluminum of 3.72 * 107 S/m and a refraction index and extinction coefficient of LP-CVD silicon nitride that have been measured in advance. Fig. 2 shows the reflectance, the transmittance and absorbance of the array.

To predict the transmittance of the FPI, we calculated the FPI transmittance in dependency of the gap between the resonators in a second step. Fig. 3 shows an appropriate model for FDTD simulation by CST software. The gap size *d* was varied during the simulation using a parameterized calculation run.

Fabrication of samples

The arrays of aluminum rings were fabricated on a 1 µm thick thermally grown silicon dioxide layer and 0.2 µm thick LP-CVD silicon nitride layer covering 300 µm thick double side polished 4'' silicon wafers by electron-beam lithography and dry etching. After etching of the silicon on the back side to a certain thickness, two wafers were bonded using a SU-8 adhesion layer face to face. The SU-8 film defines the gap between the aluminum ring resonator arrays. After wafer bonding, the remaining silicon is etched by a second etching step from both sides subsequently. In order to achieve a pressure compensation between the cavity and the outside space and for testing of the FPI by applying a pressure for membrane deflection, each optically active cavity is connected to a neighboring "dummy" cavity without reflecting structures by a fluidic channel in the SU-8 between both wafers, Fig. 4. The silicon nitride thin films in the neighboring cavities have been mechanically removed before the optical tests were conducted to ensure that no pressure difference between the cavity and outside space deflects and warps the membranes. Moreover a pneumatic access to the inner volume for deflecting the membranes by pressure is provided.

For the transmittance measurement of the FPI, a pressure difference between the inner space and the ambience was applied to deflect the membrane and to achieve different resonator cavity lengths *d*. An adhesive foil that was attached to the both sides of the samples closes up the inner space, Fig. 4. Pulling the upper foil by a micromanipulator leads to decreased cavity length *d*.

Measurement results and discussion

Fig. 5 shows the measured transmittance of a FPI at different deflection states. The curve with highest wavelength (thick violett line) is taken with approximately 4.85 µm cavity width. The first order resonance occurs at 7.81 µm. The second order resonance occurs at a wavelength of 4.76 µm.

The curve of the theoretically predicted maximum peak transmittance (thick red line) of the FPI is included into Fig. 5 for a proof of the theory. One can state that two wavelength ranges with very poor transmittance of the FPI have been identified theoretically. The first is centered at 2.9 µm, the second is at wavelength higher than 10 µm. The measurement results are in very good agreement to the theoretic results.

Tuning the FPI to lower wavelengths by pulling the foil and applying a pressure difference between inner volume and ambient, the part of the membrane carrying the reflector becomes more and more bended. A high transmittance of the FPI can be achieved with appropriate dimensions of the elements. The absorbance is crucial and the transmittance must not be too low in order to achieve sufficiently high peak transmission. One can conclude that commonly used multilayer reflectors can be replaced by metamaterial based reflectors. A careful design considering the reflectors absorbance and transmittance is necessary in order to achieve a high performance in the desired wavelength range.

MICRO AND NANOELECTRONICS / BACK-END OF LINE

The business unit "Micro and Nanoelectronics / Back-End of Line" focuses on the following main fields of activity:

- Materials, processes, and technologies for advanced back-end of line schemes in micro and nanoelectronics,
- Process technology for 3D integrated micro and nano systems,
- Modeling and simulation of processes, equipments as well as complete interconnect systems,
- Characterization and reliability assessment, starting from BEOL components towards complete chip-package interactions including 3D integrated systems.

The Back-End of Line (BEOL) comprises all process steps starting from contact level till complete wafer processing prior to electrical testing (in other words: the entire interconnect system including passivation). Depending on the specific product (high performance / low power / generic), significant changes in the Back-End of Line have been implemented within the past years due to ongoing downscaling. While transistors become faster as their dimension shrink, the interconnect system is limiting this gain in speed, because its RC product rises. Thus, signal delay time increases. Appropriate materials can reduce resistance and capacitance of the interconnect system and consequently compensate for the losses. While the past decade was characterized by the introduction of copper and low-k dielectrics, future challenges require holistic approaches as well as novel concepts. In that context, 3-dimensional integrated ICs and microsystems are promising candidates to further increase integration density as well as extend functionality. Thus, interchip connections realized by Through Silicon Vias (TSV) are required and become part of the interconnect system. Beyond this, the later stacking concept needs to be considered because of its strong interaction with the interconnect system. At Fraunhofer ENAS close meshed interrelations between technology, material science, modeling and simulation, as well as characterization and reliability assessment have been established to cope today's and future challenges.

The business unit "Micro and Nanoelectronics / Back-End of Line" is mainly driven by the core competences "Interconnect Technologies" and "Reliability of Components and Systems". Moreover, additional input comes from the core competences "System Integration Technologies", "Silicon Based Technologies for Micro and Nano Systems" and "Design and Test of Components and Systems".

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Markets and branches – relevant to this business unit – can be derived from the value chain of integrated electronic devices:

- Materials, chemicals and consumables,
- Device fabrication and testing/equipment manufacturing,
- Integrated devices (ICs) and systems (SiPs).

Sorting the final products (ICs & SiPs) by application fields, the following further classification can be conducted:

- Consumer electronics and communication,
- Medical,
- Automotive,
- Aerospace and defense,
- Industrial and instrumentation.

Within the working fields materials, processes, technologies, and simulation, research and development are dedicated mainly to consumer electronics and communication. Thereby, emphasis is on leading edge CMOS technologies with highly efficient and low parasitic interconnects. Within the working field reliability, almost all application areas are addressed.

Fraunhofer ENAS offers services in research, development and wafer processing specific to markets and branches.
Device manufacturers:

- Process development, process control methodology and methods,
- Process integration issues,
- Analytics and reliability assessment,
- Simulation and modeling.

Equipment manufacturers:

- Process development and optimization dedicated to specific equipment,
- Process and equipment simulation and modeling.

Chemical and material manufacturers:

- Evaluation, screening and development of chemicals and precursors,
- Analytics and characterization,
- Wafer processing and process optimization.

Further activities within the business unit are determined by the international semiconductor roadmap (ITRS) as well as by the global trends "Beyond CMOS" and "More than Moore". Within leading edge micro and nanoelectronics, emphasis will be on dielectrics as well as metallization and barriers, e.g.,:

- Integration of ultra low-k dielectric materials ($k = 2.0 – 2.4$), deposited by CVD or spin-on technologies,
- Alternative ultra low-k approaches, e.g., airgaps ($k < 1.3$),
- Ultrathin CVD and ALD barrier and seed layers,
- Self-forming barriers,
- Scaling of copper damascene metallization.

Beyond CMOS is characterized by new devices and materials, like carbon nanotube (CNT) FETs. Fraunhofer ENAS has started basic research in that field in close cooperation with the Center for Microtechnologies at Chemnitz University of Technology and the TU Dresden. Bringing this research to an application is an important goal for the upcoming years.

Various functionalities integrated in two and three dimensional systems earmark "More than Moore" approaches. Forwarding development of integration concepts and technologies specifically directed to inter-chip interconnections is a central research topic within that area. Moreover, integration of novel BEOL materials and processes in MEMS/NEMS applications is aimed for.

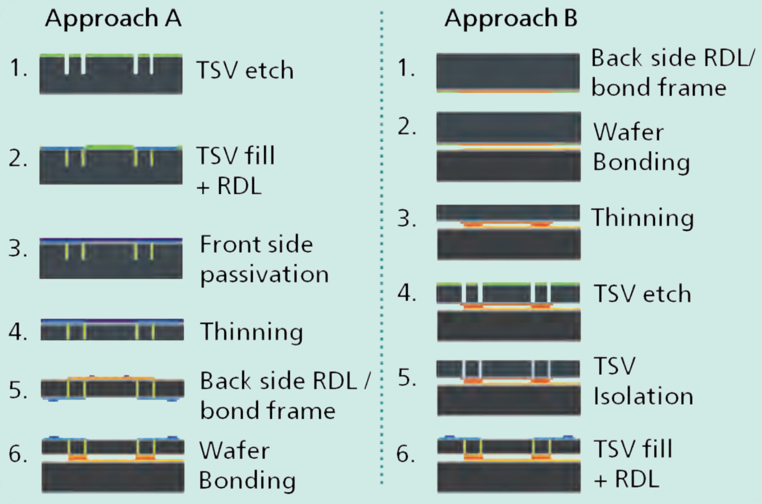

FIG. 1

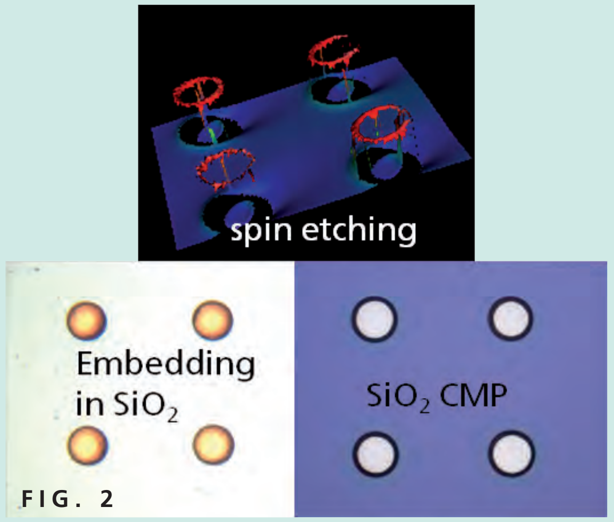

FIG. 2

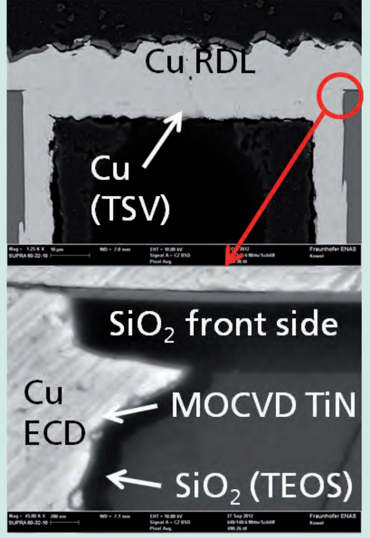

FIG. 3

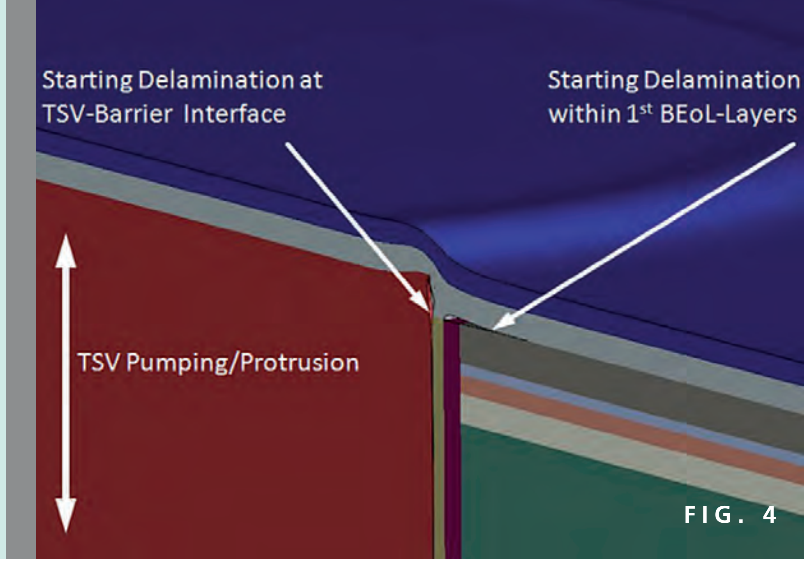

FIG. 4

3-DIMENSIONAL SMART SYSTEMS INTEGRATION – TECHNOLOGY DEVELOPMENT AND DESIGN FOR RELIABILITY

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Fraunhofer ENAS is developing solutions for 3-dimensional integrated smart systems. Compared to the fast evolving progress in microelectronics, 3D integration of MEMS represents a new quality of challenges. The implementation of complex functionalities (mechanics, optics, fluidics) comes along with the combination of various materials (silicon, dielectric, metal and polymer) as well as the realization of high aspect ratio (HAR) Through Silicon Vias (TSVs). Thereby each application has their specific requirements. Nevertheless, all 3D concepts require three major process modules: TSV fabrication, wafer thinning, and wafer bonding. Depending on the application these processes can be combined in different approaches, as shown in Fig. 1 (approach A: TSVs before bonding, approach B: TSVs after bonding).

At Fraunhofer ENAS the fabrication of HAR-TSVs starts with a deep reactive ion etching (DRIE) process using STS/SPTS tools. Varying etch parameters lead to the desired etch profile as required by subsequent processes. TSV insulation for approach A uses thermally grown oxide, whereas TEOS ozone with lower process temperatures is the choice when TSVs are implemented after wafer bonding. The type of TSV metallization (full/partial filling) strongly depends on the TSV dimensions (depth, AR) and on resulting TSV properties (mechanical stress). MO-CVD is applied to deposit highly conformal TiN based diffusion barriers and adhesion layers as well as Cu seed layers for the following electrochemical deposition of Cu.

Wafer thinning ensures the desired device thickness and helps to minimize external packaging size. It comprises a 2-step mechanical grinding (coarse and fine) followed by a wet or dry etching step in order to release the stress caused by grinding. Silicon thicknesses as low as 50 µm have been achieved using a Disco DAG 810 grinding tool. Final surface qualities after etching are in the range of a few nanometers (typical R_a = 4 nm). Chemical mechanical planarization (CMP) enhances the surface quality further (R_a = 0.2 nm for Si) as necessary for subsequent direct wafer bonding techniques.

Moreover, grinding, Si etching, and CMP are required for the TSV reveal in approach A, Fig. 2. Depending on the application the particular process flow (grinding/CMP or grinding/etching/CMP) may vary. Finally, the exposed Cu is connected using a back side redistribution layer (RDL) realized by PVD and ECD. A lower yield is observed due to TSV etch inhomogeneities that lead to non connected TSVs at the outer wafer diameter. For approach B nearly all TSVs could be connected to the front side RDL, Fig. 3.

Wafer bonding technologies for vertical stacking of wafers was used to realize the mechanical connection and stability as well as the electrical interconnection between each layer. One major requirements for 3D integration is low-temperature processing (below 400 °C), when CMOS chips will be integrated with sensor chips. When the electrical interconnect is implemented after the stacking (approach B) a broad range of bonding technologies like direct or anodic bonding but also polymer based bonding could be considered. Otherwise, when having TSVs applied as in approach A the process is limited to metal or polymer based technologies. Hereby, thermo compression bonding (Cu-Cu, Al-Al or Au-Au) was investigated for 3D integration as well as liquid phase bonding technologies like eutectic or SLID bonding.

Besides technological challenges, copper TSVs generate novel challenges for reliability analysis and prediction, i.e. to master multiple failure criteria for combined loading including residual stresses, interface delamination, cracking and fatigue. So, the thermal expansion mismatch between copper and silicon yields to stresses in silicon surrounding the TSVs which is influencing the electron mobility and as a result the transient behavior of transistors. Furthermore, pumping and protrusion of copper is a challenge for the RDL technologies already during manufacturing, Fig. 4. These effects depend highly on the temperature dependent elastic-plastic behavior of TSV copper and the residual stresses determined by the electro deposition chemistry and annealing conditions. That's why a combined simulative/experimental approach was pushed to extract the temperature to capture the residual stress state near the surface of TSVs.

The extracted properties were discussed and used accordingly to investigate the pumping and protrusion of copper TSVs during thermal cycling. Furthermore, the cracking and delamination risks caused by the elevated temperature variations during BEOL ILD deposition are investigated with the help of advanced fracture mechanics approaches (e-VCCT, CZM, X-FEM), in particular.

Acknowledgement

The authors thank Kashi Vishwanath Machani from GLOBALFOUNDRIES, Dresden as well as Kamal Karimanal and Chirag Shah from GLOBALFOUNDRIES, Sunnyvale (CA), USA, for the fruitful discussions and guiding through the technological challenges.

Fig. 1: Two exemplary technology approaches for 3D integration .

Fig. 2: TSV reveal in approach A.

Fig. 3: TSVs connected to front side RDL (approach B).

Fig. 4: Pumping and protrusion (ongoing during TC) of Cu TSVs during thermal loading.

GREEN AND WIRELESS SYSTEMS

According to the name the business unit "Green and Wireless Systems" aggregates all activities of Fraunhofer ENAS which belong to wireless, periodic data collection and/or monitoring to protect the environment (environmental monitoring), the state of objects (condition monitoring), and enabling energy systems. The business unit focuses on customer specific integration solutions for logistics and on system solutions for the condition monitoring based on MEMS/NEMS. It is divided into the two parts "Logistics" and "Smart Monitoring Systems".

Logistics

"Logistics" addresses the development and integration of components for manufacturing new smart labels, which autonomously and wirelessly transfer data, and to some extent energy sources with optimal quality at minimal production costs. They are used for instance in the automation of supply chains. Therefore application-specific antenna systems are designed and printed primary cells as well as wireless power supply systems based on near field coupling are developed. If necessary these customer specific products are produced at low cost with high throughput printing systems. Additionally a further focus is on the development of complex RF labels with integrated MEMS sensors for condition monitoring and data recording. Electronic components, that are necessary for the RF technology and sensor systems, are supplied by industrial partners.

In the field of application-specific antenna systems, the intention is to analyze the dielectric environment of the material to be marked during the lifetime in advance and to include these results in the design of the RFID solution. In addition, beyond printing as manufacturing technology work is carried out in the field of antenna design in the ultra high frequency (UHF) and super high frequency (SHF) range to achieve the highest level of electromagnetic compatibility.

In order to bring together printed elements with silicon based chips in terms of a hybrid solution there is a strong cooperation of the core competences "Printing Technologies for Functional Layers and Components", "Interconnect Technologies" and "System Integration Technologies" as well as with the business unit "Micro and Nanoelectronics / Back-End of Line".

This strategy targets at the growth market of packaging. Parallel to the activities of the pure packaging market, approaches are developed to integrate MEMS based sensors in nonrigid, thin and smart labels, which collect, store and process data measured. Such complex systems are used, e.g., for container labeling. They require an integrated, wireless power supply in addition to optimized dielectric antennas and sensor systems. For simple single-use applications, environmentally friendly primary batteries may be used, which are based on zinc-manganese dioxide and deliver voltages of 1.5 to 15 volts.

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Therefore, highly efficient production technologies are used based on printing processes. They will be further developed to inexpensively produce thin, flexible energy reservoirs in (almost) any form. Competitive advantages exist for the printed batteries last but not least from the in-house design and the existing infrastructure for their characterization and reliability testing.

Fraunhofer ENAS offers the following services:

- Antenna design and modeling,
- Prototype antenna manufacturing and metrological characterization,
- System design for energy supply by wireless near-field coupling,
- Integration of sensors/MEMS in smart labels,
- Development of assembling and packaging technologies of printed elements and silicon components,
- Adaptation of printing production technologies,
- Design and modeling of printed batteries and integration of these elements,
- Small batch production and metrological characterization of batteries.

Smart Monitoring Systems

"Smart Monitoring Systems" includes the development of system solutions for the condition monitoring using MEMS/NEMS based systems and optimized data analysis/communication. Main focus is the application of silicon based micro opto electromechanical systems MOEMS (transmission or reflection orders) in miniaturized spectrometers for gas analysis, environmental monitoring and medical applications. Today's customers are developers and users of IR detectors, spectrometers and analytical systems.

Smart monitoring systems for power line monitoring, applications for mechanical engineering and aviation are another aspect. For example they are relevant for active flow control systems, which are currently intensively studied since the airline industry calls for monitoring of components to meet the very high standards for certification. The condition monitoring of power lines aims at the optimization of the capacity utilization of energy transport while guarantee hazard free operation.

Current industrial trends in mechanical engineering and plant manufacturing address condition monitoring mainly to minimizing system failures. The implementation of sensors, electronics for signal conditioning, wireless signal transmission (necessary due to rotating parts) and self-sustaining power supply allows an autonomous and efficient operation of such systems for various applications. Examples are greece monitoring systems or the monitoring of seals.

The Fraunhofer ENAS offers the following services:

- System design and modeling,
- Technology development,
- Manufacturing of prototypes with specific technologies,
- System test,
- Development of applications.

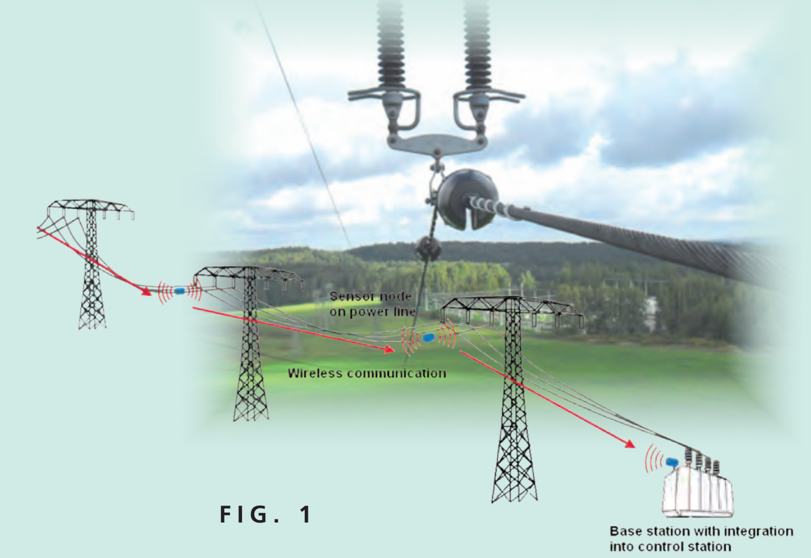

FIG. 1

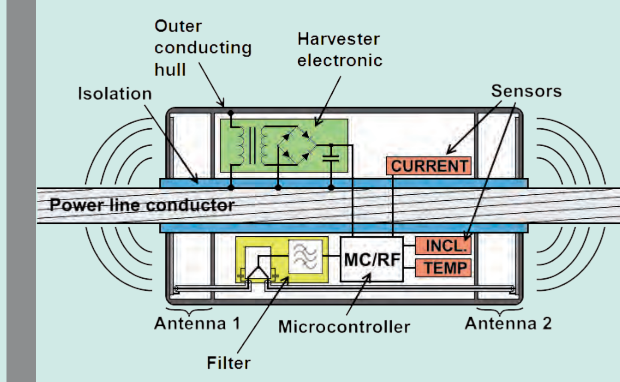

FIG. 2

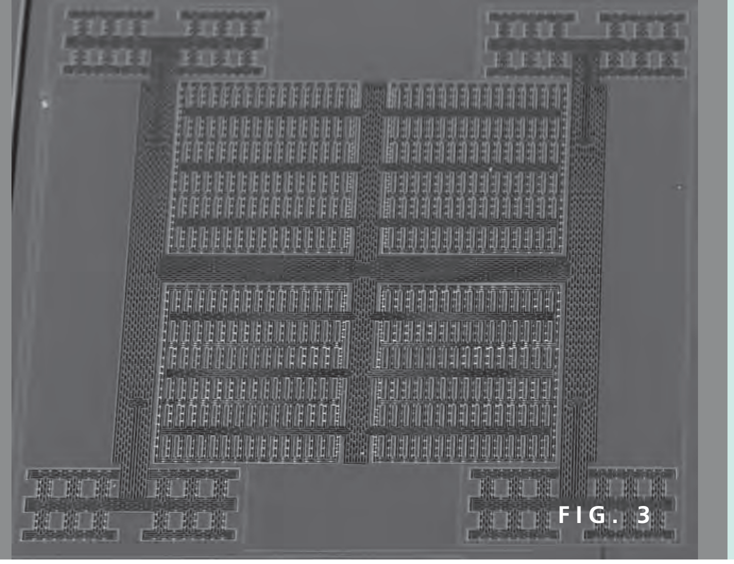

FIG. 3

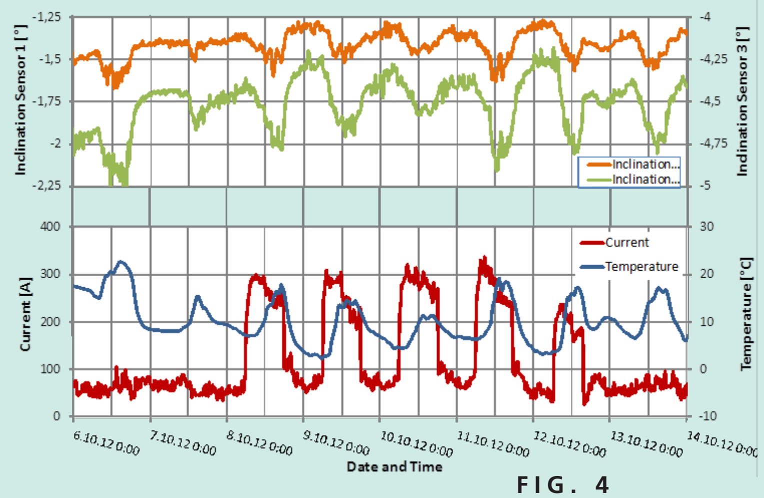

FIG. 4

AUTONOMOUS SENSOR NETWORK FOR POWER LINE MONITORING

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[1] Fraunhofer ENAS | [2] Chemnitz University of Technology | [3] MPD GmbH | [4] Fraunhofer IZM | [5] Mitteldeutsche Netzgesellschaft Strom mbH | [6] KE-Automation | [7] Unilab AG | [8] Amprion GmbH

Introduction

Because of increasing development of renewable energies as well as their fluctuating supply, the power distribution networks already reaching their load limits. A crucial point is the safety margin of minimum distance to ground and the maximum current that is defined for standardized worst case weather conditions. In order to consider the actual situation, one needs to know the actual sag of all critical sections. Fraunhofer ENAS developed together with Fraunhofer IZM, Chemnitz University of Technology, partners from industry and enviaM an energy self-sufficient sensor network that allows to monitor the sag of the lines and to optimize the utilization of the power lines.

Sensor network and sensor node

The sensor network consists of a large number of sensor nodes at intervals of a few hundred meters along a high-voltage power line. They collect the data about temperature, inclination as well as line current and send them to the neighboring nodes at regular time intervals. These data are passed along the chain, collected by a base station, and sent to the control station to the operator, see Fig. 1.

A sensor node consists of a microcontroller, a real-time clock, an electronic energy management, a 2.4 GHz transceiver, sensors for temperature, for current and for inclination of the conductor, two antennas combined with a power splitter and an antenna filter, Fig. 2. All components are housed in a conducting hull with rounded edges and a slot for easy mounting to the power line. As shown in [1] [2], the electrostatic fringing field is well suited as power source and used in this case. The sensor hull collects a certain amount of current from the fringing field between the power line and the ground.

To determine the inclination of the conductor, a two-axis precision capacitive MEMS sensor based on the Air Gap Insulated Microstructures (AIM) technology has been developed, Fig. 3. The probe mass of the sensor is deflected due to the earth's gravitational force. The primary sensor axis x determines the change of the angle of the power line nearby the isolator and characterizes the sag of the line which is related to the distance of the line to ground. The sensitivity of the inclination sensor and its temperature influence provide a resolution of 0.01°. Hence, a change of the conductor line length of 5 mm and a change of the sag of 22 mm can be resolved. The second sensor axis can be used to determine the oscillations of the power line.

For the communication to the neighboring nodes special designed antennas [3] are placed at both ends of the sensor nodes. The power splitter combines the signals from both antennas and is followed by a band-pass filter which attenuates distortion signals, in particular those generated from partial discharges at frequencies much lower than 500 MHz [4].

Characterization of the sensor network

The sensor system has been tested extensively on a 110 kV power line in field tests. Therefore the sensor nodes were mounted on a deactivated power line and subsequently operated under high voltage.

The current test period started September 2012 and is continued to 2013. Fig. 4 shows two measured sensor nodes and the correlation of temperature and measured current. The day-night variation of the temperature and the correlation of temperature and inclination are clearly visible in the data, Fig. 4. Higher temperature leads to higher negative inclination, and it is to be seen that the inclination sensor resolves the fluctuation much faster than the temperature sensor that has a certain measurement delay due to its thermal capacitance and limited thermal conductance between the temperature sensor and the power cable.

Outlook

In the field tests it has been proved that the concept of the sensor nodes and sensor network is suited for monitoring overhead power lines. Currently a field test is running over a time period of more than six months. Together with enviaM it is planned to extend these tests as long as this autonomous and energy self-sufficient sensor network allows to monitor the safety distance and to optimize the utilization of the power lines to reduce currently held short-term shutdowns of wind farms.

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Fig. 1: Sensor network with integration into control station and photograph of two mounted sensor nodes (inset).

Fig. 2: Scheme of the sensor node.

Fig. 3: SEM picture of the X-axis of the AIM sensor.

Fig. 4: Inclination, current and temperature variation of two sensor nodes during field test.

RESEARCH AND DEVELOPMENT SERVICES

In cooperation with the Chemnitz University of Technology, the University of Paderborn and partners, Fraunhofer ENAS offers the following research and development services:

Smart systems

- Optical systems:
  - Fabry-Pérot interferometer
  - NIR/MIR MEMS spectrometer
- Monitoring systems:
  - Power line monitoring system
  - Sensor system for engine condition monitoring
  - Grease sensor system
  - RFID label for transport monitoring
- Microfluidic systems:
  - Liquid based microfluidic systems – lab-on-a-chip
  - Gas based microfluidic systems
- Energy systems:
  - Printed batteries
  - Smart battery systems

Sensors

- High-precision silicon based sensors:
  - Gyroscopes
  - Acceleration sensors
  - Inclination sensors
  - Vibration sensors
- Polymer based sensors:
  - Humidity sensor
  - Quantum dot based system
  - Magnetic force / position sensors
- RF MEMS
- CNT based sensors

Technologies for microelectronics, smart systems and smart systems integration

- Silicon based technologies for MEMS/NEMS:
  - HAR technologies for high-precision MEMS (AIM, SCREAM, BDRIE)
  - Bulk technologies
  - Special technologies for RF MEMS and actuators
- Nonsilicon based technologies:
  - Printing technologies (sheet by sheet and R2R: inkjet, aerosol-jet, screen and gravure)
  - Polymer based technologies for micro and nano systems (structuring, rapid prototyping, channel sealing, ...)
- On-chip interconnects:
  - Copper metallization (barrier, seed, fill, CMP, ALD)
  - Low-k and ULK dielectrics (processes, integration)
  - Air gap structures (ultimate low-k solution)
  - Interconnects using carbon nanotubes (CNTs)
- System integration technologies:
  - Wafer bonding techniques (without and with interlayer, low-temperature bonding, usage of nanoscale effects, new materials)
  - 3D integration
- Interconnects in 3D integration (Through Silicon Vias [TSV], metallization):
  - Hybrid and vertical integration of MEMS/NEMS and electronics
- Basic technologies:
  - Surface modification (lithography, nano imprinting, CMP, ...)
  - Layer deposition (PVD, CVD, ECD, ALD, PLD ...)
  - Technology for spintronic sensors
  - Etching (wet and dry)
  - Laser micromachining (drilling, structuring, marking, …)

Design / modeling / analysis / test

- Design:
  - MEMS/NEMS
  - Design for reliability
  - Antenna design
- Modeling/simulation:
  - Process and equipment:
    - Deposition, patterning, planarization/CMP
    - Reactor, wafer and feature scale
  - Interconnect system:
    - Thermal and electrical simulation of deep submicron interconnection systems, dielectric reliability
    - Modeling of nano interconnects (resistivity of Cu nano interconnect, CNT based interconnect)
  - Stress fields for transistor performance improvement:
    - Impact of stressor films on strain in the channel
    - Geometrical and technological optimization
  - Modeling of nano materials and processes:
    - ALD, CNTs (contacts, functionalization)
  - Thermomechanical simulations
  - Reliablity and lifetime simulation
  - Crack and fracture modeling
- Analytics:
  - SEM
  - FIB
  - Profilometry
  - Antenna characterization, RF network and spectrum analysis
  - microDAC, nanoDAC, fibDAC techniques
  - micro Raman deformation and reliability analysis
  - Plasma diagnostics
- Test:
  - MEMS/NEMS
  - Micro mechanical tests
  - Lifetime
  - Local deformation tests
  - Micro and nanoreliability tests

DEPARTMENTS

PROFILES
HIGHLIGHTS
CURRENT RESEARCH RESULTS

DEPARTMENT MULTI DEVICE INTEGRATION

Head of Department: Prof. Dr. Thomas Otto

The strategic direction of the Multi Device Integration department is focused on the integration of MEMS and NEMS into functional modules and the development of MEMS and NEMS using silicon based and nonsilicon materials (nanocomposites, ceramics and polymers). In terms of smart systems integration, the department primarily combines the activities in the areas of:

- MEMS/NEMS design and electronics design,
- Micro optics,
- Fluidic integration,
- Nanocomposites,
- RF MEMS,
- Inertial sensors,
- Measurement, test and characterization,
- System integration.

The aim of the research is to develop and apply integration technologies taking account of different materials and components to provide products which are able to fulfill the users' needs under different conditions by means of smart systems integration. The necessary fundamental research to the above mentioned topics is supported by the essential collaborations in the Clusters of Excellence "Merge Technologies for Multifunctional Lightweight Structures – MERGE" and "Center for Advancing Electronics Dresden – cfaed".

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deputy director and head of department Multi Device Integration

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MEMS/NEMS design and development

Novel modeling and simulation techniques are essential for designing micro and nano electromechanical systems. Subsequent development processes require an understanding of the coupling of different physical domains at multiple levels. For this process, commercial and customized software tools are deployed for design, analysis and optimization of MEMS and NEMS. An effective linkage of these tools enhances the work of a design engineer to a great extend.
Coupled field analyses enable accurate predictions of MEMS and NEMS functional components and devices behavior. In consideration of process-induced geometric tolerances, the whole simulation chain is feasible. This includes the layout, process emulation, behavioral modeling of components with the help of the Finite Element Method (FEM) and model order reduction up to system design. The model of the device can be used to optimize the layout for a mask fabrication and the final device is ready for the test within a virtual development environment and for measurement purpose. Extracted values from parameter identification are used to improve further models for the optimization of, e.g., test structures, resonators or whole MEMS and NEMS devices.

The department has professional competence in:

- Modeling, multiphysics simulation, design and optimization of conventional MEMS and future-oriented NEMS,
- Application-oriented MEMS/NEMS conceptual, component, device and system design,
- Combination of numerical simulation and characterization methods for parameter identification,
- Development of simulation methodologies for multi-scale modeling of NEMS,
- Design of RF MEMS,
- Design of MOEMS and optical design,
- Mask design, layout and technology support.

For system development electronics plays a crucial role for the operation of sensors and actuators. Only the concentrated interplay can lead the individual elements to an overall optimal functioning system. The main points of the electronics development are analog and digital circuits and mixed signal, PCB layout and software programming.

Microoptics

The Fraunhofer ENAS develops microsystem based optomechanical setups and packages using a parameterized design, including thermal and mechanical simulations. Furthermore, the development of low-noise signal processing electronics is subject to these researches. Other priorities include testing and qualification on the component level as well as on the system level. Examples for the activities in the field of microoptics are the development and validation of infrared MEMS spectrometers and chemical sensors. Such systems can be configured for different wavelength bands and hence be used in various applications. Food studies, environmental, condition and process monitoring, medical diagnostics, metrology or the physical forensic analysis belong to the fields of application.

Fluidic integration and system technologies

Microfluidics has become an important tool for many applications, e.g., in the fields of medical diagnostics, health care, food- and environmental monitoring, chemical processing and consumer products. Microfluidic systems enable faster analyses, lower sample and reagent volumes, new methods of detection, advanced cooling mechanisms and the processing of macroscopically difficult to control chemical reactions. The integration of additional functionality into such microfluidic systems leads to smart, autonomous devices, reduces fluidic interfaces and requires less complex control and readout instrumentation. The competences include:

- Microfluidic modeling and system design,
- Fabrication of microfluidic devices in multiple materials such as polymers, glass and silicon,
- Integration of functionalities such as pumping, valving, temperature control and sensors into microfluidic systems,
- Sensors and actuators for active flow control,
- Microfluidic and thermal characterization.

Nanocomposites

As modern hybrid materials, nanocomposites combine polymeric matrices with nanoscale inclusions such as particles, fibers or tubes. Different functions are realized by different nano fillers, while the matrices ensure mechanical stability and electrical connection to the environment. In current work we deal with the development of humidity sensors, piezoresistive composite sensors for the detection of forces. Further semiconductor nanocrystals are used in nano sensors or in light-emitting systems. Polymer based nanocomposite systems are particularly suitable for material integrated functionalities, e.g., sensors in the field of condition monitoring. Currently we are developing layered systems in which semiconductor nanocrystals are embedded in various polymer matrices. The aim is to detect, for example, overloading of mechanical components, which then result in fluorescence intensity changes of the nanocrystals.

RF MEMS

The use of MEMS in microwave circuits as a replacement for conventional semiconductor devices can make a vital contribution to the optimization regarding DC power consumption and fidelity. The proprietary Air Gap Insulated Microstructure (AIM) process is now optimized for the use of high resistivity substrates and low-loss conductors. This leads to devices with very good RF performance. Due to their high-temperature stability, hermetic packaging technologies can be applied. The high quality of a hermetic chip scale package for frequencies over 60 GHz has been demonstrated.

High-performance inertial measurement

Inertial sensors are used to measure acceleration, vibration, inclination, shock and angular velocity. An advantage of the micro mechanical inertial sensors is that the manufacturing costs are much cheaper than for other mechanical or optical alternatives. The areas of application are industrial electronics, automotive, aviation, aerospace and medical technology. The main end products are navigation systems, stabilized antennas, condition monitoring systems for machinery, equipment and vehicles as well as medical monitoring devices.

Measurement, test and characterization

A method for the extremely fast determination of dimensional and material parameters based on a combination of the Finite Element Method (FEM) and the measurement of Eigenfrequencies has been developed in recent years and is now improved and adapted to different classes of MEMS devices. In fabrication sequence, the Eigenfrequencies are measured by optical vibration detection and electrostatic excitation of the sample by external optical transparent electrodes. A further step calculates the dimensions or material parameters by estimation algorithms, being performed in less than two seconds and at wafer-level. Amongst others, the following instrumentation is available:

- MEMS motion test stage including wafer probe station,
- Topography measurement instrumentation and white-light interferometer including stroboscopic illumination,
- RF MEMS test bench including wafer probe station up to 110 GHz.

Laser micromachining and laser bonding

With a very versatile laser workstation processes like bulk structuring, selective ablation of materials and laser welding can be carried out under clean room conditions. Using a picosecond laser source with four different wavelengths (1064 nm, 532 nm, 355 nm and 266 nm) a wide range of materials (polymers, metals, silicon, glass, ceramics) can be structured with a high-precision, short processing times and with an outstanding quality. The ablation process induces only very little heat to the ablation zone. Laser welding can be realized using an additional CW laser source, e.g., for medical and microfluidic applications. New designs are rapidly implemented through direct writing, that means no masks needed.

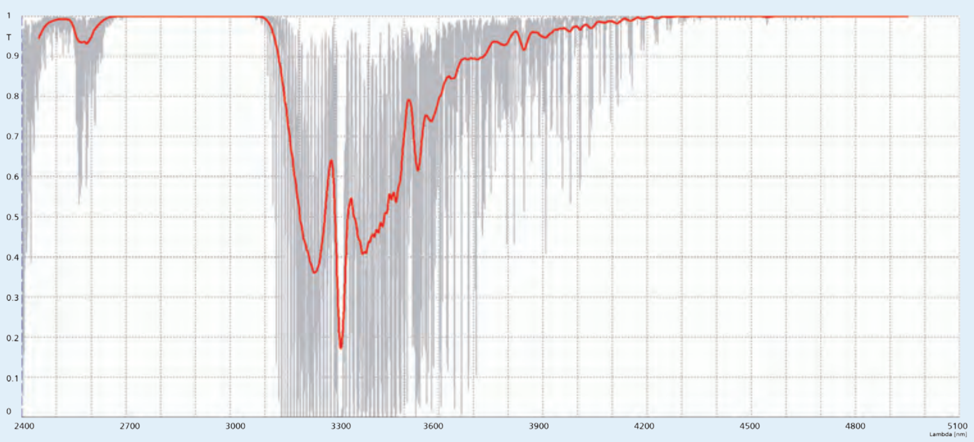

FIG. 1

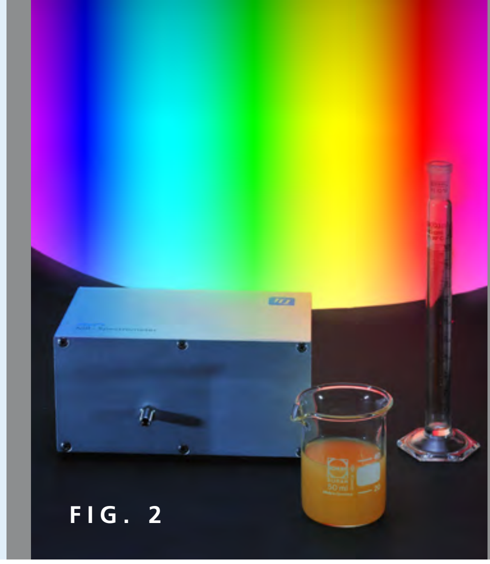

FIG. 2

COMPACT MEMS SPECTROMETER FOR THE INFRARED RANGE

Ray Saupe[1], Thomas Otto[1], Volker Stock[2]
[1] Fraunhofer ENAS | [2] TQ Systems GmbH

Mid infrared spectroscopy has been developed to a powerful and essential method of material analysis, with a steadily increasing number of industrial and scientific application fields. The so-called spectral fingerprint range enables identification of chemical compounds by their unique spectral pattern.

To provide a suitable miniaturized and portable MIR spectrometer solution at an affordable price, an existing NIR spectrometer module which already bases on microsystem technology has been expanded in its wavelength range.

The developed spectrometer belongs to the category of scanning grating spectrometers. Main component is a fast oscillating micro mirror which moves sinusoidal with high mechanical precision enabling a high stability of according wavelength axis. This is supported by a highly precise optical tracking of the actual motion. Mono-crystalline silicon guarantees a long-life operation with no wear even under harsh environmental conditions.

After entering the spectrometer through the entrance slit, the MIR radiation to be analyzed propagates toward a spherical mirror, which collimates the incident radiation and reflects it to the MEMS micro mirror. That radiation is reflected to a flat diffraction grating then, which divides it into its spectral components. According to the wavelength dependent reflection angle of the micro mirror, the desired component of diffracted light reaches an exit slit via another collimator. The following TE-cooled mercury cadmium telluride (MCT) single element detector assisted by low-noise transfer impedance amplifiers converts the monochrome radiation into electrical signals. With the help of integrated logic components a data pre-processing takes place, such as averaging, offset subtraction, detector transfer characteristic correction and noise shaping.

Due to the compact and flexible setup, the spectrometer is suitable for the use in various applications, such as process control in chemical industry, gas mixture analysis or liquid verification. The portability of the device opens up new application possibilities in mobile environment.

The industrial partner TQ Systems GmbH now offers a variety of spectrometer modules irSys M which cover 2300–3100 nm, 2400–3400 nm or 2450–4850 nm wavelength range with a spectral resolution of about 13–21 nm.

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Fraunhofer ENAS cooperates with:

Fig. 1: Transmission throuth CH_4 along 10 cm with 1 atm partial pressure.

Fig. 2: IR spectrometer.

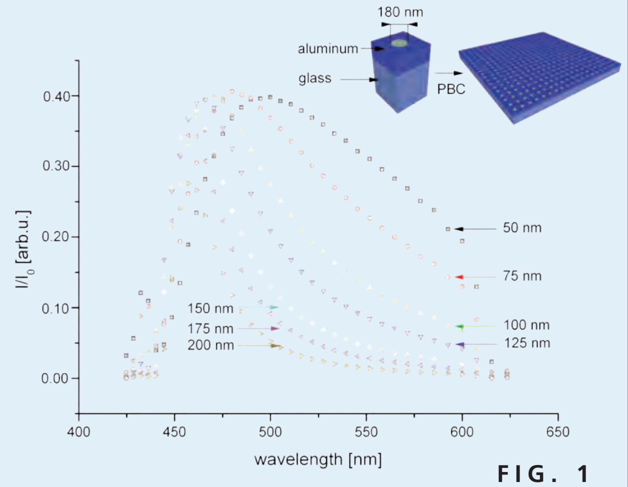

FIG. 1

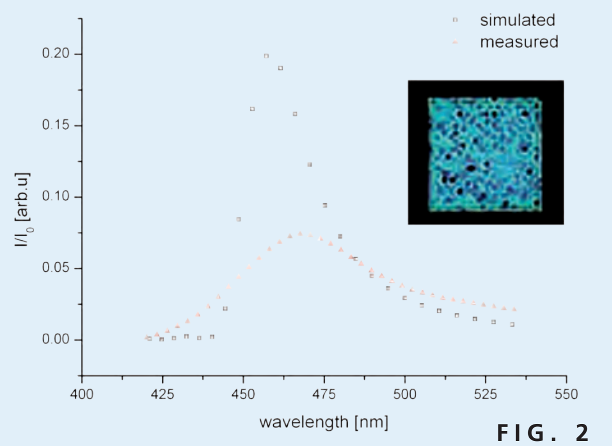

FIG. 2

OPTICAL AND NANOCOMPOSITE BASED SYSTEMS

Alexander Weiß, Thomas Otto

Driven by the demand of miniaturized and highly integrated functionalities in the area of photonics and photonic circuits, the metal or plasmon optics has become a promising method for manipulating light at the nanometer scale [1-3].
Especially the application of periodic subwavelength hole structures within an opaque metal film on a dielectric substrate holds many advantages for the realization of optical filters, since the variation of the hole diameter and the periodicity allows a selective filter response [4, 5]. In this report we describe the modeling, fabrication and characterization of a subwavelength hole array for surface plasmon enhanced transmission of light for the target structure with a hole diameter of 180 nm and a periodicity of 400 nm.
Practically, we used aluminum as guiding media. For that reason, numerical calculation regarding the transmission behavior versus layer thickness of the metal by finite difference time domain (FDTD) was done. As a guideline, the minimum metal thickness in the visible wavelength range should be the skin-depth multiplied by a factor of ten [4]. The thinner the layer is, the more radiation is allowed to pass. However, there is a minimum thickness at which a further reduction results only in a peak broadening, Fig. 1.
By using a double-molding technology via nano imprint lithography the fabrication of a subwavelength hole array with a peak wavelength of 470 nm and full width at half maximum of 50 nm from a silicon nanopillar master is demonstrated. For UV-NIL 6 inch glass wafers (Borofloat) with 100 nm sputtered aluminium were used as substrates to be patterned.
Fig. 2 illustrates the measured transmission of the nano imprinted structures compared to the simulated values showing a high correlation of the peak positions. The peak transmission of the nano imprinted structures shows a significant drop compared with the simulation results. It is assumed that after dry etching of the aluminum layer some residual aluminum still covers the nano holes. Nevertheless, the fabrication of the nano hole array by means of a double-molding technology via nano imprint lithography and its functionality could be shown.

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Fig. 1: Simulated transmission spectra for different aluminum layer thicknesses.

Fig. 2: Simulated vs. measured transmission of NIL structures. Inside: Bright field image of FIB structured reference hole array (by Max Planck Institute for Solid State Research, Stuttgart).

ACTUATORS FOR ACTIVE FLOW CONTROL

Martin Schüller, Mathias Lipowski, Eberhard Kaulfersch, Thomas Otto, Sven Rzepka, Bernd Michel

The Clean Sky program

Environmental friendliness of air traffic is of significant importance due to steadily rising passenger counts worldwide. On the one hand, air transport is a keystone to further economic growth but on the other hand it is facing all the global economic and ecological issues of today. Clean Sky, which combines the efforts of 86 organizations in 16 countries, will deliver demonstrators in all segments of civil air transport. Smart structures and integrated advanced low-noise solutions, innovative concepts for active flow and load control as well as green design, manufacturing, maintenance and recycling for airframe and systems will be demonstrated. Fraunhofer ENAS develops various fluidic actuators for active flow control which are compact, efficient and capable of being integrated.

Synthetic jet actuators

In the aviation industry synthetic jet actuators (SJA) are known for some years in the field of active flow control (AFC). A SJA is a resonant electroacoustic system in a compact design with low power consumption.

At an effectively net zero mass flow, it generates a pulse greater than zero. Important characteristics of the actuators are the resonance frequency, the exit velocity and the flow of volume or mass. A new concept developed by Fraunhofer ENAS implies the application of two membrane transducers into a Helmholtz resonator and increases the efficiency and output velocity vastly.

Pulsed jet actuators

Pulsed jet actuators (PJAs) pulse the airflow of an external pressure source to achieve high frequency and high velocity flow. In contrast to most of the known systems Fraunhofer ENAS investigates the usability of micro fabricated valves to switch the flow. These are directly integrated into an optimized chamber and controlled by sensors.

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figure (from left to right): Pulsed jet actuator, single-walled synthetic jet actuator, double-walled synthetic jet actuator, synthetic jet actuator integrated in wind tunnel model.

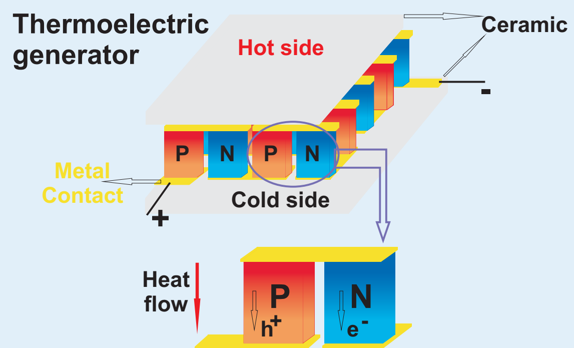

FIG. 1

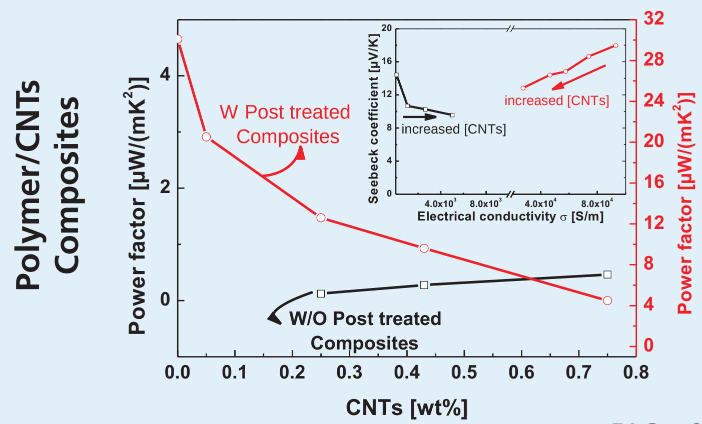

FIG. 2

ENERGY HARVESTING: POLYMER BASED MATERIALS FOR FLEXIBLE THERMOELECTRIC APPLICATIONS

Jinji Luo, Petra Streit, Detlef Billep, Thomas Otto, Thomas Gessner

Thermoelectric (TE) materials can be either used as a power generator to turn the waste heat into electricity or as a solid state Peltier cooler. The performance of TE materials is determined by a dimensionless quantity, the figure of merit (ZT). It is quantified $ZT = (\sigma S^2)/k$ (σ is the electrical conductivity, S is the Seebeck coefficient, k is the thermal conductivity and σS^2 represents the power factor).

Good TE materials are required to have a high power factor and low thermal conductivity. However, the conflicting combination among these three parameters imposes limitations on the optimization of ZT. Traditional semiconductor TE materials, e.g., Bi_2Te_3, have been widely studied and commercially developed for applications at room temperature. Despite of the high Seebeck coefficient and good electrical conductivity, these materials still face the challenge to decrease the thermal conductivity for high energy conversion efficiency. By controlling the transport of phonons and electrons, thin film TE materials with superlattice structure (p-type Bi_2Te_3/Sb_2Te_3), a ZT of ~2.4 is obtained at 300 K. However, these TE materials are generally prepared by high temperature and costly fabrication process. Moreover, the scarcity of rare earth material Te motivates for alternative TE materials. On the other hand, polymers with their low cost fabrication process, abundance and flexibility have been considered as potential applicants for TE materials. In addition, the intrinsic low thermal conductivity of polymers, which is usually one magnitude lower than that of the inorganic TE materials, and the high electrical conductivity make them becoming more suitable as TE materials. Nevertheless, polymer based TE materials still suffer from the much lower Seebeck coefficient than inorganic TE materials. There are generally three approaches to tune the TE properties of polymer materials: 1st inclusion of inorganic nanoparticles; 2nd accurate control of the oxidation level; 3rd secondary doping.

At Fraunhofer ENAS, we start from two approaches to improve the power factor of PEDOT:PSS.

- Inclusion of carbon nanotubes and combination with DMSO into PEDOT:PSS to achieve high power factor at minimum carbon nanotube loading,
- Application of environmental friendly solvent to enhance the TE properties.

Our work has demonstrated, the usage of a organic solvent leads to a high power factor 38.46 µW/(mK²), which is the highest one reported so far for PEDOT:PSS thin films.

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Fig. 1: Demonstration of thermoelectric generator.

Fig. 2: Thermoelectric properties of one composite.

DEPARTMENT
MICRO MATERIALS CENTER

Head of Department: Dr. Sven Rzepka and Prof. Dr. Bernd Michel

The competence and experience in the field of reliability research available at Fraunhofer ENAS has been the result of 25 years of industry related work. It started with studies on fracture and damage mechanics for lifetime estimations of big pressure vessels at the Institute of Mechanics. After founding the Micro Materials Center, these methodologies could be transferred and expanded into the field of electronics packaging during the 1990s and grown further into micro and nanotechnologies after the turn of the century. Becoming part of Fraunhofer ENAS, the logical next step has been made by comprehensively covering the needs of smart systems integration as well.

Today, the Micro Materials Center is able to assess and to evaluate the effects and interactions that lead to drift or degeneration of performance parameters and finally to the failure of the micro and nano systems. Strictly following the "physics of failure" approach, potential yield distracters as well as risks concerning reliability, safety and security of new technologies and products can be identified at the earliest time possible and lifetime models can be extracted. Being the result of direct cooperation, these findings directly support the development of new products and systems in industry (design for manufacturability and reliability). The ultimate goal of this effort is to fully optimize products based on numerical simulations avoiding all the time-consuming and expensive experiments prior to shipment qualification. This methodology of full "virtual prototyping" would create new system solutions at a fraction of current time and cost. Therefore, the results of the numerical simulations must be as accurate as real sample tests. Key to achieving this is a truly symbiotic alliance between simulation and experiment. Prof. Bernd Michel and the Micro Materials Center at Fraunhofer ENAS have pioneered this approach and continue leading its advancement.

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Competences

- Microreliability and nanoreliability of components, systems and devices
- Reliability for micro and nanotechnologies (clean micro and nanotechnologies)
- Thermomechanical reliability analysis
- Experiments and design for reliability of smart systems
- Crack avoidance strategies
- Reliability for avionics and space applications (JTI Clean Sky, ESA projects etc.)
- Microreliability for automotive electronics and smart sensor systems
- Reliability for batteries of electro automotive applications
- Solder reliability for micro nano interconnects
- Reliability for packaging in the micro/nano integration field
- Reliability for nanoelectronics and smart systems (3D integration, More than Moore)
- Physics of failure analysis, fatigue and creep analysis
- Design for manufacturability and reliability based on numerical methods fully calibrated and validated
- Virtual prototyping for minimum time to market in smart system product development
- Local deformation analysis (microDAC, nanoDAC, fibDAC, nanotom, Raman, EBSD, X-ray etc.)
- Analysis of internal stresses with highest spacial resolution (in MEMS, thin film stacks, BEOL structures etc.)

Advanced methods for reliability evaluation and risk management

- Local deformation analysis using various experimental techniques (e.g., FIB, nanotom etc.) combined with advanced simulation tools and lifetime prognosis (based on DIC digital image correlation strategies)
- Thermo-electric-mechanical characterization and modeling of organic, (nano) composite, and laminate materials covering viscoelastic, temperature, humidity and fatigue effects
- Crack and failure analytical methods
- Crack avoidance and crack detection methods for reliability and lifetime evaluation
- Complex loading and health monitoring techniques for combined testing (mechanical, thermal, vibration, humidity, diffusion, electrical fields)
- FibDAC, micro and nanoRaman as well as EBSD stress analysis

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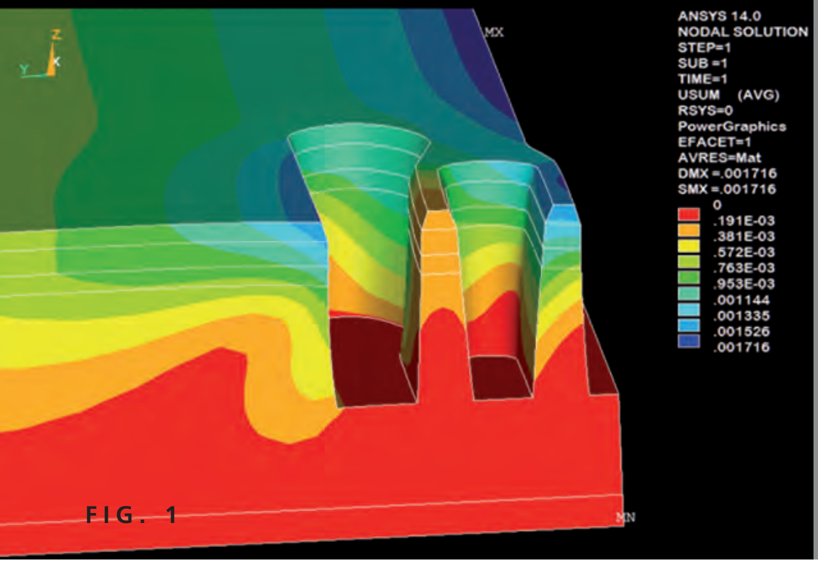
FIG. 1

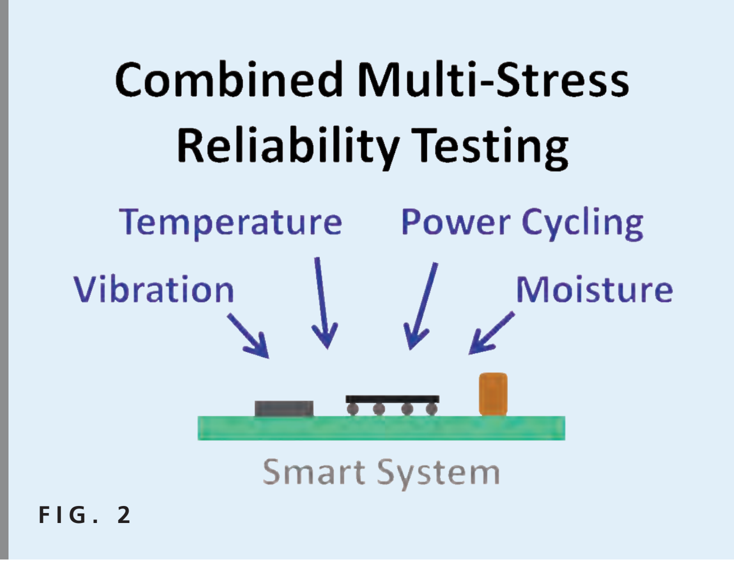

FIG. 2

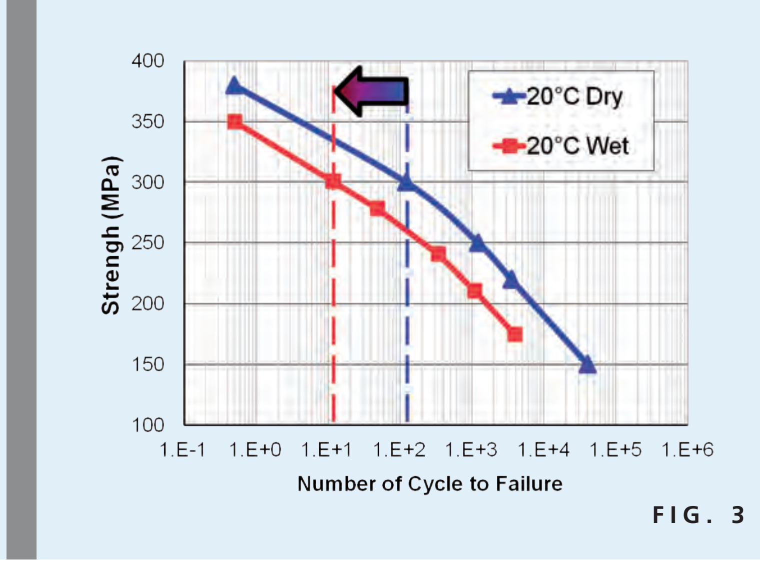

FIG. 3

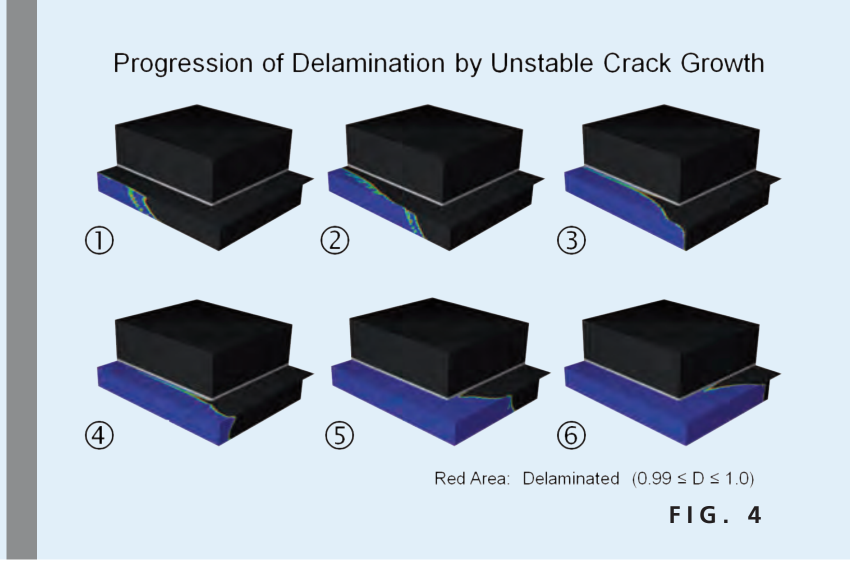

FIG. 4

RESEARCH HIGHLIGHTS

Sven Rzepka, Bernd Michel

Micro Materials Center has opened a new lab for active power cycle testing

In summer 2012, the Micro Materials Center has established a new lab dedicated to accelerated lifetime test of power electronics and smart systems by active power cycling (APC) techniques. The lab is located in the newly opened microFLEX center next to the building of Fraunhofer ENAS on the Smart Systems Campus. The APC lab offers facilities for electrical, thermal and mechanical cyclic tests. The electrical test bench consists of a cooled/heated sample stage (–55 °C … +200 °C), a powerful multi-channel current source (240 A, 6 kW), control and data acquisition hardware as well as tailored software for automated thermal-electrical probing. The mechanical test bench allows performing fatigue analyses exposing the specimen to forces up to 750 N in single shocks or ±1000 N in dynamic loads at frequencies up to 200 Hz within a wide range of environmental conditions (–70 °C … +350 °C, between 5 °C and 95 °C also at various levels of humidity).
This way, reliability and lifetime of power electronics and smart systems such as for electromobility and new energy systems can be assessed and new test methods can be developed.

Virtual prototyping helps improving yield in sub-30 nm technology

During high volume wafer processing, defective deformations of dielectrics patterns has been found in sub-30 nm BEOL stacks. They may cause incomplete metal fills that would subsequently lead to voids and early failures in the copper interconnects during test and service. The effect has been most obvious at transition regions to dense metal areas such as in double T structures. Furthermore, the conditions in the metal hard mask process turned out to also change the magnitude of the pattern deformation. Hence, the influence of local stresses built up in the BEOL stack during fabrication has been investigated in a parametric study using Finite Element Analyses (FEA) to discover the correlation between the TiN stresses and failure occurrence at various geometric representations.
As the result, the root cause of the pattern deformation could clearly be identified and effective counter measures have been developed. Process recommendations have been deduced for controlling the residual stress in the TiN mask. In addition, design guidelines considering geometric factors have been established for minimizing the pattern deformation below critical thresholds.
Applying virtual prototyping techniques, time-consuming intermediate experiments with expansive dedicated mask sets could be avoided. Instead, numerical simulation provided precise results that could easily be validated by real samples with the recommended final design. This way, FEA has been shown to allow effective BEOL stress engineering leading to improved yield and reliability of next generation interconnect systems in minimum development time.

Fig. 1: Deformation of sub-30 nm BEOL pattern due to thermal stress effects.

Fig. 2: Approach to new accelerated reliability test schemes.

New approach to system reliability testing for power electronics and smart systems

Current limitations of battery systems for fully electric vehicles are mainly related to performance, driving range, battery life, recharging time and price per unit. New cell chemistries, such as lithium sulfur (Li-S), would be able to mitigate these hurdles. However, these configurations are more prone to catastrophic failures due to a thermal runaway, i.e. to fire and explosion, than current solutions. Therefore, new and more advanced management strategies are necessary to be able to safely prevent the energy storage system from ever coming into this critical situation. A novel battery management system (BMS) architecture will be able to meet these high requirements. It expands the BMS from one centralized unit to a whole network of smart satellite systems to be located in each macro-cell or even in each individual cell. This way, the BMS can detect any abnormal magnitude of the parameters like temperature or cell pressure at earliest moment possible. This provides the lead time needed for safely preventing the critical situations as well as for always keeping the cells in optimum mode of operation. This boosts their lifetime and performance even further.
Besides the novel BMS functionalities, the issues of safety and reliability have to be addressed rigorously during the development of integration and packaging technologies. New high-temperature (≥ 300 °C) resistant joining materials have being introduced. They are required to ensure proper operation even in the unlikely case of failures. In the first phase of the project work, the challenge to Micro Materials Center has been to provide appropriate reliability tests. The planned top operational temperature even exceeds the usual maximum testing temperature. In response to that, new tests strategies have been developed, in which combine several types loads such as mechanical, thermal and electrical cycles simultaneously in order to allow accelerated yet realistic lifetime assessments.

Humidity effects on structural reliability of fiber reinforced polymers

Micro and nano functional systems like MEMS and smart systems are exposed to complex and very challenging service conditions (e.g., within airframe structures, in automotive applications under the hood, or within battery cells). Therefore, long-term reliability and structural integrity of the chassis and the printed wiring boards are of rising concern. These parts are often made of fiber reinforced polymer (FRP) laminates.
Recently, a new methodology for accelerated fatigue testing of FRP has been implemented at Micro Materials Center. It allows predicting the structural fatigue lifetime of FRP for arbitrary temperatures and loading ratios. However, it considers dry samples only. Hence, it does not suffice for comprehensive assessments of the micro/nano systems that were mentioned before.
Therefore, the testing methodology has been expanded. Choosing PCB material as typical example of a FRP structure in micro/nano and smart systems, the time/temperature shift functions

Fig. 3: Effect of moisture on the structural lifetime of fiber reinforced polymers.

Fig. 4: Realistic simulation of delamination effects in smart system packages.

have been determined for samples at various levels of humidity. Subsequently, constant strain rate and high cycle fatigue tests have been performed. A substantial decline in strength and fatigue lifetime has been seen in FRP structures as result of the moisture absorption. Determining the quantities and the correlation of this reduction in structural reliability has paved the way to a fatigue testing methodology, which also covers the humidity effects that unavoidably occur in outdoor and mobile applications.

Design for reliability of power packages based on 3D interface fracture mechanics

Interface delamination is one of the major sources of failure in smart systems integration technologies. It can occur at any interface between the dissimilar materials. In plastic power packages, thermal mismatches between die, mold compound and heat sink trigger combined shear and normal loadings. Delamination initiates when the interface adhesion threshold is exceeded. In addition, overstress failures may occur within the adjacent materials.
Theoretical evaluations of this type of failure by standard FE analyses are mostly limited. Applying strength of material approaches while the stresses tend to concentrate at interface corners and to form singularities, the well-known mesh dependence of the results occurs and jeopardizes the result accuracy. In addition, the highly nonlinear and time dependent nature of the stress situation increases the challenge further but needs to be considered because various material in the smart system just behave this way (silicon, organics, metals, solder).
Micro Materials Center has successfully implemented a new scheme of modeling these situations. It is based on 3D interface fracture mechanics, i.e., it models the damage progress directly. In the system under consideration, all interfaces are equipped with cohesive zone elements with the corresponding linear traction-separation properties assigned to them. Those properties have been determined by button shear tests prior to the numerical simulation. By means of an additional parametric study, different scenarios leading to specific adhesion properties could also be covered. This way, onset and propagation of the delamination could be computed in very close match to the experimental results. In addition, the numerical results are independent of the specific mesh configurations as required.
Applying this methodology to industrial samples, the sawing edge at the die and the interface between mold compound and heat sink could clearly been found as high risk areas. Delamination is very likely to be triggered when the critical fracture energy is lowered here. This may happen due to contamination or residues, which can easily be generated within the fabrication process. On the other hand, the simulation also showed the counter measure very clear. A simple cleaning step raises the fracture energy threshold to a level that should safely suppress the onset of any delamination.
This way, the new delamination modeling scheme has been shown as efficient tool for the design for reliability of power electronics modules.

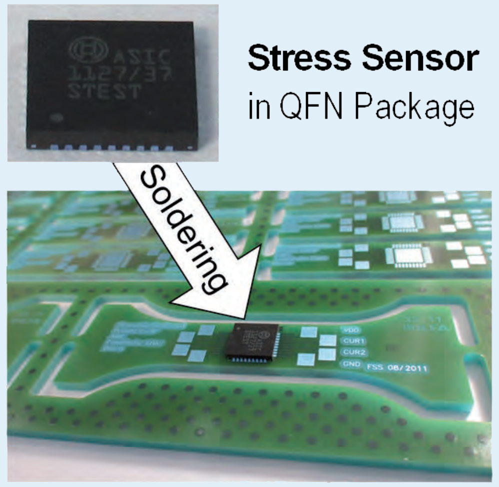

FIG. 1

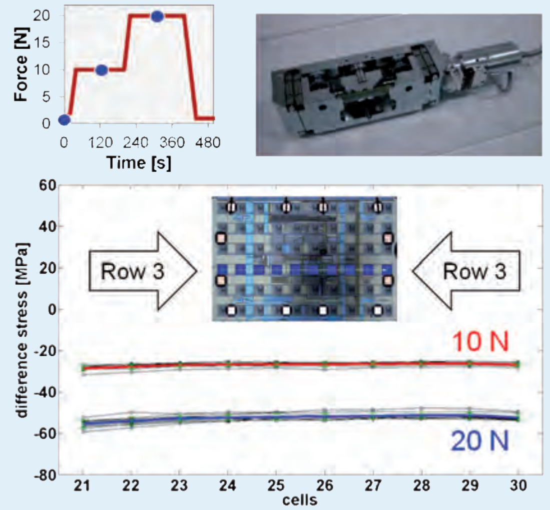

FIG. 2

STRESS CHIP MEASUREMENTS FOR PROCESS CHARACTERIZATION AND HEALTH MONITORING INSIDE SMART SYSTEM PACKAGES

Florian Schindler-Saefkow, Florian Rost, Alexander Otto, Wolfgang Faust, Bernhard Wunderle, Bernd Michel, Sven Rzepka

Introduction

Using dedicated daisy chain samples still is state-of-the-art in the qualification process of new packages for smart systems. However, broken joints only show the ultimate external effect. The root cause of the defect cannot be determined this way. Neither does the daisy chain resistance provide good information on the evolution of failure. Hence, time-consuming investigations have to be performed after the test to localize the actual failure site. In contrast to this, having access to the mechanical stresses occurring in the package throughout fabrication and tests would really help to track down the root cause easily.

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Stress sensing system

This report presents a stress sensing system, which was developed recently. It provides readings of all in-plane stress components at the die surface. The individual cells are arranged as 2D matrix with 300 µm pitch. The sensor cells are accompanied by signal conditioning, data storage and parallel/sequential conversion circuitry. The full system allows in-situ determination of the stress states before, during and after the assembly steps of new packages.

System validation

The stress chip is mounted in a QFN package and soldered to the PCB, Fig. 1. Bending tests were performed at room temperature imposing 10 N and 20 N onto a set of 10 samples. Fig. 2 shows the load profile, the testing stage and the readings of the x-y difference stress of each sample as well as on average. The typical pattern of a four point bending test is seen as the stress is almost constant along the entire row number 3 percent depicted in the graphs at the bottom of Fig. 2. The scatter in the stress results is also very low. The standard deviation in the set of samples is less than 0.9 MPa / 1.6 MPa (10 N / 20 N), which means a variance below

Fig. 1: Stress sensor test samples.

Fig. 2: Four point bending test: load profile, test stage, results.

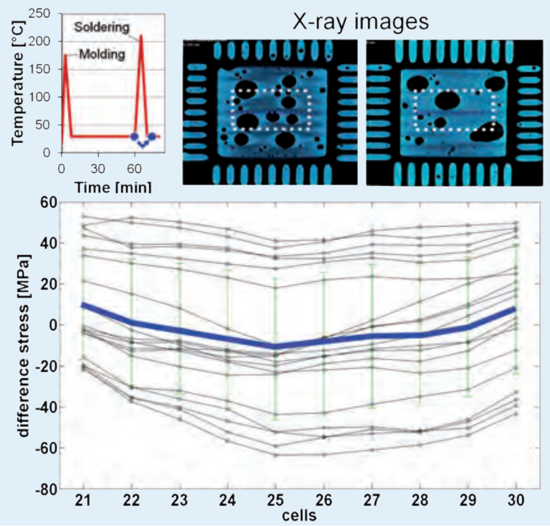


FIG. 3

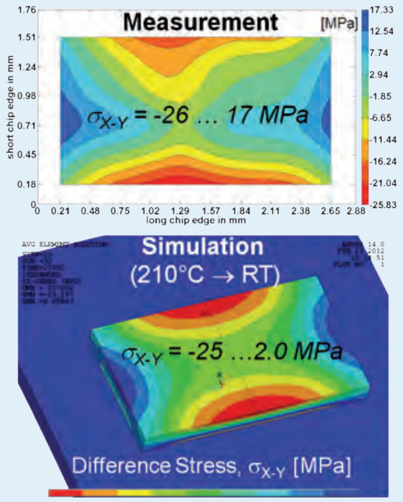


FIG. 4

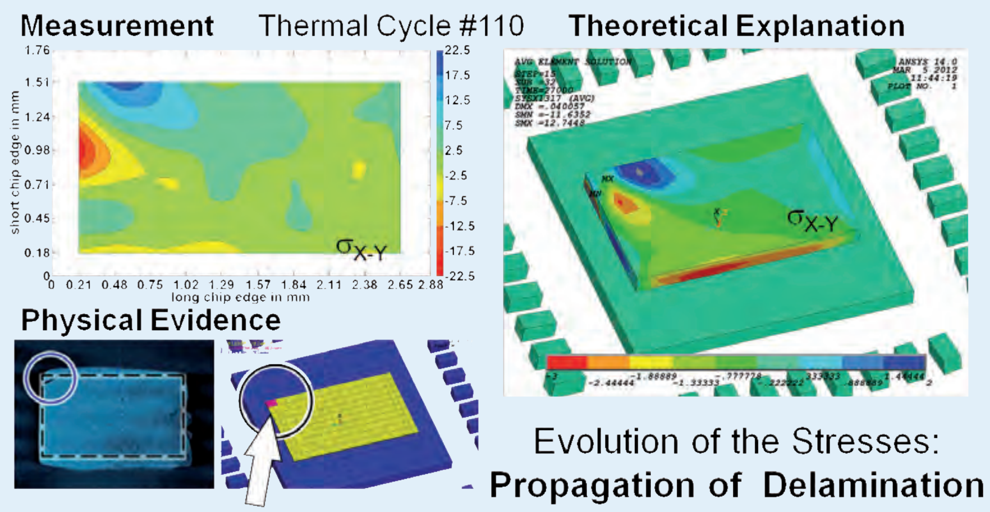


FIG. 5

3 percent. This high level of accuracy and reproducibility perfectly allows the use of the stress sensing system in practical investigations characterizing the internal situation of new packages for smart systems during fabrication and operation.

Process characterization

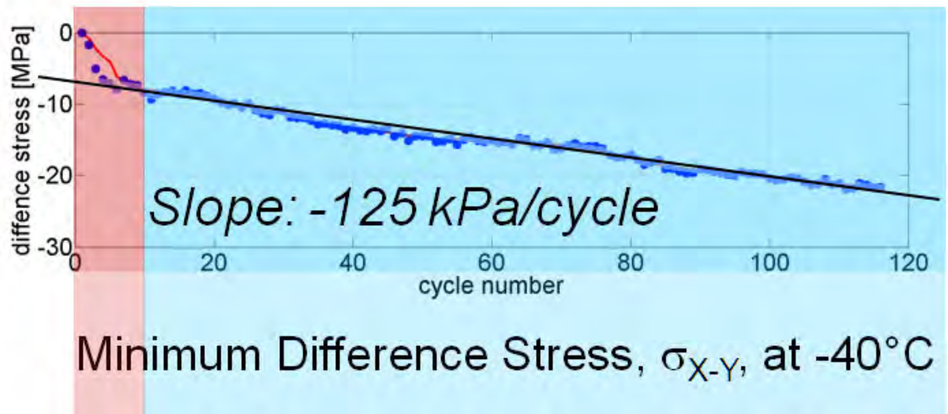
Soldering is studied as typical example of a process step. The top left graph in Fig. 3 indicates the loading situation. The stress occurring before soldering is taken as reference. Fig. 4 shows the x-y difference stresses subsequently caused by the process. The graph at the top of this figure depicts the average readings across all 10 samples. The graph at the bottom provides the result of a numerical analysis simulating the cooling from 210 °C, which is the solidus threshold of the lead-free solder alloy, down to room temperature. Distribution and magnitude of both sets of results are in close match. During the cool down, the die is warped in saddle shape leading to compression stresses along the long edges of the die's top surface (concave bending) and tensile stress along the short edges (convex bending). Analyzing the individual samples, large differences are observed. The graphs plotting the 10 individual readings of the stress cells along row number 3 of the die, bottom of Fig. 3, reveals that the local X-Y difference stress can assume any magnitude between –62 MPa and +57 MPa. This >100 MPa wide range of possible stresses is caused by flaws in the solder layer between the thermal pad of the QFN package and the PCB. Fig. 2 provides examples of X-ray images that clearly show the physical evidence. Underneath the individual cells in row number 3 may either be solder or voids. Of course, stresses of very different levels are induced by these two cases. The stress sensing system is not only able to detect but also to quantify this situation with good spatial resolution. Hence, the quality of the soldering process can be characterized objectively based on the readings of the stress sensing system.

Health monitoring

The stresses evolution has been studied during thermal cycle tests between –40 °C and +125 °C. Each cycle took 80 minutes. The stresses right before the test is taken as reference. Two clear trends are seen in the graph depicting the minimum local stress that occurs on the die after each subsequent cycle at the low temperature. Starting the test, a rapid decline in the stress magnitude is seen. It is caused by a slight plastic deformation of the thermal pad. This way, the new steady state is approached. The external constraints are change massively when the QFN component is soldered to the PCB. Obviously, it took 10 thermal cycles to reach the new steady state. After this transition, the minimum stress declines further as seen in the graph. The shallow slope of –125 kPa/cycle is quite constant until the end of the test. Fig. 5 shows the measured X-Y difference stresses generated during 110 thermal cycles (top left). The distribution is not uniform but shows a concentration at one corner. The X-ray image of the die bond film inside the QFN package reveals a flaw just at this location, Fig. 5, bottom left. Replication this irregularity by a numerical model, results in the same pattern of the stress distribution when the thermal cycle loading is simulated by a finite element analysis. Hence, the stress evolution can be explained theoretically: The flaw in the die adhesive triggers a delamination at the interface to the die, which grows from cycle to cycle towards the center of the die. Consequently, the magnitude of the stress singularity is increased leading to the measured decline in the minimum stress.

Fig. 3: Soldering process: load profile, topology of the soldered layer, stress results (row 3).

Fig. 4: Soldering process: distribution of the induced X-Y stress at the die surface.



The stress sensing system has been able to clearly detect and to quantify the effect of the progressing delamination. This way, the status of health could be monitored objectively.

Conclusion

A new stress sensing system has been introduced for assessing the mechanical situation inside of packages for smart systems. After verifying the functionality of the system by four point bending tests, two examples have been given applying it to process characterization and health monitoring tasks, respectively. The characterization of the soldering process revealed that the differences in the local stress may exceed 100 MPa in real samples – for example in cases in which voids exist in the solder film. On the other hand, accuracy and reproducibility of the stress readings have been as excellent as to suffice for the determination of a slope in stress magnitudes as shallow as 100 kPa/cycle during the health monitoring assessment example. In both cases, the new stress sensing system has been shown very precise in detecting the mechanical effects in-situ. Later on, the effects could clearly be verified by physical failure analysis and explained by numerical simulation.

Fig. 5: Health monitoring during thermo cycle test: delamination at die/adhesive interface.

DEPARTMENT PRINTED FUNCTIONALITIES

Head of Department: Prof. Dr. Reinhard R. Baumann

The department Printed Functionalities focuses on printing technologies for the manufacturing of printed products which do not solely address the human visual sense but employ these deposition technologies for the application of functional materials. These printed functionalities range from simple conductivity, semi-conductivity and isolation up to chemical activity, e.g., in batteries or catalysis. These functionalities can improve and enhance the performance and the architecture of smart systems, e.g., by printed interconnections or printed power modules. In future thus equipped products will have functionalities beyond color enabling them to perceive their neighborhood and their own state, allow the interaction with a user and the communication with computer networks, in short: convey them to an intelligent item of the internet of things.

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The Fraunhofer ENAS thin film batteries are a convincing example of employing printing technologies for the deposition of functional materials in patterns required in subsequent technological steps. Today's printers are equipped with highly advanced press and post-press technologies to produce high-quality print products. These products are solely made to be recognized by the human senses. Most commonly known is the visual reception of color and sharpness, sometimes even glossiness. Special varnishing techniques enable the printer to apply haptic elements to his products. Using special inks containing micro encapsulated odorous substances even the human scent can be addressed. These printed functionalities are state-of-the-art and they are based on the traditional printing processes gravure, offset, flexo and screen printing as well as the digital printing processes electro photography and inkjet. The today's printing technologies are well developed processes to transfer colored ink dots onto fiber based substrates, plastic foils or sheet metal. The printout is rated of good quality when the human eye sizes the well defined ensemble of screen dots as a halftone image or even a full tone area. In case of haptic or odor elements similar human sense based quality characteristics can be defined. Printing haptic or odor elements is going beyond traditional color printing, facilitating besides the regular functionality "color" further functionalities manufactured by printing.

On this note the term "printed functionality" goes far beyond color and we envision that the functionalities electrical conductivity, adapted dielectric properties, electrical semi-conductivity, electric power, electroluminescence / light emission, sensing environment, surface protection, intelligence via chip or even catalysis will be manufactured by employing press and post-press technologies. And we expect that the digital printing technology inkjet will contribute substantially by enabling the deposition of very small amounts of expensive functional materials.

Under more general aspects printing is a highly efficient image wise coating technology to deposit functional materials in a predefined thickness only at the right position on an appropriate substrate. Which means printing is an additive technology in contrast to subtractive technologies like photo lithography or etching, characterized by coating the substrate with a continuous material film initially and removing the material image wise from the substrate in expensive additional subsequent steps.

Given the today's high accuracy and reproducibility of printing based material deposition in conjunction with the remarkable potential for further developments, printing is expected to be the dominating technology for the fabrication of smart printed matter in high quantities. However, no single printing method is capable to offer an all-encompassing performance. Therefore, instead of using a single printing technology, hybrid machine combinations of contact printing methods (gravure, screen, flexo), inkjet printing, laser processing and further high volume production technologies need to be utilized. New modular machine concepts shall warrant a flexible design of manufacturing processes at reduced investment costs for smart packaging production.

The evolution in the field of printed smart objects depends on the accomplishment of the challenges in the interdisciplinary development of complex functional inks, flexible manufacturing processes and modular machine systems with integrated analogue or digital manufacturing technologies.

If these printed smart objects shall be enabled to exchange data with computer networks they need to be stuffed with wireless radio frequency (RF) communication technology, typically consisting of a Si chip and an antenna. The efficiency of RF communication strongly depends on the dielectric environment in which the antenna transmits the data. And in reality it is found that more or less every object needs an optimized antenna design for a reliable data communication. In case of printed objects it is obvious that the optimized antenna could be manufactured by printing it directly onto the object together with all the colors. The Fraunhofer ENAS department Printed Functionalities follows these ideas and hence focuses currently, besides further challenges, on the design, printing and characterization of appropriate antennas.

For all these developments mentioned above we employ traditional and digital printing technologies to manufacture new printed products, taking advantage of the additive character of the printing technologies and their high productivity. We focus on drop-on-demand inkjet, screen, and gravure printing and we develop technologies for the integration of silicon electronics into printed smart objects. An important factor for success will be our close cooperation with the Chemnitz University of Technology and further local and global industrial and academic partners.

To broaden our R&D activities we have been able to complete our MicroFLEX™ roll-to-roll machinery setup in 2012 by a Novacentrix® PulseForge® photonic sintering system to establish a whole additive manufacturing workflow for fine copper patterns on flexible substrates. Our machinery with the already established screen and inkjet printing of copper precursor ink and the additional, highly productive photonic sintering process has been presented on the drupa in Düsseldorf for two weeks. We demonstrated the on-site printing of UHF copper antennas and their successful functionality after attaching a Si RFID chip.

Our competences are:

- Printed functionalities: conductivity, semi-conductivity, insulation, energy accumulation, catalysis, light based energy conversion on various substrates,
- Printed thin film batteries and development of integrated applications,
- Research and development on antennas to match specific applications and there manufacturing employing printing technologies,
- Printed smart objects with integrated micro and nano systems,
- Device prototyping and industrialization of their manufacturing,
- Characterization of inks, functional layers, components and systems.

We offer the following services:

- Precise deposition of liquid processible materials to form patterned layers with defined properties, utilizing printing technologies,
- Specific employment of inkjet techniques for saving resources, additive material deposition,
- Printing workflow development to optimize the manufacture of new functionalities,
- Material and layer characterization: viscosity, surface tension, morphology, electronic properties, layer zoning, layer interaction,
- Development of innovative components for specific applications based on printing technologies, e.g., flexible energy/battery systems,
- Printing of conducting patterns, e.g., antennas or electrodes,
- Design, simulation, printing and experimental characterization of customized RFID antennas.

FIG. 1

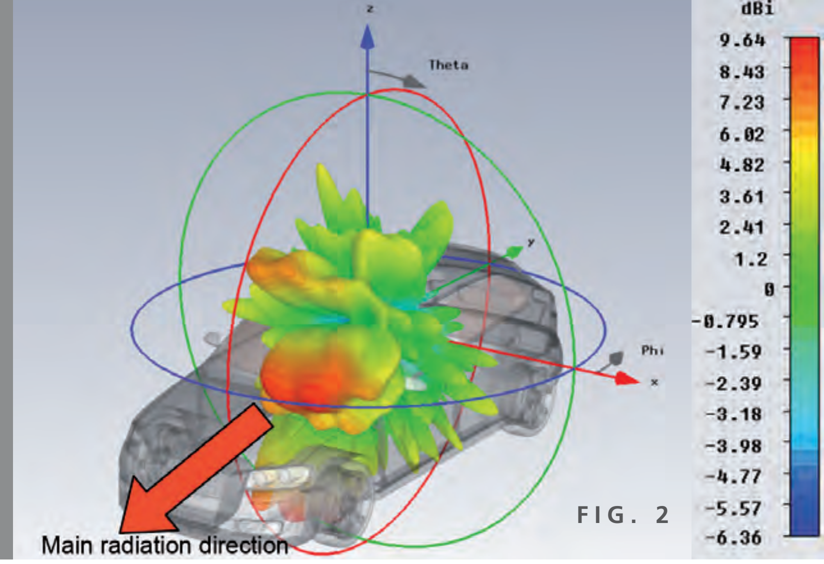

FIG. 2

R2R SCREEN PRINTED RFID TRANSPONDER ANTENNAS FOR VEHICLE TRACKING SYSTEMS

Ralf Zichner, Reinhard R. Baumann

Introduction

Vehicle tracking systems are already used in a variety of applications. For research the following example was chosen and is described below: the access and exit controlling of cars in car parks and industrial sites employing a long range ultra high frequency (UHF) RFID system. This means that an RFID reader system using electromagnetic waves identifies a vehicle wirelessly, checks the access authorization digitally and performs the opening and closing of the barrier system, see Fig. 1.

The identification is carried out over a vehicle-mounted (windshield) transponder, comprising a transponder antenna and a Si chip. Its functionality (sending and receiving capabilities) largely determines the overall functionality of the identification system. State-of-the-art RFID transponder (Al etched antenna and Si chip) enable reading distances of up to 5 m with a maximum output power of 2 W.

Targeting the highest demands on the reliability of such systems, a reading distance greater than 5 m with 100 percent reliability is the aim.

In the following the design and simulation, printing and characterization of roll-to-roll (R2R) printed transponder antennas are presented. Therefore the paper addresses the complete development and production chain. Anyhow, several printed UHF RFID antennas [3, 4] have been developed up to now, but they are not matched for the application specific dielectric environment and therefore they are not functional for, e.g., vehicle tracking systems.

In general, to support the growing UHF RFID market [5] the demand of highly functional antennas needs to be fulfilled. With this development we can address new applications and establish the world of printing in the world of RFID, which is classically based on photolithography.

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Fig. 1: Vehicle tracking scenario.

Fig. 2: Simulation result (antenna directivity) of an antenna electromagnetic wave propagation simulation taking into account of a real vehicle geometry.

FIG. 3

FIG. 4

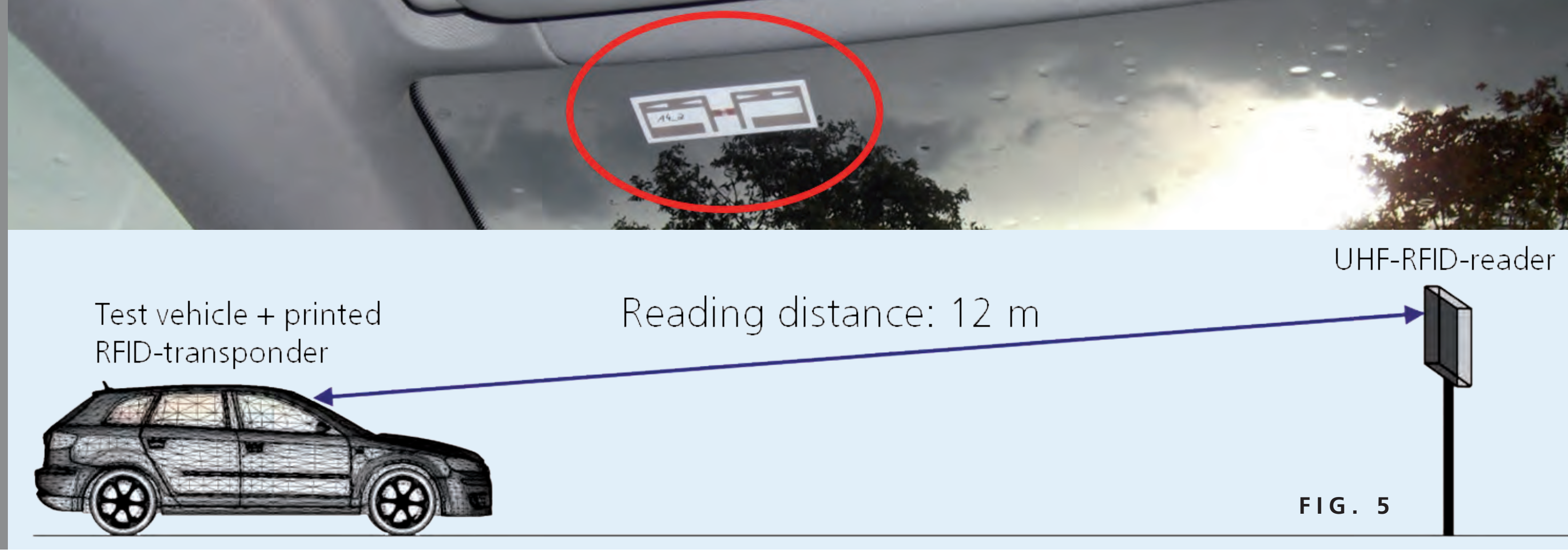

FIG. 5

Experiments

Antenna design and simulation

The antenna design, shown in top of Fig. 5, was designed with regard to the specifications listed below.

- Resonance Frequency: 868 MHz
- RFID Chip Impedance: (12 – j132) Ohm @ 868 MHz (NXP UCODE G2XM)
- Planar single layer design (max. size: 4.5 cm * 7.5 cm)
- R2R screen printing on flexible substrates and high functionality on windshield glass
- Radiation in driving direction (circa 2 m over the ground)
- Transponder (antenna and RFID chip) read/write range > 5 m

The antenna (including a complete vehicle body) was designed in the software “CST Microwave Studio Suite” and hereafter the antenna characteristics were calculated. The antenna was thereby positioned on the inside of the driver’s windshield. Special attention with regard to the antenna characteristics is to direct the radiation pattern, see Fig. 2. This is characterized by a radiation characteristic of the antenna in the direction of travel (see red area) with a high directivity gain of 9.6 dBi. Adjacent to said main beam direction, the antenna design has also several main and side lobes, which do not affect the antenna performance significantly negative.

Antenna printing

R2R gravure as well as sheet by sheet screen printed RFID transponder antennas have been already investigated [6]. In this paper we focus on R2R screen printing. The manufacturing of the antennas in a R2R printing process was carried out with printing machine depicted in Fig. 3. The following process parameters were applied:

- Rotary screen unit: Stork RSI Compact,
- 215 mesh PET screen,
- Silver Ink: Sun Chemical CRSN2442,
- Substrate: coated paper (UPM DIGI _finesse gloss 150 g/m²),
- Web speed: 2.4 m/min,
- Heating: Ceramic Heater (Elstein) and IR-unit (Heraeus + energy converter 400).

The printing result is shown in Fig. 4.

Antenna characterization

The metrological characterization was performed on the one hand in terms of pure antenna properties and on the other hand in respect to the RFID application, see Fig. 5.

Fig. 3: Fraunhofer ENAS R2R printing machine microFLEX™ (3D-Micromac, Germany).

Fig. 4: R2R printed antenna on paper substrate.

For metrological characterization of the RFID functionality the described RFID chip was electrically contacted to the printed antenna. This assembly was fixed to the inside of the vehicle’s windshield and, as shown in Fig. 5, verified metrologically by use of the UHF RFID reader Sirit Infinity 510 (P_t = 1 W, circularly polarized patch reader antenna 8.5 dB). A maximum read distance of 12 m was achieved.

Summary

In this report the design and manufacturing of high performance R2R screen printed RFID transponder antennas are shown. These systems were verified in a vehicle tracking system application. Due to their high performance read distances were achieved with up to 12 m. This enables 100 percent readability of the transponder in distances up to 8 m. By this example it is shown that for vehicle tracking systems printed RFID antennas, which are manufactured in a highly productive and inexpensive way, are highly suitable.

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Fig. 5: Printed UHF RFID transponder antenna plus Si chip on a vehicle windshield and a scheme of a real UHF RFID transponder reading measurement scenario.

DEPARTMENT BACK-END OF LINE

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The department Back-End of Line focuses on

- Materials and process development,
- Process integration,
- Modeling and simulation

for interconnect systems in ultra large-scale integrated CMOS devices (ULSI) as well as MEMS and NEMS components.

Competences and research fields

The main competences and research fields of the department BEOL are in the fields of:

- Low-k and ultra low-k (ULK) dielectrics,
- Metallization for micro and nanoelectronics as well as for 3D and system integration,
- Airgaps for low parasitic capacitances in nano electronic interconnect systems,
- Process and equipment modeling and simulation,
- Modeling and simulation of interconnect materials and systems,
- Planarization and surface modification for BEOL and MEMS/NEMS fabrication,
- Wafer-level integration of carbon nanotubes for interconnects, CNT-FETs and sensors,
- Magnetoresistive sensors based on spin valve systems.

Special emphasis is placed on integrating low-k and porous ultra low-k materials into copper damascene interconnect systems. The specific properties of those materials require a modified integration pattern adapted to the respective material. For their successful integration especially etching and cleaning techniques, k-restore processes after patterning, diffusion barrier compatibility and low down force barrier and copper CMP are investigated. For this and to evaluate porous low-k dielectrics properties, several optical, mechanical, thermal and electrical characterization techniques are applied.

New interconnect architectures are under investigation for example with respect to the integration of carbon nanotubes and airgaps. Here, not only the potential for manufacturing such structures is studied, but also their electrical, thermal and mechanical impact on the interconnect system. Development and optimization of the single process steps as well as the complete technology are accompanied by electrical characterization and modeling/simulation of airgap and carbon nanotube containing interconnect systems.

3D and system integration require metallization solutions for redistribution layers, specific wafer bonding techniques and, of course, for high aspect ratio through silicon vias (TSVs). By providing several process solutions, like PVD, CVD and ALD barrier and seed layers, copper CVD and electroplating (ECD) these fields can be addressed for different feature geometries and various applications. For wafer thinning of different substrate materials, processing solutions are developed using grinding, spin etching and CMP.

Developing new technologies requires new or optimized processes and equipment. To realize this, Fraunhofer ENAS is developing advanced models and simulation tools, e.g., for PVD, CVD and CMP. They support the development of improved deposition and polishing techniques by optimizing process conditions, reactor configuration and feature topography. By means of appropriate simulations it is possible to estimate chances and risks of new technologies and to determine convenient process windows while minimizing costs of processing test runs with large scaled wafer diameters and batches. The knowledge and experience gained from the simulations are made available to our customers and partners to optimize process parameters and equipment.

The department closely collaborates with the Center for Microtechnologies (ZfM) at Chemnitz University of Technology. This is not only expressed by shared cleanroom facilities and equipment. Many results of the basic research work carried out at the ZfM have been successfully transferred to application by the Back-End of Line department at Fraunhofer ENAS. For example, the integration of low-k materials and the development of novel processes such as for the atomic layer deposition (ALD) of metals and growth of carbon nanotubes continue to be important areas of work at both institutions.

Services

We offer the following services related to the fields described above:

- Wafer processing (deposition, patterning, thinning, planarization),
- Thin film measurement and characterization, incl. SEM, FIB, STEM, EDX, XPS, FTIR, Raman spectroscopy,
- R&D services for processes and technology development,
- In-situ process diagnostics,
- Modeling and simulation of processes and equipment,
- Modeling and simulation of interconnect materials and systems.

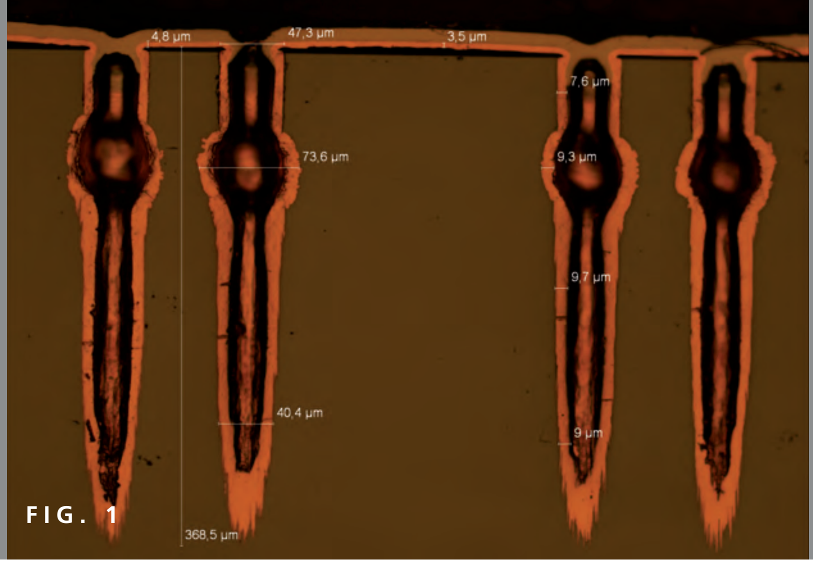

FIG. 1

Results of R&D Projects in Brief

Metallization for on-chip interconnects

Moving from sputtered diffusion barriers to CVD and ALD barriers in 28 nm technology nodes and below requires the investigation and adaption of the interface between the metal nitride diffusion barrier and the porous SiCOH dielectric in via and trench patterns. Within the project NOLIMIT funded by the Free State of Saxony Fraunhofer ENAS is performing basic investigations to characterize the porous dielectric surface after plasma treatments and the interface to CVD and ALD diffusion barriers like TiN and TaN. In collaboration with Prof. Krause-Rehberg and his group at the University of Halle positron annihilation lifetime spectroscopy (PALS) has been applied for these investigations using the ELBE positron source (EPOS) at the Helmholtz-Zentrum Dresden-Rossendorf giving new insights in precursor penetration into the porous dielectric material.
For MOCVD copper metallization an in-situ chamber clean is in development for the Cu deposition chamber allowing increased times between wet cleans and more stable processing conditions.

Metallization for 3D interconnects

The European project JEMSiP-3D in the "ENIAC/AENEAS" framework was successfully completed in 2012. A CVD based barrier / Cu seed layer deposition technology especially suited for (very) high aspect ratio (HAR) TSV metallization was developed and evaluated. The process is showing improved film coverage in HAR TSVs, where sputtering processes fail to yield continuous seed layers for subsequent Cu ECD is also available for customers.

Department News

Modeling and simulation

A new research topic has been set up concerning the simulation of atomic layer deposition processes. The expected results will support understanding of ALD processes under development at Fraunhofer ENAS using a recently installed ALD/CVD nano deposition cluster system involving in situ analytics like XPS.

Fraunhofer ENAS joins forces with other institutes in the ALD Lab Dresden

Fraunhofer ENAS with its ALD activities in the department BEOL joined the ALD Lab Dresden in 2012. The ALD Lab Dresden is a collaboration of currently 6 research institutes in Saxony applying and developing atomic layer deposition (ALD). The participating institutes have brought together their expertise and capabilities in ALD and beyond. Thus a unique competence center in atomic layer deposition has been formed. Activities are ranging from fundamental research and precursor evaluation to large scale process development for novel materials for industrial coatings, future electronic devices and energy harvesting devices etc.

Fig. 1: Metallization of deep TSVs by Cu MOCVD and following Cu ECD (by Atotech); the high step coverage of the Cu CVD process ensures the deposition of ECD also in undercut region.

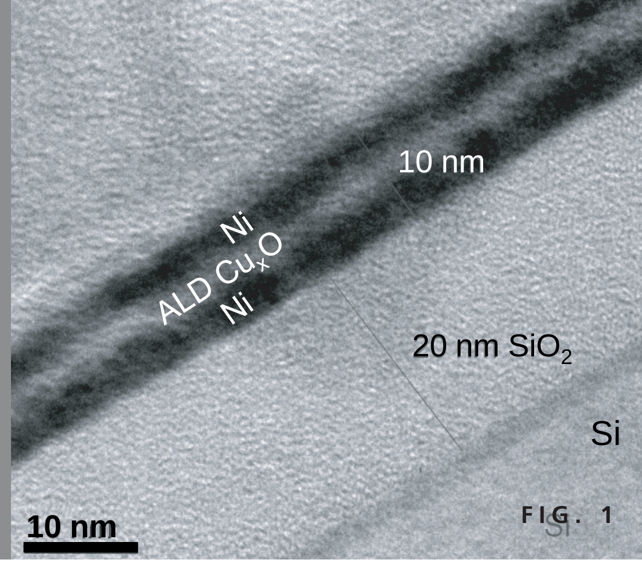

FIG. 1

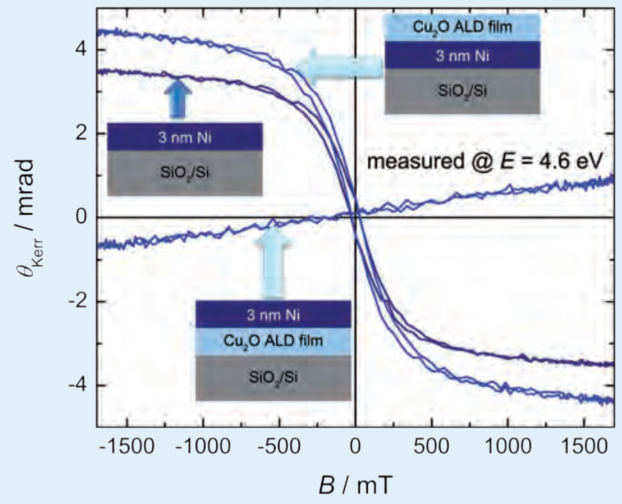

FIG. 2

NANOLAYERS FOR SPINTRONIC SENSOR DEVICES

Thomas Wächtler, Ramona Ecke, Stefan E. Schulz

In recent years, quantum effects observed in materials systems on the nanoscale are gaining increasing attention also for practical applications. With improvements in established methods and evolving new techniques to deposit thin films, effects like the giant magnetoresistance (GMR) are becoming interesting also for sensor devices. The department Back-End of Line is dedicated to the development of technologies for GMR based sensors. The basic element of such a device is a thin film stack with alternating magnetic and nonmagnetic metallic layers, each of which needs to be controlled precisely in thickness on the nanoscale. Devices like the GMR sensor are the basis for the measurement and control of magnetic, electrical or mechanical parameters. Compared to other sensors, such as based on the Hall effect, GMR sensors have the advantage of higher sensitivity, energy efficiency and further miniaturization.

Within the "nanosystem integration network of excellence – nanett", atomic layer deposition (ALD) processes are under development to create nanometer thin film systems. ALD allows growing thin films with precise thickness control even in nanostructures. Being meanwhile state-of-the-art to deposit different oxide films for microelectronic devices, ALD of metals is an active area of R&D worldwide. In the project nanett, an ALD processing sequence to grow alternating layers of copper as a nonmagnetic metal with other ferromagnetic layers was developed. Together with the Chair Inorganic Chemistry at Chemnitz University of Technology (Prof. H. Lang), a precursor system was established to deposit copper oxide by ALD which is subsequently reduced to copper. To obtain the desired films, minor amounts of catalytic metals are introduced into the precursor solution. This unique approach has already led to one patent and three further patent applications. The process can be successfully combined with nickel to form thin film stacks, Fig. 1. Measurements of the magneto-optical properties (cooperation with Prof. G. Salvan, Chair Semiconductor Physics at Chemnitz University of Technology) revealed that the behavior of the ferromagnetic nickel film can drastically be influenced by ultra-thin ALD copper oxide, Fig. 2. This could be helpful for a magneto-optical sensor principle as well. To create all-ALD based GMR devices, novel precursors for cobalt ALD are studied, along with processes for depositing nickel oxide and nickel. It could be shown that the properties of ultrathin nickel oxide films can drastically be influenced depending on the ALD process itself.

We kindly acknowledge the German Federal Ministry of Education and Research (BMBF) for funding the project nanett (FKZ: 03IS2011B).

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Fig. 1: Thin film stack of nickel films and an ALD copper oxide film.

Fig. 2: Magneto-optical properties of the nickel/copper oxide thin film system: Depending on the combination, the magneto-optical properties of nickel can be controlled and drastically altered by the ALD copper oxide.

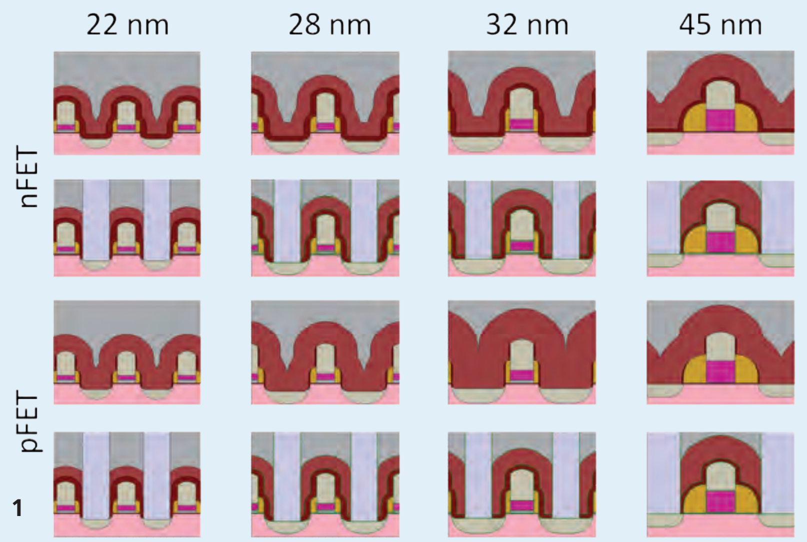

FIG. 1

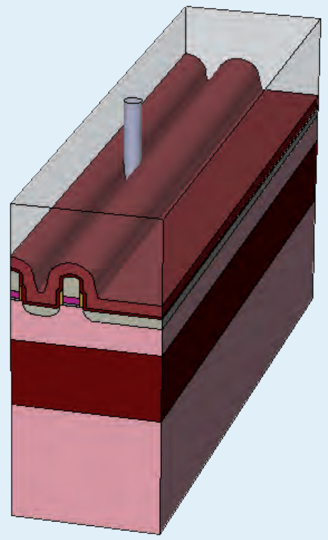

FIG. 2

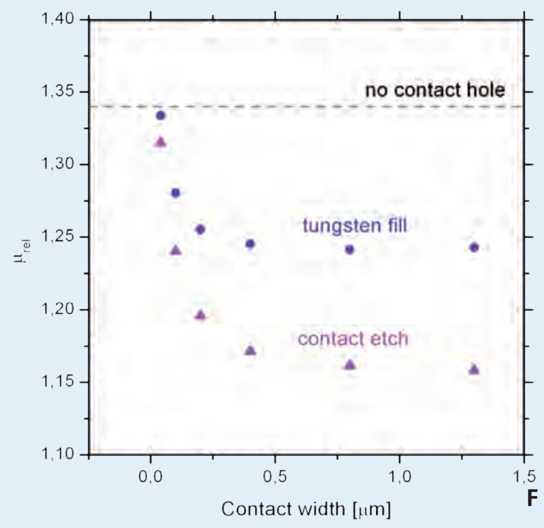

FIG. 3

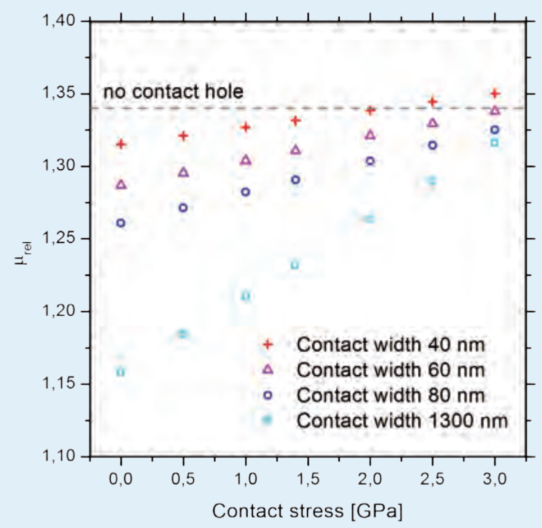

FIG. 4

A THREE-DIMENSIONAL PARAMETERIZED SIMULATION MODEL FOR ULSI TRANSISTORS WITH STRAINED SOURCE/DRAIN CONTACTS AND STRAINED NITRIDE LINERS

Jörg Schuster, Stefan E. Schulz

Introduction

Straining the silicon in the channel of ULSI transistors is one of the key enabling technologies for increasing the performance of modern processors while simultaneously reducing its power consumption. Usually several stressor technologies such as strained nitride liners or SiGe pockets are combined to achieve the desired stress levels in the transistor channel. In the present work we focus on strained nitride liners and how their performance is influenced by the formation of the source/drain contacts. Contact formation requires opening of the stressor film which will lead to a partial stress release. In addition, a strained contact metallization will act as an additional stressor on the transistor channel.
An analysis of the actual strain state in the transistor channel of ULSI devices by analytical techniques is very demanding and still far from routine use. Thus, to date simulation is the only mean to study and optimize the function of the various stressors.
Usually two-dimensional models are convenient for the modeling of stress transfer from a stressor to the channel. However, if source/drain contacts are present three-dimensional models are required due to the small dimensions of the contacts. In general, three-dimensional simulation models are very demanding with respect to simulation time as well as to memory requirements. Thus a careful model design and optimization is required.

Transistor model

The flexible three-dimensional model described in this report was developed within the CoolTrans project together with GLOBALFOUNDRIES and Chemnitz University of Technology. Within that project, a comparison of the stressor performance between different technology nodes including several technology options was indented. Thus a highly flexible and adaptive model is required.
In a first step, a number of important technology parameters and dimensions have been identified. Based on these, a parameterized two-dimensional transistor model was built, Fig. 1. All dimensions have been chosen in such a way that the models cross sections are as close as possible to real device cross sections measured by electron microscopy. For robustness, the basis model of the transistor including the gate contact and spacer was constructed based on simple geometric elements using SYNOPSYS SENTAURUS Structure Editor.

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Fig. 1: Cross sections of the transistor models from 22 nm to 45 nm.

Fig. 2: 3D transistor model (32 nm nMOS, only right part shown).

The basic geometric model can now be used in a second simulation step which is a process simulation step. Using SYNOPSYS SENTAURUS Process, we were able to simulate the deposition of the nitride liner while simultaneously the stress in the growing film is considered solving the equations of thermomechanics. Depending on the type of stress in the film (tensile or compressive) and how the stress is created, slightly different simulation strategies are required. In a similar way, further process steps such as TEOS oxide growth, contact hole formation and contact metallization are added.
In this stage, the model is still two-dimensional and all objects including the contacts have an infinite width and can be considered as trench-like. Before the model is switched to a three-dimensional one, a thorough optimization is performed in order to make the mesh, which is used for the numerical solution, as coarse as possible while conserving the required accuracy of the results. Calculations based on this model are now very fast and the memory requirements are low.
Now, having a compact and robust model we can switch to three dimensions by modeling contacts with a finite width and a circular cross section, Fig. 2. Again, SYNOPSYS SENTAURUS process is used for modeling the process steps including a strained contact metallization. By increasing the contact width to a very high value, the three-dimensional model can be compared to the two-dimensional one and indeed identical stress distributions are found in the channel for wide trench-like contacts which resemble the two-dimensional situation.

Performance and results

Based on the procedure described above a very robust and computationally efficient three-dimensional parameterized model for ULSI transistors including strained source/drain contacts and strained nitride liners is now available at Fraunhofer ENAS. Due to the optimization of the model, the computer time required is on the order of several tens of minutes. Thus the model is suitable for extensive simulations including parameter variations and simulation based process and design optimization.
Within the CoolTrans project the model was used for a detailed analysis of the interplay between strained nitride liners and contact metallization. It was found that the contact formation may have a drastic influence on the stress transfer from the nitride liner to the transistor channel, Fig. 3. In case of very wide contacts, the performance gain due to the strained nitride liner is completely lost when the liner is opened for contact formation. This performance loss can be partially recovered by using high-stress tungsten in the contact, Fig. 4. However, due to process limitations only tensile strain is available for the contact metals and thus only nMOS transistors having a tensile strained nitride liner will benefit from this performance recovery. In contrast, the pMOS which requires stress of the opposite sign for a performance gain (compressive nitride liner) will always be degraded by contact formation and no recovery is possible by a strained contact metallization. Details and further results of the study are summarized in an upcoming paper [1].

[1] Schuster, J.; Schulz, S. E.; Herrmann, T.; Richter, R.; Microelectronics Engineering (2013), in press.

Fig. 3: Influence of the contact width on the nMOS performance μ_{rel} (32 nm node).

Fig. 4: Performance recovery by a strained contact metallization for an nMOS transistor (32 nm node).

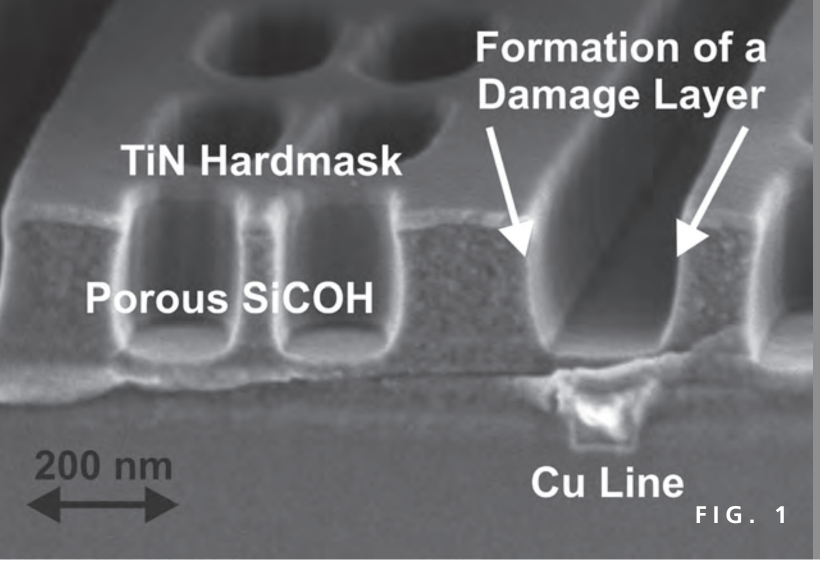
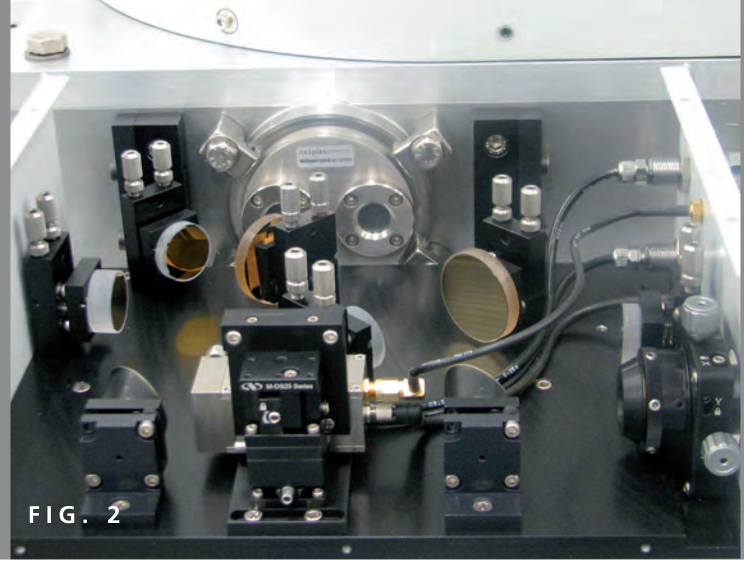


FIG. 1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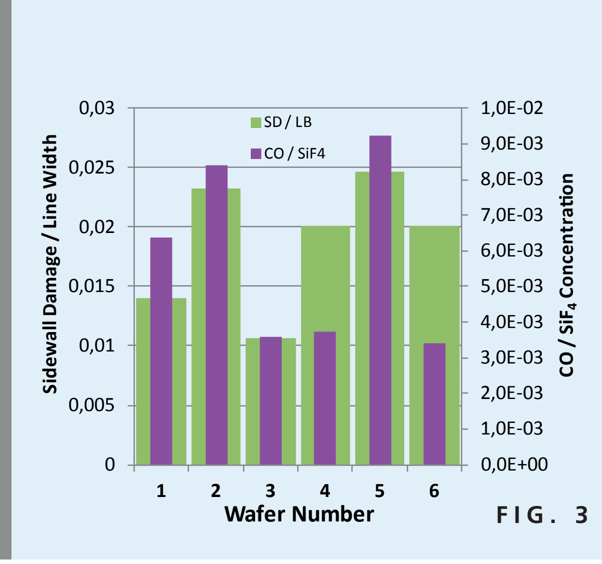

FIG. 3

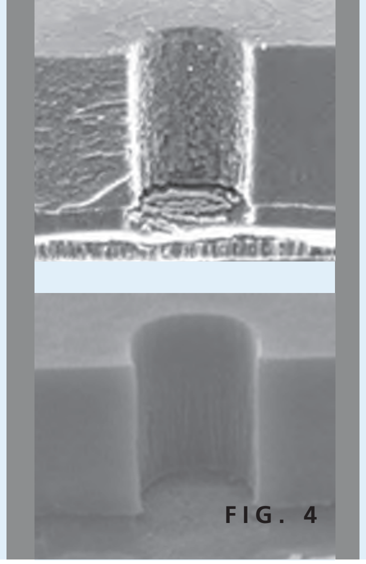
FIG. 4

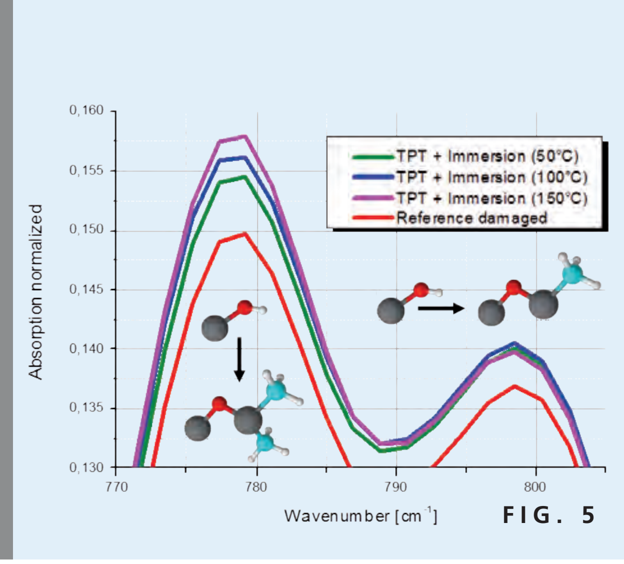

FIG. 5

INTEGRATION OF POROUS SiCOH AS INTERLEVEL DIELECTRIC INTO NANOELECTRONICS TECHNOLOGIES: OPTIMIZATION OF PATTERNING PROCESS SEQUENCE

Sven Zimmermann, Nicole Ahner, Tobias Fischer, Stefan E. Schulz

With further scaling of interconnect dimensions in modern nano electronic devices delay times and crosstalk effects in the copper interconnect system become more and more important. To overcome such problems interlevel dielectrics with strongly reduced k-values, so-called ultra low-k materials, are under investigation. The integration of these materials into industrial back-end of line schemes is challenging. The Fraunhofer ENAS has worked in this topic for 10 years in which ostensible real process wafers provided by the industrial partner GLOBALFOUNDRIES were used. Due the strong cooperation with the Fraunhofer CNT most of the achieved results were transferred to 300 mm equipment for the direct application in the GLOBALFOUNDRIES process line.

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Development of a less damage RIE process

In order to reduce the k-value of the dielectric materials, several Si-O bonds of conventional SiO_2 based insulators are replaced by hydrophobic Si-CH_3 groups, which reduce the polarizability and prevent moisture uptake. Patterning processes for such materials take place in fluorocarbon plasmas with different admixtures to avoid material damage by the formation of a polymer film and to enhance the anisotropy. During such processes the Si-CH_3 bonds will be cracked chemically and free silicon bonds will be occupied by hydrophilic silanol groups, Si-OH. This effect is most pronounced in the sidewalls of vertical geometries and leads to the formation of a graded carbon depletion layer, denoted in Fig. 1. The results are an enhanced line-to-line capacitance and undesirable crosstalk effects. For the application of porous SiCOH materials in the 28 nm technology node, a maximum damage layer thickness of $\leq$ 1 nm is allowed.

Detailed knowledge of the relationship between plasma conditions and process results are necessary for the development of an etch process with reduced damaging behavior. Thus quantum cascade laser absorption spectroscopy QCLAS was introduced to measure species in the etch plasma with a high sensitivity and a low detection limit. The adaption of this optical measurement method to an Oxford system 100 etch chamber at the Fraunhofer ENAS is shown in Fig. 2. Some identified correlations between geometrical process results and specie concentrations, measured with QCLAS, are shown in Fig. 3.

Fig. 1: Trench patterning in the 28 nm technology node, formation of a damage layer in the sidewalls.

Fig. 2: Adaption of the QCLAS System to an Oxford System 100 ICP etch chamber.

Wetting optimized etch residue removal

The post-etch residual removal takes place after SiCOH patterning to remove resputtered material and polymers from surfaces and sidewalls of etch trenches and vias with good compatibility to Cu/low-k technology, see Fig. 4. With decreasing feature sizes additionally wetting concerns come into focus as due cleaning liquids may not be able to enter small features like vias or a pattern collapse during drying occurs, which destroys narrow low-k dielectric trenches. The activities in this topic include the evaluation of different organic solvent and water based cleaning liquids with respect to their cleaning capability, wettability, toxicity and environmental friendly character. Furthermore the well defined admixture of selected surfactants offers the possibility to improve the wettability and the dynamic character of cleaning liquids.

Recovery processes for plasma damaged ultra low-k materials

Aside from a less damage configuration of the patterning processes the repair of damaged areas in the sidewalls of etched geometries is an important topic. Such processes bases on the replacement of undesirable silanol groups by recent methylsilyl groups. The main reaction bases on the dissociation of complex repair molecules, e.g., OMCTS or HMDS, followed by the reaction of methylsilyl fragments with silanol groups. Typically such processes will be performed by the direct immersion of etched geometries into special liquids including repair molecules at elevated temperatures. In the past such immersion processes were combined with different thermal or UV treatments to improve the repair effect and to enhance the long time stability. The FTIR spectra in Fig. 5 demonstrate the successful reintegration of Si-CH_3 ($SiMe_1$) and Si-$(CH_3)_2$ ($SiMe_2$) groups.

Acknowledgement

The project described in this publication has been funded in line with the technology funding for regional development (ERDF) of the European Union and by funds of the Free State of Saxony.

Fig. 3: The ratio of sidewall damage and line width correlates with the ratio of CO and SiF_4 concentration, measured with QCLAS.

Fig. 4: Removal of etch residues from different via geometries using an optimized cleaning procedure.

Fig. 5: Selected results of recovery processes consisting of a thermal pretreatment (TPT) and a direct immersion in an OMCTS precursor: the peaks mark the conversion of silanol-groups into silylmethyl groups.

DEPARTMENT SYSTEM PACKAGING

Head of Department: Dr. Maik Wiemer

The department System Packaging is working in the fields of packaging technologies for MEMS and NEMS covering topics from zero level packaging up to second level packaging. The potentials and the importance of packaging and system integration are manifold, ranging from hybrid integration of the components on application-specific substrate carriers over monolithic integration of electronic, sensing and actuating components on a silicon substrate to the vertical integration, in which 3D stacking takes place on chip and wafer-level. In addition to the increasing functionality and reliability, the miniaturization and the smart systems integration are the greatest challenges for "More-than-Moore" development. With the department's research work this trend results in new, customer-specific applications.

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Wafer bonding and wafer-level packaging

The term wafer bonding describes all bonding techniques for joining two or more wafers with and without interlayer. Standard methods, such as silicon direct bonding, anodic, eutectic, adhesive and glass frit bonding are used, but also adapted and continuously developed for specific requirements. Current research focuses on surface pre-treatment technologies as well as on low-temperature bonding, with the process temperature below 200 °C. Another important field of research for these low-temperature procedures is the usage of nanoscale effects and new material combinations. Examples for nanoscale effects are reactive bonding with nanoscaled multilayers or the reduction of the melting temperature with only a few nanometer thick interlayers. Moreover, new materials were integrated as intermediate layers to reach eutectic combinations or solid liquid interdiffusion (SLID) effects, e.g., Cu, Au, Sn, Si. With these materials based bonding technologies metallic joints could be performed with a process temperature of about 200 °C. Furthermore the laser assisted bonding allows selective bonding without any temperature influence on the functional elements.

Other methods for the technological developments are constituted by the increasing diversity of materials used in microsystems technology. Materials, in particular plastics, metals and ceramics are currently analyzed to respect aspects such as temperature and media resistance and low costs during the product development. One example for this is the polymer bonding, which aims a tight bonding of plastics, covering the whole surface. Moreover, research is done in the fields of thermo compression bonding and the direct integration of functional ceramics.

All wafer bonding techniques are characterized in terms of their bonding quality, strength, and hermiticity. The competence of the department System Packaging involves the dicing and the chip and wire bonding as well as technologies for the integration of complex, miniaturized and even intelligent systems.

Surface modification and pre-treatment

Besides a wet chemical pre-treatment of the wafer, it is possible to increase the bond strength of direct bonded materials via chemical reactive plasma discharge. This pre-treatment can be applied to the whole area or to local points. Here similar stable bond interconnections as in high-temperature bonding can be realized, even at curing temperatures of only 200 °C. The plasma parameter adequate for this specific discharge and thus for the activation, highly depends on the input power, the used gases, the gas pressure, the gas density, the volume of the reactor and the geometry of the plasma chamber. According to this, the parameters have to be individually defined and adjusted for any application and for every material to be used.

For some wafer bonding technologies a clean and especially oxide free surface is preferred. Using Cu-Cu thermo compression bonding the intimate contact at atom scale of both Cu surfaces are necessary for self diffusion. Any passivation layer would prevent atom exchange and joining of the two substrates. Therefore pre-treatment processes for metal based bonding are investigated intensively. In general dry processes like formic acid has some advantages for fabrication reasons. Also other processes like plasma, laser or chemical reactive media were applied for better wafer bonding.

Characterization and measurement

Wafer bonding technologies and bonded substrates respectively were in particular characterized in terms of their electrical and mechanical bonding quality, tightness and hermiticity. Here, research methods, such as infrared, ultrasonic and scanning electron microscopy, including FIB and EDX analyses, are applied to detect failures, voids and other critical states in an early process step. Maszara Blade test, micro chevron test and shear test are used to evaluate the bond strength. Here special test samples are necessary to evaluate the mechanical strength at wafer-level. Also new materials like described above have to be considered in the test planning. One important point is the standardization of these tests to get a comparable result of mechanical strength. The department works closely together with German standardization institutes but also worldwide with SEMI organization. The hermiticity of bonded wafers or chips is analyzed by combined spectroscopic leakage tests (helium, nitrous oxide) and bow measurements using white light interferometry. Leakage rates up to a resolution of 1×10^{-11} mbar l/s could be measured that way. To reach an even higher resolution the devices could be also electrically characterized with integrated resonant structures. Accompanying to current technological developments the MEMS packaging technologies are characterized and evaluated, too. For this reason also other tensile, pressure and shear tests, electrical tests as well as climate, vibration and temperature tests are available in cooperation with other departments of the Fraunhofer ENAS.

Nanoscale effects and imprinting

In order to make use of the nano effects in MEMS packaging, the department System Packaging analyzes nanoscale intermediate layers and layer systems using PLD, PVD and Aerosol-jet deposition. Furthermore, surface and material effects are investigated and characterized on the basis of metallic nanostructures. These nanostructures are applied to new bonding techniques on chip and wafer-level. The aim of these investigations is to achieve a permanent and hermetic sealed joint between two wafers, using the lowest process temperature possible. Furthermore new application fields for nano patterns are, e.g., optics, electronics, and medical technology.

Molding micro and nanostructures by UV nano imprint lithography and hot embossing enables a precise formation of micro optical and microfluidic structures using nano and micro scaled master tools. Here, the basic distinction is to make between hot and cold embossing processes. In opposition to thermal nano imprinting no temperature is required for UV nano imprint lithography (UV-NIL). The pattern transfer is realized with UV exposure after imprinting the working stamp into the certain resist. This technology enables the patterning of silicon substrates in a range of 50 nm and beyond.

Aerosol-jet and screen printing

Next to the possibilities that are given with other printing techniques, e.g., inkjet printing the aerosol-jet technology has outstanding advantages. It is possible to perform a selective deposition process as an additive process including a wide variety of materials onto a wide variety of substrates without conventional masks or thin film equipment. Aerosol-jet printing is a noncontact direct writing technology which allows the deposition of various functional materials such as particle inks, polymers, etchants and paste like fluids. Especially the deposition of electrical conductive materials enables the realization of electrical interconnects over topographic structures and surfaces. Additionally other materials like polymers, adhesives, etchants, ceramics and bio-related materials could be printed with a minimum width of about 10 µm.

As a material transfer technology screen printing is mainly used for selective deposition of intermediate layers for wafer bonding. With microstructured stencils paste-like inks could be transferred to an electronic or semiconductor substrate through a polymeric or metallic screen. Current research is done to further improve the minimal printable lateral and vertical feature sizes, that are at the moment around 60 µm and 10 µm respectively. Furthermore the implementation of screen printable functional materials like conductive silver nanoparticle paste into microelectronic production processes is in focus of interest.

MEMS packaging and 3D integration

The meaning of MEMS packaging can be deduced from its portion of costs by producing a microsystem. Herein, proportional costs ranging from 20 percent to 95 percent are likely to arise, whereas this wide margin results from specific application requirements. On the one hand side the MEMS package has to allow access for the desired media to be measured, like liquids, gases or light. But on the other hand it has to shield the MEMS from outer unwanted influences, and thus to guarantee long-term functionality. Current packaging technologies are not only applied to passive elements such as inertial or gas sensors, but also to active elements like micro mirrors and print heads. In view of the further advanced system integration, electronic components can also be implemented into the MEMS packaging.

In addition to the integration on wafer-level and hybrid integration on chip level, integration technologies in the third dimension are developed. 3D integration has obvious advantages. For one, it can reduce the size of a chip and for another it can improve the signal quality. In vertical stacks like this it is of highest importance to consider the influence of each bonding technology on materials, but also on the electrical and thermal behavior of the whole system.

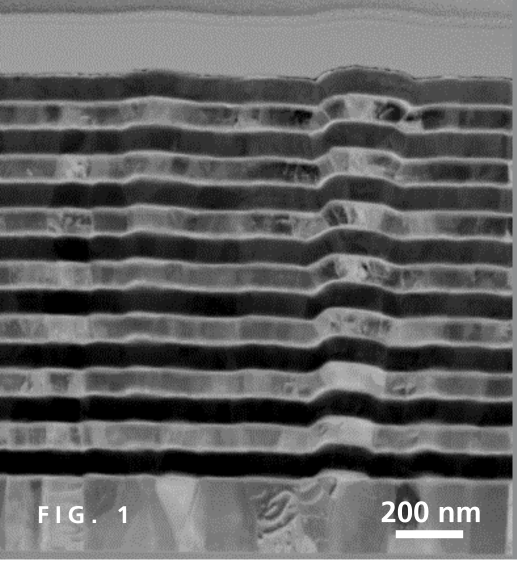

FIG. 1

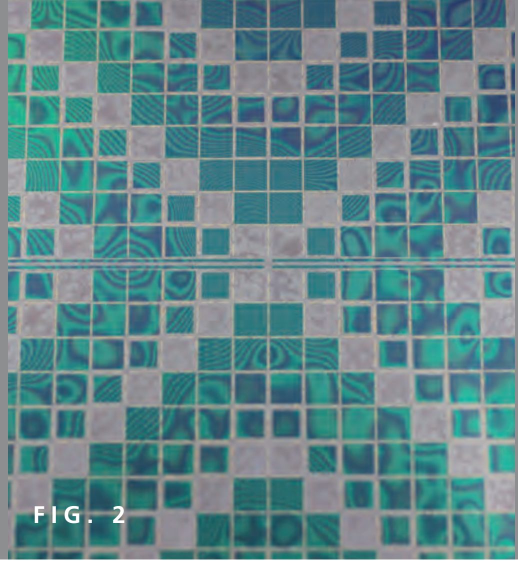

FIG. 2

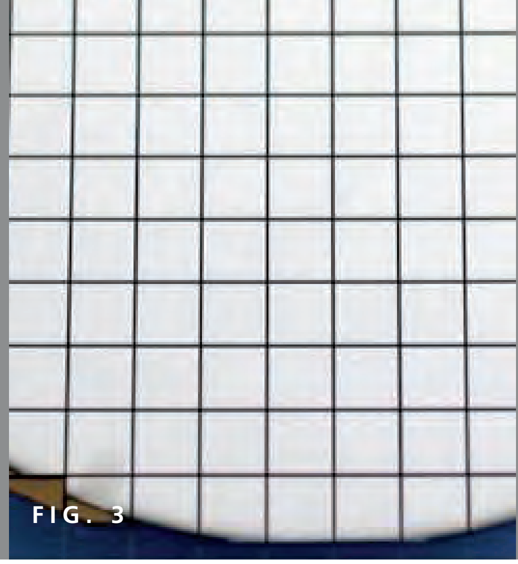

FIG. 3

HERMETIC AND ROOM TEMPERATURE WAFER-LEVEL PACKAGING BASED ON NANOSCALE ENERGETIC SYSTEMS

Jörg Bräuer, Eric Tomoscheit, Silvia Hertel, Jan Besser, Maik Wiemer

Introduction

Reactive bonding is a new wafer bonding technique and is becoming an attractive approach for MEMS packaging due to several advantages: short bonding time, high bond strength and internal heating, thus, lower process temperatures compared to traditional bonding techniques, such as glass frit bonding, can be achieved.

Reactive wafer bonding technology

Reactive wafer bonding is based on a self-sustaining exothermic reaction in integrated nanoscale energetic material systems (iRMS). Such iRMS typically consist of several alternating layers of two different thin metals, Fig. 1. The bonding approach focuses on the direct deposition and process flow integration of thin (total stack thicknesses smaller than 2.5 µm) iRMS onto the substrate. In general, the bonding partner is deposited with a bonding layer, such as Al, Au, Cu or Pd. For wafer bonding no substrate heating and no additional surface pre-treatment of metal layers is necessary.

Results and characterization

Typically Si-Si, Si-glass (cf. Fig. 2), Si-ceramic as well as ceramic-ceramic are used wafer material combinations. Bond frame widths investigated ranged from 20 µm to 500 µm and chip geometries ranged from 3 x 3 mm² to 10 x 10 mm². It could be demonstrated that high yield wafer bonding after dicing is possible, Fig. 3. Maximum shear strength of 340 MPa could be measured for different substrate combinations. In addition to that, it was proven that high-temperature stable (up to 400 °C for 400 h) as well as reliable (up to 2000 temperature shock cycles at −40 °C/ +130 °C) bond interfaces can be achieved. Hermiticity testing according to MIL-STD 883G has shown, that tight bond interfaces even for very large chips (10 x 10 mm²) can be achieved.

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Fig. 1: Microstructure of iRMS.

Fig. 2: Bonded 6" wafer glass-Si.

Fig. 3: Yield after dicing of 4" wafer – Si-Al_2O_3 ceramic (detail).

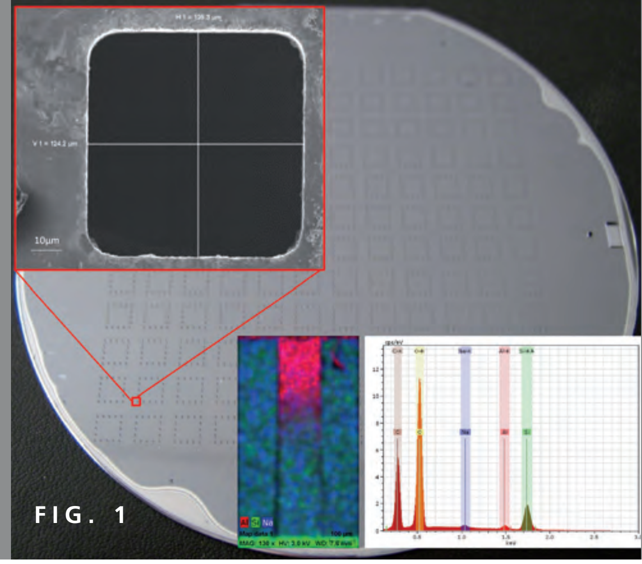

FIG. 1

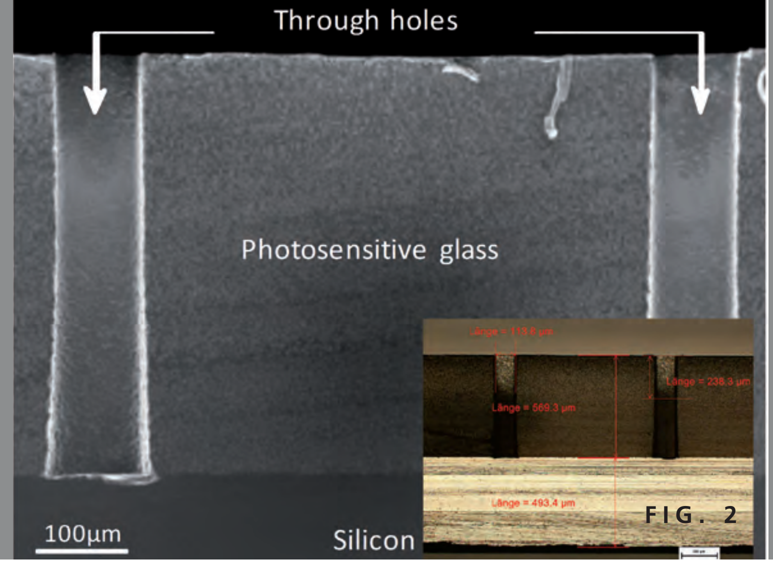

FIG. 2

3D INTEGRATION FOR MEMS DEVICES USING PHOTOSENSITIVE GLASS

Dirk Wünsch, Jan Besser, Christian Hofmann, Maik Wiemer

The global trend towards to vertical integrated devices and systems, namely 3D integration, will further enhance the need for wafer bonding. In particular, direct wafer bonding has a major advantage within the MEMS packaging because no additional intermediate layers, like in eutectic or adhesive bonding, are required. This technique uses the formation of covalent bonds caused by the atomic contact of two clean and smooth surfaces. One possibility to achieve these perfect smooth surfaces without contaminations and a sufficient flatness on wafer scale is the implementation of chemical mechanical processes (CMP) prior to bonding.

In addition to wafer bonding the creation and filling of through-holes in glass are essential for optical MEMS packaging, Fig. 1. In that context, photosensitive glasses like Foturan® are of special interest. Foturan® can be exposed directly using a 310 nm light source and standard lithography techniques. The process feasibility for fabricating a 4" Foturan®/silicon wafer-level stack was examined. The process flow includes patterning of Foturan® glass wafer, CMP of the Foturan® surfaces, pre-bonding of polished Foturan® and silicon surfaces, low temperature annealing of wafer stacks and metallization of the Foturan® through-holes via magnetron sputtering. The Foturan® through-holes are realized by a UV direct exposure with the help of a conventional lithography mask followed by an annealing step and an etching process in a 12 percent HF solution.

The CTE mismatch between silicon and Foturan® of roughly 3 requires low temperatures and activated surfaces to generate a wafer bond. After polishing the wafer stacks were directly bonded at room temperature and annealed at 150 °C. The metalized and patterned silicon Foturan® stacks were characterized by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX). Via magnetron sputtering a reliable metallization up to a depth of 200 µm could be realized, Fig. 2.

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Fig. 1: Scanning electron microscope (SEM) image of a Foturan® through-hole (left) and an optical image of a direct bonding Foturan®/silicon wafer stack (right).

Fig. 2: Energy dispersive X-ray spectroscopy (EDX) with metallization up to a depth of 200 µm.

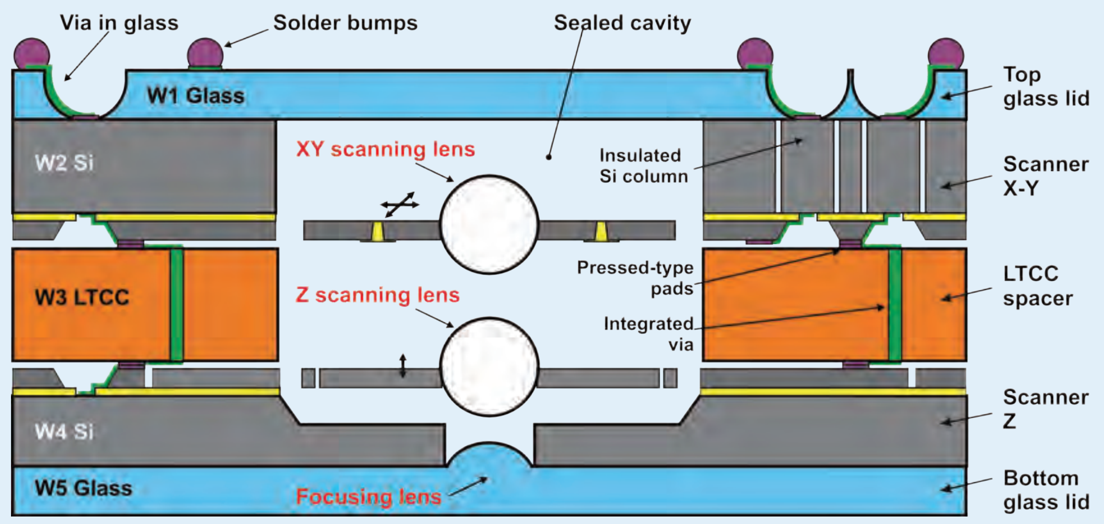

FIG. 1

BONDING AND CONTACTING OF VERTICALLY INTEGRATED 3D MICROSCANNERS

Maik Wiemer, Marco Haubold

In this work we describe the bonding and contacting of a micromachined vertically integrated 3D microscanner, which is a key component for a number of scanning imaging microsystems, such as chip based confocal microscopes or optical coherence tomography (OCT) probes for micro endoscopy. The 3D microscanner is composed of two electrostatic silicon MEMS micro actuators which are vertically aligned and anodically bonded with glass and ceramic components to create a hermetically sealed cavity for scanning microlenses, Fig 1.

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This bonding concept was chosen since it offers the potential to integrate three different materials with dissimilar CTEs. The optical systems demands for a transparent glass substrate. Hence, other materials are necessary which are compatible to the utilized glass and provides us the opportunity to fabricate the scanners as well as the spacer. The applied LTCC material has a similar CTE to glass and Si and is also anodically bondable. Silicon on the other hand is well known for forming of the X-Y and Z scanner. In conclusion the anodic bonding process, as a very simple bonding technology, is especially capable to integrate the prefabricated components into an optical system.

In order to assemble the whole MEMS scanner, seven different substrates have to be bonded. Based on this stack, three different bonding technologies are necessary. These are Si-Si direct bonding to fabricate the customized SOI substrates for scanner etching, the glass-Si anodic bonding to protect the scanner against the environment and the LTCC-Si bonding to mechanically and electrically join the X-Y scanner with the Z scanner. The LTCC substrate is used to create the space between both scanners and to allow free movement of the micro lenses. The LTCC that is being used here shows a matched CTE to silicon (3.4 ppm/°C vs. 3.2 ppm/°C) and its special composition allows for anodic bonding to silicon just as typical borosilicate glass wafers. Because the anodic bonding can only be realized between Si and glass or Si and LTCC respectively, the bonding sequence has been chosen in a way, that Si and glass or LTCC are used alternating. The bonding sequence starts with the fabrication of SOI wafers. These substrates are used to etch the X-Y scanner as well as the Z scanner. For this direct bonding a wet and plasma pre-treatment, a vacuum bonding process and an annealing step are applied. The bonding is done at low pressure (< 1×10^{-4} mbar) using a standard bonding equipment. For the annealing step the parameters are 800 °C, 6 h in nitrogen in a horizontal furnace. At the beginning of the bonding process a glass ball lens has to be integrated into the Z scanner. Subsequently, wafer no. 4 (Z scanner) and wafer no. 3 (LTCC spacer) are bonded anodically. This first stack must be bonded to the X-Y scanner based on an anodic bonding process likewise. In this case the interface consists again of LTCC and Si. From experimental results can be concluded that at bonding conditions of 400 °C and 400 V a fracture toughness value higher than 0.6 MPa$\sqrt{m}$ could be reached, corresponding to a sufficient bonding strength.

Afterwards a second lens has to be integrated into the X-Y scanner. To close the system a cap lid has to be bonded on top. The cap lid is formed from borosilicate glass and can be anodically bonded to the scanner stack. The glass wafer contains isotropically etched holes for contacting the underlying layers. The last step to realize a hermetic sealing a bottom lid made of glass must be bonded on the bottom side of the Z scanner. That can also be done anodically. For example, the anodic bonding between silicon and glass can be performed at 360 °C to 400 °C and 600 V to 800 V.

Because all the necessary contacts (GND, driving voltage 4x – X-Y scanner and 1x – Z scanner) should be arranged on the top side of the top lid, vertical through silicon/glass/LTCC vias have to be integrated. During the wafer bonding the contacts on each wafer must be connected to the next level. The contacts between the wafers W2 and W4 and the ceramic wafer W3 are formed by gold thermo compression bonding during the anodic bonding processes. The used chromium and gold layer thicknesses are 20 nm and 200 nm respectively, deposited by sputtering. The thermo compression bonding was done in a wafer bonder at 400 °C for 30 minutes at a tool pressure of 7 MPa. After annealing at 300 °C for 3 h the contact resistance decreased to a mean value of 3.2 ohm, having a contact area of 100 µm x 100 µm. The contacts inside the holes of the top glass lid are formed by a sputtered chromium/gold multilayer (thickness 20 nm / 1000 nm) directly after the wafer bonding process.

The reliability of the contacts has been tested by thermal shock cycles (100 cycles, –40 °C to +120 °C, 30 min – 1 min – 30 min). To compare the results we measured the pull strength before and after shock loading which did not show significant influence to the fracture force.

Fig. 1: Cross-sectional view of 3D microscanner.

DEPARTMENT
ADVANCED SYSTEM ENGINEERING

Head of Department: Dr. Christian Hedayat
in cooperation with Prof. Dr. Ulrich Hilleringmann

The department Advanced System Engineering (ASE) focuses its research and development activities on the topics design, simulation and characterization of micro and nano electronic systems. In this context all design stages – starting from circuit design over system integration up to the investigation of electromagnetic reliability – are considered.

The department works in close collaboration with the University of Paderborn on developing simulation methods for heterogeneous micro and nano electronic systems as well as for specific wireless devices such as RFID systems. The goal of all these activities is the characterization and optimization of complex electronic systems in order to assess their electromagnetic reliability as well as the signal and clock integrity at high frequencies. This is done not only at the IC-level but also for packages, modules and PCB. This research provides a crucial contribution to the development of reliable miniaturized systems.

The main competences and long-term experiences of the department ASE are in the fields of:

- RFID antennas and circuits,
- Advanced 3D near-EM-field scanning,
- Advanced modeling and analysis of EMC and SI effects,
- Mobile wireless smart sensor systems,
- EMC/EMR of micro and nano electronic systems,
- Design methodologies for device integration,
- Efficient modeling and simulation methodologies for mixed-signal devices,
- Model based development methods for heterogeneous systems in package.

Today's electronic development is much more complicated than just some years ago. While electronic components become smaller, the signal-to-noise ratio as well as the absolute signal level decreases. This necessitates methods for the precise measurement and calculation of electromagnetic effects of analogue and mixed signal systems. In this context the competences of the department ASE concerning electromagnetic reliability and model driven design can support the system designer with efficient fast simulation methodologies (like black box modeling and event-driven modeling).

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Unfortunately not all parasitic and coupling effects of complex high density systems can be predicted with the help of such EDA tools and the associated simulation approaches during the design phase. Therefore it is very helpful for the system designer to have the possibility to visualize the EM field of first prototypes with the help of the new 3D near-field scanning technology developed by Fraunhofer ENAS, department ASE. This technology provides a powerful methodology allowing the precise detection of coupling paths and the characterization of antenna patterns (e.g., RFID design). Necessary redesigns can be efficiently realized and evaluated.

These areas have been systematically developed and their success is reflected in numerous R&D projects in collaboration with industry partners, specifically MESDIE (MEDEA+), PARACHUTE (MEDEA+), EMCpack (PIDEA+), JTI Clean Sky (EU), PARIFLEX (BMBF), A3NFM (BMWI/AiF), SUPA (BMWI/AiF) and EMC Cubuslay (BMWI/AiF).

The Fraunhofer ENAS department ASE closely cooperates with the University of Paderborn (Faculty of Electrical Engineering, Computer Science and Mathematics) within the competence network future EMC/RF modeling and simulation methodologies. A very close cooperation exists especially with Prof. Dr. Ulrich Hilleringmann, Chair for Sensor Technology at the Department of Electrical Engineering and Information Technology of the University of Paderborn.

Prof. Dr. Ulrich Hilleringmann

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Current works and research fields

The design of complex modern electronic devices requires the usage of adequate system level modeling technologies. ASE supports these requirements by the development of black box modeling approaches, analogue circuit and mixed-signal simulation concepts as well as event-driven simulation methods. Electromagnetic and thermal aspects of such systems can be analyzed by state of the art measurement and accompanying 3D field simulation. Such methodology is necessary to predict and guarantee the reliability of power and high-speed systems.

The developed modeling and simulation concepts have been enclosed within an object-oriented library that has been implemented within the EDA-tools of our industrial partners.
By the use of high-performance measurement equipment various microelectronic systems and integrated components can be optimally characterized with respect to physical and EMC/SI/RF constraints. A central part in this context is the innovative self-developed near-field scanning system that maps the electromagnetic field emitted by a device under test. It integrates a high-precision 3D shape acquisition system for a collision-free close-contact near-

field measurement with a high spatial resolution of the electromagnetic field distribution. Besides the efficient simulation and the design of advanced micro packaged systems, a solid know-how is developed in the area of mixed-signal IC modeling and design methodologies for reliable clock synthesizing systems (such as Phase Locked Loops).

The design activities concentrate not only on electronic systems for telecommunications, radar and automotive applications, but also on the challenging new area of energy harvesting and smart wireless sensor systems. The department focuses here in particular on the design of optimized antenna and energy management strategies.

Competences and services

The main competences of the department ASE are:

- Wireless energy supplies,
- Mobile wireless smart sensor systems,
- RFID antennas and circuits,
- Advanced modeling and analysis of EMC and SI effects,
- EMC/EMR of micro and nano electronic systems,
- Design methodologies for multiple device integration,
- System modeling and simulation,
- Model based development methods for heterogeneous systems in package,
- Advanced 3D near-field scanning (high spatial resolution, 9.0 kHz – 6.0 Hz),
- RF and EMC characterization through modeling,
- RF and EMC measurement up to 20 GHz,
- Measurements on wafer,
- Modeling and simulation using
  - » CST µWave Studio,
  - » AnSys (HFSS),
  - » Cadence (HSPICE and Spectra),
  - » Customer-specific solutions.

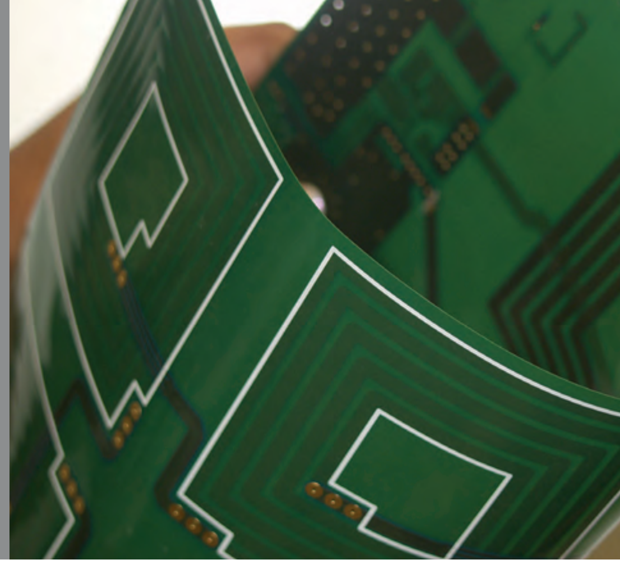

FIG. 1

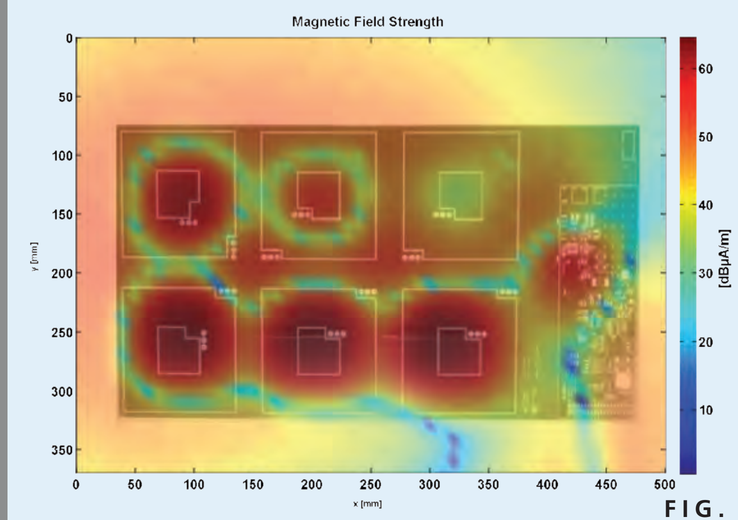

FIG. 2

SUPA – THE INVISIBLE REVOLUTION

Maik-Julian Büker, Volker Geneiß, Ulrich Hilleringmann, Christian Hedayat, Thomas Gessner

The conference table of the future will show no more cables: Notebooks will be supplied directly via the desktop with power and are connected by wireless USB or WiFi to the local network and to the projector.
To let this vision become reality, the department ASE has developed the base of this innovative technology together with a consortium of industrial companies within the scope of the project SUPA (Smart Universal Power Antenna) promoted by the Federal Ministry of Economy and Technology (BMWi).
SUPA is the wireless infrastructure of the future for the data transfer and energy supply of mobile devices. The inductive power supply system consists of a transmitter and a receiver unit. The transmitter unit is invisibly integrated inside or below surfaces and transfers the power as well as the data to the SUPA compatible user device (e.g., a smart phone or a notebook).
The challenge of this development is to insure that the complete furniture surface can be used for the power transfer and that a maximum power of 50 W can be supplied to each single device on the table.
Because the power antenna system also includes a data antenna, various devices, such as TFT monitors or notebooks, can be wirelessly connected by this technology. Besides, the working range for data and energy transference is consciously minimized (approx. 5 cm to 10 cm). This leads to a low radiation level and optimizes the safety and the confidentiality of the data exchange.
It is planned to obstruct SUPA transmitter modules in all office and public areas to achieve a wide cover of supply points. To reach this goal a huge number of contacts with famous manufacturers from the areas of IT, tool machines and the furniture branch have been built up in the course of the last two years.

On October 22, 2012, the start-up company "SUPA wireless GmbH" was founded. The aim of this company is to further develop the technology by adapting it to specific custom needs and to introduce it into the market. There are various prospective applications, such as the integration of the transmit antennas into office desks. For example an ultrabook equipped with a corresponding flat receiving antenna could be powered wirelessly once it is placed on the desktop. Together with Fujitsu Technology Solutions and the Fraunhofer ENAS department ASE the new company is currently implementing the new technology into a marketable product.

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Following enterprises and universities take part in the project SUPA beside Fraunhofer ENAS:

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

CHRISTMANN
INFORMATIONSTECHNIK + MEDIEN

EUSKIRCHEN
MANUFAKTUR

HOTOPRINT

The project is funded by:

Bundesministerium
für Bildung
und Forschung

ZIM
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Zentrales Innovationsprogramm Mittelstand
Kooperationen

Fig. 1: Array of sending antennas on flexible PCB.

Fig. 2: Magnetic field distribution of the activated antennas.

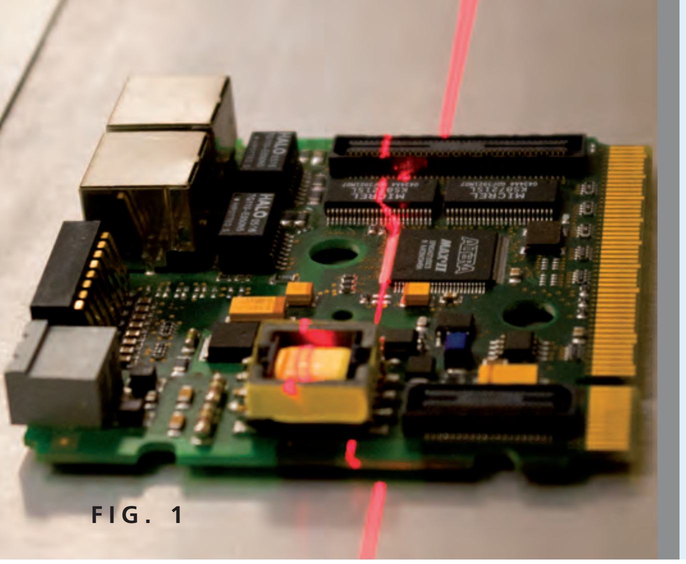

FIG. 1

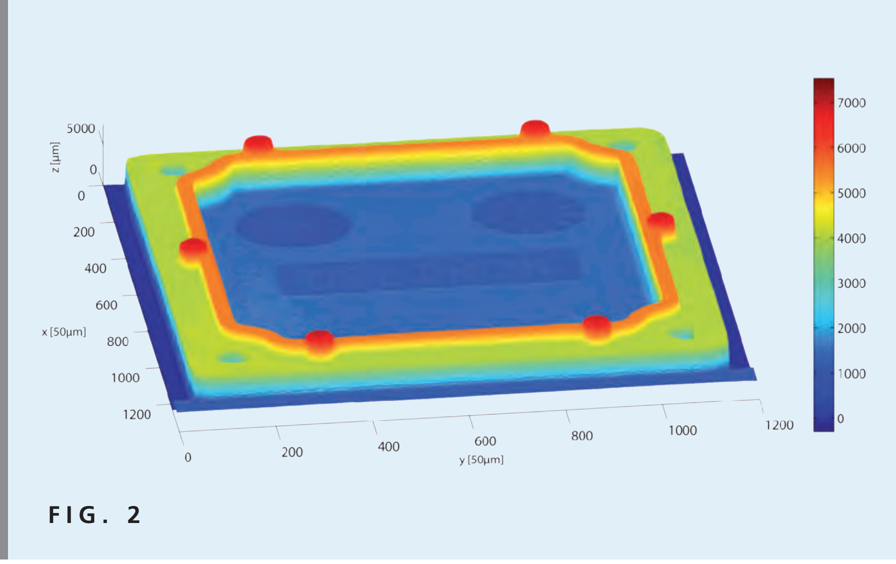

FIG. 2

A HIGH-PRECISION 3D SCAN FOR OPTIMAL NEAR-FIELD SCANNING

Matthias Bachmann, Britta Gerken, Thomas Mager, Christian Hedayat

As electronic components become smaller, their signal-to-noise ratio decreases, making every new generation of a circuit more sensitive to perturbations. For the developers of electronic circuits this means that they increasingly need to consider the electromagnetic compatibility (EMC) of their systems. The 3D near-field scanner is a novel measurement device for EMC analysis close to the surface of electronic components and assemblies. For optimal sensitivity the EM field probe must be placed and moved as close as possible over the surface of the device under test (DUT) without colliding with it. Therefore a very precise knowledge of the dimensions and the contour of the DUT is needed and a high-precision contactless shape acquisition system (SAS) is necessary.

Current high-precision contactless 3D reconstruction technologies such as interferometry, confocal microscopy or computer tomography require very expensive hardware and long measurement times. A fast, reliable and cost-effective technology is the laser light sectioning technique commonly known as 3D laser scanning. Its precision is sufficient for the purpose of industrial quality inspection or art digitalization especially when homogeneous matt nonmetallic surfaces are considered. However the high-precision requirements of the 3D near-field scanning domain and the complex contour of the DUT surface require more accuracy and robustness.

The precision of the 3D laser scan data is decreased by different measurement errors which originate either in the imaging process or in the process of laser-surface interaction. It has been shown by previous work that the errors in the imaging process can be significantly reduced using a 3D camera model and an automatic calibration routine. But the effects of the laser surface interaction such as reflections on metallic parts or laser speckle noise could not be processed with without reliable image data or a reflection model.

The aim of this research project, carried out by Fraunhofer ENAS together with the Technical University of Dortmund (TUD)'s department for Image Processing, consists in the development of methods for the enhancement of 3D laser scanning data with a high resolution image based 3D reconstruction technique known as photometric stereo or shape from shading.

Within this project, the partner TUD provides the expertise in the area of photometric stereo, reflection models and radiance map generation. The main focus of the work of the department ASE consists in the integration and quantitative evaluation of the image based methodology. Therefore precise registration algorithms are a crucial issue as well as quantitative accuracy examination tests including special examination bodies.

The development of the SAS addresses not only the near-field scanning domain, but also other applications where precise 3D models have to be created from existing parts.

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The following research institutions take part in the project beside Fraunhofer ENAS:

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

technische universität dortmund

The project is funded by:

Bundesministerium für Bildung und Forschung

ZIM impulse für wachstum
Zentrales Innovationsprogramm Mittelstand Kooperationen

Fig. 1: Contactless 3D shaping of an electronical system using laser light sectioning technique.

Fig. 2: 3D reconstruction of an aluminium cover plate.

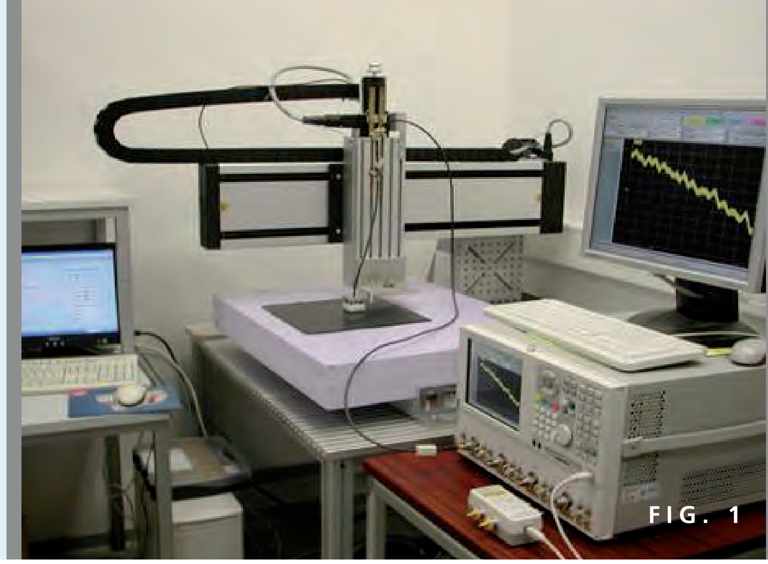

FIG. 1

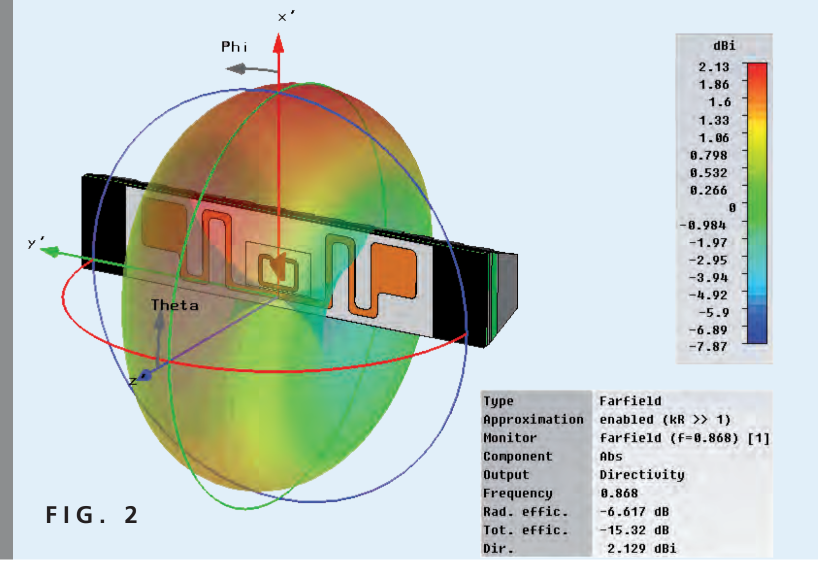

FIG. 2

TRACKING/AUTHENTICATION OF HETEROGENEOUS OBJECT USING EMBEDDED UHF RFID TAG

Kelash Kanwar, Volker Geneiß, Thomas Mager, Ulrich Hilleringmann, Christian Hedayat

RFID technology is widely used in various industries to track, identify or authenticate objects by attaching an electronic tag to it. In this context, one industrial application focused at the department ASE of the Fraunhofer ENAS is the embedding of RFID tags inside heterogonous materials like rubber belts. An exhaustive feasibility study was done for Optibelt GmbH by embedding special designed RFID tags inside their transmission belts. Major aim of the project was to improve the logistic handling of various kinds of rubber transmission belts.

The first step to achieve the desired objective was the selection of an appropriate RFID frequency. The RFID technology works at different ISM frequency bands (LF, HF, UHF e.t.c) and the UHF band (865-868 MHz) was selected due to its combined advantages in terms of overall implementation costs, tag size, high read range and tag operation independent of line of sight.

Commercial available UHF RFID tags were tested for this purpose but their physical dimensions and their performance in terms of read range was not sufficient for the Optibelt transmission rubber belts. The performance of such RFID tags decrease mainly because of the characteristic parameters of the various rubber belts like relative permittivity, tangent loss, shapes and thickness. Therefore, it was required to design specific RFID tags in order to ensure the desired performances in terms of operating range and wide directivity. Therefore it is indispensable to know the electrical parameters of the different materials which are used in the fabrication of various kinds of rubber belts. For that reason a simple and cheap measurement setup was built in the lab. Based on the gathered results, an optimized tag antenna has been designed with the help of electromagnetic simulations involving an appropriate CAD model of a rubber belt and taking into account its real electrical and geometrical parameters. The major benefit of the electrical modeling of complex structures is that it enables the easy characterization and optimization of tag antenna parameters like gain, directivity and impedance match. Using this approach, further optimized tag antennas designs can be performed for any kind of rubber belts.

After solving the problems concerning the embedding of RFID tags to rubber materials, the next step is the implementation of sensor functionalities into the tags in order to monitor physical parameters like temperature, strain or pressure during operation. Currently available RFID modules with sensing applications are typically big and need additional power supply or do not operate at UHF band. The design of such small, energy-efficient and integrated sensing tags for the use in heterogeneous and harsh environments is a great challenge for future purposes.

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Following enterprises and universities take part in the project beside Fraunhofer ENAS:

optibelt

UHF tagItron

UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

Fig. 1: CAD-Model of an RFI tag embedded in a rubber belt.

Fig. 2: Measurement set-up for the characterization of the electrical parameters ε and tan(δ).

COOPERATION

WITH SCIENCE AND INDUSTRY

COOPERATION WITH enviaM

The Mitteldeutsche Netzgesellschaft Strom mbH (MITNETZ STROM) is a energy provider and has an electric supply network of nearly 26,000 km^2, which is located in Saxony, Saxony-Anhalt, Brandenburg and parts of Thuringia. We asked Kay Lehman to answer some questions.

Fraunhofer ENAS: Germany has decided to use more and more renewable energies like wind or solar energy. What are the main challenges behind?
Kay Lehmann: The electrical power grid in Germany, for historical reasons, has been constructed as a top-down system. This means that the electrical energy is generated in large quantities in the power plants, and then transferred to the consumer. But this principle of centralized power generation will no longer exist in future. Due to the increased input of renewable energy there is sometimes more energy available than can be used in the respective areas. The volatile energy carriers wind and solar radiation are also still dependent on the daytime and weather, which also complicates the exact calculation of the necessary transport capacity. The high-voltage grids have limited capacity because they are as I said originally not designed for such a duty. An obvious solution would be the extension and reconstruction of the power grids. But the authorization procedures for new overhead lines can sometimes take up to 10 years. The development of renewable energy is still increasing and thus there have to be other solution options. One of them is overhead power line monitoring.

Fraunhofer ENAS: With respect to power line monitoring enviaM has strongly supported the development of the ASTROSE system. What are the benefits of such a system?
Kay Lehmann: The most important parameters for the overhead line operation are sag, current flow and the conductor temperature which are all interdependent. With raising current flow the temperature increases and therefore also the sag. To minimize the risks posed by the high voltage, certain external clearances of the conductors to other objects have to be observed. With an increased feeding of wind energy the fixed limit of the continuous current rating can quickly be reached. The power input needs to be stopped. But the wind does not only power the wind turbines, it also cools the conductors. It is possible that the lines still not have reached their proper cut capacity, it is hard to determine how strong this cooling actually is. ASTROSE can help here. The system determines the actual sag, the temperature and the current flow in every span of the power line. So the actual capacity of the overhead line can be determined and renewable energies can be integrated better.

Fraunhofer ENAS: Resuming the project, what has worked well, what needs improvement?
Kay Lehmann: The whole project was characterized by a high effectiveness and real innovation. This needs to be uprated as the team consists of partners from different research institutes. Especially has to be mentioned, that the project managers from Fraunhofer ENAS and Fraunhofer IZM did a great job.

About Kay Lehmann:
Kay Lehman studied electrical power engineering at the BTU Cottbus. In 1997 he started to work as an engineer for power system planning at ESSAG. After the fusion to enviaM as well as the foundation of the electrical utility companies of the enviaM group he is responsible for the basics of project management and mains operation since 2008. The development of innovative network technologies, among them the implementation of ASTROSE (described on page 30) in the 110 kV overhead system of the MITNETZ Strom, belongs to his tasks.

About enviaM:
The enviaM group has nearly 1.5 million customers and is so the leading regional energy provider in the eastern part of Germany. 19 companies belong to enviaM group. The biggest one is the enviaM AG.

For more information, please visit www.enviam.de

COOPERATION WITH INDUSTRY WITHIN THE GERMAN LEADING-EDGE CLUSTERS PROGRAM

The Federal Ministry of Education and Research launched a competition in the summer of 2007 under the slogan "Germany's Leading-Edge Clusters - more innovation, more growth, more employment". There were 15 clusters selected within three rounds of the competition. The regional concentration of innovative players is a key characteristic of each cluster. The basis for the selection and funding of a Leading-Edge Cluster is the development of common strategic goals and the definition of future development projects in a particular area of technology. The involvement of the key players in the region's innovation and value-added chains is a major prerequisite. Each cluster gets a funding over 5 years.
The Fraunhofer Institute for Electronic Nano Systems is a reliable partner in two Leading-Edge Clusters of Germany. One is the cluster "Cool Silicon" in Saxony and the second one is "it's OWL".

The projects are funded by:

Bundesministerium
für Bildung
und Forschung

Cool Silicon

The aim of the Leading-Edge Cluster "Cool Silicon" is to build the technology basis for a massive increase of energy efficiency in the information and communications technology (ICT) sector. The cluster has started to work in 2009. Currently 98 partners are working in the Leading-Edge Cluster. Fraunhofer ENAS participates in two areas. The first one is Area 1 – Micro and Nanotechnologies: Technologies for energy-efficient computing platforms. The second one is Area 3 - Networked Sensors, which dedicated to the development of energy autarkic, wireless sensor networks.
For more information please visit: www.cool-silicon.de/en

COOL SiLiCON

it's OWL

Starting in 2012, 174 companies, universities, research institutes of East-Westphalia-Lippe are working within the Leading-Edge Cluster "it's OWL". The aim of the cluster is to develop smart technical systems for companies working in mechanical engineering, electrical engineering and automotive. The contribution of our department Advanced System Engineering within this cluster focuses on the field of intelligent self-organized wireless sensor nodes and sensor networks.
For more information please visit: www.its-owl.de

it's owl
Intelligente Technische Systeme
OstWestfalenLippe

COOPERATION WITH INDUSTRY (SELECTION)

3D-Micromac AG, Chemnitz, Germany

Advanced Micro Devices (AMD), Sunnyvale, USA
Advaplan Inc., Espoo, Finland
Air Products and Chemicals, Inc., Allentown (PA) and Carlsbad (CA), USA
Airbus Deutschland GmbH, Bremen, Germany
Alenia Aeronautics, Casoria, Italy
alpha-board gmbh, Berlin, Germany
AMIC Angewandte Micro-Messtechnik GmbH, Berlin, Germany
Amitronics GmbH, Seefeld, Germany
AMO GmbH, Aachen, Germany
Amprion GmbH, Dortmund, Germany
AMTECH GmbH, Chemnitz, Germany
Analog Devices, Raheen, Ireland
Arentz Optibelt, Höxter, Germany
austriamicrosystems AG, Unterpremstätten, Austria
AVANTOR Performance Materials, Europe
AVL List GmbH, Graz, Austria
AXUS Technologies, Chandler (AZ), USA

Benteler Automobiltechnik GmbH, Paderborn, Germany
Berliner Nanotest and Design GmbH, Berlin, Germany
BiFlow Systems GmbH, Chemnitz, Germany
BioTec-Klute GmbH, Paderborn-Borchen, Germany
Boehringer, Ingelheim, Germany
Robert Bosch GmbH, Reutlingen and Stuttgart, Germany
Bruker Biospin, Karlsruhe, Germany
BuS GmbH, Riesa, Germany
CAD-FEM GmbH, Grafing, Germany
Cascade Microtech Dresden GmbH, Germany
Centro Ricerche Fiat S.C.p.A., Turin, Italy
Chemnitzer Werkstoffmechanik GmbH, Chemnitz, Germany
Christmann Informationstechnik + Medien GmbH, Ilsede, Germany

CLAAS KGaA mbH, Harsewinkel, Germany
Clean Tech Campus GmbH, Chemnitz, Germany
Continental AG, Germany
Continental Automotive GmbH, Regensburg and Nuremberg, Germany
CREAVAC-Creative Vakuumbeschichtung GmbH, Dresden, Germany

DAS Photonics SL, Valencia, Spain
DBI – Gastechnologisches Institut gGmbH, Freiberg, Germany
DBI Gas- und Umwelttechnik GmbH, Leipzig, Germany
Denso Corporation, Kariya, Japan
Diehl Hydrometer, Arnsbach, Germany
Digades GmbH, Zittau, Germany
DiscoEurope, Kirchheim, Germany
Drägerwerk AG & Co. KGaA, Lübeck, Germany

EADS Deutschland GmbH, Corporate Research Center Germany, Department Microsystems, Munich, Germany
EADS Innovation Works, Munich, Germany
EDC Electronic Design Chemnitz GmbH, Chemnitz, Germany
ELMOS Semiconductor AG, Dortmund, Germany
elprotek GmbH, Buchen, Germany
Endress und Hauser AG & Co. KG, Stahnsdorf, Germany
enviaM GmbH, Halle, Germany
EPCOS AG, Munich, Germany
Erwin Halder KG, Achstetten-Bronnen, Germany
EV Group Europe & Asia/Pacific GmbH, St. Florian am Inn, Austria
EVOLEO Technologies Lda, Maia, Portugal
Exalos AG, Schlieren, Switzerland

FACRI, Xi´an, China
Fairchild Semiconductor GmbH, Aschheim, Germany
First Sensor Technology GmbH, Berlin, Germany
Flexo-Print Bedienfelder GmbH, Salzkotten, Germany
Frottana Textil GmbH & Co. KG, Großschönau, Germany
FSG Automotive GmbH, Oelsnitz, Germany

GEMAC, Chemnitz, Germany
Gemalto, La Ciotat, France
GFal, Teltow, Germany
GF Messtechnik, Teltow, Germany
GPP Chemnitz – Gesellschaft für Prozeßrechner-programmierung mbH, Chemnitz, Germany
GLOBALFOUNDRIES, Dresden, Germany
Gyrooptics Company Ltd., St. Petersburg, Russia

Häcker Automation GmbH, Schwarzhausen, Germany
Helenic Aerospace Industry S.A., Schimatari, Greece
Hella, Lippstadt and Bremen, Germany
Hispano Suiza, Colombes (Paris), France
Hotoprint Elektronik GmbH & Co. KG – Leiterplatten, Lamspringe, Germany
Huawei Technologies CO., LTD – Telecommunication Products, Düsseldorf, Germany, and Shenzhen, China

IBM, Zurich, Switzerland
IFU-Diagnostic Systems GmbH, Lichtenau, Germany
Impact Clean Power Technology S.A., Warszawa, Poland
Infineon Technologies AG, Munich, Dresden and Warstein, Germany, and Villach, Austria, and Bristol, UK
InfraTec GmbH, Dresden, Germany
Intel, Sophia Antipolis, France
IoLiTec Ionic Liquids Technologies GmbH, Heilbronn, Germany

Jenoptik Lasersystems, Jena, Germany
JUMATECH GmbH, Eckental, Germany

KE Elektronic, Limbach-Oberfrohna, Germany
KEMET Electronics Italia srl, Sasso Marconi, Italy
KSG Leiterplatten GmbH, Gornsdorf, Germany

LG Electronics, Korea

M&S Mikrotechnik und Sensorik GmbH, Hermsdorf, Germany
Magh und Boppert, Paderborn, Germany
MED-EL Medical Electronics, Innsbruck, Austria
MELEXIS, Bevaix, Switzerland
memsfab GmbH, Chemnitz, Germany
micro resist technology GmbH, Berlin, Germany
Microelectronic Packaging Dresden GmbH, Dresden, Germany
MicroSystems, Wüstenbrand, Germany
mikroglas chemtech GmbH, Mainz, Germany
Multitape GmbH, Büren-Ahden, Germany

NB Technologies GmbH, Bremen, Germany
neoplas control GmbH, Greifswald, Germany
Northroup Grumman LITEF GmbH, Freiburg, Germany
NXP, Eindhoven, The Netherlands, and Hamburg, Germany

Ocè B.V., Venlo, The Netherlands
Optibelt GmbH, Höxter, Germany
OSRAM Opto Semiconductors GmbH, Regensburg, Germany

paragon AG, Delbrück, Germany
Philips Applied Technologies, Eindhoven, The Netherlands
Phoenix Contact, Blomberg, Germany
printechnologics GmbH, Chemnitz, Germany
ProTec Carrier Systems GmbH, Siegen, Germany
PVATePla AG, Feldkirchen, Germany

LONG-TERM COOPERATION WITH TOHOKU UNIVERSITY IN SENDAI, JAPAN

Rainer Euskirchen Büro-Design GmbH, Bielefeld, Germany
RF-Embedded GmbH, Stephanskirchen, Germany
RHe Microsystems GmbH, Radeberg
Ricoh Company, Ltd., Yokohama, Japan
Rohde & Schwarz GmbH & Co. KG, Munich, Germany
Rolf Schäfer Beschichtungskomponenten (robeko), Münchweiler, Germany
Roth & Rau AG, Hohenstein-Ernstthal, Germany
RWE AG, Essen, Germany

Sagem Orga GmbH, Paderborn, Germany
SAW Components Dresden GmbH, Germany
Schaeffler Group, Germany
Schenker Deutschland AG, Dresden, Germany
Schott Mainz & Schott Glas, Landshut, Germany
Schreiner Group GmbH & Co. KG, Oberschleißheim, Germany
Sedemat GmbH, Oelsnitz, Germany
Senseor, Sophia Antipolis, France
Sensitec GmbH, Lahnau, Germany
Sentech Instruments GmbH, Berlin, Germany
SF Automotive GmbH, Freiberg, Germany
SHINKO ELECTRIC INDUSTRIES CO., LTD., Nagano, Japan
SICK AG, Waldkirch and Ottendorf-Okrilla, Germany
Siegert TFT GmbH, Hermsdorf, Germany
Siemens AG, München, Germany
Silex Microsystems, Sweden
SMD-Production-Technology, Krefeld, Germany
Solardynamik GmbH, Berlin, Germany
Sony Corp., Semiconductor Business Unit, Japan
STF Schweißtechnische Fertigung GmbH, Chemnitz, Germany
ST Microelectronics, Crolles and Paris, France, Agrate Brianza, Italy, and Munich, Germany
SÜSS Microtec AG, Munich and Sternenfels, Germany

tagltron GmbH, Paderborn-Salzkotten, Germany
TAKATA Sachsen GmbH, Elterlein, Germany
TDK-EPC AG & Co. KG, Berlin, Germany
Thales-Avionics, Valence and Orsay, France
Toyota, Japan
TQ-Systems GmbH, Chemnitz, Germany
Turboméca, Bordes, France

Unilab GmbH, Düsseldorf, Germany

Volvo, Goeteborg, Sweden
VW Oelsnitz, Germany

Wincor-Nixdorf, Paderborn, Germany

X-FAB SEMICONDUCTOR FOUNDRIES AG, Erfurt and Dresden, Germany

Zentrum Mikroelektronik Dresden AG, Dresden, Germany
Zuken GmbH, Hallbergmoos, Germany

All institutes of the Fraunhofer-Gesellschaft are focusing on applied research. For that reason also Fraunhofer ENAS has established a strong cooperation with industry on the one hand. To be successful for a long time the institute also needs basic research on the other hand. For that reason Fraunhofer ENAS cooperates with national and international universities. We asked Professor Masayoshi Esashi, one of the worldwide MEMS pioneers, to answer some questions concerning the cooperation between Fraunhofer ENAS and Tohoku University in Sendai, Japan.

Fraunhofer ENAS: Prof. Esashi, Tohoku University and Fraunhofer ENAS have developed a long-term relationship of trust. What are the reasons for a university like Tohoku University to cooperate with Fraunhofer-Gesellschaft?
Prof. Esashi: It is beneficial for us to learn the successful collaboration system with University and industry in Fraunhofer ENAS. Owing to our cooperation we have achieved successful results especially in the fields of packaging technologies and MEMS materials.

Fraunhofer ENAS: In 2012 the Fraunhofer Project Center has been established in Sendai. What are your expectations?
Prof. Esashi: The Fraunhofer Project Center is named "NEMS/MEMS Devices and Manufacturing Technologies at Tohoku University". We expect to apply our achievements including patents to industry and to have more closer relationship with companies.

Fraunhofer ENAS: Resuming the last years of cooperation, what has worked well, what needs improvement?
Prof. Esashi: We have a long-term cooperation. In 2012 just the 8th Fraunhofer Symposium within the Sendai Micro Nano International Forum was held. We could have closer mutual understanding between Prof. Gessner (the director of Fraunhofer ENAS), Prof. Kotani (the director of WPI-AIMR) and Prof. Satomi (the president of Tohoku University) during the 8th Fraunhofer Symposium.

About Prof. Esashi:
Masayoshi Esashi received the B.E. degree in electronic engineering in 1971 and the Doctor of Engineering degree in 1976 at Tohoku University. He served as a research associate from 1976 and an associate professor from 1981 in Tohoku University. Since 1990 he has been a professor. Since 2008 he belongs to the honorary doctors of the Faculty Electrical Engineering and Information Technology of the Chemnitz University of Technology. Now Prof. Esashi is working in the World Premier International Research Center – Advanced Institute for Materials Research (WPI-AIMR) and the director of Micro System Integration Center (μSIC) at Tohoku University.

About Tohoku University:
The university was established in 1907 as Japan's third Imperial University, it became the first Japanese university to accept female students. Tohoku University has become one of Japan's leading universities, with 10 faculties, 16 graduate schools, 3 professional graduate schools, 6 research institutes, and affiliated research and education centers. In 2007 the Japanese government has created so-called World Premier International Research Center at excellent universities with the goal to promote outstanding, international visible research. So the Advanced Institute for Materials Research had been established at the Tohoku University.

For more information, please visit www.tohoku.ac.jp

COOPERATION WITH NATIONAL AND INTERNATIONAL UNIVERSITIES AND RESEARCH INSTITUTES

Interdisciplinary cooperation is the key for success. In order to realize research targets Fraunhofer ENAS has established a strategic network with universities in Germany and worldwide.

Cooperation with universities in Germany

A very strong cooperation exists with the Chemnitz University of Technology especially with the Faculties of Electrical Engineering and Information Technology, Natural Sciences and Mechanical Engineering. This cooperation ensures synergies between the basic research conducted at the Chemnitz University of Technology (CUT) and the more application-oriented research at the Fraunhofer ENAS.

The main cooperation partner at the Chemnitz University of Technology is the Center for Microtechnologies, which belongs to the Faculty of Electrical Engineering and Information Technology. Together with the Center for Microtechnologies the Fraunhofer ENAS carries out research and development in the fields micro and nanoelectronics, micro mechanics and microsystems technologies.
Main topics are:

- Development of technologies and components for micro and nano electromechanical systems, like sensors, actuators, arrays,
- Development of technologies for metallization systems in micro and nanoelectronics,
- Design of components and systems,
- Nanotechnologies, components and ultrathin functional layers.

The cooperation results in a common use of equipment, facilities and infrastructure as well as in the cooperation in research projects, like nanett "nanosystem integration network of excellence" and international research training group "Materials and Concepts for Advanced Interconnects and Nanosystems" as well as support for the DFG research unit "sensoric micro and nano systems".

Printed functionalities and lightweight structures are topics of the cooperation with the Faculty of Mechanical Engineering. Printing technologies are just well established at the Chair of Digital Printing and Imaging Technology. Using printing technologies conducting, insulating and semiconducting materials are printed and used for different functionalities, starting from antennas up to batteries.

The department Advanced System Engineering located in Paderborn continues the close cooperation with the University Paderborn especially in the field of electromagnetic reliability and compatibility as well as SUPA technology.

Within the clusters of excellence and the leading edge cluster program of Germany Fraunhofer ENAS cooperates with the excellence university TU Dresden.

International cooperation

The Fraunhofer Institute for Electronic Nano Systems ENAS maintains a close contact with numerous other universities and research institutes via participation in projects and European technology platforms.

Heterogeneous Technology Alliance HTA
Together with the other institutes of the Fraunhofer Group Microelectronics Fraunhofer ENAS participates in the Heterogeneous Technologies Alliance. Together with CEA-Leti, CSEM and VTT joint research projects are acquired and done. HTA is a novel approach to creating and developing microtechnologies, nanoelectronics, and smart systems for next-generation products and solutions. By pooling the capabilities and facilities of the four leading European microelectronics research bodies the HTA creates coherence and synergies between leading teams and research infrastructures in the fields of miniaturization and systems integration.

Cooperation with universities in Asia
In Asia, long-term cooperation exists with the Tohoku University in Sendai, the Fudan University Shanghai and the Shanghai Jiao Tong University. Two examples will be given.

The cooperation of both, Fraunhofer ENAS and also Center for Microtechnologies, with the Tohoku University in Sendai, Japan, is a very successful one. As a principal investigator Prof. Dr. Thomas Gessner got an own WPI research group belonging to the division Device/Systems within the WPI Advanced Institute for Material Research. The group is managed by Prof. Yu-Ching Lin since November 2008. Focus of the research is smart systems integration of MEMS/NEMS, especially the integration of heat generating materials for wafer bonding, the integration of CMOS and MEMS as well as the fabrication of nanostructures using self-organizing and self-assembling. This cooperation has been strengthened by the Fraunhofer project center "NEMS / MEMS Devices and Manufacturing Technologies at Tohoku University" which started to work in April 2012. It is the first project center of the Fraunhofer-Gesellschaft in Japan. The basic science together with excellent scientists at Tohoku University, the exchange of scientific results and the development of new applications as well as patents belong to the main objectives of the project center.

Within the international graduate school "Materials and Concepts for Advanced Interconnects and Nanosystems" young engineers work together with researchers from other German and Chinese universities. They are specialized in electrical engineering and microelectronics, material sciences as well as physicists and chemists and develop together new materials and processes as well as new concepts for interconnect systems in integrated circuits. The project makes essential contributions not only to the solution of problems of nanoelectronics. It supports and requests an interdisciplinary and cross-cultural communication and cooperation. Participants at these projects are the Institute of Physics, the Institute of Chemistry and the Center for Microtechnologies of the Chemnitz University of Technology as well as the Technical University Berlin, the Fudan University Shanghai, the Shanghai Jiao Tong University, the Fraunhofer Institute for Reliability and Microintegration IZM and the Fraunhofer Institute for Electronic Nano Systems ENAS. The research program of the International Research Training Group comprises nine projects at the German institutions, as well as eight at Fudan University and three at Shanghai Jiao Tong University.

MULTIPLE EXCELLENT – COOPERATION WITHIN CLUSTERS OF EXCELLENCE

Fraunhofer ENAS works in two clusters of excellence, which have been accepted in June 2012.

Germany funds Excellence Initiatives for Cutting-Edge Research at Institutions of Higher Education. On June 15, 2012, the grants committee decided about the proposals of the third round of the excellence initiative. All selected proposals will be funded over a time period of five years starting from November 2012.
Fraunhofer ENAS and the Center for Microtechnologies of the Chemnitz University of Technology work in two of these clusters of excellence, which have been accepted in June 2012.

The projects are funded by:

DFG

Merge Technologies for Multifunctional Lightweight Structures – MERGE

The Cluster of Excellence of the TU Chemnitz "Merge Technologies for Multifunctional Lightweight Structures – MERGE" is coordinated by Prof. Kroll, Director of the Institute of Lightweight Structures of the Faculty of Mechanical Engineering. The main object of the cluster is the fusion of fundamental technologies suitable for the resource-efficient massproduction of lightweight structures of high-performance and functional density. In order to make the structures much more intelligent, microsystems, smart sensors, actuators and electronics will be integrated. Fraunhofer ENAS is mainly working in research area D – Micro and Nanosystems Integration.
For more information please visit: www.tu-chemnitz.de/MERGE

Center for Advancing Electronics Dresden

Specifically, it is the vision of cfAED that future CMOS technology will be complemented with new technologies (augmented CMOS), resulting in heterogeneous architectures to form highly efficient information processing environments. Scientists of the Center for Microtechnologies of Chemnitz University of Technology and Fraunhofer ENAS will also work in the Carbon Path of the Cluster of Excellence "Center for Advancing Electronics Dresden" of the TU Dresden coordinated by Prof. Fettweis. Carbon is clearly an outstanding candidate for advancing electronics beyond today's boundaries. Within the Carbon Path, the scientists of the cluster will explore carbon nanotubes (CNTs) as the currently most advanced form of carbon for use in electronic systems. The main application is wireless communication.
For more information please visit: http://tu-dresden.de/cfaed

NANETT – NANO SYSTEM INTEGRATION NETWORK OF EXELLENCE

At a glance

Profoundly multidisciplinary collaboration is the key for establishing enduring international top-level research and competitive innovations in the field of micro and nanotechnologies. Under the direction of the Chemnitz University of Technology and the Fraunhofer Institute for Electronic Nano Systems the research consortium nanett „nano system integration network of excellence" was formed to bring together the different competences of nine renowned scientific institutions in the field of applied nanotechnologies:

- University of Technology Chemnitz
- Fraunhofer Institute for Electronic Nano Systems
- Fraunhofer Institute for Reliability and Microintegration
- Fraunhofer Institute for Applied Polymer Research
- Leibniz Institute for Solid State and Materials Research Dresden
- Leibniz Institute of Polymer Research Dresden
- Leibniz IHP Frankfurt
- University of Applied Sciences Mittweida
- Helmholtz-Zentrum Berlin für Materialien und Energie GmbH

The strategic direction of the network is the connection of fundamental with application-oriented research in the promising domains of nanotechnology and system integration technology with the aims of transferring science into applications and being an attractive, competent and solid partner for the industry. The network is one of the successful initiatives of the program "Spitzenforschung und Innovation in den Neuen Ländern", funded by the Federal Ministry of Education and Research (BMBF). The grant of the BMBF for the whole R&D joint venture amounts 14 million euros. The project started in November 2009 with a funding period of five years.

Research topics

The further development of the critical dimensions into the nanometer scale and the discovery of novel physical phenomena on the atomic or molecular level have offered completely new solutions in the fields of microelectronics, biotechnology, measurement technology and others. The opportunity to create smart systems by integrating intelligence and novel functions in components or materials is of huge relevance to some of the most important technological concepts for the future like internet of things, ambient intelligence, smart home, smart grids or smart factory. Besides highly efficient data communication and data processing the interaction with the environment is an essential part for smart systems. The extraction of different kinds of information from the environment by miniaturized and integrated sensor systems is used for fulfilling the increased demand for security and sustainable resource utilization in production and logistic processes as well as the handling of processes with a high degree of complexity. Topics like localization, food safety, observation of vulnerable people, diagnosis of diseases and pathogenic substances, dosing of medicine as well as controlling of production lines, cargo flows and building technology are coming more and more into the focus of research and development. For all these applications there is a need for autonomous and networked

nanett
nano system integration network of excellence

micro and nano systems. Therefore the partners of the nano system integration network of excellence work on smart sensor systems, which are doing the job of sensory organs in complex systems. By using nanotechnologies the functional range and the energy efficiency can be enhanced, the size can be shrunk and the production cost can be reduced.

As a basis for these activities important technological questions and application constraints have been identified and summarized in three flagship projects. In the first three years period, the research was focused on the integration of component level within the projects. On the basis of concrete technological problems superordinate approaches have been investigated. In the second two year period, which started in November 2012 the flagship projects will be cross-linked in order to focus on heterogeneous system level integration.

Flagship project A: "Nanoscale material systems for magnetoresistive sensors" is aiming towards application of novel nano patterned spintronic structures. Spintronic devices realized by magnetic nanostructures are a new research area. It is based on the spin dependent transport of electrons at magnetic/nonmagnetic interfaces which can be manipulated by external fields. With such devices magnet fields can be measured very fast and with high accuracy in all three spatial directions. The researchers focused on the deposition and the patterning of novel anorganic and organic/anorganic material systems. Processes like atomic layer deposition, sputtering, nano imprint lithography and laser patterning have been investigated for creating magnetic nanostructures.

The challenges in flagship project B: "NEMS/MEMS electronic integration for energy-efficient sensor nodes" are manifold. Best performance of the systems is claimed with a high integration level, high reliability and robustness. The systems should work energy autonomous and maintenance-free over several years. Science and industry will focus on physical, chemical and biological sensors, energy-efficient communication and data processing, energy generation as well as system integration for realizing cost-efficient smart systems. Since the performance of the data processing and transferring systems is growing faster than the power consumption of electrical devices and circuits can be reduced, technologies for energy-efficient communication like wake-up receivers or networking strategies of sensor nodes and concepts for energy harvesting and management have to be developed.

Flagship project C: Material integrated sensors based on nano effects is related to functional materials whose properties are based on nanostructures, which are integrated into the materials, mainly polymers. These nanocomposites are used for realizing sensor functions within the material instead of integrating discrete sensor systems. Especially for fiber reinforced polymers structural health monitoring is an important issue. Aim of the project is the development of a smart component, which can detect and visualize temporary load states in an indicative layer. Since a permanent monitoring of the whole component is economically and technologically not reasonable, the storage of the load state is an important issue. In future the sensor functions shall be enhanced by actuator materials, so that adaptive components can be realized, which react independently on environmental conditions. For example the stiffness of a device is changing in respect to a mechanical load. So, the advantages of nano effects can be used by mass fabricated products.

Highlights in 2012

After three years of intensive collaborative research in the network of excellence the scientists presented the results of the first funding period at the third status seminar held at the University of Technology in Chemnitz on November 6, 2012. The speaker of the network Prof. Thomas Gessner welcomed more than 120 researchers and guests from industrial partners for giving an overview about the finished projects and the goals for the second funding period. The leader of the three flagship projects Prof. Manfred Albrecht, Dr. Steffen Kurth and Prof. Thomas Otto presented the latest results of all network partners. Beside this overview talks from every flagship project two scientists presented their special topics in detail. The highlight has been several demonstrators which showed the results for energy-efficient sensor nodes. During a poster presentation the young scientists and the guests could discuss the research results in detail.

For more information please visit our website:
www.nanett.org/
or contact us via e-mail: nanett@tu-chemnitz.de

The project is funded by:

Bundesministerium für Bildung und Forschung

SPITZENFORSCHUNG & INNOVATION IN DEN NEUEN LÄNDERN

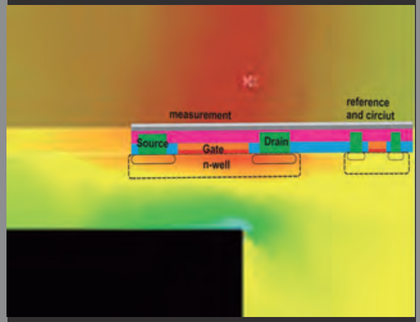
figure (page 89): The nano system integration network of excellence nanett brings together many scientists of nine different research institutes.

figure (page 92, left): Researchers of the Fraunhofer ENAS are working on thin magnetic film stacks deposited by atomic layer deposition.

figure (page 92, right): An interdisciplinary team is analyzing the performance of the developed wireless sensor network.

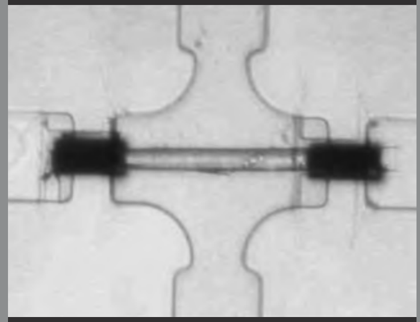
figure (page 93) Dr. Ulrike Staudinger from the Leibniz IPF in Dresden is preparing polymer nanocomposites based on carbon nanotubes.

Silicon Nano Sensors



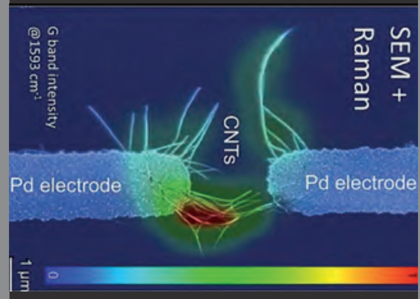
SoC CMOS FET working as a silicon strain sensor

Modeling and Integration of Nanotubes



Opto-fluidic sensor element

Novel Materials and Technologies for Sensor Applications



Nano characterization

FOR 1713
SMINT

DFG RESEARCH UNIT 1713
SENSORIC MICRO AND NANO SYSTEMS

At a glance

The Deutsche Forschungsgemeinschaft (DFG) has established the research unit 1713 "Sensoric Micro and Nano Systems" at the Chemnitz University of Technology (CUT) for a period of three years, starting in March 2011. Besides the Fraunhofer Institute for Electronic Nano Systems (Fraunhofer ENAS), also professorships of the Center for Microtechnologies from the Faculty of Electrical Engineering and Information Technology, the Faculty of Natural Sciences and the Leibniz Institute for Solid State and Materials Research (IFW) Dresden are involved in the research unit. Speaker of the research unit is Prof. Thomas Gessner.

The scientific aim of the research unit is the integration of nanostructures and novel materials as well as the spatial and functional integration of heterogeneous components in micro and nano systems. Especially for the integration of nanotechnologies and the development of novel materials the collaboration between the Center for Microtechnologies and the Institutes of Physics and Chemistry are of great concern. Together with the Fraunhofer ENAS and the Leibniz IFW Dresden the competences in the areas of design, fabrication, characterization and reliability of micro and nanostructures and of integration and packaging technologies will be combined for working on the complex scientific tasks arising from the development of multifunctional micro and nano systems.

Technological routes

The realization of the research goals in the first funding period of the research unit 1713 is based on three independent technological routes:

- Silicon Nano Sensors,
- Modeling and Integration of Nanotubes,
- Novel Materials and Technologies for Sensor Applications.

Within the technological route "Silicon Nano Sensors", nanostructures based on state-of-the-art MEMS technologies are integrated in microsystems for utilizing nano effects in transducers by incooperating nanostructures – as it is shown in the left picture. Such structures within transducer elements need new pathways for interconnecting the signal processing with the sensor element due to the decrease of the signal-to-noise ratio. Furthermore, new concepts for the design and the packaging of nano systems are being developed, because flexibility and interactions between different components are essential for heterogeneous systems.

The second technological route "Modeling and Integration of Nanotubes" covers the whole bandwidth from atomistic modeling of carbon nanotubes (CNTs), over process development for deposition and integration of nanotubes, characterization by scanning probe techniques up to the application for microfluidics and sensors. For application-oriented simulations structural defects, contact properties as well as contaminations by subsequent processes have to be taken into account. The evaluation of realistic models requires highly accurate characterization methods; therefore an analytics with a spatial resolution in the nanometer range is necessary. The requirements on the integration processes are investigated for applications of nanotubes within microfluidic systems and resonators as well as sensors.

Syntheses, patterning and integration of magnetic materials is in the focus of the third technological route "Novel Materials and Technologies for Sensor Applications". Novel geometric configurations like nanoparticle arrays will be reproducibly processed by self-assembly and rolling up of thin film systems will be fabricated as well as fundamentally studied.

Junior researcher workshops – SMINT meetings

The need for interaction within multifunctional and heterogeneous systems also reflects the research unit itself. Communication between project groups is the most essential part for a prosperous cooperation. Therefore, thematically focused workshops have been established where key topics of the research unit were discussed. Topical talks, mostly given by external guests, introduce the fundamentals for a general understanding. This part is followed by talks about the current work and challenges within the research unit.

June 2012: The SMINT research unit was guest at the Leibniz IFW Dresden. Magnetic micro and nanostructures were the main topic. We were able to gain guest speakers to talk about the fundamentals of micro and nano magnetism. At the same time, the recent results of magnetic multilayer showing GMR effect in a rolled-up geometry were presented – as well as other interesting research within the Leibniz IFW and the Institute of Physics at Chemnitz University of Technology.

October 2012: The SMINT research unit met at the Chemnitzer Fachtagung Mikrosystemtechnik – Mikromechanik & Mikroelektronik, organized by the Faculty of Electrical Engineering and Information Technology, where industrial partners were took part. Each single project of the research unit contributed by giving a presentation about its current work. This has lead to an intensive interchange with the participants of the conference.

November 2012: The SMINT research unit was guest at the Institute of Physics of Chemnitz University of Technology. Focus of the workshop was the broad topic nano characterization. One of the main challenges is the optical investigation of nanostructures, as the refraction limit of light only allows a spatial resolution of a few hundred nanometers. Here, novel concepts need to be investigated and applied to get a higher resolution. One of the famous examples within the research unit is the tip-enhanced Raman spectroscopy (TERS), where structures like carbon nanotubes can be locally characterized with a few nanometers of resolution – in a nondestructive way. An example is shown in the right picture of page 94.

The next SMINT meetings for 2013 are already planned. In January, the SMINT will be guest at the Institute of Chemistry. The planned topic is the functionalization of carbon allotropes, especially carbon nanotubes. Another interesting SMINT meeting concerns strained micro and nanostructures – as acceleration and strain sensors belong to the main competences of the Center for Microtechnologies.

The commonality of all the meetings is that external partners and researchers within the research unit could join their knowledge to find solutions for current and challenging problems in open-minded and active discussions.

For more information please visit our website
www.zfm.tu-chemnitz.de/for1713
or contact us via e-mail: info@zfm.tu-chemnitz.de

The project is funded by:

DFG

figure:
Chinese and German attendees of the IRTG summer school took place at the Lake Zeuthen near Berlin in 2012.

INTERNATIONAL RESEARCH TRAINING GROUP

"Materials and Concepts for Advanced Interconnects and Nanosystems"

At a glance

Since April 2006, the International Research Training Group (Internationales Graduiertenkolleg 1215) "Materials and Concepts for Advanced Interconnects", jointly sponsored by the German Research Foundation (DFG) and the Chinese Ministry of Education, has been established between the following institutions:

- Chemnitz University of Technology,
  - Institute of Physics,
  - Institute of Chemistry,
  - Center for Microtechnologies,
- Fraunhofer Institute for Electronic Nano Systems ENAS,
- Fraunhofer Institute for Reliability and Microintegration IZM,
- Technische Universität Berlin,
- Fudan University, Shanghai,
- Shanghai Jiao Tong University.

After a successful evaluation in March 2010, the second period of the IRTG program started in October 2010, now extending the scientific topic to "Materials and Concepts for Advanced Interconnects and Nanosystems". The International Research Training Group will be funded until March 2015.

This International Research Training Group (IRTG) is the first of its kind at Chemnitz University of Technology. It is led by Prof. Ran Liu of Fudan University and Prof. Di Chen of Shanghai Jiao Tong University as the coordinators on the Chinese side as well as Prof. Thomas Gessner as the coordinator on the German side. A graduate school like this offers brilliant young PhD students the unique opportunity to complete their PhD work within about three years in a multidisciplinary environment. Currently there are 19 PhD students of the German and 15 of the Chinese partner institutions involved in the program. The different individual backgrounds of the project partners bring together electrical and microelectronics engineers, materials scientists, physicists and chemists. In particular, the IRTG is working to develop novel materials and processes for nano systems as well as new concepts for connecting the individual transistors within nano electronic circuits. Smaller contributions are additionally made in the field of device packaging and silicides for device fabrication. In this respect, the IRTG is providing solutions for nanoelectronics and smart systems integration.

Research program

The research program of the IRTG concentrates on both applied and fundamental aspects to treat the mid- and long-term issues of microelectronics metallization and nano system integration. So, atomic layer deposition (ALD) of metals, new precursors for metal-organic chemical vapor deposition (MOCVD), ultra low-k dielectrics and their mechanical and optical characterization together with inspection techniques on the nanoscale are considered. New and innovative concepts for future microelectronics such as carbon nanotube interconnects or molecular electronics along with silicides to form links to front-end of line processes are of interest, as well as the evaluation of manufacturing-worthy advanced materials. Moreover, the research program addresses reliability and packaging issues of micro devices. Highlighting links between fundamental materials properties, their characteristics on the nanoscale, technological aspects of materials and their applications to microelectronic devices is the main objective of the program. Among the topics related to sensor applications, magnetic film systems on curved surfaces of nanoparticles are studied with respect to their performance as giant or tunnel magnetoresistance (GMR or TMR) sensor. Further works are related to polymer composite materials to be used in thermoelectric systems.

Nevertheless, the principal idea of the IRTG is four-fold: The research program defines the framework of the activities and the topics of the PhD theses. This is accompanied by a specially tailored study program including lectures, seminars and laboratory courses to provide comprehensive special knowledge in the field of the IRTG. The third part of the program comprises annual schools held either in China or Germany, bringing together all participants of the IRTG and leading to vivid discussions during the presentation of the research results. Moreover, an exchange period of 3 to 6 months for every PhD student at one of the foreign partner institutions is another essential component. Besides special knowledge in the scientific field, these activities will provide intercultural competencies that cannot easily be gained otherwise. In that respect, the IRTG also prepares the PhD students for an even more international economy.

Highlights 2012

One of the greatest highlights for the IRTG in 2012 was the summer school held in Berlin end of July. It was just the 7th summer school organized within the IRTG. Eight students and professors of Fudan University and also eight from the Shanghai Jiao Tong University took part. Additionally to the presentations of the PhD students scientists have been invited to give special talks. One of them was Prof. Christophe Detavernier from the University Gent in Belgium. He spoke about his work in the field of atomic layer deposition of nano porous materials. As always, the scientific program of the summer school was accompanied by cultural and social events.

There were five Chinese students working at the partner institutes in Chemnitz and one German student working at the Fudan University.

For more information please visit our website
www.zfm.tu-chemnitz.de/irtg
or contact us via e-mail: info@zfm.tu-chemnitz.de

The project is funded by:

DFG

and

Chinese Ministry of Education

GESSNER GROUP – A RESEARCH GROUP OF WPI-AIMR IN JAPAN

Tohoku University was founded in 1907 as the third Imperial University of Japan; from its start, it displayed to the world a commitment to an "Open Door" policy. This policy has contributed to producing a large number of notable research achievements and outstanding scholars, including Nobel Prize in Chemistry in 2002. The Tohoku University is a leading research-intensive university and has a worldwide recognized strength in materials engineering and science. The university is comprised of 10 undergraduate faculties, 16 graduate schools, 3 professional graduate schools, 6 research institutes, 13 research centers, and a university hospital. As of May 2012, there were about 6000 faculty and staff members as well as approximately 18,000 students.

Fraunhofer-Gesellschaft is Europe's leading research institution with more than 22,000 employees and 66 institutes and independent research units. The Fraunhofer Institute for Electronic Nano Systems ENAS has developed world-class expertise in smart systems integration by using micro and nanotechnologies. Individual solutions are sought in direct contact with industrial customers. The key objective of Fraunhofer-Gesellschaft is to transform scientific expertise into applications for practical use. Fraunhofer thus makes a significant contribution to technology transfer between universities and industry.

Fraunhofer ENAS and the Tohoku University have been cooperating with each other in the field of new materials for microelectronic systems for many years. Fraunhofer-Gesellschaft concluded a cooperation agreement with the City of Sendai in 2005. Collaboration between Fraunhofer-Gesellschaft and the Tohoku University was further enhanced in 2008 while the Japanese government chose 6 excellent universities, including the Tohoku University to establish so-called World Premier International Research Center (WPI) with the goal to increase international cooperation and research with benefit for society. Within the framework of the WPI-AIMR (World Premier International Research Center Initiative – Advanced Institute for Materials Research) at the Tohoku University Prof. Gessner, the director of Fraunhofer ENAS, was invited as so-called principal investigator to establish a research group in the field of NEMS/MEMS devices and micro/nano manufacturing technologies at the Tohoku University. The Gessner Group will be funded by WPI for a period of 10 years.

Being managed by assistant professor Yu-Ching Lin since November 2008, the Gessner Group at Tohoku University and the Fraunhofer ENAS developed a close collaboration through intensive scientific and staff exchange. These joint efforts have successfully proved and have evidenced that the fundamental research work done by the Gessner Group's researchers as well as by researchers from other groups of WPI-AIMR, on the one hand, and the R&D work carried out at Fraunhofer ENAS, on the other hand, are complementary in the field of new materials for microelectronic systems. Both partners strongly benefit from the expertise of the other. Both, Fraunhofer ENAS and Tohoku University reveal different experience on similar research topics in the field of new materials for microelectronic systems, alternative equipment and complementary access to different major manufacturers of microsystems and semiconductor devices as well as to equipment and material suppliers.

These partners wish to further intensify their cooperation towards a more successful promotion of scientific research and technology transfer on the Japanese market on common fields of interest with particular focus on NEMS/MEMS devices and micro/nano manufacturing technologies.

To achieve this aim, the Fraunhofer ENAS and WPI-AIMR of Tohoku University did set-up a joint strategic research initiative by establishing a research and development unit at the Tohoku University in the form of a "Fraunhofer Project Center" with the participation on the side of Tohoku University in particular of the Gessner Group as well as other researchers from WPI-AIMR groups. The Fraunhofer Project Center "NEMS / MEMS Devices and Manufacturing Technologies at Tohoku University" has effectively started on April 1, 2012. The Fraunhofer Project Center shall be a platform for common research and development activities, within both institutions but also with respect to industrial customers.

The Fraunhofer Project Center is run to the benefit of both partners as a vehicle for:

- R&D cooperation in advanced manufacturing technologies and the development of new materials for microelectronic systems with a focus on NEMS/MEMS devices and micro/nano manufacturing technologies;
- Facilitating and expediting the commercialization of research and the transfer and adoption of new materials manufacturing technology by industry, particularly manufacturers of microsystems and semiconductor devices and other new markets in the field of micro/nano systems manufacturing sectors;
- Introducing methods and standards of Fraunhofer-Gesellschaft for contract research to the research community in Japan and in particular focus on training the next generation of engineers and technicians through joint research programs;
- Entering the Japanese R&D and technology transfer market with the option to establish a Fraunhofer subsidiary if this joint initiative proves successful.

Through the Fraunhofer Project Center research and development activities, the Fraunhofer ENAS and WPI-AIMR of Tohoku University shall strive to create worldwide visible excellent research by transforming basic knowledge into real applications that benefit society and aids the further development of both partners.

For more information please visit our websites or contact us via e-mail.

Gessner Group of WPI-AIMR:
www.wpi-aimr.tohoku.ac.jp/gessner_labo/
e-mail: yclin@mems.mech.tohoku.ac.jp

Fraunhofer Project Center "NEMS / MEMS Devices and Manufacturing Technologies at Tohoku University"
www.enas.fraunhofer.de
e-mail: esashi@mems.mech.tohoku.ac.jp

COOPERATION WITH UNIVERSITIES AND RESEARCH INSTITUTES (SELECTION)

ACREO, Kista, Sweden

CEA-LETI, Grenoble, France
CEA Liten, Grenoble, France
Centre Suisse d'Electronique et de Microtechnique (CSEM), Neuchâtel, Switzerland
Centro de Tecnologia da Informação Renato Archer – CTI, Campinas, Brazil
Centrum für intelligente Sensorik Erfurt e.V., Erfurt Germany
Chongqing University, Chongqing, China
CIRA Italian Aerospace Research Centre, Capua, Italy

Delft University of Technology, Delf, The Netherlands
Deutsches Zentrum für Luft- und Raumfahrt e.V., Institut für Kommunikation und Navigation, Wessling, Germany
Dublin City University, Dublin, Ireland

École Nationale Supérieure des Mines de St-Étienne, France
ESA European Research and Technology Centre, Noordwijk, The Netherlands
ESISAR, Institut Polytechnique De Grenoble, Groupe INP Grenoble, Valence, France
ETH Zurich, Switzerland

Femto-ST, Besançon, Frankreich
Forschungszentrum Rossendorf, Germany
Fraunhofer CSP, Halle, Germany
Fraunhofer EMFT, Munich, Germany
Fraunhofer FHR, Wachtberg, Germany
Fraunhofer IAP, Golm, Germany
Fraunhofer IBMT, Potsdam, Germany
Fraunhofer IBP, Stuttgart, Germany
Fraunhofer IFAM, Bremen and Dresden, Germany
Fraunhofer IISB, Erlangen, Germany
Fraunhofer IPMS, Dresden, Germany
Fraunhofer IPT, Paderborn, Germany
Fraunhofer ISIT, Itzehoe, Germany
Fraunhofer IWM, Halle, Germany
Fraunhofer IWU, Chemnitz, Germany
Fraunhofer IZFP, Dresden, Germany
Fraunhofer IZM, Berlin and Dresden, Germany
Fraunhofer LBF, Darmstadt, Germany
Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
Friedrich-Schiller-Universität, Jena, Germany
Fudan University, Shanghai, China
Fundação Centros de Referencia em Tecnologias Inovadoras – CERTI, Florianopolis, Brazil
Fundação Oswald Cruz – FioCruz, Curitiba, Brazil

GFaI Gesellschaft zur Förderung angewandter Informatik e.V., Berlin, Germany

Helmholtz-Zentrum Berlin, Germany
Holst Center, Eindhoven, The Netherlands
HTWK – Leipzig University of Applied Sciences, Leipzig, Germany

IMEC, Leuven, Belgium
INCAS – National Institute for Aerospace Research, Bucharest, Romania
Institut für Solarenergieforschung, Hameln-Emmerthal, Germany
Instituto Nacional de Técnica Aeroespacial, Madrid, Spain

Joanneum Research, Graz, Austria
Johannes Kepler Universität, Linz, Austria
Joseph Fourier University, Grenoble, France

Katholieke Universiteit Leuven, Leuven, Belgium
KIMM, Daejeon, Korea
Konkuk University, Chungju, Korea
Kungliga Tekniska Högskolan KTH, Stockholm, Sweden

Laboratoire d'Electronique, Antennes et Télécommunications, Sophia Antipolis (Nice), France
Leibniz IFW, Dresden, Germany
Leibniz IHP, Frankfurt/Oder, Germany
Leibniz INP, Greifswald, Germany
Leibniz IOM, Leipzig, Germany
Leibniz IPF, Dresden, Germany
Linköping University, Linköping, Sweden

Massachusetts Institute of Technology, Cambridge/Boston, USA
Max-Planck-Institut für Mikrostrukturphysik, Halle, Germany
Mid Sweden University, Sweden
MIRDC, Kaohsiung, Taiwan

NanoTecCenter Weiz Forschungsgesellschaft mbH, Weiz, Austria

Physikalisch-Technische Bundesanstalt Braunschweig (PTB), Germany

Royal Institute of Technology, Stockholm, Sweden
RWTH Aachen University, Aachen, Germany

Shanghai Jiao Tong University, Shanghai, China
Sunchon National University, Sunchon, Korea
Swerea IVF, Mölndal (Gothenburg), Sweden

Technische Universität Berlin, Germany
Technische Universität Dresden, Germany
Technische Universität Dortmund, Germany
Technische Universität Ilmenau, Germany
Technische Universität München, Germany
Technische Universiteit Eindhoven, The Netherlands
Tohoku University, Sendai, Japan
TSINGHUA University, Beijing, China
Tyndall National Institute, Cork, Ireland

Universidade Estadual de Campinas – UNICAMP, Centro de Componentes Semicondutores, Campinas, Brazil
Universidade Federal de Pernambuco, Recife, Brazil
Universidade Federal do Paraná, Curitiba, Brazil
Universitat Autònoma de Barcelona CAIAC, Barcelona, Spain
Universität Leipzig, Germany
Universität Paderborn, Germany
Université de Rouen, Saint-Etienne-du-Rouvray, France
University of Aalborg, Denmark
University of Aix-Marseille, France
University of Applied Siences Mittweida (FH), Germany
University of Aveiro, Portugal
University of California, Berkley, USA
University of Montpellier, France
University of Naples "Federico II", Naples, Italy
University of Nevada, Reno, USA
University of Nice-Sophia Antipolis, France
University of Technology Chemnitz, Germany
University of Tokyo, Japan
University of the West of England, Bristol, United Kingdom
University Paris Diderot, France

VTT Technical Research Centre, Finland

Westsächsische Hochschule Zwickau (FH), Zwickau, Germany

Xiamen University, Xiamen, China

figure: Smart Systems Campus Chemnitz.

smart systems campus
TechnoPark Chemnitz

SMART SYSTEMS CAMPUS CHEMNITZ

The Smart Systems Campus Chemnitz is an innovative network with expertise in micro and nanotechnologies as well as in smart systems integration. This technology park provides renowned scientific and technical centers with entrepreneurial spirit and business acumen and an economic boost at a location where everything is on the spot. A close cooperation of science, applied research and industry is there an everyday reality and reflects a strategy that is being fulfilled.

The partners of the Smart Systems Campus Chemnitz are:

- Chemnitz University of Technology with Institute for Physics, Center for Microtechnologies (ZfM) and Center for Integrated Lightweigth Construction (ZIL),
- Fraunhofer Institute for Electronic Nano Systems ENAS,
- Young companies within the start-up building,
- Companies within the business park.

Chemnitz University of Technology

The Chemnitz University of Technology is the main partner for basic research. The Institute of Physics belongs to the Faculty of Natural Sciences. The research is characterized by an exemplary close intertwining between chemistry and physics. It is reflected particularly in the focused research topics overlapping between both institutes of the faculty.

The Center for Integrated Lightweigt Construction (ZIL) belongs to the Institute of Lightweight Structures of the Faculty for Mechanical Engineering. The scientific work is focused on the development and investigation of integrative plastic processing technologies for the resource-efficient manufacturing of lightweight structures and systems. The coupled structure and process simulation together with analytical and numerical methods provide important information for optimized structure and process parameters.

The Center for Microtechnologies (ZfM), founded in 1991, belongs to the Faculty of Electrical Engineering and Information Technology. It is the basis for education, research and developments in the fields of micro and nanoelectronics, micro mechanics and microsystem technologies in close cooperation with various chairs of different CUT departments.

The ZfM's predecessor was the "Technikum Mikroelektronik" which was established in 1979 as a link between university research and industry. So the Chemnitz University of Technology has had a tradition and experience for more than 30 years in the fields of microsystem technology, micro and nanoelectronics, as well as opto-electronics and integrated optics.

The key of success is the interdisciplinary cooperation of different chairs within the ZfM. The board of directors consists of:

- Chair Microtechnology (Prof. Gessner),
- Chair Microsystems and Precision Engineering (Prof. Mehner),
- Chair Circuit and System Design (Prof. Heinkel),
- Chair Electronic Devices of Micro and Nano Technique (Prof. Horstmann),
- Chair Electrical Measurement and Sensor Technology (Prof. Kanoun),
- Chair Power Electronics and Electromagnetic Compatibility (Prof. Lutz),
- Chair Materials and Reliability of Microsystems (Prof. Wunderle).

Additionally two departments belong to the ZfM, the department Lithograpy/Etch/Mask as well as the department Layer Deposition. The ZfM facilities include 1000 m² of cleanrooms, whereby 300 m² of them belong to clean-room class ISO4. Modern equipment was installed for processing of 4", 6" and 8" wafers.

Start-up building

The start-up building for companies related to the sector mentioned before forms an important part of the campus. There is space for approx. 15 start-up companies. In the present time the following companies are working there:

- Berliner Nanotest und Design GmbH (common labs with EUCEMAN, Chemnitzer Werkstoffmechanik GmbH, AMIC Angewandte MicroMesstechnik GmbH, Amitronics GmbH, SEDEMAT GmbH, Clean Technologies Campus GmbH),
- memsfab GmbH (common lab with Leibniz IFW),
- EDC Electronic Design Chemnitz GmbH,
- LSE Lightweigth Structure Engineering GmbH,
- SiMetrics GmbH,
- saXXocon GmbH,
- BiFlow Systems GmbH,
- Turck Duotec GmbH.

Business park

The campus does not only open doors for young entrepreneurs in the start-up building, but expanding companies can also make use of neighboring space on a business park. Companies can build their own building according to their requirements on an area measuring up to 7 hectares.

The first company in the park is the 3D-Micromac AG which develops and manufactures highly efficient and innovative machines for laser micro machining. Since May 2012 there is a second building – the microFLEX-Center. The building is rent by 3D-Micromac AG and Fraunhofer ENAS as a common research and production line.

Further expansion of the campus in 2013

Currently there is the third building of the business park under construction. Based on its very positive development the EDC Electronic Design Chemnitz GmbH has started to construct an own building, which will be finished in 2013.

Additionally a new building for interdisciplinary basic research will be built on the campus. It is the "Center for Materials, Architectures and Integration of Nano Membranes – MAIN" at the Chemnitz University of Technology. The project is led by Prof. Schmidt, Professorship of Materials for Nanoelectronics. The interdisciplinary research combines the expertise of the Faculty of Electrical Engineering and Information Technology including the Center for Microtechnologies and the Faculty of Natural Sciences. The construction of the new building will start still within 2013.

EVENTS

EVENTS OF THE FRAUNHOFER ENAS

Fraunhofer ENAS opened its doors to the public and to partners

Chemnitz workshop on Nanotechnology, Nanomaterials, Nanoreliability

In 2012 Fraunhofer ENAS continued the Chemnitz Workshops on Nanotechnology, Nanomaterials, Nanoreliability. This series started in 2010. In 2012 four departments organized a special half day workshop with experts from industry and research. Special topics were:

- Sensor networks, smart grids, on April 26, organized by department Multi Device Integration,
- Smart medtech systems, on May 24, organized by department System Packaging,
- Nanosensors, on September 27, organized by department Back-End of Line,
- Printing technologies, on December 11, organized by department Printed Functionalities.

This series of workshops will be continued in 2013. Selected presentations will be published within an issue of MICROMATERIALS & NANOMATERIALS, which is a publication series of the Micro Materials Center of Fraunhofer ENAS.

Opening ceremony of microFLEX-Center

The increasing staff number of Fraunhofer ENAS forces the institute to expand. A new building on the Smart Systems Campus Chemnitz – the microFLEX-Center – enables the Fraunhofer ENAS to rent offices and labs without constructing an own building. The microFLEX-Center was opened on Mai 11, 2012. 3D-Micromac AG, a company fabricating equipment for laser micro machining and located on the Smart Systems Campus, is the second renter and established its new production hall on the first floor of the building.

The opening ceremony was accompanied by the 10th anniversary of 3D-Micromac AG. After a half-day workshop introducing the Smart Systems Campus Chemnitz, new trends in laser micro machining and digital fabrication on flexible substrates, a celebrating ceremony took place in the evening. Professor Sabine von Schorlemer, Saxon State Minister for Science and Culture, Professor Ulrich Buller, Senior Vice President Research Planning of the Fraunhofer-Gesellschaft, as well as the Mayor of Chemnitz, Barbara Ludwig, addressed not only greetings but pointed out, that the new microFLEX-Center is an example of fruitful cooperation between industry and applied research.

figure:
The microFLEX-Center opened in May 2012.

10th anniversary of Fraunhofer ENAS representative office in Shanghai, China

On September 5, 2012, the Fraunhofer ENAS celebrated together with 40 guests from industry, science and politics the 10th anniversary of its representative office in Shanghai. The office is located in the German Chamber of Commerce in the China Fortune Tower. Fraunhofer ENAS is representated by Mr. Shi Min.

Chinese and German long-term cooperation partners were invited for short welcome speeches. The rector of the Chemnitz University of Technology and member of the advisory board of Fraunhofer ENAS, Professor Arnold van Zyl, followed the invitation. In his greeting he stressed the cooperation between Chemnitz University as well as Fraunhofer ENAS and Fudan University as well as Shanghai Jiao Tong University in the International Research Training Group, a joint program for PhD students. Thomas Schmidt, Member of Saxon State Parliament, forwarded congratulation of the Prime Minister of Saxony. Additionally, Han Xiaoding, Chief Representative of the Fraunhofer Representative Office Beijing, and Jan Noether, Chief Representative of the Delegation of Germany Industry and Commerce in Shanghai, adverted to different economic sectors Germany and China are cooperating in. Professor Liu Ran from the School of Microelectronics at the Fudan University and Professor Wen Zhiyu from the Microsystems Research Center at the Chongqing University emphasized the scientific and cultural exchange in student exchange programs. Also representatives of SUSS MicroTec (Shanghai) Co. Ltd. and China's Flight Automatic Control Research Institute (FACRI) in Xi'an congratulated Professor Gessner and Fraunhofer ENAS to 10 years of successful projects in China.

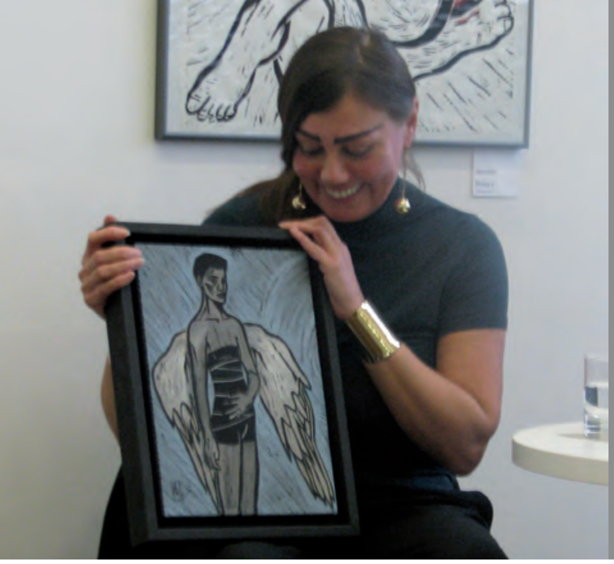
Research Award of Fraunhofer ENAS

The researcher Jörg Bräuer has received the Research Award 2012 of Fraunhofer ENAS for his outstanding scientific work and research in the field of reactive bonding. The Research Award goes annually to scientists who can demonstrate excellent results in a research field of microelectronics and microsystems technology.

Jörg Bräuer is investigating reactive multilayer systems and their application as internal heat sources for reactive bonding. By the impact of a single low energy impulse a self-propagating chemical reaction within the system delivers the heat for the joining process. Jörg Bräuer was demonstrating this reaction by an experiment during his presentation on the occassion of the ceremony in the Günnewig Hotel Chemnitzer Hof. He explained that the bonding process is a room temperature process. This ensures that the components are not exposed to high temperatures over a large area. The technology also offers new ways of joining temperature-sensitive materials with different thermal expansion coefficients, such as metals and polymers, without causing thermal damage. Temperature problems in joining processes have become a thing of the past.

figures:
left: Professor Thomas Gessner with Chinese and German speakers at the 10th anniversary of Fraunhofer ENAS Representative Office in Shanghai; (from left to right: Prof. Liu Ran, Han Xiaoding, Jan Noether, Prof. Arnold van Zyl, Prof. Thomas Gessner, Thomas Schmidt, Prof. Thomas Otto, Prof. Zhiyu Wen, a representativ of FACRI, Dr. Gong Li and Shi Min).

right: Jörg Bräuer received the Science Award 2012 of Fraunhofer ENAS.



SCIENCE MEETS ARTS

The art exhibitions within the building of Fraunhofer ENAS have been continued

In 2012, the researchers have gotten again the opportunity to meet local painters in private discussions. Our event series "Science meets Arts" has been continued with the exhibition of three artists in the building of Fraunhofer ENAS.

We started with the first female painter exhibiting in our building under the title "The pen is thinking – the knife is feeling". In March, Fraunhofer ENAS invited to a gallery talk with the artist Dagmar Zemke to finish her exhibition starting in fall 2011. The Chemnitz artist mainly showed female portraits as drawings, linocuts and woodcuts. During the gallery talk she explained the process creating pictures.

In May 2012, Klaus Hirsch opens the second exhibition of the year with the title "Expectations". He exhibited 26 pictures – drawings, paintings, woodcut and lithographic prints – in black and white with a modest coloration. The human being is a central theme of his drawings. In September 2012, Klaus Hirsch spoke in the gallery talk about his works and showed a screen for lithographic printing. The talk ended with a tour through the exhibition guided by the artist.

Since November 2012, Axel Wunsch has presented his works in the Fraunhofer ENAS headquarter. The artist lives and works in Chemnitz and has filled our building with colorful paintings and drawings. "Pastel-drawings" is also the title of this third exhibition in the year 2012. The drawings show men, buildings, animals and the artist himself.

We want to express our thanks to Georg Felsmann who strongly supports us in organizing the exhibition and the cooperation with the painters.

figures:
left: Dagmar Zemke shows a wood cut screen during the gallery talk.
right: Klaus Hirsch, Thomas Gessner and Georg Felsmann (from left to right) during the vernissage of the exhibition „Expactations" in the headquarter of Fraunhofer ENAS in May 2012.

FRAUNHOFER ENAS AT EVENTS

In 2012 the Fraunhofer ENAS attended and organized various events, conferences and trade fairs all around the world.

Smart Systems Integration SSI 2012 in Zurich, Switzerland

At Smart Systems Integration 2012 in Zurich 307 experts from 25 countries met to exchange experiences about the latest developments. The popularity has been on the same high level as in 2011 and therefore confirms the outstanding significance of Smart Systems Integration for the industry.
The smart systems integration conference is part of the activities of EPoSS – the European technology Platform on Smart Systems Integration. First time a session manufacturing has been integrated into the program. In order to push forward the international activities and to promote cooperations worldwide two special sessions focusing on US markets had been integrated in the conference program.
„The congress has shown that smart systems are introduced in more and more fields of our daily live. Energy saving based on smart systems as well as smart developments in traffic and cities – so-called smart cities – are good examples. Also the European Commission announced the high relevance of smart systems and smart systems integration and will increase the funding of smart systems integration, even SMEs will benefit from this.", said Professor Gessner, director of the Fraunhofer Institute for Electronic Nano Systems ENAS and chairman of Smart Systems Integration 2012.
Also for the first time the event was co-located to MEMS Executive Congress Europe, a conference of the US based MEMS Industry group. This has highlighted 2012's special focus on the United States. "Co-locating our first MEMS Executive Congress in Europe with Smart Systems Integration Conference and Exhibition proved an excellent idea," said Karen Lightman, managing director, MEMS Industry Group. "The two events share a synergistic focus. The mission of MEMS Industry Group is to advance MEMS across global markets, and MEMS is an important component of smart integrated systems. Thus, our attendees share some common interests. Add compelling speakers and rich content to the mix for both events, and you have the foundation for a very successful co-location!"
At the accompanying exhibition 22 exhibitors presented themselves to a highly qualified audience. 18 publishers from Germany, Switzerland, Belgium, France, UK and Italy showcased their topic-related publications.

figure:
Günther Lugert (left) and Thomas Gessner (right) hand over the best paper award of SSI 2011 to Andreas Nebeling during the award ceromony at SSI 2012.

figure: Prof. Dr. Arnold van Zyl, rector of Chemnitz University of Technology, speaks at the opening session of the Chemnitzer Fachtagung Mikrosystemtechnik.

Conferences and workshops 2012

Fraunhofer ENAS organized the following small conferences and workshops on international conferences:

Session "Carbon nanotubes for sensors and circuits" on IEEE 9th International Multi-Conference on Systems, Signals and Devices	Chemnitz, Germany	2012, March 21–23
Tutorial Series on the international conference "EuroSimE 2012"	Lisbon, Portugal	2012, April 15
Conference "MicroClean 2012"	Gruena, Germany	2012, May 21–23
Workshop "Prognostic Health Monitoring and Solder Damage Mechanisms" on the international conference "iTherm 2012"	San Diego, USA	2012, May 31
Workshop "Micro- and Nanoreliability"on the international conference NSTI Nanotech 2012	Santa Clara, USA	2012, June 18–21
Workshop "Reliability Issues and Characterization in the Micro-Nano Region" on the conference Materials Science and Engineering	Darmstadt, Germany	2012, September 25
8th Fraunhofer-Symposium	Sendai, Japan	2012, November 20

Fraunhofer ENAS took part in following conferences and workshops (selection):

Materials for Advanced Metallization MAM 2012	Grenoble, France	2012, March 11–14
Smart Systems Integration SSI 2012	Zurich, Switzerland	2012, March 21–22
IEEE 9th International Multi-Conference on Systems, Signals and Devices	Chemnitz, Germany	2012, March 21–23
SPIE Photonics Europe	Brussels, Belgium	2012, April 16–20
7th Annual Conference of the Thai Physics Society (SPC)	Phra Nakhon Si Ayutthaya, Thailand	2012, May 9–12
3rd IEEE International Workshop on Low Temperature Bonding for 3D Integration (LTB-3D) 2012	Tokyo, Japan	2012, May 22–23
AMAA Advanced Microsystems for Automotive Applications	Berlin, Germany	2012, May 30–31
13th IEEE Conference on Thermal and Thermomechanical Phenomena in Electronic Systems ITHERM	San Diego, USA	2012, May 30 – June 1
Large-area, Organic & Printed Electronic LOPE-C	Munich, Germany	2012, June 19–21
AVS 12th International Conference on Atomic Layer Deposition (ALD 2012 & BALD 2012)	Dresden, Germany	2012, June 17–20
Actuator	Bremen, Germany	2012, June 18–20
Vth International Conference On Molecular Materials MOLMAT 2012	Barcelona, Spain	2012, July 3–6
1. Elektronik Wireless Power Congress	Munich, Germany	2012, July 4–5
The International Conference on Flexible and Printed Electronics (ICFPE 2012)	Toyko, Japan	2012, September 6–8
International Conference on Digital Printing Technologies/Digital Fabrication 2012	Quebec, Canada	2012, September 9–13
Semiconductor Conference Dresden-Grenoble (ISCDG)	Grenoble, France	2012, September 24–26
MEMS-Conference on Semicon Europe	Dresden, Germany	2012, October 8–11
Chemnitzer Fachtagung Mikrosystemtechnik – Mikromechanik & Mikroelektronik	Chemnitz, Germany	2012, October 23–24
IEEE Conference RFID-TA12	Nice, France	2012, November 5–7
VDE-Kongress Smart Grid – Intelligente Energieversorgung der Zukunft	Stuttgart, Germany	2012, November 5–6
IEEE 14th Electronics Packaging Technology Conference	Singapore	2012, December 5–7

Fraunhofer ENAS trade fair and exhibition activities 2012

In 2012, Fraunhofer ENAS presented its research results on 20 German and international trade fairs and exhibitions. Twelve of them were held in Germany. These mostly international exhibitions focused on electro mobility, mechanical engineering, aviation, printing, sensor technologies, semiconductor industry and materials. On eight shows in Japan, China, USA and Europe Fraunhofer ENAS presented developments on nanotechnology, microelectronics and sensors.

This year, one main exhibit was the sensor system for condition monitoring of power lines developed together with Chemnitz University of Technology, Fraunhofer IZM, enviaM and other partners from industry within the project ASTROSE. This system supports the energy poviders to optimze the utilization of power lines with respect to renewable energies. The development called attention to the visitors at HANNOVER MESSE, SSI as well as Micromachine exhibition in Japan. You find further information about the system on page 30.

Wireless power transmission was another highlight at the booths of Fraunhofer ENAS in 2012. The institute showed examples like light cubes, mobile phone or monitor powered wirelessly by SUPA technology.

Together with other Fraunhofer institutes Fraunhofer ENAS has presented results within JTI Clean Sky on two air shows, So, Fraunhofer ENAS showed various sensors, actuators, monitoring solutions and systems for aviation on Farnborough Internalional Airshow and ILA Berlin Air Show. During the Berlin Air Show, the Fraunhofer-Gesellschaft and partners signed a letter of intent about Clean Sky 2. The consortium wants to continue the project until 2020 to contribute to less emission, energy saving and eco-friendly aviation.

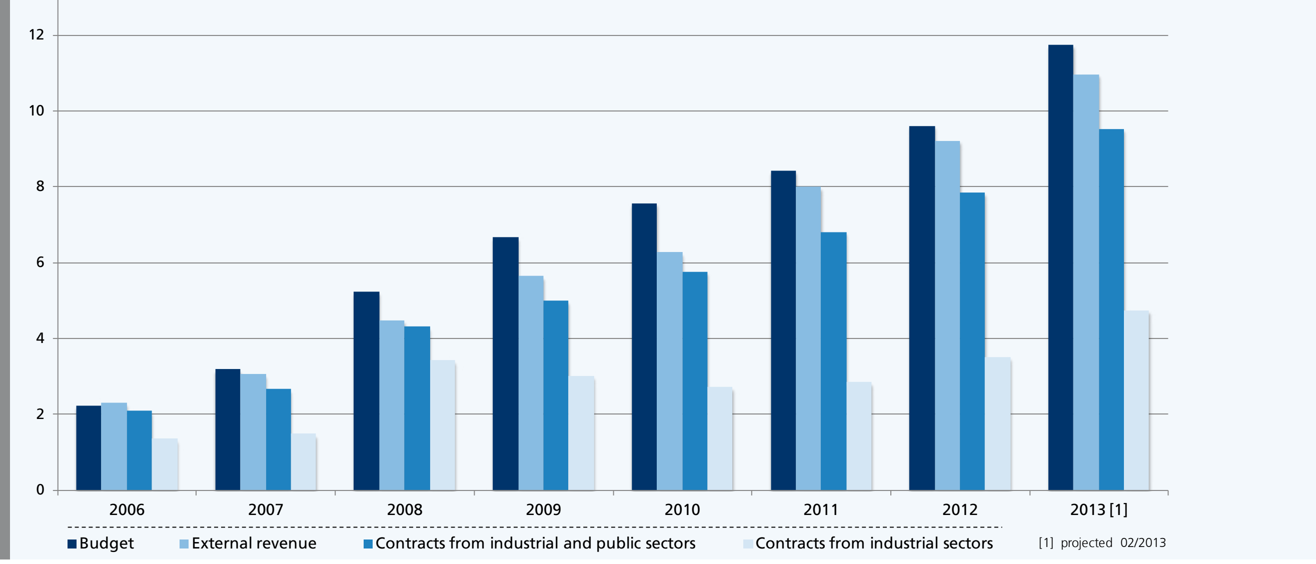
On drupa 2012 in Düsseldorf, institute staff supported the 3D-Micromac AG and the Print and Media Institute of Chemnitz University of Technology. The partners exibited jointly the modular roll-to-roll processing system for the digital fabrication of printed functionalities – microFLEX™. Printing and sintering of antennas based on copper-nano-inks were demonstrated.

For the first time, Fraunhofer ENAS exhibited on MATERIALICA in Munich. Besides analytic tools like a NIR microspectrometer, the institute presented nanocomposite layers and electromechanical transducers for smart lightweight structures.

Fraunhofer ENAS participation in trade fairs 2012

February	nano tech 2012 – International Nanotechnology Exhibition & Conference	Tokyo, Japan
	elektro:mobilia 2012	Cologne, Germay
March	SEMICON China	Shanghai, China
	SMART SYSTEMS INTEGRATION 2012 – European Conference & Exhibition	Zurich, Switzerland
April	HANNOVER MESSE 2012	Hanover, Germany
May	SENSOR+TEST 2012 – The Measurement Fair	Nuremberg, Germany
	drupa – print media messe	Düsseldorf, Germany
June	Sensors Expo & Conference	Rosemont, USA
	LOPE-C – Large Area, Organic & Printed Electronics Convention	Munich, Germany
	Silicon Saxony Day 2012	Dresden, Germany
	SIT 2012 – Sächsische Industrie- und Technologiemesse	Chemnitz, Germany
July	Farnborough International Airshow 2012	Farnborough, UK
	Exhibition Micromachine/MEMS 2012	Tokyo, Japan
September	ILA Berlin Air Show 2012	Berlin, Germany
	5th NRW Nano-Conference 2012	Dortmund, Germany
October	SAME 2012 – Sophia Antipolis Microelectronics Conference	Sophia Antipolis, France
	SEMICON Europa 2012	Dresden, Germany
	11. Chemnitzer Fachtagung Mikrosystemtechnik – Mikromechanik & Mikroelektronik –	Chemnitz, Germany
	MATERIALICA 2012	Munich, Germany
December	SEMICON Japan 2012	Tokyo, Japan

FACTS AND FIGURES



FRAUNHOFER ENAS IN FACTS

Human resources

The institute's success is rooted in the minds of its employees and their knowledge of details and relationships, products, technologies and processes. In 2012 our first own apprentices finished their vocational training successfully. In cooperation with the Chemnitz University of Technology and the University of Paderborn students and young scientists have successfully defended their thesis. Some of them belong now to our staff.

Eight employees joined the team, bringing the total staff at Fraunhofer ENAS in Chemnitz, Paderborn and Berlin to 105 at the end of 2012. The majority of our staff are qualified scientists and engineers. Fraunhofer ENAS offers job training as micro technology technicians. Currently there are six apprentices employed.

At the end of 2012 there were 43 interns, student assistants and students working on their Bachelor, Master or Diploma thesis employed. These regular team members belong to our source for coming new scientists and technicians.

Financial situation

The year 2012 was a successful one. Fraunhofer ENAS was able to increase the third-party funds as well as the number of projects. So within 2012, Fraunhofer ENAS reached clearly increased external funds of 9.21 million euros. This is an increase of 15.4 percent compared with 2011. The revenues quota is excellent with 96 percent. Contracts from German and international industry as well as trade associations reached just 3.49 million euros. This is almost 36.4 percent of the total operating budget of 9.6 million euros. In 2012, the operation budget has increased of 14 percent.

Own equipment investment of 1.17 million euros was realized in 2012. Additionally 0.64 million euros have been invested in basic equipment for the building and special financing.

FRAUNHOFER ENAS IN ZAHLEN

Personalentwicklung

Der Erfolg eines jeden Unternehmens und auch jeder Forschungseinrichtung steckt in den Köpfen der Beschäftigten, ihrem Wissen über Details und Zusammenhänge, Produkte, Technologien und Verfahren. 2012 schlossen unsere ersten Azubis erfolgreich ihre Ausbildung ab. In Kooperation mit der TU Chemnitz und der Universität Paderborn haben Studentinnen und Studenten sowie junge Wissenschaftlerinnen und Wissenschaftler ihre Graduierungsarbeiten erfolgreich verteidigt. Einige von ihnen verstärken jetzt unser Team.

Es wurden acht Mitarbeiterinnen und Mitarbeiter eingestellt, sodass zum Ende 2012 105 Personen an den Fraunhofer ENAS Standorten Chemnitz, Paderborn und Berlin beschäftigt waren. Fraunhofer ENAS bildet seit 2009 Mikrotechnologen aus. Zurzeit befinden sich sechs Mikrotechnologen in der Ausbildung.

Ende 2012 waren darüber hinaus 43 Praktikanten, Diplomanden/Masterstudenten und studentische Hilfskräfte bei Fraunhofer ENAS beschäftigt. Dieser Mitarbeiterstamm erweist sich in wachsendem Maße als Quelle für den Nachwuchs von Wissenschaftlern und Technikern.

Finanzielle Situation und Invest

2012 war für Fraunhofer ENAS ein erfolgreiches Jahr. Sowohl die Drittmittelerträge als auch die Anzahl der Drittmittelprojekte sind deutlich gestiegen. In 2012 erreichte Fraunhofer ENAS externe Erträge in Höhe von 9,21 Millionen Euro. Das sind 15,4 Prozent mehr als im Vorjahr. Die Ertragsquote liegt bei sehr guten 96 Prozent. Die Aufträge aus deutschen und internationalen Industrieunternehmen erreichten 3,49 Millionen Euro. Bei einem im Jahr 2012 um 14 Prozent gestiegenen Betriebshaushalt von 9,6 Millionen Euro entspricht damit der Industrieanteil 36,4 Prozent.

Die eigenen Geräteinvestitionen im vergangenen Jahr betrugen 1,17 Millionen Euro. Darüber hinaus wurden 0,64 Millionen Euro für die Ausstattung des Gebäudes bzw. Sonderfinanzierung investiert.

ADVISORY BOARD IN 2012

The advisory board supports the board of directors of the Fraunhofer-Gesellschaft as well as the institute´s management concerning strategic developments. The committee members provide an interconnective network with industry and local organizations.

In 2012, we welcomed Professor Arnold van Zyl as new member of our advisory board. Following Professor Klaus-Jürgen Matthes as new rector of the Chemnitz University of Technology, he entered the advisory board in June 2012.

The members of the Fraunhofer ENAS advisory board were in 2012:

Chairman:
Prof. Dr. Udo Bechtloff, CEO, KSG Leiterplatten GmbH

Deputy chairman:
Prof. Dr. Hans-Jörg Fecht, Director of the Institute of Micro and Nanomaterials, Ulm University

Members of the advisory board:
MRn Dr. Annerose Beck, Saxon State Ministry of Sciene and Art
Prof. Dr. Maximilian Fleischer, Siemens AG
Dr. Arbogast M. Grunau, Director Product Development, Schaeffler KG
RD Dr. Ulrich Katenkamp, Federal Ministry for Education and Research
Dr. Jiri Marek, Director Sensorics, Robert Bosch GmbH
MDgin Barbara Meyer, Saxon State Ministry of Economy, Technology and Transportation
Dr. Udo Nothelfer, UNTeC Technology Consulting
Prof. Dr. Ulrich Schubert, School of Chemistry and Earth Sciences, Jena University
Uwe Schwarz, Manager Development MEMS Technologies, X-FAB Semiconductor Foundries
Prof. Dr. Arnold van Zyl, Rector, Chemnitz University of Technology
Helmut Warnecke, CEO, Infineon Technologies Dresden GmbH & Co. OHG

figure:
The advisory board at its meeting in 2012 – (from left to right) Helmut Warnecke, Annerose Beck, Ulrich Katenkamp, Udo Nothelfer, Wolfgang Buchholtz, Thomas Gessner, Markus Ulm, Udo Bechtloff, Reinhard Baumann, Uwe Schwarz, Alexander Kurz, Arnold van Zyl, Maximilian Fleischer.

DISSERTATIONS IN 2012

April 4, 2012
PhD: Nicole Ahner
Topic: Wetting Optimized Solutions for Plasma Etch Residue Removal for Application in Interconnect Sysems of Integrated Circuits
Institution: Chemnitz University of Technology

April 12, 2012
PhD: Christopher Wiegand
Topic: Contributions to the analysis, the modeling and the simulation of digital phase-locked loops
Institution: University of Paderborn

November 23, 2012
PhD: Roman Forke
Topic: Mikromechanisches kraftgekoppeltes Sensor-Aktuator-System für die resonante Detektion niederfrequenter Schwingungen
Institution: Chemnitz University of Technology

AWARDS IN 2012

In 2012 the first apprentices in micro technologies finished their vocational training at Fraunhofer ENAS. Erik Birke graduated with “sehr gut” (very good) and was honored as one of the best apprentices in the Fraunhofer-Gesellschaft. On Nov 6, 2012, Doctor Alexander Kurz, senior vice president personell and legal affairs, handed out the prizes for the best apprentices in a ceremony in the headquarter of the Fraunhofer-Gesellschaft in Munich.

Every year the VDE/VDI-Society Microelectronics, Microsystems and Precision Engineering (GMM) awards young researchers for outstanding publications of the last three years. 2012 the GMM prize was handed out to two awardees. Jörg Bräuer has got the GMM prize for his researches in reactive bonding and the paper “A Novel Technique for MEMS Packaging: Reactive Bonding with Integrated Material Systems”. He was honored during the 3rd Symposium on Microelectronics in Berlin on September 26, 2012.

Further research fellows of Fraunhofer ENAS were honored with different awards in 2012. You find a selection in the following list.

Best Paper Award:

- Hermann, S.; Fiedler, H.; Yu, H.; Loschek, S.; Bonitz, J.; Schulz, S.E.; Gessner, T.: Wafer-level approaches for the integration of carbon nanotubes in electronic and sensor applications. IEEE 9th International Multi-Conference on Systems, Signals and Devices, Chemnitz, 2012, March 21–23.
- Dudek, R.; Doering, R.; Pufall, R.; Kanert, W.; Seiler, B.; Rzepka, S.; Michel, B.: Delamination modeling for power packages by the cohesive zone approach. InterSociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, ITHERM, San Diego, USA, 2012, May 30 – June 1.

Best Poster Award:

- Lorwongtragool, P.; Sowade, E.; Baumann, R.R.; Kerdcharoen, T.: Towards Polymer/CNT Gas Sensor using Inkjet printing. 7th Annual Conference of the Thai Physics Society (SPC), Phra Nakhon Si Ayutthaya, Thailand, 2012, May 9–12.
- Zienert, A.; Schuster, J.; Gessner, T.: Quantum Transport Through Carbon Nanotubes with Metal Contacts. The Vth International Conference On Molecular Materials MOLMAT 2012, Barcelona, Spain, 2012, July 3–6.
- Zichner, R.; Baumann, R. R.: R2R Screen Printed RFID Transponder Antennas for Vehicle Tracking Systems. The International Conference on Flexible and Printed Electronics (ICFPE 2012), Toyko, Japan, 2012, September 06–08.

Best Interactive Paper:

- Espig, M.; Siegel, F.; Hammerschmidt, J.; Willert, A.; Baumann, R.R.: Central Challenges When up Scaling the Manufacturing of Thin-Film Battery Applications. NIP28 – 28th International Conference on Digital Printing Technologies / Digital Fabrication 2012, Quebec, Canada, 2012, September 9–3.

figure (from left to right): Maik Reimann (instructor), Eric Birke (apprentice) and Dr. Alexander Kurz (senior vice president personell and legal affairs of the Fraunhofer-Gesellschaft) at the award ceremony for the best apprentices in 2012.

PROMOTION OF YOUNG TALENTS

Since three years Fraunhofer ENAS is offering job training as micro technology technician at the institute. It is based on a dual education model. It combines practice at the institute or a company with the training of theory at school. In 2012 our first two apprentices finished their vocational training with very good and good results. Right now there are six apprentices.

The institute also supports students with the opportunity to combine their studies with the practical scientific work in laboratories and offices of Fraunhofer ENAS. End of 2012 there were 43 students employed as interns, student assistants and students working on their thesis, may be bachelor, master or diploma thesis.

Fraunhofer-Gesellschaft is committed to a policy of equal opportunities for men and women, and supports efforts to create an equitable work life balance. Moreover the Fraunhofer-Gesellschaft is committed to bringing more women into applied research. It aims to increase the proportion of female scientists in all areas where they are currently underrepresented. In order to achieve this objective different actions have been done. So the workshop “Design Thinking meets Fraunhofer” had been organized at Fraunhofer ENAS. Thirteen female students participated in this workshop on October 26. They are studying electrical engineering and information technology, mechanical engineering, informatics or economic sciences. After short presentations by female scientists of Fraunhofer ENAS a lab tour and a discussion with young scientists had been organized. In the afternoon the students learned more about design thinking methods and applied them for smart systems, which are in the focus of Fraunhofer ENAS. Some of the young ladies are now with Fraunhofer ENAS, in order to do a practice or a thesis.

Fraunhofer ENAS supports also the activities of the Chemnitz University of Technology which are related to pupils, like summer and winter schools, day of the open doors and others. So Fraunhofer ENAS provides guided tours through the institute and presents prototypes and overviews to special topics for pupils interested in technical science. First time Fraunhofer ENAS took part on “Brilliant Social”. On July 17 two pupils were working one day at Fraunhofer ENAS. Their salary had been donated to social projects. These are a children’s home in India, a school for handicapped children in Tanzania and a training center for delinquent children in Guyana.

Kids creative is a special competition for kids in kindergarten organized by Fraunhofer-Gesellschaft. The goal is to awake the inquiring mind of kids. Also Fraunhofer ENAS employees try to do this. For that reason the kindergarten “Sonnenschein” in Jahnsdorf took part in kids creative in 2012. The kids got the second prize from Fraunhofer-Gesellschaft for their “Hebi”, that is a crane with a special platform for catering of construction workers and a glass bead for children watching the work.

figure:
left: Hebi – the contribution to Fraunhofer competition “kids creative” from kindergarten “Sonnenschein”.
right: Femal students discuss on the workshop “Design Thinking meets Fraunhofer”.

MEMBERSHIPS (SELECTION)

Memberships of Fraunhofer scientists

acatech (Council of Technical Sciences of the Union of German Academies of Sciences)	Prof. T. Gessner	member
Academy of Sciences of Saxony, Germany	Prof. T. Gessner	member
Academy of Sciences, New York/USA	Prof. B. Michel	member
Advanced Metallization Conference AMC	Prof. S. E. Schulz	member of the executive committee
Arnold Sommerfeld Gesellschaft zu Leipzig/Germany	Prof. B. Michel	scientific advisory board
Board of "KOWI", Service Partner for European R&D funding, Brussels/Belgium	Prof. T. Gessner	member
Deutscher Verband für Schweißen und verwandte Verfahren e. V.	Dr. M. Wiemer	chairman AG A2.6 „Waferbonden"
Digital Fabrication Conference (DF) of IS&T	Prof. R. R. Baumann	conference chair, chair steering team
Dresdner Fraunhofer Cluster Nanoanalytics	Dr. S. Rzepka	steering committee member
Engineering and Physical Science Research Council, UK	Prof. B. Michel	referee
EPoSS (European Platform on Smart Systems Integration)	Prof. T. Gessner, Prof. T. Otto	member of the steering group
European Center for Micro- and Nanoreliability (EUCEMAN)	Prof. B. Michel, Dr. S. Rzepka, Prof. B. Wunderle, J. Hussack	president, committee members
EuroSimE	Prof. B. Wunderle, Dr. R. Dudek	members of the conference committee
German Science Foundation	Prof. T. Gessner	referee
Humboldt Foundation	Prof. B. Michel	referee
International Conference on R2R Printed Electronics	Prof. R. R. Baumann	advisory committee
International Conference ICEPT	Dr. J. Auersperg	technical committee member
International Conference IPTC	Dr. J. Auersperg	technical committee member
International Symposium for Flexible Organic Electronics (IS-FOE)	Prof. R. R. Baumann	advisory board
International Symposium Technologies for Polymer Electronics TPE	Prof. R. R. Baumann	advisory committee
International Young Scientists Conference Printing Future Days	Prof. R. R. Baumann	general chair
IS&T – Society for Imaging Science & Technologies	Prof. R. R. Baumann	vice president
ITherm Conference	Prof. B. Wunderle	program committee member
Large-area, Organic and Printed Electronics Convention, LOPE-C	Prof. R. R. Baumann	advisory board, scientific chair
Materials for Advanced Metallization MAM	Prof. S. E. Schulz	member of scientific program committee
European Executive Congress of the MEMS Industry Group	Dr. M. Vogel	committee member
MEMUNITY	Dr. S. Kurth	Member of executive committee
Microsys Berlin 2012 Conference	Prof. T. Otto	Member of program committee
Microsystems Technology Journal	Prof. B. Michel	editor-in-chief
National Research Agency, France	Prof. B. Michel	referee
NSTI Nanotechnology Conferences	Prof. B. Michel	reliability track chairman
Organic Electronics Association (OE-A)	Prof. R. R. Baumann	member of the board

Senatsausschuss Evaluierung der Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz (WGL)	Prof. T. Gessner	member
SEMICON Europa	Prof. T. Gessner, Dr. M. Vogel	program committee members of MEMS conference
Smart Systems Integration Conference	Prof. T. Gessner, Prof. T. Otto, Prof. B. Michel Dr. C. Hedayat, Dr. K. Hiller	conference chair, members of program committee

Memberships of Fraunhofer ENAS

Cool Silicon e.V.	Dresden, Germany
Dresdner Fraunhofer-Cluster Nanoanalytik	Dresden, Germany
European Center for Micro and Nanoreliability EUCEMAN	Berlin, Germany
European Platform on Smart Systems Integration EPoSS	Berlin, Germany
Industrieverein Sachsen 1828 e. V.	Chemnitz, Germany
IVAM Microtechnology Network	Dortmund, Germany
MEMS Industry Group®	Pittsburgh, USA
Nano Technology Center of Competence "Ultrathin Functional Films"	Dresden, Germany
Organic Electronics Association OE-A	Frankfurt/Main, Germany
Organic Electronics Saxony e.V. OES	Dresden, Germany
Semiconductor Equipment and Materials International (SEMI)	San Jose, USA
Silicon Saxony e.V.	Dresden, Germany

PATENTS

Title: Sensormodul und Verfahren zum Herstellen eines Sensormoduls
Country: DE
Patent Number: 10 2012 010 509.6
Date of Application: May 21, 2012

Title: Verfahren zur Fixierung einer beweglichen Komponente eines mikromechanischen Bauelementes
Country: DE
Patent Number: 10 2012 010 549.5
Date of Application: May 29, 2012

Title: Supraballs bestehend aus Nanopartikeln/Verfahren und Vorrichtung zum Erzeugen einer dreidimensionalen Stuktur auf einem Substrat
Country: EP
Patent Number: PCT/EP2012/063280
Date of Application: July 6, 2012

Title: Flexibles mikrofluidisches System
Country: EP
Patent Number: EP12179918.3
Date of Application: August 9, 2012

Title: Galvanische Nanoschichtsysteme für Fügeverfahren in der Mikrosystem- und Sensortechnik
Country: US
Patent Number: 13/146,759
Date of Patent: August 24, 2012

Title: RFID Antennenstrukturen
Country: DE
Patent Number: 102012215334.9
Date of Application: August 29, 2012

Title: Mikrofluidisches System mit Temperierung
Country: EP
Patent Number: EP12186645.3
Date of Application: September 28, 2012

Title: Vorrichtung zur effizienten Energieübertragung mit hoher Frequenz
Country: EP
Patent Number: PCT/EP2012/070227
Date of Application: October 12, 2012

LECTURES

Chemnitz University of Technology

Advanced Integrated Circuit Technology
Lecturers: Prof. Dr. S. E. Schulz, Dr. R. Streiter

Technologien der Mikroelektronik
Lecturers: Prof. Dr. T. Gessner, Prof. Dr. S. E. Schulz, Dr. R. Streiter

Mikrotechnologie
Lecturers: Prof. Dr. T. Gessner, Dr. R. Streiter

Micro optical Systems
Lecturer: Prof. Dr. T. Otto

Technologies for Micro and Nano Systems
Lecturers: Prof. Dr. K. Hiller, Dr. A. Bertz

Technologien für Mikro- und Nanosysteme
Lecturers: Prof. Dr. T. Gessner, Dr. D. Reuter

Prüftechnik Mikrosystemtechnik
Lecturer: Dr. S. Kurth

Micro- and Nanoreliability
Lecturer: Prof. Dr. B. Wunderle

Technische Zuverlässigkeit
Lecturer: Dr. S. Rzepka

Werkstoffe der Mikrotechnik
Lecturer: Prof. Dr. B. Wunderle

Werkstoffe der Elektrotechnik
Lecturer: Prof. Dr. B. Wunderle

Ausgabesysteme Einführung – Einführung in Geräte der Druckausgabe
Lecturers: Prof. Dr. R. R. Baumann, A. Grimm, E. Sowade

Ausgabesysteme I – Druckausgabegeräte allgemein
Lecturers: Prof. Dr. R. R. Baumann, E. Sowade

Ausgabesysteme II / Output Systems II – Druckausgabegeräte Inkjet und Elektrofotografie
Lecturers: Prof. Dr. R. R. Baumann, J. Hammerschmidt

Digital Fabrication – digitale Fabrikationstechniken
Lecturer: Prof. Dr. R. R. Baumann

Druckvorstufe I – Druckdatenaufbereitung
Lecturers: Prof. Dr. R. R. Baumann, F. Siegel

Medientechnisches Kolloquium
Lecturer: Prof. Dr. R. R. Baumann

Output Systems II – Druckausgabegeräte Inkjet und Elektrofotografie
Lecturers: Prof. Dr. R. R. Baumann, J. Hammerschmidt

Prepress II – Algorithms and Data Management of Prepress
Lecturers: Prof. Dr. R. R. Baumann, F. Siegel, Dr. A. Willert

Visuelle Wiedergabequalität – technische Beurteilung von Druckausgaben
Lecturers: Prof. Dr. R. R. Baumann, Dr. A. Willert

Typografie und Gestaltung
Lecturers: Prof. Dr. R. R. Baumann, A. Grimm

Lectures of International Research Training Group at the Chemnitz University of Technology

Microelectronics Technology
Lecturers: Prof. Dr. T. Gessner, Prof. Dr. S. E. Schulz

Interconnect Processes and Technology
Lecturer: Prof. Dr. S. E. Schulz

Design and Simulation of Micro- and Nanosystems
Lecturers: Prof. Dr. T. Otto, Dr. D. Billep

TU Dresden

Einführung in die Finite Element Methode
Lecturer: Dr. S. Rzepka

Interconnect Reliability: Elektro- und Stressmigration, in the lecture course Mikroelektroniktechnologie
Lecturer: Dr. S. Rzepka

University of Paderborn

Theorie und Anwendung von Phasenregelkreisen (PLL-Systeme)
Lecturer: Dr. C. Hedayat

Mikrosensorik
Lecturer: Prof. Dr. U. Hilleringmann

RFID-Funketiketten: Aufbau und Funktion
Lecturer: Prof. Dr. U. Hilleringmann

Technologie hochintegrierter Schaltungen
Lecturer: Prof. Dr. U. Hilleringmann

Integriert-optische Sensoren
Lecturer: Prof. Dr. U. Hilleringmann

Halbleiterbauelemente
Lecturer: Prof. Dr. U. Hilleringmann

Halbleiterprozesstechnik
Lecturer: Prof. Dr. U. Hilleringmann

Mikrosystemtechnik
Lecturer: Prof. Dr. U. Hilleringmann

Micro-Electro-Mechanical Systems
Lecturer: Prof. Dr. U. Hilleringmann

PUBLICATIONS (SELECTION)

Books

Wiemer, M.; Wuensch, D.; Braeuer, J.; Gessner, T.: Chapter Plasma-Activated Bonding.; in the book: Handbook of Wafer Bonding, ed. by Peter Ramm, James Jian-Qiang Lu, Maaike M. V. Taklo (2012), pp 101–118. ISBN: 978-3-527-32646-4.

Papers

Abo Ras, M.; Schacht, R.; May, D.; Wunderle, B.; Winkler, T.; Michel, B.: Universal test system for the characterization of the most common thermal interface materials. 7th Workshop on Thermal Management, 2012, La Rochelle, France, 2012 Feb 1–2.

Ahner, N.; Zimmermann, S.; Schaller, M.; Schulz, S.E.: Optimized wetting behavior of water-based cleaning solutions for plasma etch residue removal by application of surfactants. Solid State Phenomena, 187 (2012), pp 201–205, ISSN: 1012-0394.

Ali, E.; Hangmann, C.; Wiegand, C.; Hedayat, C.; Kraus, D.: Event-Driven Simulation Of The 2nd Order Voltage Operated Charge-Pump PLL. SAME 2012, Conference, Sophia Antipolis, France, 2012 Oct 2–3.

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