Fraunhofer

ENAS

FRAUNHOFER INSTITUTE FOR ELECTRONIC NANO SYSTEMS ENAS

Cover page:
Building of the Fraunhofer Institute for Electronic Nano Systems ENAS:
The light elements integrated in the facade of the building symbolize copper innterconnects

cover photo: Fraunhofer ENAS

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FRAUNHOFER ENAS

PREFACE

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

2010 is a very special year for Fraunhofer ENAS. In June 2010 Fraunhofer ENAS passed a technology audit as a part of the strategy process. The auditors, experts from industry and science, pointed out that the overall focus of the Fraunhofer ENAS is very promising. All working fields have a visionary component and it can be expected that market-relevant technologies and products will be developed. The Executive and the Senate of the Fraunhofer-Gesellschaft decided to convert the Fraunhofer Research Institution into the Fraunhofer Institute for Electronic Nano Systems ENAS on January 1, 2011.

The strategic alliance between the Fraunhofer ENAS and the Center for Microtechnologies of the Chemnitz University of Technology ensured strong synergies in technology and device development also in 2010. The strong cooperation with the Fraunhofer IZM Berlin has been especially continued in the field of nano assembly and packaging for MEMS and NEMS.

Fraunhofer ENAS is internationally active. It cooperates very actively within in the European Platform on Smart Systems Integration EPoSS and is a member of groups, networks and alliances. Our representatives in Japan, China and Brazil support our international activities.

The smart systems integration addresses the trend to even smaller multi functional, self organizing systems with an interface for communication with the outside world. Smart systems technologies and their integration will have a significant impact on the competitiveness of entire sectors as aeronautics, automotives, security, logistics, medical technology and process engineering. It will consequently contribute to solving major socio-economic problems in the health, environment, mobility and other domains.

The Fraunhofer Institute for Electronic Nano Systems is positioning itself to meet these challenges. The basic requirement for our continued success in research and development is, of course, the committed work of our staff. Due to the increase of turnover, the staff level of Fraunhofer ENAS increased in 2010. The department Micro Materials Center got a second head, Dr. Rzepka.

In January 2010 the InfraTec GmbH Dresden got the PRISM Award at the Photonics West from SPIE, the Society of Photographic Instrumentation Engineers, for the Fabry-Perot interferometer commonly developed with ZfM and Fraunhofer ENAS. End of 2010 the researcher and developer Dr. Nenad Marjanovic has been awarded with Tesla Prize of the Serbian Ministry for Diaspora.

In our capacity as a research institute of Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., research and development for industrial applications are our prime and natural concern. R&D work is carried out on behalf of large national and international companies as well as small and medium-sized enterprises, network operators and the public sector such as State of Saxony, the Federal Government and the EU. The institute's success is rooted in the minds of its employees and their knowledge of details and relationships, products, technologies and processes. The institute's performing power is based on our staff's creativity and optimism as well as the support of many of our business partners and sponsors. We would like express our thanks to all of them.

Director of the Fraunhofer Institute for Electronic Nano Systems

Prof. Dr. Thomas Gessner

Liebe Freunde und Partner des Fraunhofer-Instituts für Elektronische Nanosysteme,
sehr geehrte Damen und Herren,

das Jahr 2010 ist für das Fraunhofer ENAS ein besonderer Meilenstein. Im Juni 2010 wurde Fraunhofer ENAS im Rahmen des Strategieprozesses auditiert. Die Auditoren, Experten aus Industrie und Wissenschaft, schätzten ein, dass die Gesamtausrichtung von Fraunhofer ENAS erfolgsversprechend ist. Alle Arbeitsgebiete besitzen eine visionäre Komponente und deren Umsetzung in marktrelevante Technologien ist zu erwarten. Durch Beschlüsse des Vorstands und des Senats der Fraunhofer-Gesellschaft wurde die Fraunhofer-Einrichtung zum 1. Januar 2011 in das Fraunhofer-Institut für Elektronische Nanosysteme ENAS überführt.

Auch in 2010 sicherte die strategische Allianz zwischen Fraunhofer ENAS und dem Zentrum für Mikrotechnologien der Technischen Universität Chemnitz Synergien in der Technologie und Systementwicklung. Für die inhaltliche Weiterentwicklung in Richtung der Mikro- und Nanosysteme wurde die enge Kooperation mit dem Fraunhofer IZM Berlin, insbesondere auf dem Gebiet der Nano-Aufbau- und Verbindungstechnik, weitergeführt.

Mit der Mitarbeit im Rahmen der Europäischen Plattform für Smart Systems Integration EPoSS, der Mitgliedschaft in Verbünden und Verbänden aber auch Repräsentanten in Japan, China und Brasilien ist das Fraunhofer ENAS international aufgestellt.

Die Smart Systems Integration adressiert den Trend zu immer kleineren multifunktionalen, sich selbst organisierenden Systemen mit Schnittstellen zur Kommunikation mit der Außenwelt. Die Technologien für intelligente Systeme und ihre Integration werden signifikant die Wettbewerbsfähigkeit der verschiedenen Branchen wie Luft- und Raumfahrt, Automobilbau, Sicherheit, Logistik, Medizin- und Prozesstechnik beeinflussen. Konsequenter Weise werden sie beitragen, sozialökonomische Probleme im Bereich Gesundheit, Umwelt, Mobilität und anderen zu lösen.

Das Fraunhofer-Institut für Elektronische Nanosysteme stellt sich diesen Herausforderungen. Grundvoraussetzung für unsere erfolgreichen Forschungs- und Entwicklungsleistungen ist der engagierte Einsatz der Mitarbeiterinnen und Mitarbeiter unseres Hauses. Basierend auf der Steigerung der Erträge erhöhte sich der Personalbestand des Fraunhofer ENAS in 2010. Die Abteilungsleitung des Micro Materials Centers wurde durch Herrn Dr. Rzepka verstärkt.

Nachdem im Januar 2010 die InfraTec GmbH Dresden auf der Photonics West durch die SPIE für das gemeinsam mit Fraunhofer ENAS und ZfM entwickelte Fabry-Perot-Interferometer mit dem PRISM Award geehrt wurde, konnte Ende 2010 Dr. Nenad Marjanovic den Tesla-Preis Serbiens für seine herausragenden wissenschaftlichen Arbeiten entgegennehmen.

Als Institut der Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. ist für uns Forschung und Entwicklung für industrielle Anwendungen ein selbstverständliches Anliegen. Die Forschungs- und Entwicklungsarbeiten werden im Auftrag nationaler und internationaler Großunternehmen und KMUs, der öffentlichen Hand, des Landes Sachsen, des Bundes und der EU durchgeführt. Der Erfolg eines jeden Unternehmens steckt in den Köpfen der Beschäftigten, ihrem Wissen über Details und Zusammenhänge, Produkte, Technologien und Verfahren. Die Leistungskraft beruht auf Kreativität, Leistungsbereitschaft und Optimismus der Mitarbeiterinnen und Mitarbeiter sowie der Unterstützung durch zahlreiche Geschäftspartner und Förderer. Ihnen allen gilt mein besonderer Dank.

Der Leiter des Fraunhofer-Instituts für Elektronische Nanosysteme

Prof. Dr. Thomas Gessner

FRAUNHOFER-GESELLSCHAFT - PROFILE

Research of practical utility

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.

At present, the Fraunhofer-Gesellschaft maintains more than 80 research units in Germany, including 60 Fraunhofer Institutes. The majority of the more than 18,000 staff are qualified scientists and engineers, who work with an annual research budget of €1.65 billion. Of this sum, more than €1.40 billion 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 non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

FRAUNHOFER-GESELLSCHAFT - IM PROFIL

Forschung für die Praxis

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.

Die Fraunhofer-Gesellschaft betreibt in Deutschland derzeit mehr als 80 Forschungseinrichtungen, davon 60 Institute. Mehr als 18 000 Mitarbeiterinnen und Mitarbeiter, überwiegend mit natur- oder ingenieurwissenschaftlicher Ausbildung, bearbeiten das jährliche Forschungsvolumen von 1,65 Milliarden Euro. Davon fallen 1,40 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 erarbeiten 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 an Fraunhofer-Instituten wegen der praxisnahen Ausbildung und Erfahrung 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 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 CNT, EMFT, ENAS, ESK, FHR, HHI, IAF, IIS, IISB, IMS, IPMS, ISIT, IZM and the guest Fraunhofer FOKUS, IDMT and IZFP-D belong to this Fraunhofer group. Its membership consists of thirteen institutes as full members and three as associated members, with a total workforce of around 2,700 and a combined budget of roughly €255 million. 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 two cross-sectional business areas

- Technologies for Communication
- Semiconductor Technologies

and five application-oriented business areas

- Ambient assisted Living
- eMobility
- Light
- Security
- Entertainment.

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FRAUNHOFER-VERBUND MIKROELEKTRONIK

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 CNT, EMFT, ENAS, ESK, FHR, HHI, IAF, IIS,IISB, IMS, IPMS, ISIT, IZM sowie als Gäste Fraunhofer FOKUS, IDMT und IZFP- D. Das sind dreizehn Institute (und drei Gastinstitute) mit ca. 2700 Mitarbeiterinnen und Mitarbeitern. Das jährliche Budget beträgt etwa 255 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 zwei Querschnittsgeschäftsfelder

- Halbleitertechnologien
- Technologien der Kommunikationstechnik

und fünf anwendungsorientierte Geschäftsfelder

- Ambiente Assistenzsysteme
- Energieeffiziente Systeme und eMobility
- Licht
- Sicherheit
- Unterhaltung.

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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 and are focused on 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 concerned with research and construction in very small structures. 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 nanostructure.

The alliance focuses its activities on the following main topics:

- Nanobiotechnology
- Nanomaterials
- Technology transfer and consulting
- Nano processing / handling
- Nanooptics and -electronics
- Measuring methods/ techniques

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Fraunhofer ENAS is represented by:
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FRAUNHOFER-ALLIANZ NANOTECHNOLOGIE

Fraunhofer ENAS ist seit 2009 Mitglied der Fraunhofer-Allianz Nanotechnologie. Zur Allianz gehören 20 Fraunhofer-Institute und Einrichtungen (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 Allianz Nanotech mit Fragen zur Toxizität und dem sicheren Umgang mit Nanopartikeln.

Nanotechnologie ist eine Querschnittstechnologie, die sich mit der Forschung und Konstruktion in sehr kleinen Strukturen beschäftigt. 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 PROFILE

Smart Systems Integration by Using Micro and Nano Technologies

The Fraunhofer-Gesellschaft is one of the leading organizations for applied research in Germany and Europe. Its core purpose is the pursuit of knowledge of practical utility. The Fraunhofer Institute for Electronic Nano Systems ENAS is focusing on smart systems integration by using micro and nano technologies.

In semiconductor technologies / microelectronics the strategic research agenda of the European Nanoelectronics Initiative Advisory Counsil ENIAC as well as the International Technology Roadmap of Semiconductors ITRS predicts with "More Moore" and "More than Moore" not only a further downscaling of the structural dimensions but also the diversification of technologies. Main topic of this so-called "More than Moore" strategy is the integration of different components in one system to ensure the multifunctionality of the system itself.

The European Platform on Smart Systems Integration EPoSS takes up this trend to multifunctional devices and smart systems. Smart systems go beyond microsystems for single physical, biological or chemical parameter measurements combined with signal processing and actuating functions. Smart systems integration addresses the demand for miniaturized multifunctional devices and specialized connected and interacting solutions. Multidisciplinary approaches featuring devices for complex solutions and making use of shared and, increasingly, self-organising resources are among the most ambitious challenges.

Fraunhofer ENAS is working in both fields. In the "More Moore" field Fraunhofer ENAS focuses on metallization and interconnect systems as well as on reliability of microelectronic components. In the field of smart systems or "More than Moore" sensors, actuators as well as communication units and therefore more functionalities are integrated into one system. Systems integration will determine the economic success of manufacturers and users coming mostly from consumer electronics, telecommunication, mechanical engineering, medical technology, and automotive. To ensure long-term competitiveness, a sophisticated technological potential is necessary. The Fraunhofer ENAS is positioning itself to meet these challenges and participates very actively in the further development of Smart Systems Integration.

The foci of Fraunhofer ENAS are strongly affected by developments of nanotechnology and ensured by the following unique features of Fraunhofer ENAS within the Fraunhofer-Gesellschaft:

- High precision MEMS and NEMS
- Digital pilot station (Inkjet-Technikum), adaptive printing technologies inclusively material development and characterization
- Nano systems: system design and nano reliability
- Wafer bonding for 3D system integration
- Interconnect technologies, back-end of line for nano electronics and nano systems

The main research areas of Fraunhofer ENAS are clearly visible in the structure of the institute. Six departments belong to Fraunhofer ENAS:

- Multi Device Integration (MDI)
- Micro Materials Center (MMC)
- Printed Functionalities (PF)
- Back-end of Line (BEOL)
- System Packaging (SP)
- Advanced System Engineering (ASE)

FRAUNHOFER ENAS IM PROFIL

Smart Systems Integration unter Nutzung von Mikro- und Nanotechnologien

Forschen für die Praxis ist die zentrale Aufgabe der Fraunhofer-Gesellschaft. Im Fokus des Fraunhofer-Instituts für Elektronische Nanosysteme ENAS steht die Forschung und Entwicklung auf dem Gebiet der Smart Systems Integration unter Nutzung von Mikro- und Nanotechnologien gemeinsam mit Partnern.

Diese Ausrichtung ist in den internationalen Roadmaps und den strategischen Forschungsagenden des European Nanoelectronics Initiative Advisory Councils ENIAC und der industriegetriebenen European Platform on Smart Systems Integration EPoSS klar unterlegt. Im Bereich Halbleitertechnik/Mikroelektronik zeigen die strategische Forschungsagenda von ENIAC sowie die International Technology Roadmap of Semiconductors ITRS nicht nur das weitere Downscaling der Strukturbreiten im Bereich „More Moore" sondern mit „More than Moore" die weitere Diversifizierung von Technologien für Systeme auf. Im Vordergrund steht die Multifunktionalität. Die Smart Systems Integration greift diesen Trend zu miniaturisierten multifunktionalen Baugruppen und Systemen auf. Smart Systems, sogenannte intelligente Systeme, gehen weit über die derzeit typischen Anwendungen der Mikrosystemtechnik, d.h. einzelne physikalische, biologische oder chemische Parametermessungen kombiniert mit Signalverarbeitung und Aktuatorfunktion hinaus. Fachübergreifende Herangehensweisen, die zu Systemen für komplexe Lösungen führen und verteilte sowie in zunehmenden Maße selbstorganisierende Ressourcen nutzen, gehören zu den anspruchsvollsten Herausforderungen.

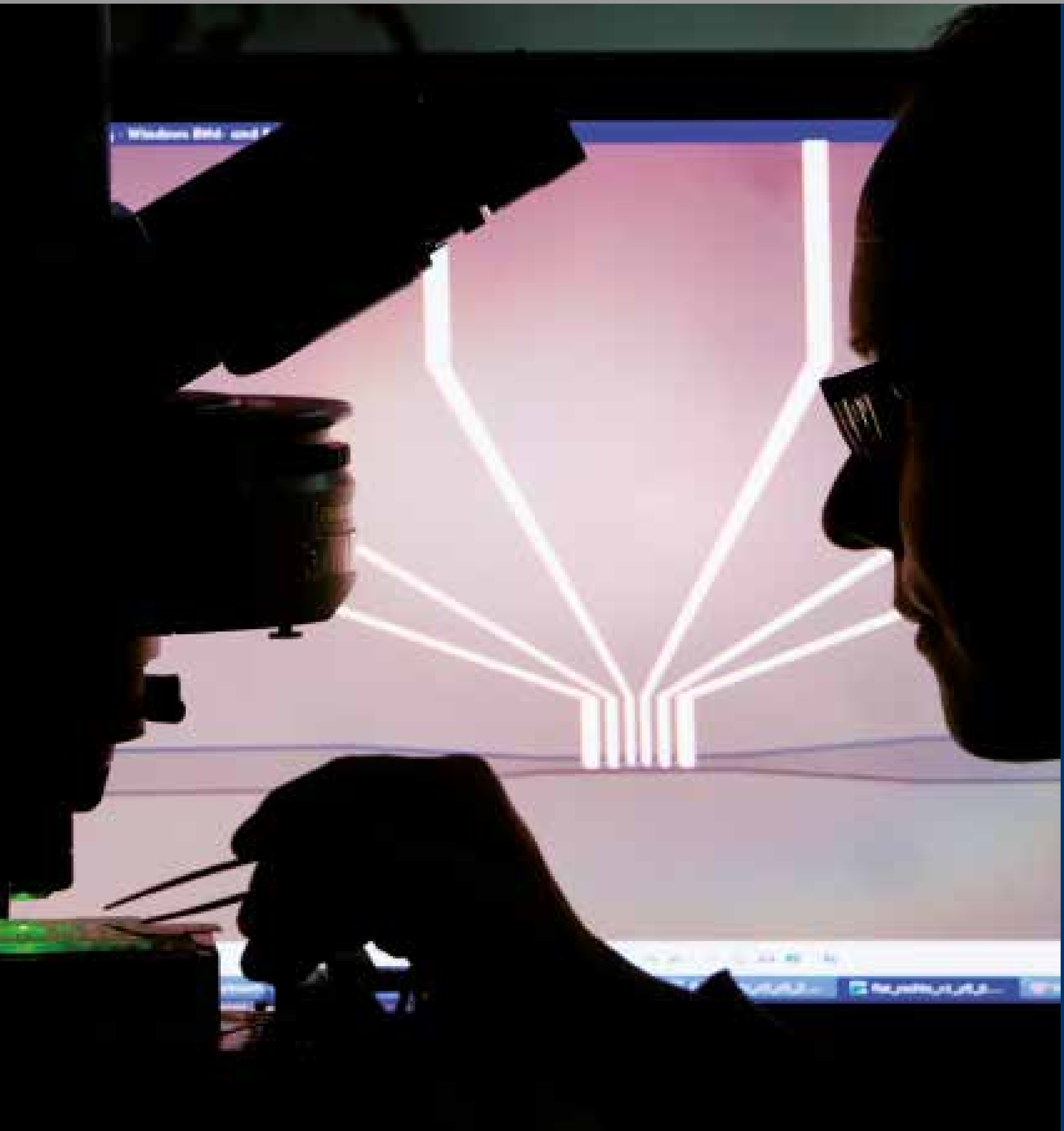
Fraunhofer ENAS verfolgt mit Smart Systems Integration und More Moore beide Strategien. Einerseits wird an Metallisierungs- und Interconnect-Systemen sowie an der Zuverlässigkeit für mikroelektronische Komponenten geforscht (More Moore). Andererseits gilt es, zunehmend mehr Funktionalität, etwa Sensoren, Aktoren oder Kommunikationsschnittstellen, in das Gesamtsystem zu integrieren. Systemintegration wird zunehmend den ökonomischen Erfolg der Hersteller und Anwender der Konsumgüterelektronik, Telekommunikation, Maschinenbau, Medizintechnik und Automobilbau bestimmen. Um langfristig wettbewerbsfähig zu sein, ist ein hoch entwickeltes technologisches Potential unabdingbar. Das Fraunhofer ENAS stellt sich diesen Herausforderungen und arbeitet sehr aktiv an der weiteren Entwicklung der Smart Systems Integration.

Diese Entwicklungsschwerpunkte des Fraunhofer-Instituts für Elektronische Nanosysteme ENAS werden in Summe durch starke Impulse der Nanotechnologien geprägt und sind vor allem durch die folgenden Alleinstellungsmerkmale innerhalb der Fraunhofer-Gesellschaft geprägt und gesichert:

- Präzisions-Silizium MEMS und NEMS
- Inkjettechnikum, adaptierte Drucktechnologien, inklusive Materialformulierungen
- Nanosysteme: Systemdesign und Nanoreliability
- Waferbonden für die 3D-Systemintegration
- Interconnecttechnologien, Back-end of Line (BEOL) für Nanoelektronik und Nanosysteme.

Die wesentlichen Forschungsgebiete des Fraunhofer ENAS spiegeln sich in der Struktur des Instituts wieder. Organisatorisch ist Fraunhofer ENAS in sechs Abteilungen gegliedert:

- Multi Device Integration (MDI)
- Micro Materials Center (MMC)
- Printed Functionalities (PF)
- Back-end of Line (BEOL)
- System Packaging (SP)
- Advanced System Engineering (ASE)



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DEPARTMENT MULTI DEVICE INTEGRATION

Head of the 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 non-silicon materials (nanocomposites, ceramics and polymers). In terms of Smart Systems Integration, the department combines primarily the activities in the areas of:

- MEMS/NEMS design / Electronics design
- Microoptics
- Fluidic integration
- Nanocomposites
- RF-MEMS
- Inertial sensors and measurement
- Measurement, test and characterization
- System integration.

The aim of the research is to develop and apply integration technologies taking into 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.

MEMS/NEMS Design

Novel modeling and simulation techniques are essential for designing innovative 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 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.

We own the following core competences:

- 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.

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 micro system based opto-mechanical 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. One example is the development and validation of infrared MEMS spectrometers is exemplary for the activities in the field of microoptics. Such systems can be configured for different wavelength bands and hence be used in various applications. Food studies, environmental 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 health care, 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 competencies include

- Microfluidic modeling and system design
- Fabrication of microfluidic devices in multiple materials such as polymers, glas 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 ensuring 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 and with the use of semiconductor nanocrystals for nano-sensors or in light-emitting systems.

Polymer-based nanocomposite systems are particularly suitable for the material-integrated functionalities, e. g., sensors such as 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, as changes in fluorescence 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 signal attenuation. 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.

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 and 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

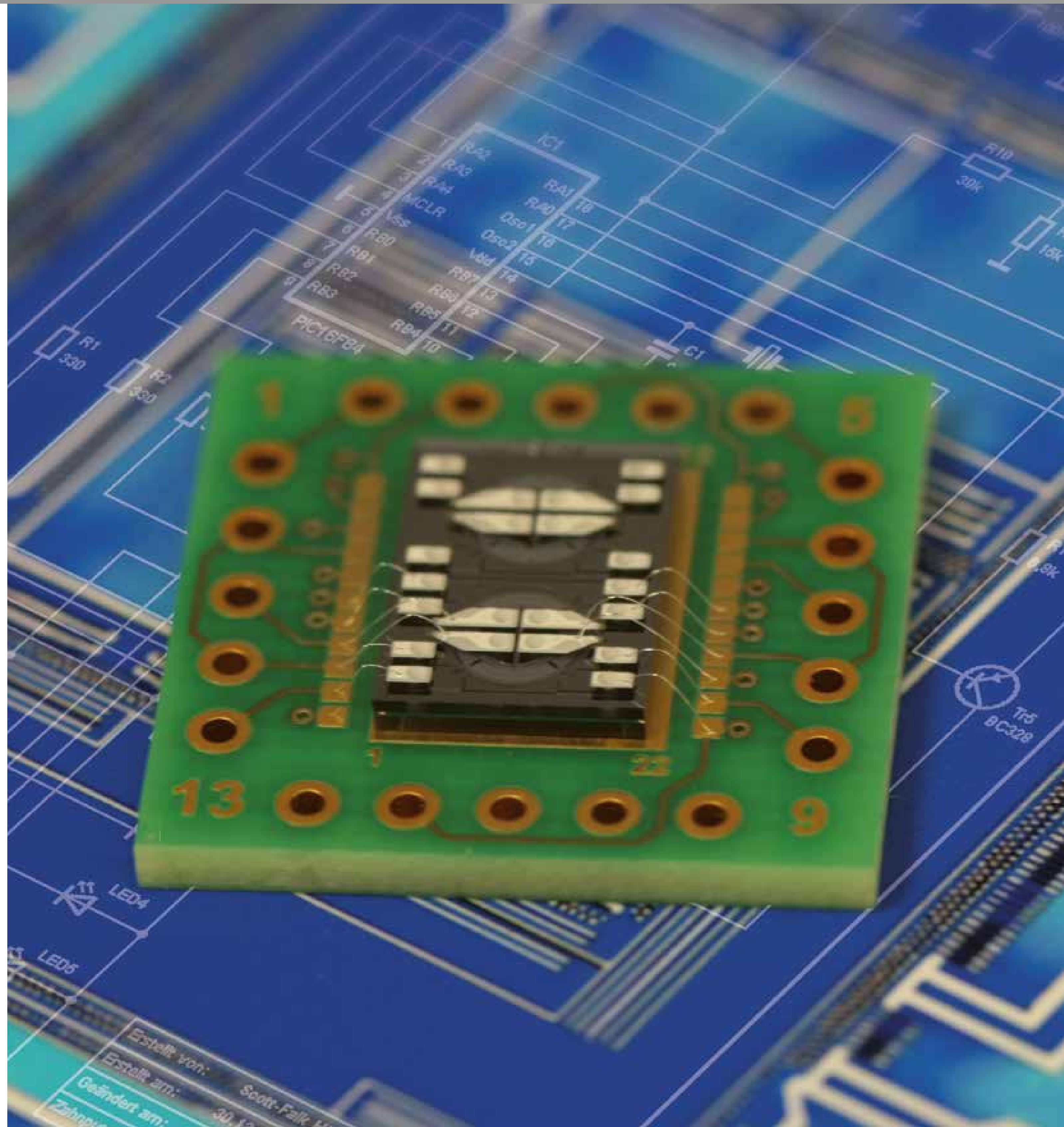
A method for the extremely fast determination of dimensional and material parameters based on a combination of the Finite Element Method (FEM) and the measurement of Eigenfrequencies has been developed in recent years and is now improved and adapted to different classes of MEMS devices. In fabrication 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

Microstructur Vario Laser

Laser micromachining is a powerful tool. New designs can be rapidly implemented through direct writing (no masks needed) and processing of computer-generated files. Especially picosecond pulse laser machining is capable of delivering high precision, short processing times and outstanding quality at the same time for nearly every material using a 10 W-Picosecond Laser machine with four different wavelengths (1064 nm, 532 nm, 355 nm and 266 nm) and additionaly a continuous wave Thulium fiber laser (1908 nm). By manipulating a range of parameters, i. e. power, pulse frequency, mark speed, focal spot diameter etc., an optimal result can be achieved.



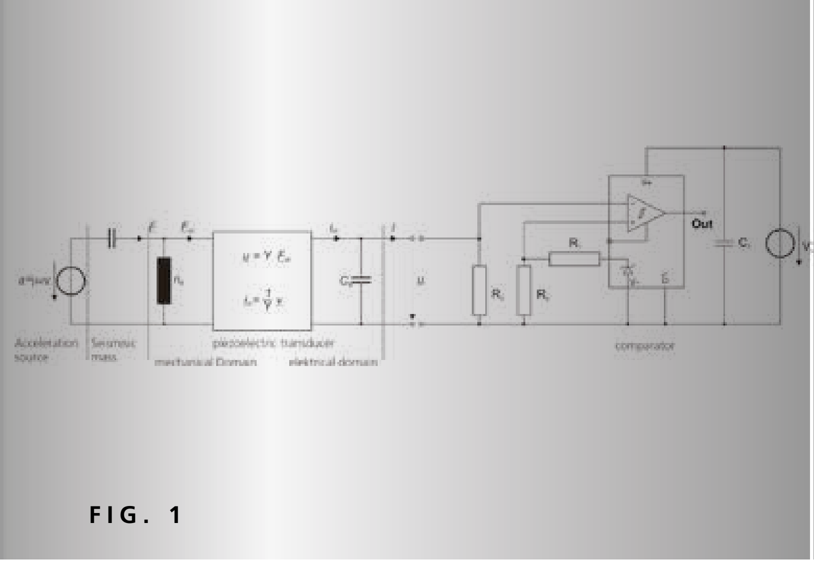


FIG. 1

FIG. 2

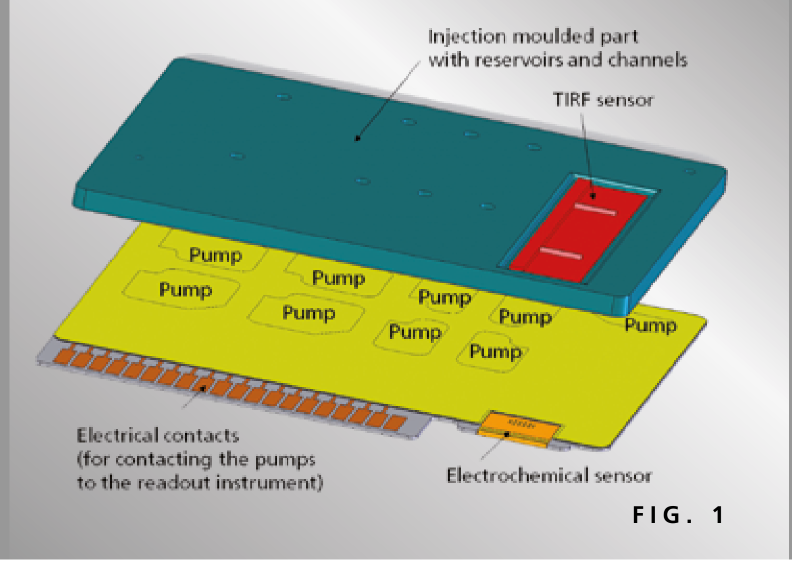


FIG. 1

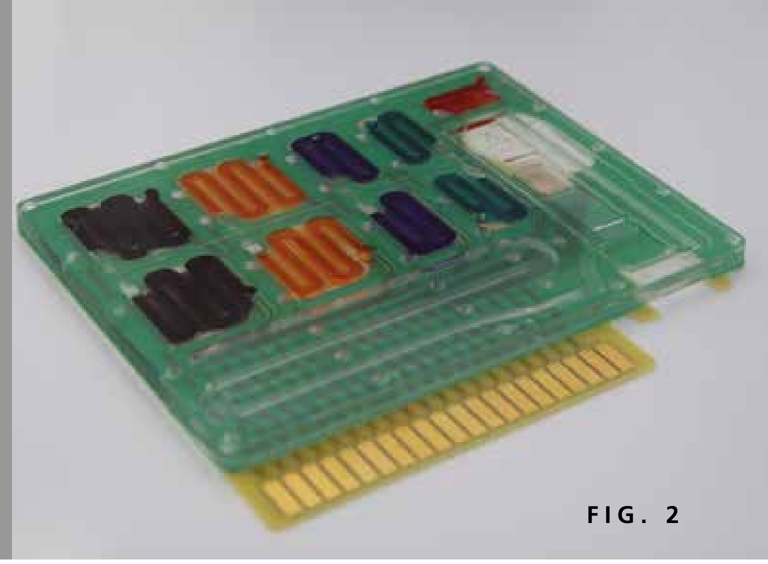


FIG. 2

ENERGY MANAGEMENT BASED ON WAKE-UP-GENERATOR

Robert Schulze, Delef Billep

The energy consumption of sensor systems has to be reduced to achieve a long term operation without limiting the functionality. Therefore, novel concepts for the power management of smart systems are required. Due to the implementation of an additional transducer - a wake-up-generator capable of being integrated - it is possible to use the power-down-mode of the sensor system during a period without external excitation. Thus, a quiescent current consumption of the sensor system of less than 1.35 µA was achieved in experimental setups at the Fraunhofer ENAS with commercial a PVDF and a PZT transducer (Fig. 2). Using a wake-up-generator, it would be feasible to prolong the durability of a conventional battery supply for at least ten times.

A system with wake-up-generator remains in the power-down mode until an excitation signal occurs. Switching to the normal mode takes only a few microseconds, thus almost all kinds of excitation signals are observable.

The introduced wake-up-generator is based on a piezoelectric transducer, which does not need additional energy to convert mechanical into electrical signals.

The wake-up-generator provides a digital output signal due to the usage of a comparator circuit (Fig.1). A certain threshold level can be set by adapting the resistor values. If the comparator input signal reaches the threshold level, the wake-up-generator activates the microcontroller to switch from the power-down to the normal mode.

It could be shown, that the quiescent current consumption of the wake-up-generator is 327 nA (Fig.2). The acceleration of the sensor by lifting leads to a well defined signal at the comparator.

Consequently, the wake-up-generator is useful for applications having long idle periods, such as condition monitoring systems, geophysical sensors, and sensors for consumer electronics.

Furthermore, we propose the integration with the AIM-Technology. The wake-up-generator will be adapted for the energy management of other sensors.

Legend:

Fig. 1: Lumped Element model of the wake-up-generator and the electronics

Fig. 2: Experimental setup to test the wake-up-generator electronics concerning the quiescent current consumption

FRAUNHOFER IVD PLATFORM

Jörg Nestler

The Fraunhofer ivD Platform (www.ivd-plattform.fraunhofer.de) combines the competencies of seven institutes within the Fraunhofer-Gesellschaft and shows extensive interdisciplinary experiences and expertise in all fields of service and development up to production. That guarantees the adaption of customer-specific problems to tailor-made solutions and serves to solve problems from any biomarker to ivD-products that can match the needs of the market.

Lab-on-Chip System

The core of the Fraunhofer ivD Platform is a self-contained, active, microfluidic cartridge developed by ENAS. Such a cartridge holds an electrochemical or optical biosensor, reagents as well as integrated microfluidic actuators (pumps). Together with a readout instrument it can run a bioassay in a fully automated way without any fluidic interfaces to the instrument. The cartridge is produced by low-cost injection-moulding and bonding processes.

Cartridge Design

The microfluidic cartridge consists of two main parts (Fig. 1). The bottom part provides the integrated micropumps together with an electrical interface to the instrument. The injection-moulded top part of the cartridge incorporates the reservoirs and the microfluidic channel system. The reservoirs can be filled from the top through filling holes. The cartridge contains eight reservoirs with different volumes (up to 150 µl), two sensor areas (for the electrochemical and optical read-out) and a waste reservoir. It has the size of a credit card enabling the application as point-of-care product.

Safety

To avoid any fluidic interface to the instrument, reagents are stored directly in the reservoirs (Fig. 2) and transported through the microchannel system by means of low-cost pumps. The integration of the micropumps avoids contamination and interfacing issues.

Legend

Fig. 1: Schematic of the microfluidic cartridge

Fig. 2: Photography of a microfluidic ivD-cartridge with filled reservoires.

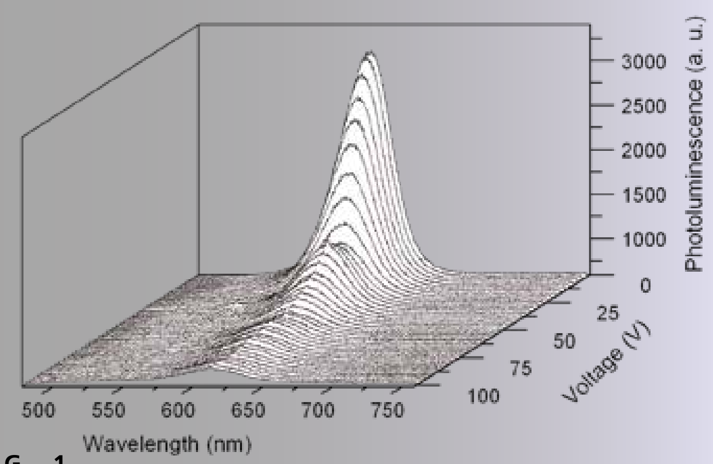


FIG. 1

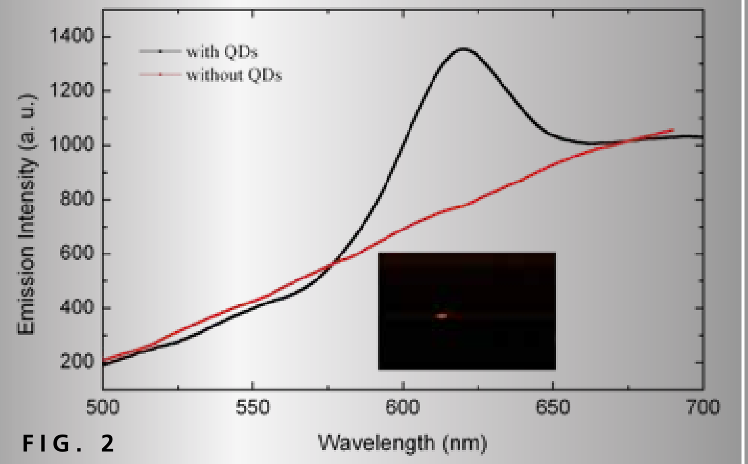


FIG. 2

OPTICAL AND NANOCOMPOSITE-BASED SYSTEMS

Jörg Martin

Polymeric nano- and microcomposites combine properties of the surrounding (polymer) matrix material as well as the embedded micro- or nanoscale fillers. Previously investigated materials were, beside different polymers filled with metal oxide and rare earth compounds, primarily nanocomposites based on conducting polymers and quantum dots (nanocrystals) for optical applications. Quantum dots show several advantages compared to organic light emitters. Among them are excellent chemical stability and narrow emission bands. Additionally the emission wavelength can be tuned in a broad spectral range only by changing the size of the nanoparticles. This is a large benefit for integration of these emitters into micro systems since incompatibilities between different organic materials can be avoided.

We managed to excite the nanocrystals electrically in 2 different ways - first as nanosensors with charge dependend fluorescence properties and second as light emitters in an all-spin-coated quantum dot LED (QD-LED). The produced thin-film-composites consist of CdSe/ZnS core/shell nanoparticles, which are embedded in various dielectric or conductive organic semiconductor matrices. By means of time-resolved confocal micro-spectroscopy we have particularly investigated the influence of charges on the quantum dot fluorescence. As an example, Figure 1 shows the reduction of nanocrystal fluorescence, when an increasing voltage is applied across such a nanocomposite layer stack.

Furthermore, over the last decades semiconductor nanocrystals gained increasing importance regarding the use in quantum dot light-emitting diodes (QD-LED). In published characteristic QD-LED arrangements, layer stacks are mostly formed by two or more process steps including spin-coating, thermal deposition or vapor deposition. A reduction in process steps and thus lower material costs are desirable for an efficient preparation of QD-LEDs. Therefore we prepared an all-spin-coated CdSe/ZnS core shell type QD-LED only consisting of hole injection layer (HIL), QD layer (QDL), and electron transport layer (ETL) showing electroluminescence at 610 nm, as displayed in Fig. 2.

Legend:

Fig. 1: Reduction of quantum dot photoluminescence as result of an applied increasing external voltage.

Fig. 2: Emission spectra of electrically excited layers with and without embedded CdSe/ZnS nanocrystals. Insert shows emission of prepared quantum dot LED.

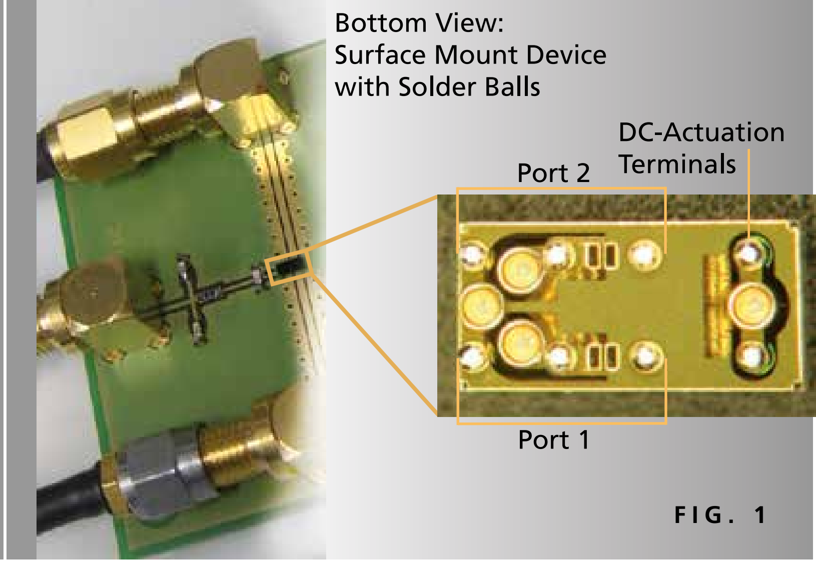


FIG. 1

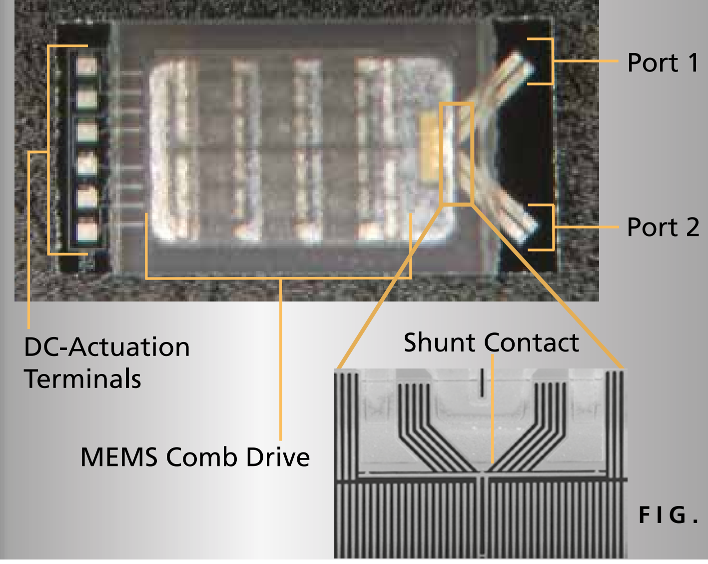


FIG. 2

RF-MEMS SWITCHES

Stefan Leidich, Steffen Kurth

The use of micro electro mechanical systems (MEMS) in microwave circuits as a replacement for conventional semiconductor devices leads to reduced DC-power consumption, lower signal attenuation, and higher quality factor of passive devices. Our proprietary Air Gap Insulated Microstructure (AIM) technology has been optimized for the use of high resistivity substrates and low loss conductors. The process is well suited for the fabrication of RF-MEMS like switches or variable capacitors.

Fig. 1 shows a DC–4 GHz ohmic contact switch mounted on an evaluation board. The dimensions of the chip are 3.0 mm x 1.5 mm x 0.5 mm. Due to the high temperature stability of the MEMS elements, the use of hermetic packaging technologies, in this case anodic bonding, is possible. The glass cover wafer contains via holes for vertical access to the RF and DC signals and solder balls. Hence, mounting by common reflow solder technique is supported. The actuation of the switch is oriented laterally within the plane of the wafer. The part of the device that is exposed to RF signals is physically and electrically separated from the part that realizes the actuation. Consequently, the optimization of both parts can be performed individually.

The actor mechanism of the switch consists of 570 comb shaped electrodes. Each electrode is 80 µm long and up to 50 µm deep. The width of the electrodes is between 1.0 and 2.0 µm. Hence, the capacitance density and therewith the mechanical force is large. High force is a key prerequisite for fast actuation and reliable switching of ohmic contacts. The force is even further increased by a special technique to reduce the separation between the driving combs beyond the limit of fabrication. The initial separation of 4.5 µm is reduced to 1.2 µm by a proprietary post process technique. The movable structure is shifted to new resting position and fixed to this position permanently by micro welding. The process is conducted on wafer scale using semi-automated test equipment.

Due the small size of the MEMS elements itself, the upper cut-off frequency is mainly determined by the package. Fig. 2 shows a revised design for operation at 60 GHz and above. The series contact was replaced by a shunt contact to reduce the influence of capacitive coupling on the isolation. The measured insertion loss at 60 GHz is 1.2 dB and the isolation is 18 dB. The connection with the carrier substrate is realized by stud bumps. The carrier provides feedlines with equal or similar dimensions. Due to the small height of the stud bumps the discontinuity of the line impedance is reduced to a minimum. Using the described technique to reduce the electrode separation, the actuation voltage was reduced to 5.0 V. Even at this low voltage, the switching time is fast as 10.3 µs.

We believe that the applied fabrication technology and the use of lateral movement is well suited for the fabrication of RF-MEMS. The well defined mechanical properties of silicon and the freedom of design yield devices with high reliability and good RF performance.

Legend:

Fig. 1: DC-4 GHz series contact switch mounted on evaluation board

Fig. 2: DC-60 GHz shunt contact switch

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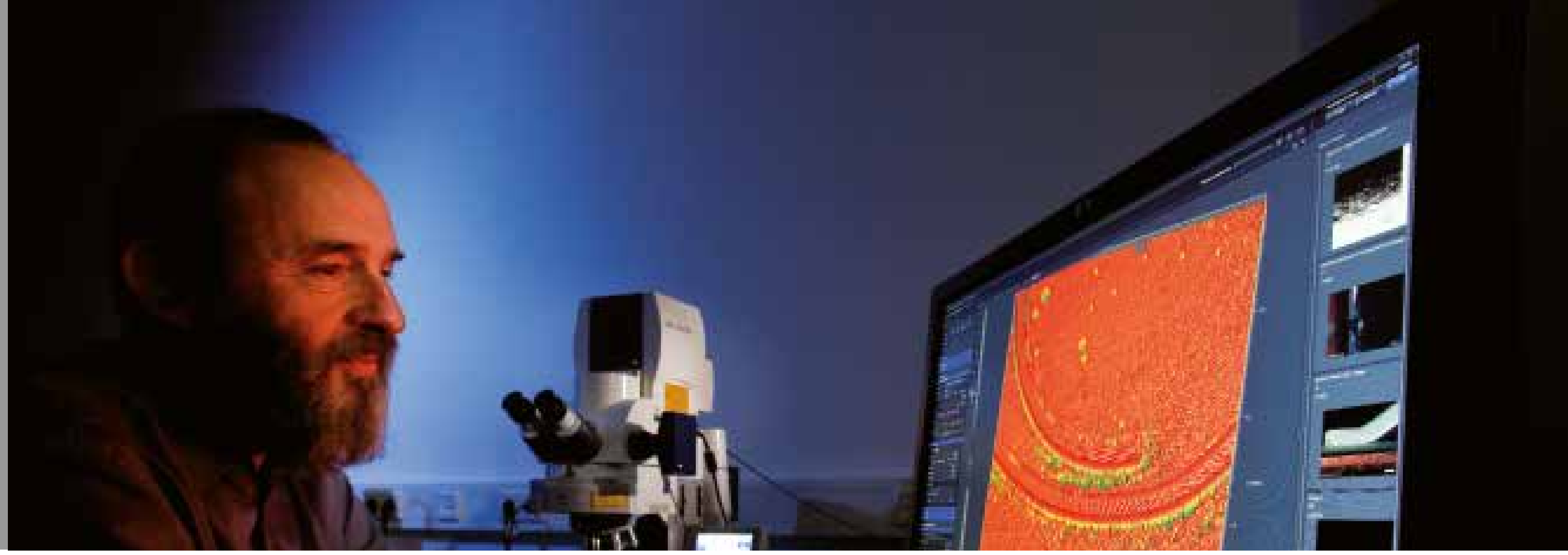


DEPARTMENT MICRO MATERIALS CENTER

Head of the Department: Prof. Dr. Bernd Michel, Dr. Sven Rzepka

Competences:

- Microreliability and Nanoreliability of Components, Systems and Devices
- Reliability for Micro- and Nanotechnologies (Clean Micro- and Nanotechnologies)
- Thermo-mechanical Reliability Analysis
- Experiments and Design for Reliability of Micro-Nano-Integration
- Crack Avoidance Strategies
- Reliability for Avionics and Space Applications (JTI Clean Sky, ESA Projects etc.)
- Microreliability for Automotive Electronics and Sensorics
- Reliability for Batteries of Electro Automotive Applications
- Solder Reliability for Micro-Nano Interconnects
- Reliability for Packaging in the Micro-Nano Integration Field
- Reliability for Micro- and Nanoelectronics (3d Systems Integration, More than Moore)
- Local Deformation Analysis (microDAC, nanoDAC, FIBDAC, nanotom, Raman, EBSD, X-ray etc.)
- Analsysis of Internal Stresses (in MEMS, Wave Analyses etc.)
- Physics of Failure Analysis, Fatigue and Creep Analysis
- Reliability for Solar Applications and Photovoltaics

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 life-time prognosis (based on DIC digital image correlation strategies)
- Crack avoidance and crack detection methods for reliability and life-time evaluation
- Complex loading and health monitoring techniques for combined testing (mechanical, thermal, vibration, humidity, diffusion, electrical fields)
- Crack and failure analytical methods
- Modular modeling applied to reliability analysis
- Lock-in thermography, micro- and nanoRaman, EBSD stress analysis

Research Highlights

1. Reliability Analysis in the Field of Micro-Nano-Integration (MNI)

Fraunhofer ENAS in 2010 has acquired important new research projects in the field ofMicro-Nano-Integration (MNI)I in Germany (BMBF projects as C-Hybrid) in Nanoelectronics (cooperation and contacts with globalfoundries and automotive electronics (Bosch, Siemens, Infineon, Continental Automatics et al.) and has received good results in several European projects (nanoPack, nanoInterface, Smart Sense etc.).

2. New Research Group 'Clean Tech Reliability' contributes to greener transport solutions

Established in 2009, the new research group 'Clean Tech Reliability' has widened the field of research work by combining nano and micro technologies with 'clean and green' principles of protecting the sustainability of natural resources. The first projects are dedicated to public and individual transportation. Within the European Joint Technology Initiative (JTI) Clean Sky, the group has developed a new approach to fatigue testing of organic materials eventually allowing the use of new carbon and nano composite materials in airframe structures leading to a substantial reduction in weight and, hence, in fuel consumption of future aircrafts. Within the European Green Car Initiative (EGCI), a new architecture for battery management systems has been proposed by this group. Integrating micro-sensors into each cell, efficiency and lifetime of the Li-ionic batteries will be increased. This paves the way for the full electrical vehicles to enter the mass market within the next decade.

3. EUCEMAN – The European Center for Micro and Nanoreliability now is coordinated by ENAS.

The Berlin EUCEMAN headquarter now is also operated now by Micro Materials Center of ENAS. EUCEMAN has become the leading European initiative (network) in the field of reliability for micro-nano-integration. Important labs from Germany and from many European countries contribute (e.g. UK, France, Austria, The Netherlands, Poland, Romania, Switzerland et al.). The network has become a very important initiator for new European projects in the field of reliability. See also www.euceman.com

4. Important projects in the field of solder reliability analysis and prediction

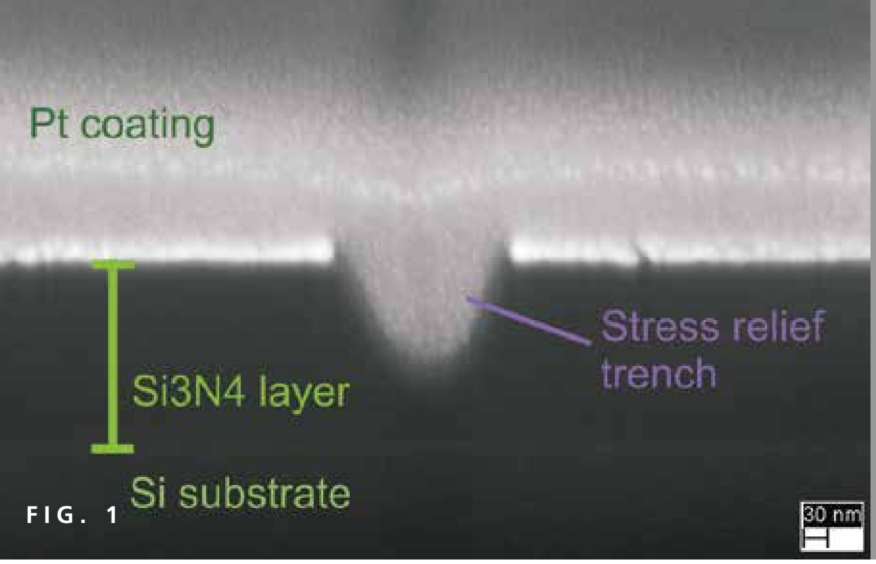
Several activities on computational design of reliable microsystems, electronic and MEMS packages as well as their interconnects have been conducted to save on expensive prototype development and testing. Both, the more demanding environmental conditions, e.g. due to positioning of electronic devices under the hood in automotive applications, and the development of advanced interconnection technologies were addressed to guarantee high reliability standards for several industrial users. The behavior of high temperature leadfree solders like INNOLOT or AuSn have been found challenging in terms of constitutive description as well as fatigue prediction. Various theoretical parametric studies have been performed to analyses the thermal fatigue behavior for new components, highly miniaturized joints or newly established interconnection technologies like the copper pillar joints.

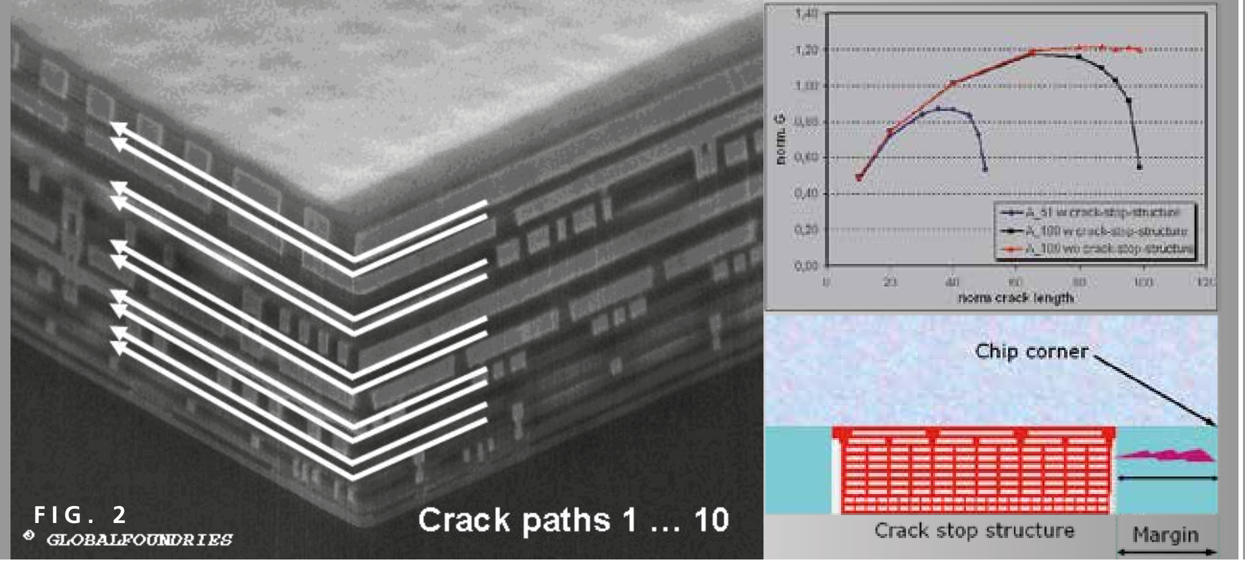
5. New Activities in Determination of Internal Stresses in Micro Nano Integration

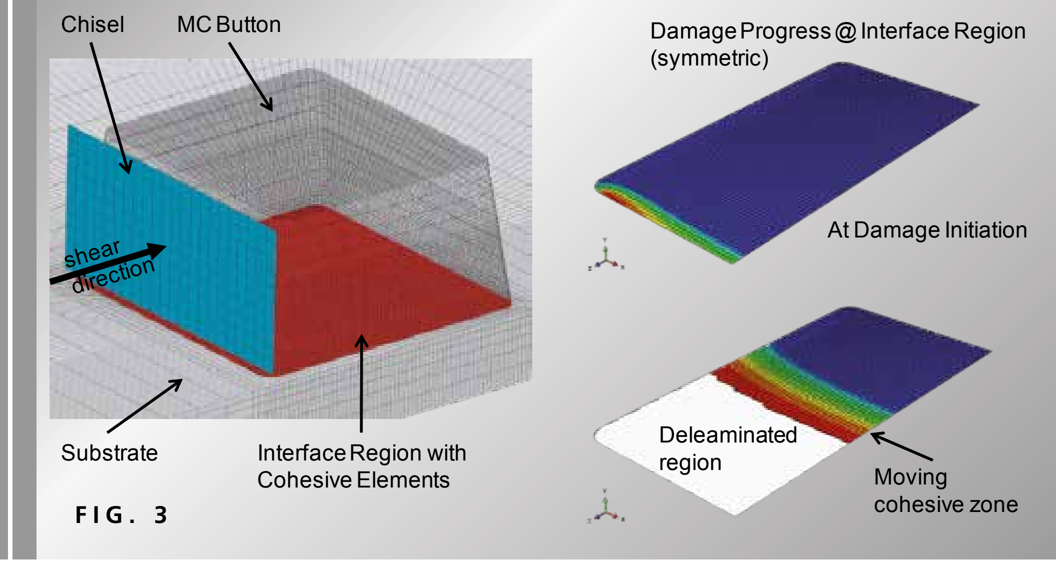
Mechanical stresses induced in chips by wafer fabrication and the subsequent packaging processes have led to an increasing concern in manufacturing of electronics and MEMS devices. New stress measurement methods of high spatial resolution are being developed and improved at Fraunhofer ENAS. Recent developments aim at better access to stresses in patterned multilayer systems on semiconductor wafers with new material usage. E.g. the fibDAC stress relief technique is a unique new method, which allows extremely local stress measurements where established methods cannot be applied. FIB ion milling causes tiny stress relief deformations captured by DIC (Digital Image Processing) algorithms and utilized for stress determination. Furthermore, several other stress measurement methods based on local bow, micro/nanoRaman spectroscopy, electron and x-ray diffraction are kept at hand for specific customer needs. Besides contract services for semiconductor and microsystem manufacturers, our stress measurements tools provide basic input data in larger research project, like for example in the frame of NOLIMIT, a Saxony funded project for the development of reliable BEOL semiconductor structures.

6. Virtual Prototyping for future BEOL and 3-D TSV structures

Increasing the performance of multilevel BEOL systems and mastering the design of TSV chip stacking are the two strategic goals of interconnect technology in the current decade. Together with its partners at Global Foundries, Infineon, Robert Bosch and others, Fraunhofer ENAS substantially contributes to this effort. The department Micro Materials Center provides all means and tools for true virtual prototyping of future BEOL and 3-D TSV structures: Advanced fracture mechanics is applied to assess the thermo mechanical reliability risks in the micro / nano structures based on nonlinear multi-field finite element analysis. These numerical simulations are fully supported and validated by innovative experimental techniques of accelerated life testing and physical stress and failure analyzes. This way, the functional design is complemented by that for manufacturing and reliability without adding time consuming experiments.







RELIABILITY ASSESSMENT IN THE MICRO/NANO TRANSITIONAL RANGE – NEED FOR COORDINATED EXPERIMENTAL AND NUMERICAL WORK

Jürgen Auersperg, Dietmar Vogel, Rainer Dudek, Sven Rzepka, Bernd Michel

The ongoing electronics industries drive for miniaturization and increasing functional integration is pushing the feature sizes down to the nanometer range. Furthermore, harsh environmental conditions and new porous or nanoparticle filled materials introduced on both chip and package level (in particular low-k and ultra low-k dielectric materials in Back-End-of-Line structures of advanced CMOS technologies) cause new challenges for reliability analysis and optimization.

Substantial activities have been started in this context combining experimental and numerical methods towards optimized fracture resistance of those structures under chip package interaction and manufacturing aspects by means of integral bulk and interface fracture concepts, VCCT and cohesive zone models in multi-scale and multi-failure modeling approaches with several kinds of imperfections.

As important preconditions for high-quality simulations, nano-indentation AFM, FIB and EBSD provide the desired properties, while FIB-based trench techniques by means of deformation analyses by grayscale correlation and numerical simulations provide the intrinsic stresses especially of thin films in BEOL layers.

The approach takes several aspects into account:

- Multi-level modeling utilizing substructuring and sub-modeling techniques within the "conventional" finite element method as well as the consideration of the close neighborhood of structural dimensions in design and morphology of newly developed materials in BEOL layers of advanced Cu/Low-k 90, 45…32 nanometer CMOS technolo-gies (grain sizes, size-dependent material properties). This is of greatest interest for new developments in CMOS technologies from actually 45 nm down to <22 nm structures and requires to further progress the application of advanced molecular dynamics methodologies together with hybrid approaches coupling it with finite element methods. Ways appropriate in this context are the direct coupling via homogenization in unit cells as well as the extraction of material properties with the help of simulative experiments.
- Multiple failure mode evaluation for overload prevention and thermo-mechanical fatigue evaluation of inelastic and viscoplastic materials and bimaterial interfaces – mod-ified Coffin-Manson-approaches, adapted Paris-Erdogan-approaches evaluating the damage propagation as well as the life time.
- FEA-based Design of Experiments (DoE) und optimization with respect to multiple simultaneously existing failure modes. This demands for parameterized models, allowing the variation of designs, interconnect technologies, geometric parameters, material properties and manufacturing conditions (cure conditions, thermal treatment control and sequential build up) and model preparations for failure evaluations (CZM- und VCCT-elements, damage models, J-integral contours).
- Investigation of the influence of CPI (chip package interaction) aspects on damage and cracking/delamination risks inside the BEOL-structures.
- Reduction of the damaging and cracking of BEOL-structures during manufacturing - the flip-chip reflow process, especially.
- Utilization of novel FE-simulation techniques like advanced damage mechanics approaches and XFEM (extended finite element method) allow estimating damage and crack initiation and propagation without to assume initial cracks and their initial locations.
- Residual stresses in the back-end layer stack caused by the different manufacturing processes have an essential impact on damage behavior, because they superpose functional and environmental loads. Their determination is a critical issue on account of the high spatial resolution necessary for typical BEOL-structure sizes. A determination of residual stresses by means of finite element simulations is problematic due to the large amount of process steps and the numerous physical/chemical processes to be considered. Well established measurement methods either do not exhibit the necessary spatial resolution or show other limitations. That's why new stress measurement methods with high spatial resolution are developed at the Fraunhofer ENAS: Among them are nanoscale stress relief techniques (fibDAC), nanoRaman and electron back-scattering (EBSD) based approaches. E.g. the fibDAC makes use of tiny trenches placed with a FIB (focused ion beam) equipment at the position of stress measurement. Digital image correlation algorithms applied to SEM micrographs captured before and after ion milling allow to conclude on stresses released. A respective example is given in Fig. 1.
- The trends of miniaturization, higher power, higher environmental loads, and integration of heterogeneous structures of microsystems all demand for thermo-mechanical reliability as a truly critical design criterion. Because of their heterogeneous nature the interfaces of these precision materials compounds are particularly crucial. Current design rules are frequently not able to take care of these complicated failure risks and need to be improved. Both interface toughness testing and numerical modeling have to be combined to work out strength prediction capabilities for application towards adhesion failure. As these adhesion properties are dependent on a variety of parameters, both processing dependent and dependent on the materials combinations themselves, this is a huge task. Cohesive zone modeling is one opportunity to give a theoretical framework for this task. Applications currently being developed for power electronic devices show a great need also for the determination of critical interface parameters. A quick evaluation method can be based on the button shear test, which is well accepted in industry and has been applied for many years in different ways. However, most of these applications lack a theoretical investigation of the delamination process. This weakness has been overcome by both experimental and theoretical means applied at Fraunhofer ENAS. Measurements of the delamination progress were made by the optical correlation technique microDAC. Cohesive zone modeling of the tests allow the determination of the critical interface energy release rates, see Fig. 3.

Legend

Fig. 1: Trenches milled by focused ion beam equipment cause measureable local stress relief

Fig. 2: Crack driving force vs. crack length and margin of a chip-edge crack under CPI

Fig. 3: Interface fracture characterization by button shear FE-modeling

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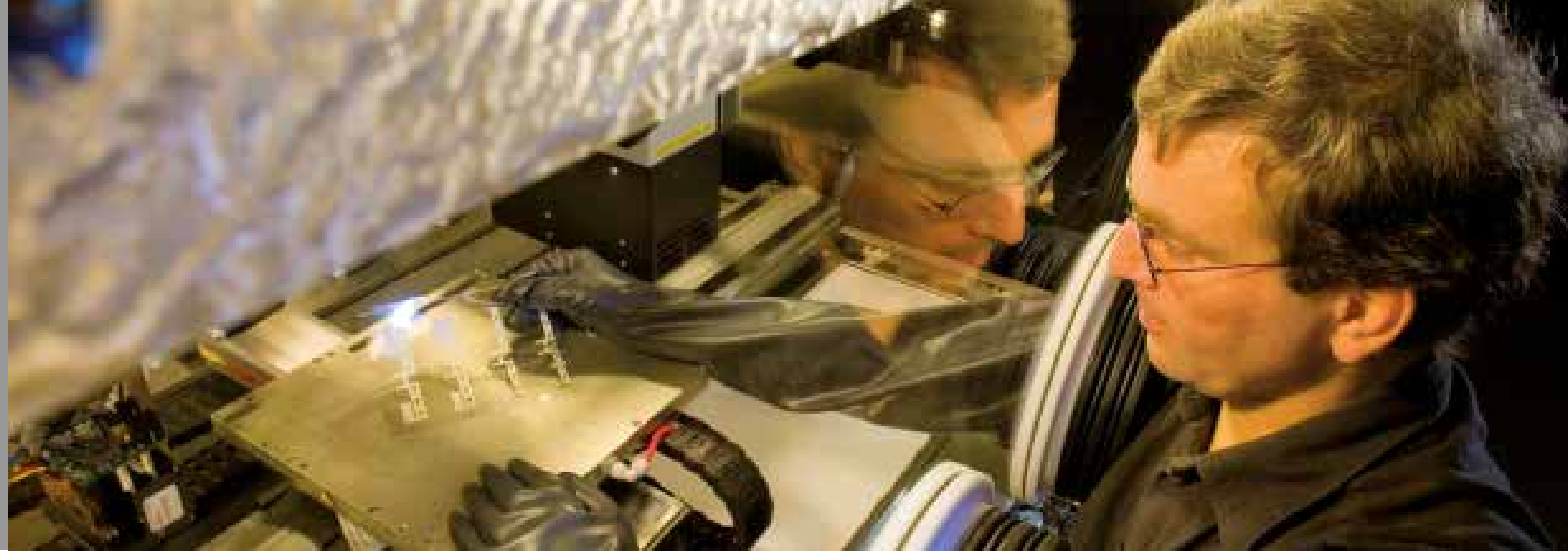

DEPARTMENT PRINTED FUNCTIONALITIES

Head of the 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.

Since 2009 the publication of a printed battery is raising worldwide attention. The highlight in 2010 has been the nomination of this battery for the RTCC (Responding to Climate Change 2011) report delivered to the UN. Also new demonstrators have been developed and manufactured to underline the flexibility of usage of this battery. New investigations in this area are done in a close cooperation between ENAS, Chemnitz University of Technology and Printechnologics.

The 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, Electro-Luminescence / 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 imagewise 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 imagewise 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 ENAS department of 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.

Our Competences are:

- Printed functionalities: conductivity, semi-conductivity, insulation, energy accumulation, catalysis, light based energy conversion
- Printed thin film batteries
- 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 resources-saving, 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

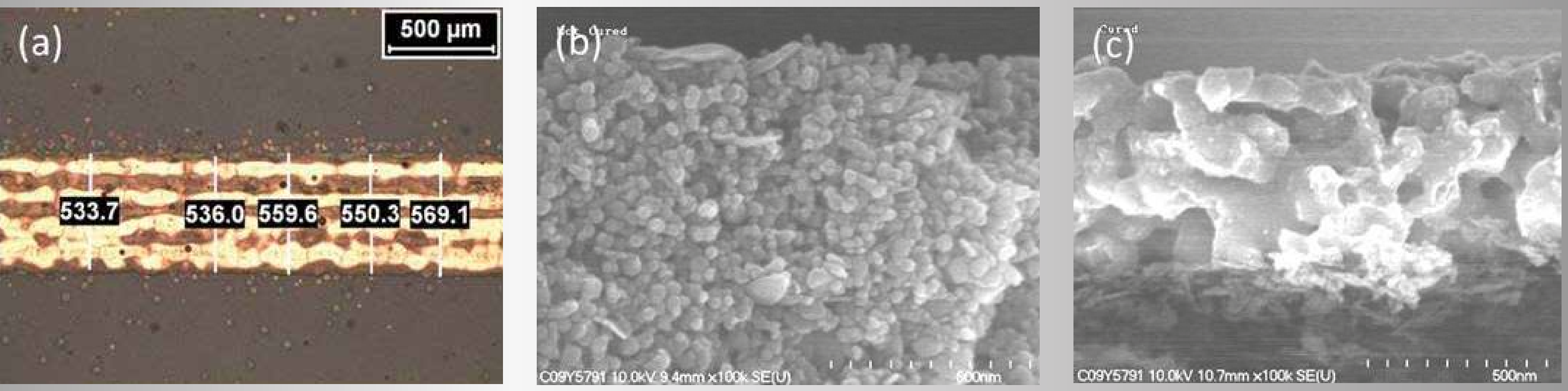

FIG. 1

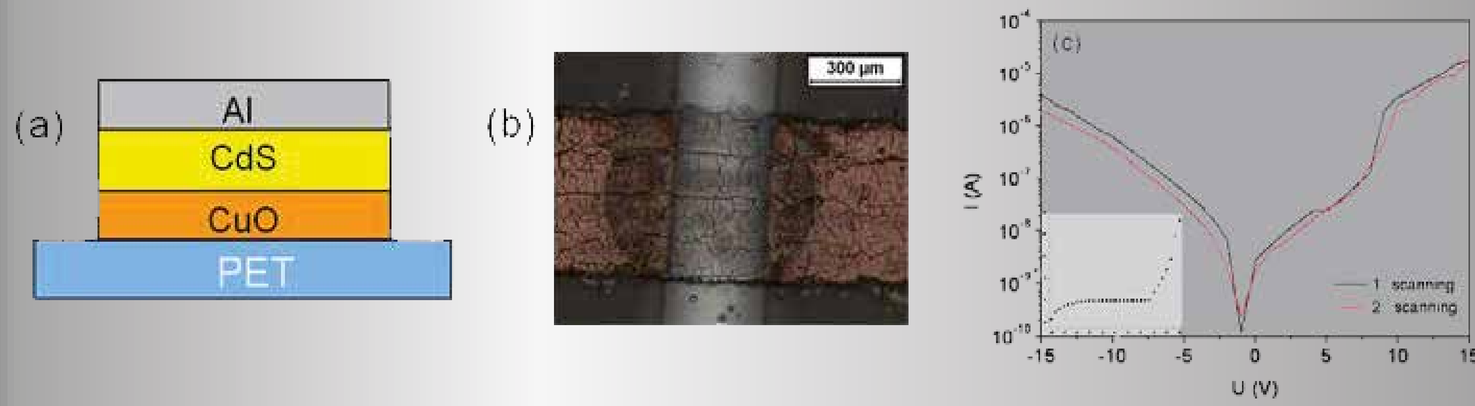

FIG. 2

PRINTED OXIDE ELECTRONICS

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Abstract

The inkjet printing technology is one of the most promising alternatives to photolithographic and masking technology allowing additive patterning of functional materials such as conductors, insulators, and semiconductors on a substrate. In particular, printable amorphous oxides have some advantages due to their atmospheric and temperature stability and relatively high field-effect mobility.

A proof of principle of preparing Schottky diodes from metal oxide and nanoparticles based inkjet inks under ambient conditions and on Polyethylene terephthalate (PET) foil is presented. The fabrication includes a low temperature photonic sintering of inkjet printed CuO and CdS quantum dot inks. This was accomplished by using proprietary high-intensity flash lamps at very short pulse durations allowing us to use a low-cost (PET) plastic film as the substrate material.

The device properties require further optimization, but obtained results may open novel routes for the development of a next generation of Large Area Printed Electronics based on printed quantum dots of amorphous metal oxides, sintered photonically without any distortion of the plastic substrate.

Introduction

The inkjet printing technology allows additive patterning of functional materials such as conductors, insulators, and semiconductors on flexible substrates. Compared to organic semiconductors amorphous oxides have numerous advantages due to their atmospheric and temperature stability, relatively high field-effect mobility, which make them competitive candidates to be integrated in functional devices and flexible smart systems [1]. However, high sintering temperatures, in some cases up to 400 °C, are required to remove residual organic components upon printing, which are necessary to prepare stable solutions of these materials as inkjet inks [2, 3]. Here, we are reporting the inkjet printing of copper-oxide (CuO) based inks, their sintering behavior under ambient conditions by a photonic treatment and the application of the conductive sintered pattern as the rectifying-contact for cadmium sulfide (CdS) based Schottky diodes. The CdS based Scottky diodes were inkjet fabricated on Polyethylene terephthalate (PET) and characterized electrically.

Experimental

In the last decade, colloidal nanocrystals or quantum dots have been widely investigated due to their possible applications in fields as optoelectronic, photocatalysis and biological labeling [4-6]. Semiconductor quantum dots can be fabricated via several techniques [7-9].

For this study, the CdS was synthesized in two phase synthetic routes to obtain oil soluble nanoparticles. This method allows very slow particle growth and thus crystal size and quality can be controlled easily. High quality CdS nanoparticles with average size of approx. 6 nm were obtained after 6 hours.

CuO-ink (Metalon ICI-003) from NovaCentrix was inkjet printed from water based solution and sintered in order to form the diode rectifying-contact [10]. That was accomplished by using the photonic sintering PulgeForge® tool in ambient conditions by applying light pulses with an energy of 7,6 J/cm² in app. 10 milliseconds allowing us to use low-cost PET plastic film as substrate material. The resulting CuO stripe shows 100 mΩ/sq resistance, which is equivalent toΩ 1/3 of Cu bulk conductivity.

CdS was inkjet printed from toluene solution (2.1 wt%) on the top of the CuO stripe. The printed CdS films were wet-chemically treated by potassium hydroxide (KOH) (1 M) to form the device active layer. Basic approach to neutralized oleic acid (capping agent) by basis (KOH) allows us to obtain functional CdS thin films at the room temperature and under ambient conditions.

Finally, the device fabrication was finished by sputtering of Al through a shadow mask to form an ohmic-contact [11]. The electrical characterization of the Diodes was performed by using a Keithley 2616 SourceMeter in ambient conditions.

Results

Figure 1(a) shows a printed CuO stripe on PET, whereas Figure 1(b) and 1(c) shows SEM images of photonic sintered CuO stripe by PulseForge®, respectively. The resulting CuO features are semi porous structures with an uneven surface.

Figure 2(a) and 2(b) shows a device structure and optical image of fabricated diode. In a case of fabricated Schottky diode, in forward direction electron current is injected into CdS. Figure 2(c) shows I-V characteristic of CdS based Schottky diode in a semi-logarithmic and linear plot (inset).

Poor rectification ratio, as seen from the logarithmic I-V curve, can be attributed to the poor interface between CuO and CdS, presence of interface trap states, as well as to the new, to-be-optimized sintering process. Further optimization of the printing and sintering processes is in progress.

Nevertheless, the obtained Schottky diodes based on printed amorphous metal oxide quantum dots and manufactured under ambient conditions at room temperature open novel routes for the development of a next generation of Large Area Printed Electronics.

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Fig. 1: (a) Optical image of printed CuO line on PET,
(b) SEM image of as printed CuO ink, and
(c) SEM image of CuO photonic sintered by PulseForge®

Fig. 2: (a) Device structure,
(b) optical image of diode, and
(c) I-V characteristic of CdS based Schottky diode in semi-logarithmic and linear representation (inset)

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DEPARTMENT BACK-END OF LINE

Head of the Department: Prof. Dr. Stefan E. Schulz

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 & Research Fields

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

- Low-k and ultra-low-k (ULK) dielectrics
- Metallization for microelectronics and nanoelectronics
- Metallization for 3D and system integration
- Airgaps for low parasitic capacitances in nanoelectronic 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

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 airgap structures is studied, but also their electrical, thermal and mechanical impact on the interconnect system. Two approaches for wet etch removal of the sacrificial SiO2 have been developed, called "Spacer" and "Mask" approach. Development and optimization of the single process steps as well as the complete technology are accompanied by electrical, mechanical and thermal modeling and simulation of airgap-containing interconnect systems.

3D and system integration require metallization solutions for flip chip techniques, chip scale packages and, of course, for high aspect ratio "through silicon vias" (TSVs). By providing several process solutions, like PVD and CVD barrier and seed layers, copper CVD and electroplating (ECD) these fields can be addressed for different feature geometries and various applications.

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 is it 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, planarization)
- Thin film measurement and characterization
- 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

Results of R&D Projects in Brief

On-chip Interconnects

Within the joint research projects STRUCTURE and EURU.net processing and integration of porous and dense low-k materials are studied together with GLOBALFOUNDRIES, IMEC, Air Products, and Mallinckrodt Baker.

To investigate etch damages in low-k materials arising from plasma etching, well and less suitable plasma species were identified by means of in situ diagnostics along with methods for a multivariate data analysis developed in-house. The knowledge gained enables an optimization of etching processes and a fundamental understanding of the chemical behavior of low-k/ULK materials in etch plasmas.

The interface between etch and cleaning processes plays an important role for a successful removal of etch residues in small trenches and vias. Depending on the plasma chemistry sidewall surfaces can be hydrophilic or hydrophobic, which significantly impacts the penetration of small trenches by cleaning liquids. In cooperation with the cleaning solution suppliers Air Products and Mallinckrodt Baker wetting optimized and Cu/low-k compatible cleaning liquids are developed. To repair the damaged ULK material a liquid phase restore process in combination with different thermal and UV pre- and post treatments was analyzed. It was shown, that moderate thermal treatments enhance the insertion of the repair chemicals into the films. An UV-treatment was shown to support the formation of a networked and repaired structure in the surface near areas of the dielectric. The analysis showed that choosing moderate temperatures below 150°C for thermal treatment and short radiation times for UV-treatment gave the best results in repairing plasma damaged low-k films.

Metallization for 3D interconnects

Within the "ENIAC" European project JEMSiP-3D a CVD based barrier / Cu-seed layer deposition technology for TSV metallization is developed and evaluated. To overcome limitations of existing Cu-CVD process solutions a new Cu-CVD chamber with a direct liquid injection system from Kemstream has been installed. This injection system enables a very efficient flash vaporization with almost no condensation at internal chamber and pipeline walls. In that way it becomes possible to efficiently vaporize thermally unstable compounds without the risk of clogging.

Using this system, new copper precursors developed by Air Liquide are tested under industry-compatible conditions on 200 mm wafers.

CMP Process Development

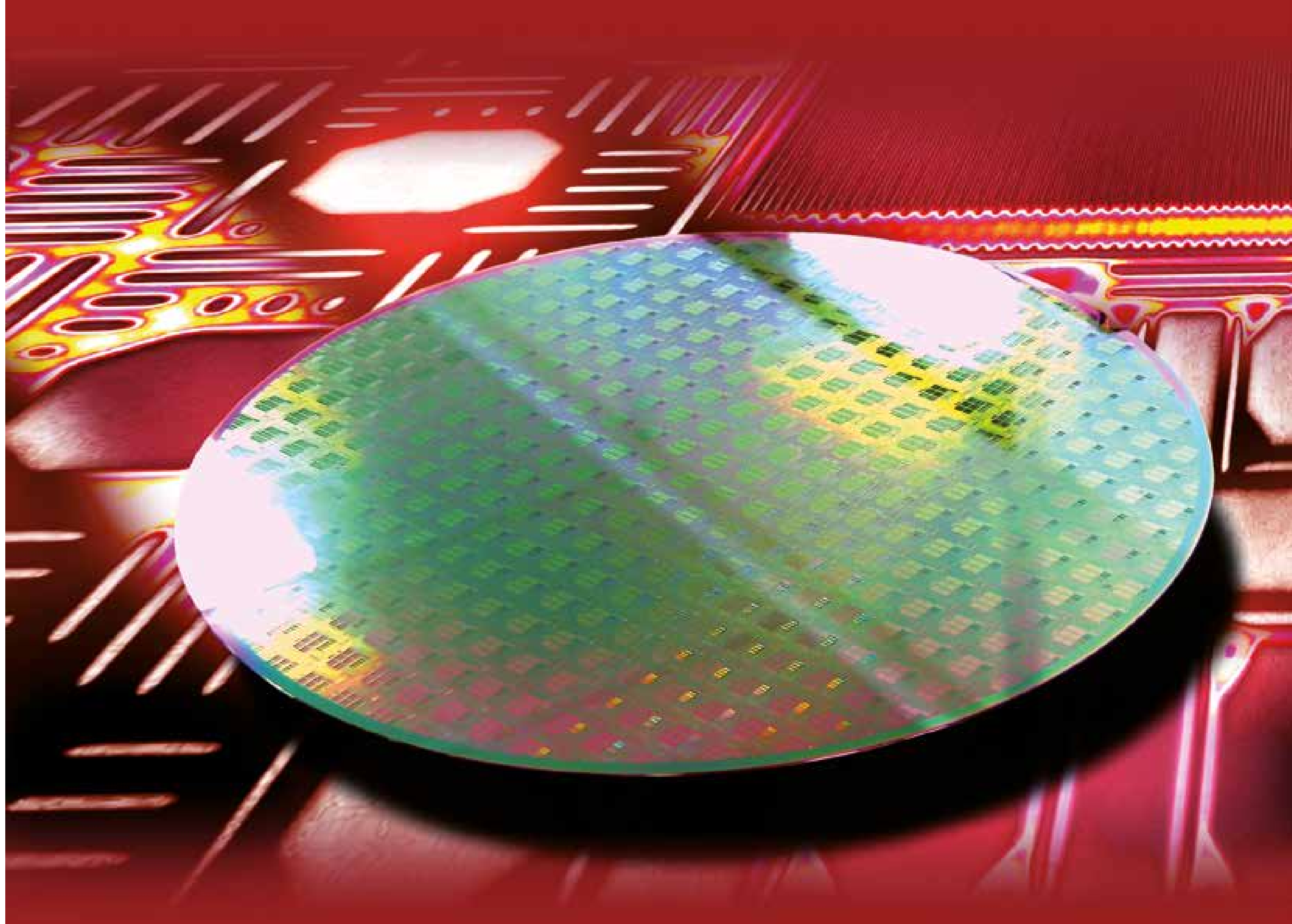
In collaboration with the department Systems Packaging, reliable CMP pre-treatments have been developed which enable a direct bonding of Foturan wafers, either with other Foturan wafers or with silicon wafers. According to the chemical nature of glass, silicon oxide polishing processes were used as the starting point. Within a series of experiments duration and down force of the main polishing step were varied and different consumables tested. Moreover, time and down force of the subsequent buffing were varied. Excellent bonding results were obtained from a main polishing step using alkaline Klebosol slurry on IC1000 polishing pads with a down force below 3 psi, and a polishing time less than 2 minutes. The buffing step was done using DI water on Politex pads with a down force of 1 psi, and a buffing time of 1 minute. Standard brush cleaning using DI water and megasonic was applied after CMP.

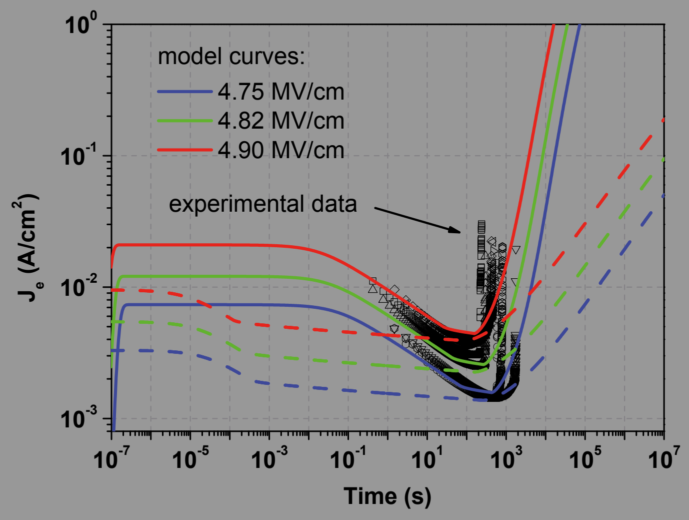
Simulation and Modeling

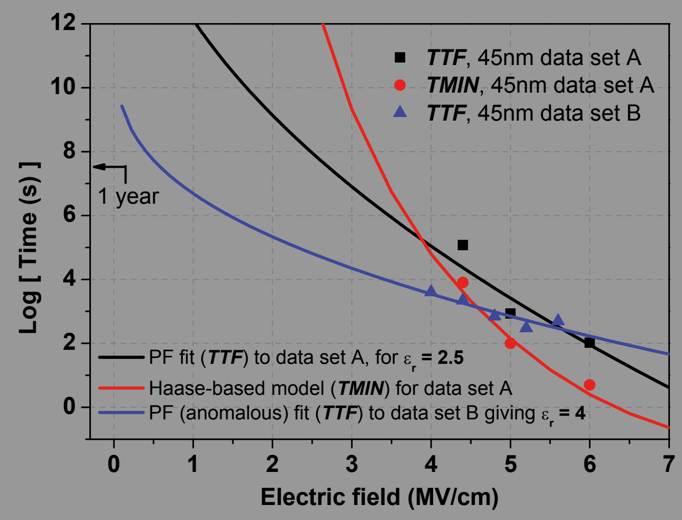
The triennial project SIMKON has been finished. In cooperation with GLOBALFOUNDRIES the deposition of tantalum-based barrier films and copper seed layers in damascene structures of high aspect ratio was simulated to support the extension of advanced PVD to future technology nodes. The influence of process conditions, feature geometry, and target ageing on step coverage, film composition, and energy deposition was studied. Modeling of the dielectric degradation and lifetime predictions as well as the calculation of conductance in nanoscaled interconnects were further main concerns of this project.

Within the project COOLTRANS, technological and simulation efforts for the improvement of stressor films have been continued in close cooperation with GLOBALFOUNDRIES. A simulation model for the prediction of stress transfer from the stressor films to the transistor channel has been developed which will be the basis for the future optimization of the processes and devices with respect to the channel mobility enhancement. In parallel, new processes and materials are developed and evaluated in order to achieve higher stress levels in the films.

A new research field has been set up concerning the simulation of silicon-based solar cells. In cooperation with Roth & Rau AG the cell efficiency shall be further improved by applying advanced concepts and developing optimized designs.







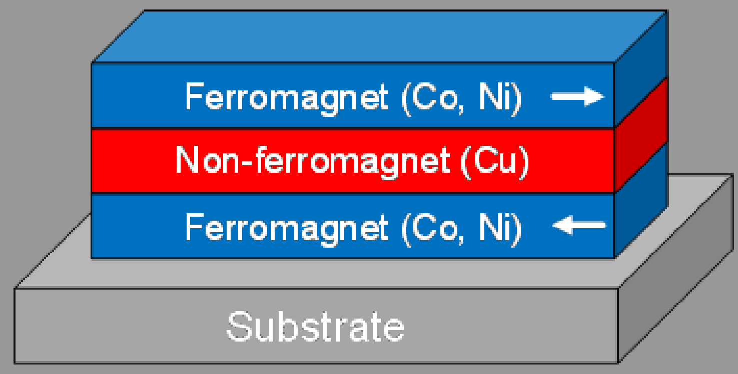


Fig. 1: Typical layer stack of GMR spin-valve sensors

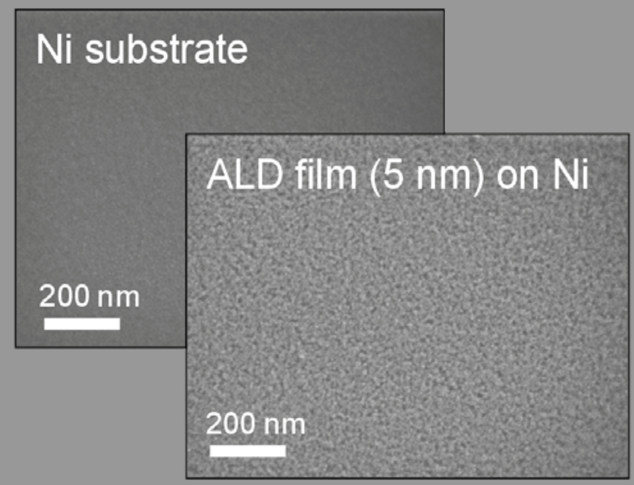


Fig. 2: SEM (scanning electron microscope) top view investigations before and after ALD on nickel substrates

MODELING OF DIELECTRIC RELIABILITY IN ADVANCED CU DAMASCENE INTERCONNECT SYSTEMS

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Introduction

The scaling down of the BEOL interconnects together with the use of novel, less stable low-k and ULK dielectrics cause a growing concern about the time-dependent dielectric breakdown (TDDB) effect. In the framework of the joint project SIMKON with GLOBALFOUNDRIES we investigated and modeled the TDDB mechanisms based on constant-voltage bias-temperature-stress (BTS) experiments performed at GF. We based the most of our modeling on the numerical model of Haase [1] which has a good physical basis and assumes the degradation of the dielectric just by the leakage current itself. For lifetime modeling we further used the Poole-Frenkel lifetime model [2]. The models allow an estimate of the lifetime at operational conditions.

Results and discussion

By two modifications of the Haase model and an adjustment of model parameters we achieved a very good agreement of the model and experimental BTS dependencies. Fig. 1 shows a comparison of several experimental dependencies (90-nm-technology node) at the same BTS conditions (U = 40V, T = 100°C) and the corresponding model dependencies for the original Haase model (dashed lines) and the modified Haase model (full lines). It is obvious that the modified model reproduces the experimental dependencies substantially better than the original model.

Fig. 2 shows a comparison of the dependence of the time to failure, TTF and/or the time of the minimum leakage current, TMIN (for comparison with the Haase-based model in which the TTF is not well defined) on the electric field for two different experimental data sets (A and B) from the 45-nm-technology node with the corresponding model dependencies. The data set A can be reproduced very well with the Haase-based model. The Poole-Frenkel lifetime model comes into question for this data set, either. The data set B shows a much weaker dependence of the TTF on the electric field and the Haase-based model can be excluded in this case. We found that the data set B can be well explained with the so called anomalous Poole-Frenkel effect which can occur in case of compensation in the dielectric (presence of both electron traps and donor states) and which already has been observed previously in BTS experiments [3]. This comparison indicates that there are different TDDB mechanisms in effect and depending on the process conditions and technology, one of them prevails and determines the TDDB behaviour. For a better understanding of the mechanisms further experiments are needed, particularly at lower electric fields.

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ALD PROCESSES FOR THE DEPOSITION OF SPINTRONIC LAYER STACKS

Thomas Wächtler, Steve Müller, Stefan E. Schulz

Within the research consortium nanett "nano system integration network of excellence – application of nano technologies for energy-efficient sensor systems", the department Back-end of Line is working on the development of novel atomic layer deposition (ALD) processes for the application in magnetic sensor systems, such as giant magnetoresistance (GMR) spin-valve sensors. Figure 1 shows a typical design of a GMR system, which is composed of alternating ferromagnetic and conductive non-magnetic layers. Up to now, these layers are deposited by physical vapor deposition (PVD), especially by sputtering or by the expensive molecular beam epitaxy (MBE) technique. Especially in case of PVD growth, softening of interfaces could occur due to intermixing effects during the sputtering processes, so that the GMR effect decreases [1]. In contrast, ALD appears very appropriate to avoid these drawbacks as a consequence of the possibility of low-temperature film growth and the self-limiting growth characteristic, offering film thickness control at the Ångström level.

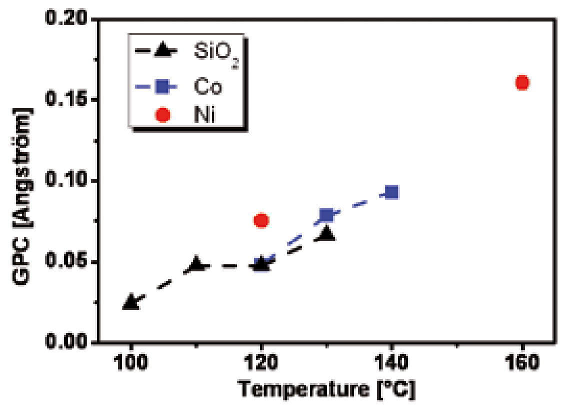

Fig. 3: GPC (growth-per-cycle) as a function of temperature for ALD on Co, Ni and SiO_2

In the current work, the first promising approach was the utilization of ultrathin ALD Cu films as a conductive non-magnetic layer on sputtered Co and Ni substrates as magnetic layers. The ALD of metallic copper films is realized by a two-stage process flow. At first, copper oxide layers are prepared by a thermal ALD process. A subsequent gas phase reduction process reduces these oxide films to metallic copper. The Cu_2O/CuO ALD is based on the Cu (I) β-diketonate precursor [($^nBu_3P)_2$Cu(acac)] and a mixture of water vapor and oxygen ("wet O_2") as co-reactant at temperatures between 100 and 130 °C. The ALD process was studied in detail on Ta, TaN, Ru and SiO_2 substrates [2]. Furthermore, the investigation of the ALD process on magnetic Co and Ni substrates shows the growth of smooth and continuous copper oxide films, as depicted by the SEM top view images in Figure 2 after the ALD on 10 nm nickel. In addition, the growth per cycle (GPC) on Co and Ni in comparison to SiO_2 as a reference substrate is shown in Figure 3. The huge challenge for the subsequent reduction process is to achieve an efficient reduction on arbitrary substrates at low temperatures (< 130 °C) in order to avoid agglomeration of the ultrathin copper films. Formic acid vapor-phase treatments seem to be a promising approach [3].

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DEPARTMENT SYSTEM PACKAGING

Head of the 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 abundant, 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 stacking takes place in the third dimension on chip and wafer level. In addition to the 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.

Facts 2010:

- 11 Scientists
- 1 Mio. Euro Budget
- 30 publications
- 3 patent applications

Nano Scale Effects

In order to make use of the nano effects in MEMS packaging, the department System Packaging analyzes nano scale 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 nano structures. These nano structures 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.

Molding micro and nano structures by UV nano imprint lithography and hot embossing enables a precise formation of micro optical and micro fluidic structures using nano and micro scaled master tools. Here, the basic distinction is to make between hot and cold embossing processes. The process temperature when hot embossing glass, not sintered ceramics and thermoplastics is above the glass transition temperature of the respective material. The research work of the department System Packaging does not only include the development of embossing processes, but also the design and production of silicon master tools (equipped with non-stick coating, if necessary), tools with patterned photo resist and electroplated molded nickel tools (UV-LIGA).

MEMS Packaging and 3D Integration

The meaning of MEMS packaging can be deduced from its portion of costs by producing a micro system. Herein, proportional costs ranging from 20 per cent to 95 per cent are likely to arise, whereas this wide margin results from specific application requirements. The MEMS package has to allow access for the desired mediums to be measured, like liquids, gases or light, but at the same it has to shield these materials 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 definite 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 importance to pay attention to the influence of each bonding technology on materials, but also on the electrical and thermal behavior of the whole system. To characterize and evaluate these technologies in terms of their tightness and strength, different measuring tools and valuation guidelines are available at the department System Packaging.

Wafer Bonding

The term wafer bonding describes all bonding techniques for joining two or more wafers with and without interlayer. Standard methods, such as the silicon direct bonding, the anodic, eutectic, adhesive and the glass frit bonding are used, but also enhanced for specific requirements. Actual research focuses 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 nano scale effects. Examples for nano scale effects are reactive bonding with nano scaled multilayers, or the reduction of the melting temperature with only a few nanometer thick interlayers. Moreover, 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 embrace 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

One aspect that is of great importance when bonding substrates is their surface quality. Whereas, the roughness of the surfaces of relatively thick intermediate layers, such as glass paste or epoxy, plays a more or less subordinated role. It is the atomic contact between bonding partners in technologies without intermediate layers that is of great significance. Anodic bonding techniques require surfaces with a roughness Ra<1 nm. For other techniques a pre-treatment through specific processes, such as the plasma activation or the hydrophilisation is of importance.

Chemical mechanical polishing (CMP) is implemented and developed for microsystems technology as well as in the field of 3D integration. A challenge and subject of investigation for the CMP is the extreme aspect ratio between the structure dimension and the structure distance. In addition to the CMP of aluminum, copper and germanium, which are investigated for 3D integration processes, silicon and silicon dioxide can be polished. This, for instance, is of significance, when producing innovative SOI-substrates with buried silicide-layers, which are needed for the devices of the BiCMOS-technology.

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 gasses used, the gas pressure, the glass tightness, 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.


FIG. 1

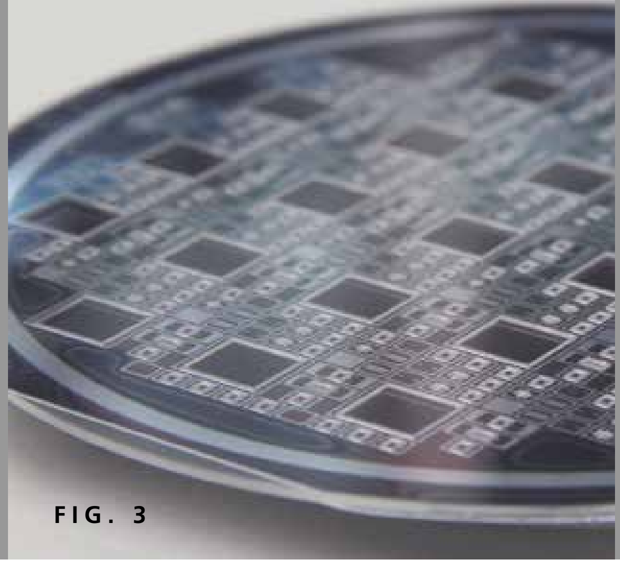
FIG. 3

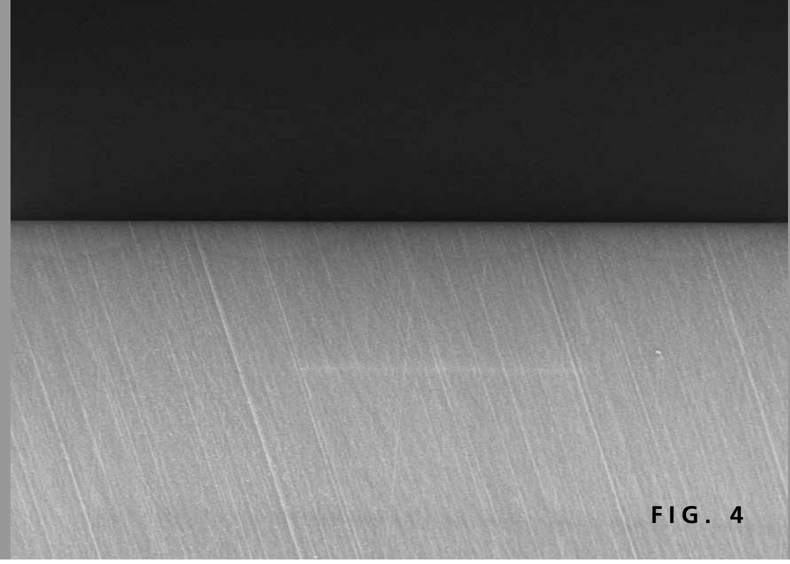
FIG. 4

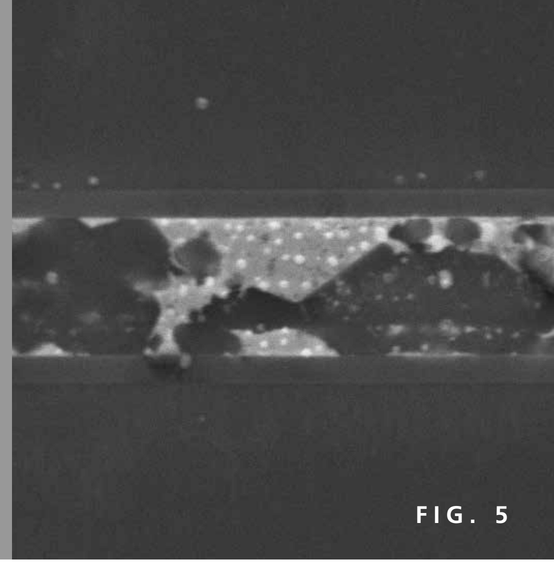
FIG. 5

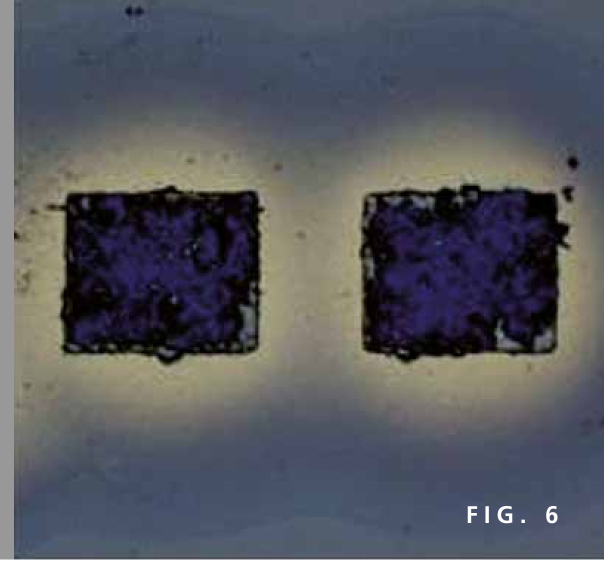
FIG. 6

LOW TEMPERATURE WAFER BONDING TECHNOLOGIES

Mario Baum, Dirk Wünsch, Marco Haubold, Chenping Jia, 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. One research focus is put on low temperature wafer bonding technologies for joining two or more substrates with process temperature below 400 °C to avoid thermal and mechanical stress as much as possible. Furthermore the low temperatures open new possibilities for joining different substrate materials with different thermal expansion properties. So standard methods, such as the silicon direct bonding, the anodic, eutectic, adhesive and the glass frit bonding are developed and adapted for low bonding temperatures, but also nano scale effects were investigated to decrease the process temperature of certain bonding technologies, e.g. reactive nano bonding. At least the quasi simultaneous laser assisted bonding allows selective bonding without any temperature influence on the functional elements.

Direct Bonding

Direct bonding uses the formation of covalent bonds if two clean and smooth surfaces are joined and subsequent annealed at temperatures above 800 °C. But for many applications with integrated microelectronic by using heterogeneous substrate materials in one system it is essential to reduce these high temperatures. One possibility for this reduction is the usage of surface activating procedures prior to bonding, like low and atmospheric pressure plasma activation (Fig. 1). There exist multiplicities of low pressure plasma modes, which can be applied to activate the wafer surface. Besides remote and sequential plasma a commonly used mode is reactive ion-etching (RIE). Key materials for high-frequency systems such as mobile telephones and optical communication systems are ferroelectric single crystals such as lithium tantalate ($LiTaO_3$) or lithium niobate ($LiNbO_3$). The aim is the development and optimization of the direct bonding process for the heterogeneous material combinations lithium tantalate / silicon ($LiTaO_3$/Si). The process gas as an impact factor of the bond strength is shown in Figure 2 for $LiTaO_3$/Si wafer stacks. The highest bond strength measured with the micro chevron test can be achieved with a combined two-stage RIE-plasma (O_2/N_2-RIE). The bond strength with a minimal mean variation over the complete wafer stack can be dramatically enhanced compared to the non-activated reference wafer stack.

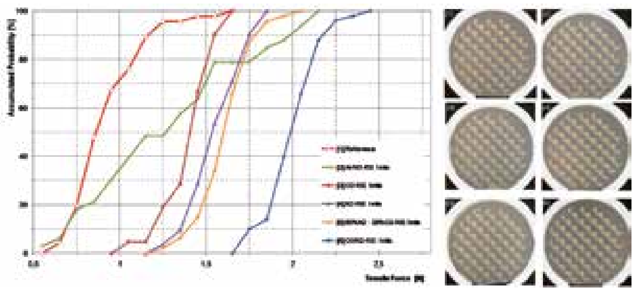
FIG. 2

Anodic Bonding

Anodic bonding has been widely applied to MEMS packaging in for many decades. Nevertheless there is still a demand for further improvements in order to meet nowadays requirements. Following this spirit, the department system packaging adapted the anodic bonding process to the challenging encapsulation process for RF MEMS switch below 200°C. Therefore a silicon-glass-glass triple stack has been fabricated, protecting the temperature sensitive structure against environmental impacts such as moisture, particles, atmospheric pressure and oxidizing species (Fig. 3).

Beside traditional low temperature bonding technologies for the assembly of silicon wafers with similar substrates or glass wafers, the application of laser radiation onto the bonded interface refers to a quasi-room temperature bonding technique. When the laser is operated dynamically, a sequential bonding process is realized and all kinds of pattern can be realized. The temperature due to the absorbance of the electro-magnetic radiation enhances the bonding process at atomic level and forms mechanically stable bonds between the adhering surfaces. A cross-sectional image of the bonding interface can be found in Figure 4. Beside the radiated area, the substrate material is not affected by the local treatment. In conclusion, materials or devices with properties, critical to the process temperature are compatible to this packaging technology and even material combinations with a significant mismatch in its coefficient of thermal expansion (CTE) become available for hermetic encapsulation.

Eutectic Bonding and SLID Bonding

From a great variety of bonding techniques eutectic and SLID bonding has got a special importance today because both hermetically sealed packages and electrical interconnects could be performed within one bonding process. Furthermore, there are some advantages such as low processing temperature, low resultant stress induced in the final assembly, and high bonding strength. Within the department System Packaging the development and investigation of several eutectic and SLID bonding technologies are investigated, performed and developed. So material combinations like AuSi, AlGe, AuSn, and CuSn were experimental characterized regarding the mechanical and micro structural properties as well as the hermeticity and conductivity of the bond interconnect.

Up today not every detail of the micro structural processes during liquid phase bonding like eutectic and SLID is cleared completely. Especially the reproducibility and reliability of such bonds are still under investigation. Next to the main advantages of AuSi eutectic bonding like availability in micro technologies and the most dramatically decrease in bonding temperature regarding to the melting temperatures of Au and Si (Fig. 5), the long-term stability and the liquid phase processing are drawbacks of the technologies. However, the eutectic temperature of AuSi around 363 °C at a Si concentration of about 19 at.% and Si as substrate material make AuSi to the most interesting bonding interlayer next to AlGe with a eutectic point of 420 °C, AuSn with 280 °C, and CuSn with 230 °C respectively.

Application example: Assembly of capacitive ultrasonic transducer

Wafer bonding is an important technology to micro sensors fabrication. For bulk micromachined devices, it is especially indispensable. There is a broad spectrum of bonding technologies, including anodic bonding, adhesive bonding, thermal compression bonding and direct bonding. Among them, direct bonding is one of the most attractive methods, in that it combines the advantages of high bonding strength, low process temperature, adaptive to device materials and low thermal mismatch. An ultrasonic transducer was developed that is assembled through direct bonding of a metalized membrane carrier and a place holder under vacuum condition. Surface profile measurement validates the hermeticity of the bonding process. Functionality of the transducer has been confirmed by transmission experiments in both air and water.

Legend

Fig. 1: Plasma activation tool in a SÜSS mask aligner with an activated pressure sensor in cooperation with Fraunhofer IST, Süss Microtec AG and Epcos AG

Fig. 2: Bond strength and optical images for different activated $LiTa0_3Si$ wafer stacks

Fig. 3: Silicon-Glass-Glass triple stack for RF-MEMS packaging

Fig. 4: Alternating pattern at the silicon-glass interface due to the absorption of laser radiation (top - glass substrate, bottom – silicon substrate)

Fig. 5: SEM image of an AuSi bonding interface

Fig. 6: AuSi Pad structures with Au diffusion zones

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DEPARTMENT ADVANCED SYSTEM ENGINEERING

Head of the Department: Dr. Christian Hedayat

Short Portrait

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 this 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 system
- 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 complicate 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).

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 ENAS 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 its validity can be 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) and PARIFLEX (BMBF).

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.

Trends

The design of complex modern electronic devices requires the usage of adequate system level modeling technologies. The 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.

Based on high-performance measurement equipment - including the innovative self-developed Near-Field Scanning System - various microelectronic systems and integrated components can be optimally characterized with respect to physical and EMC/SI/RF constraints. Besides the efficient simulation and 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.

The Fraunhofer ENAS department ASE is ready to tackle all these challenges.

Competences

The main competences of the ASE department are:

- 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-EM-Field scanning system

Services

We offer the following services:

- RF and EMC Characterization and Modeling
- Vector Network Analysers for 4 Port Measurement (300 KHz – 20 GHz)
- RF-Probing Station for On Wafer measurements (300 µm Pitch Size, 40 GHz)
- 3D Near-Field Scanner (high resolution, 9 kHz – 6.0 Hz)
- Spectrum Analyzer (9 kHz – 26.5 GHz)
- Power Meter (-30 dBm to +20 dBm)
- Digital Oscilloscope
- Communication Signal Analyzer with 20 GHz TDR/Sampling Heads
- RF Signal Generator (up to 3.2 GHz, analogue modulations)
- Modeling and Simulation Competences
  - » CST µWave Studio
  - » AnSys (HFSS)
  - » Cadence (HSPICE and Spectra
  - » Custom-specific solutions

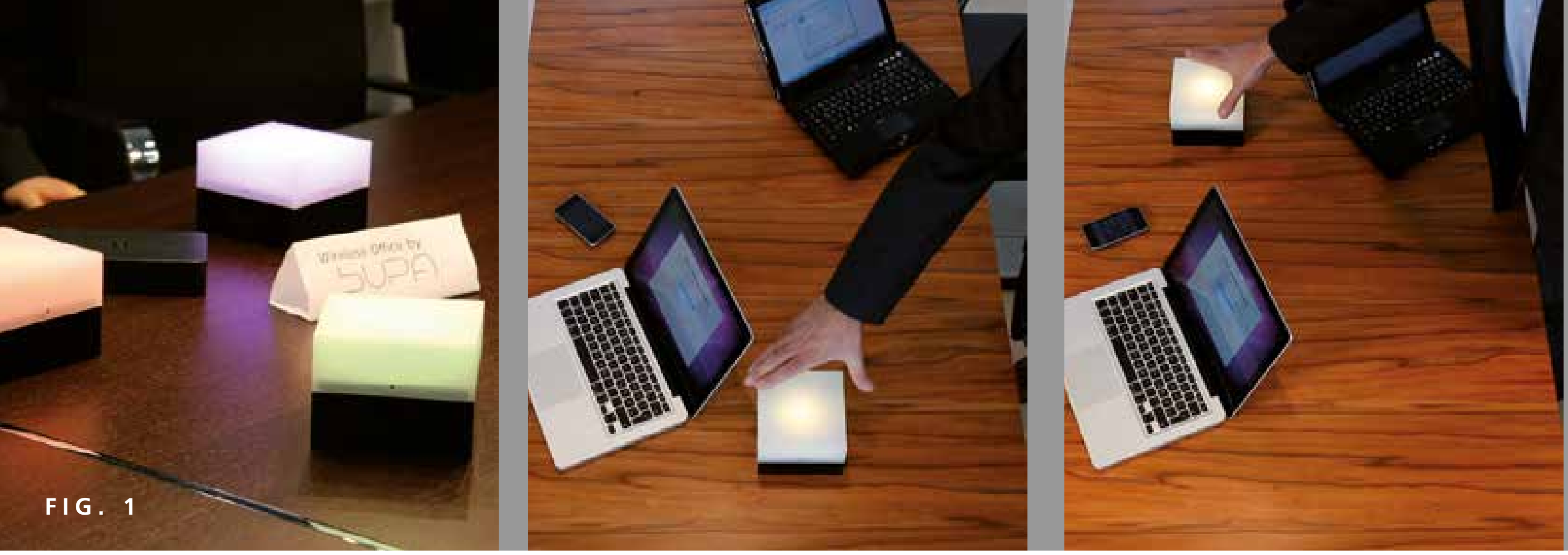


FIG. 1

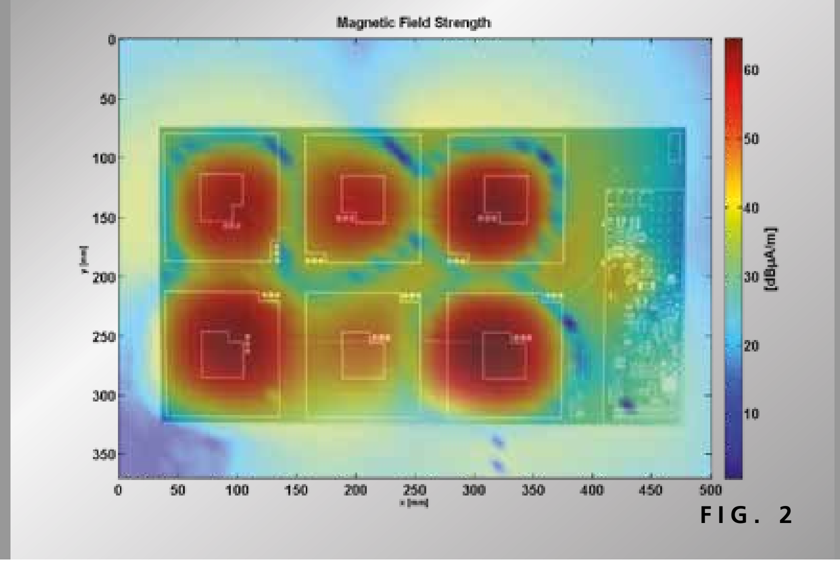


FIG. 2

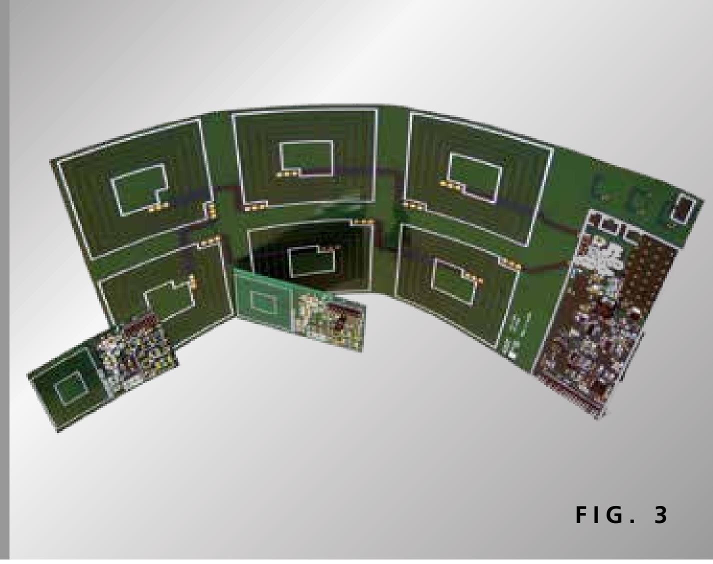


FIG. 3

SUPA – THE INVISIBLE REVOLUTION

Christian Hedayat

On the conference table of the future there are no more cables: Notebooks were supplied directly via the desk top with power and are connected by wireless USB or wireless LAN to the LAN and with the beamer.

To let this vision come true, the department ASE develops 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 electrical power supply of the devices works based on the principle of electric induction. Hence, the 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 over an antenna structure to the SUPA compatible user device (e.g. a smart phone or a notebook). The transmitter antenna structure is not limited according to surface size, because several power and data antennas can be panelized to cover whole tables or table arrangements as one transmitter antenna array.

The determining challenge is it to design this infrastructure in such a way that really the complete furniture surface can be supplied. Nowadays available solutions typically require the adjustment of the devices at a defined place to be supplied or cannot provide enough power. The advantage for the user is that he can position his device at any place on the table and will be supplied there with power. Because the antenna serves at the same time as a data antenna, various devices can link up each other by this technology. Besides, the working range for data and energy transference is consciously minimised (approx. 5 cm to 10 cm) keep the radiation level as low as possible and to optimise safety of interception of the data networks.

Beside the comfort advantages for the user cost advantages also arise concerning the power and data infrastructure of buildings, because several working places may be fed by one power and data connection. For the application of SUPA as an infrastructure solution this means that the transmitter antenna structures are obstructed in all office and public areas to achieve a wide cover of supply points. To reach this goal intensive market studies are carried out already in the current development stage through the involved industrial partners with regard to a wide application of the technology in the commercial sphere.

Furthermore numerous advantages arise in the area of furniture design:

No more visible or hidden cable canals and wiring boxes for network, beamer and the electricity supply are needed. Flaps and cover strips are not necessary any more. With a piece of furniture equipped with the SUPA technology the infrastructure is invisible. The electric modules can be fabricated on up to 125 µm thin substrate material to be integrated into the wooden structure.

Further Application Areas for SUPA

Beside the application in the conference area the technology can be used in many areas of the public life:

In the train or airplane you work with your laptop on the table at your seat that is equipped with SUPA. You are immediately connected to the WAN over a secured data interface. Due to the low working range no interferences with other users or the sensitive board electronics are to be feared. At the same time you don't need to think about your accumulator operation time, because your device is supplied with power.

In the rental car you put your Smartphone in the SUPA storage dish. It is charged and linked up to vehicle immediately.

Also at the hotel or café many other ranges of application are conceivable.

Legend

Fig. 1: Wirelessly powered illuminations and IT-devices suplied by the SUPA-Technology

Fig. 2: Focused energy distribution of a power emission antenna array

Fig. 3: Array of inductive power emission and reception antennas on flexible carriers

The project is promoted by:

Bundesministerium für Wirtschaft und Technologie

ZIM impulse für wachstum Zentrales Innovationsprogramm Mittelstand

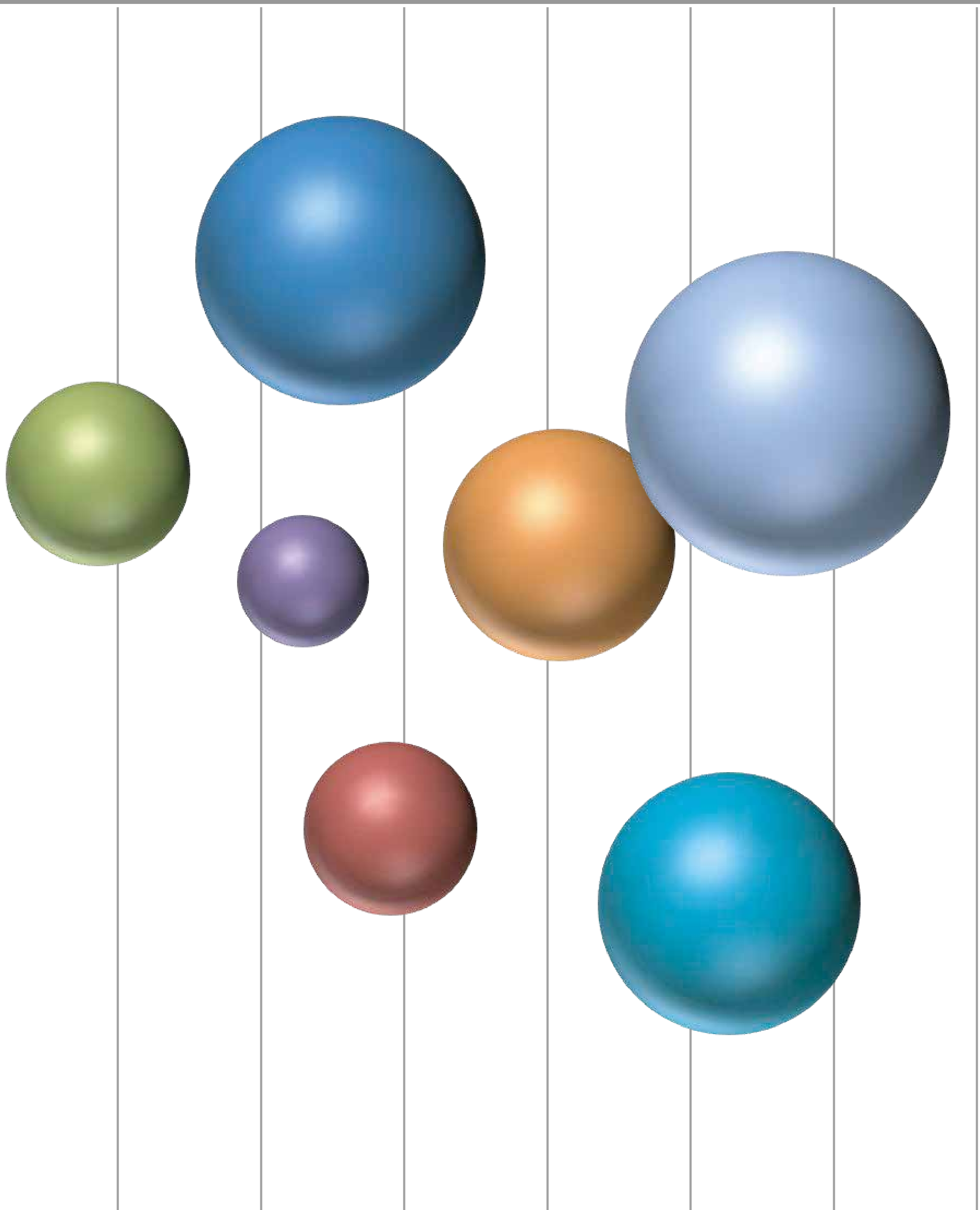
The following enterprises and universities take part to the project SUPA beside Fraunhofer ENAS:

UNIVERSITÄT PADERBORN Die Universität der Informationsgesellschaft

CHRISTMANN INFORMATIONSTECHNIK + MEDIEN

EUSKIRCHEN MANUFAKTUR

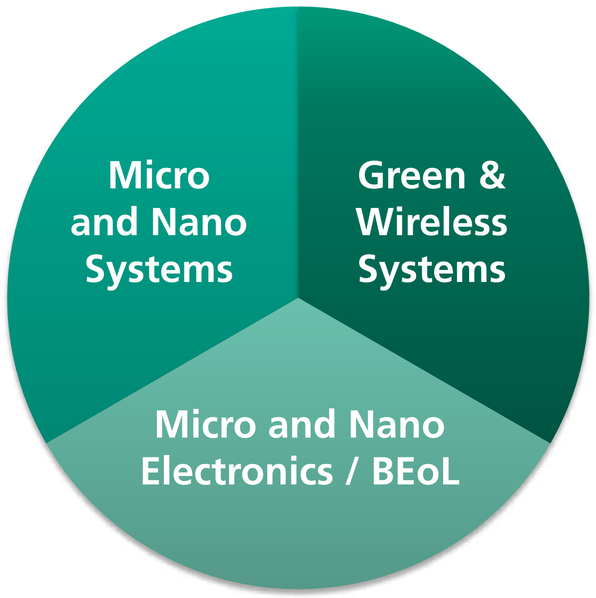
HOTOPRINT Hotoprint Elektronik GmbH & Co. KG Leiterplatten



BUSINESS UNITS

BUSINESS UNITS OF FRAUNHOFER ENAS

In 2010 the Fraunhofer Institute for Electronic Nano Systems has continued to work on the strategy. In this process business units and core competences have been defined and the existing technology and application roadmaps have been updated. In June 2010 this strategy has been audited by industrial and scientific representatives. The auditors stated that Fraunhofer ENAS is working on hot topics. All these topics have a visionary component and the transition into market relevant products is expected. In autumn 2010 he Executive Board and the Senate of the Fraunhofer-Gesellschaft have decided to convert the Fraunhofer Research Institution for Electronic Nano Systems to a Fraunhofer Institute on January 1st, 2011.



In order to ensure a longterm scientific and economic success Fraunhofer ENAS has defined three business units:

- Micro and Nano Systems,
- Micro and Nano Electronics / Back-end of Line as well as
- Green and Wireless Systems.

They address different markets and different customers.

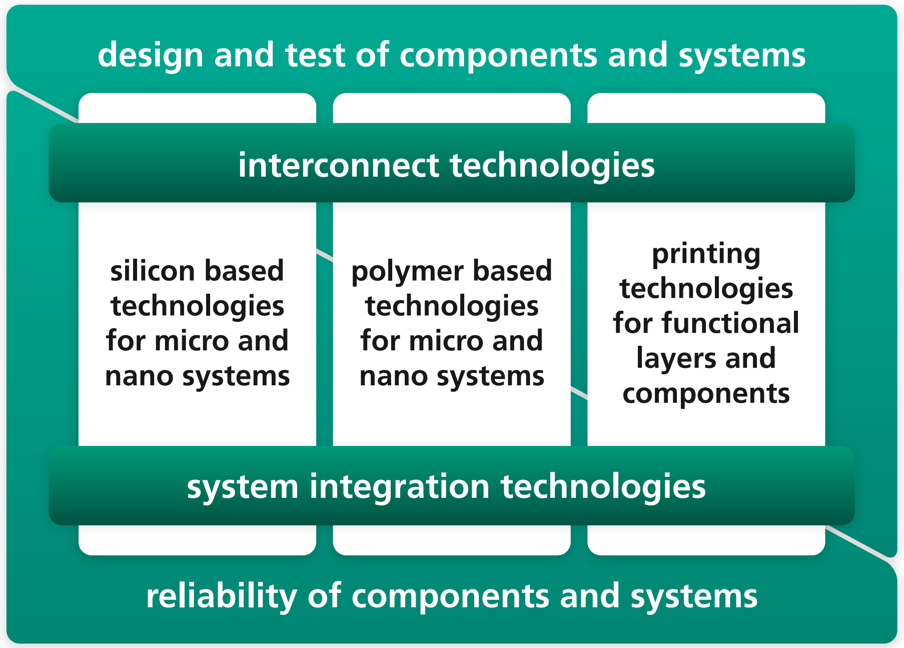
The core competences are an indicator for the specific technological know-how of the Fraunhofer Institute for Electronic Nano Systems. Fraunhofer ENAS accesses on a broad variety of technologies and methods for smart systems integration. There have been defined seven core competences, which are the inner 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 life time 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.

The core competences are based on the know-how of the employees of the six departments of Fraunhofer ENAS. It needs to be mentioned that departments contribute 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 more in detail. The description will be supported by examples, that means by projects which belong to the business units.

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 Precision 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 Micro and Nano Technologies", "Polymer Based Micro and Nano Technologies", "System Integration Technologies" as well as "Reliability of Components and Systems".

High Precision MEMS/NEMS

"High Precision MEMS/NEMS" includes the development of prototypes and system solutions of high precision micro electro mechanical systems (MEMS) and nano electro mechanical systems (NEMS). The focus is on high precision actuators for optical MEMS as well as on high precision inertial sensors for industrial applications, navigation and medical application. MEMS/NEMS design and modeling. Fraunhofer ENAS provides services in:

- 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 sensoric as well as actuatoric functionalities as integrative components of smart systems. Focus is on nano composite based sensors as well as material integrated actuators for polymeric micro systems. Thereby two different markets are addressed. The first one is industrial process monitoring and the second one medical and life science. Related to nano composite based sensors industrial process monitoring is especially of 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 nano composites
- Customer specific configuration of the nano composites for specific applications, e.g. in lightweight structures engineering
- Condition monitoring based on cost-effective nano composite based sensors
- Development of customer specific fully integrated sensor and actuator solutions
- Common developments with SMEs in the field of molecular diagnostics and cell biology

RF-MEMS

"RF-MEMS" comprises manufacturing of components for radio frequency applications, which electrical properties may vary based on implementation of micromechanical 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

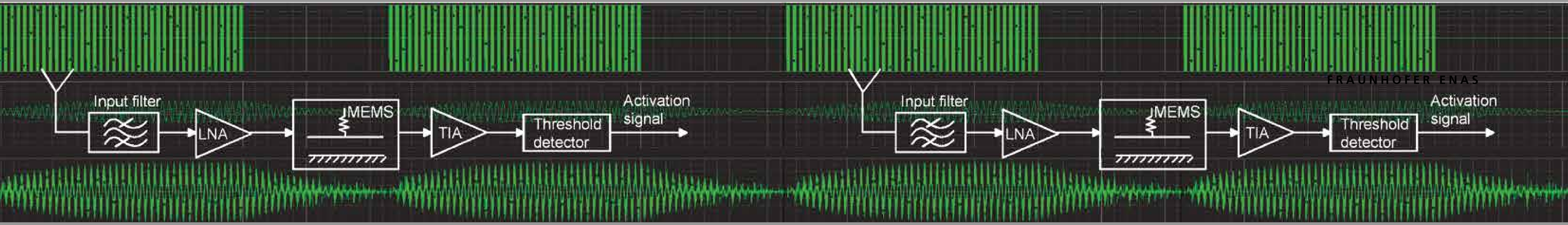


Fig. 2: Wake-Up Receiver concept

MEMS BASED WAKE-UP RECEIVER FOR AUTONOMOUS SYSTEMS

Sven Voigt, Markus Nowack, Stefan Leidich, Steffen Kurth, Andreas Bertz

The communication in information technology is more and more based on radio links. Despite the advanced development of the performance of the electronics for distributed sensors, sensor networks, signal processing and communications, the required power is in most cases too high to achieve long battery life time or even self-sufficient operation. In every application that needs an ad hoc data transfer, the radio receiver is active all time and consumes the major part of energy (10…20 mW typically). It limits the application opportunities, since usually less than 100 µW power is available for self-sufficient miniaturized systems that are supplied by small solar panels for instance. To overcome this situation, so called wake-up receivers (WuRx) have been introduced in recent years. This additional extremely low power receiver with low data rate detects radio signals in the particular frequency channel and activates the main transceiver only when data communication is requested. Bas van der Doorn [1] presented a low cost WuRx for 868 MHz. He combined a transceiver CC1100 and a simple diode demodulator. Gamm et al [2] followed this approach and combined a 2.4 GHz passive front end based on a diode demodulator with commercially available CC1101 transceiver.

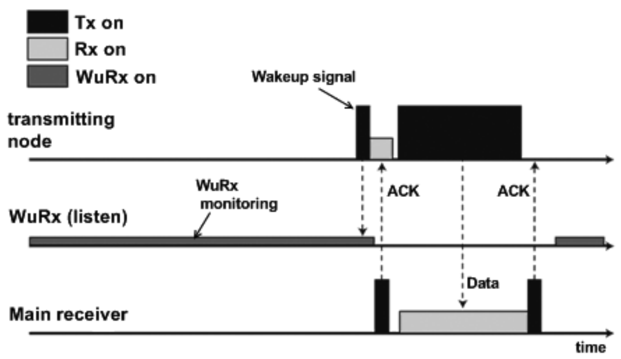


Fig. 1: Communication scheme with Wake-Up-Receiver

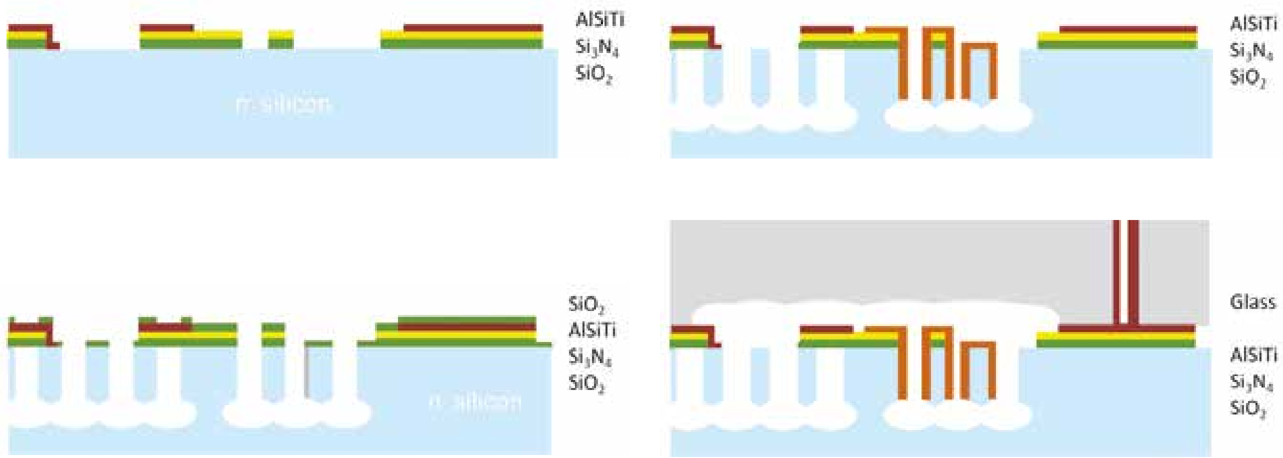


Fig. 3: Cross sectional view at different stages of fabrication technology

This report shows how to implement MEMS/NEMS devices in a novel approach to a WuRx. The wake-up signal is used to activate the main receiver for a short period of time to transfer data (Fig. 1).

The concept of a direct down conversion receiver with frequency pre-selection by LC filter at the input and a passive MEMS mixer including a mechanical narrow band signal filter, a very low power transimpedance amplifier and a threshold detector is applied (Fig. 2). A low noise amplifier is inserted at the input as an option. Due to the intrinsic non-linearity of the electrostatic force that is generated by a first pair of electrodes having 0.5 pF capacitance, a modulated RF input signal (wake-up signal) is transferred into the base band frequency and excites the mechanical motion of the narrow band filter. Using a modulation frequency equal to the resonance frequency of the MEMS, the received RF power is accumulated in the mechanical domain. Due to the high quality factor of the mechanical oscillation, even small RF amplitudes are detectable. The filter is capacitively read out by applying bias voltage of 1.5 V at a second pair of electrodes with approximately 40 pF capacitance. The transimpedance amplifier eliminates the influence of parasitic capacitance of the wiring onto the sensitivity because of its low input impedance. The wake-up signal activates the main receiver, if detected.

First samples have been fabricated by a special MEMS-technology (Fig. 3, [3,4]), based on 50 µm deep dry etching and side wall passivation (so called Bosch process) and a subsequent isotropic dry etch step to release the structure from the substrate. The electrodes are completely separated from the bulk for low parasitic capacitance. In the section of the RF electrodes, noble metal is deposited by sputtering using a shadow mask in order to improve the electrode conductivity and to reduce RF loss. The metal covers both, the wafer surface and the etched side walls that contribute to the major part of the input capacitance. The reduction of the gap between the fixed and movable comb electrodes is important for the sensitivity of the WuRx. By using a special gap reduction mechanism the gap can be reduced from 3.5 µm to less than 400 nm (Fig. 4), which is considered essential to achieve the required sensitivity. The mechanical narrow band filter operates at vacuum pressure. The quality factor is determined by the vacuum pressure inside. A vacuum encapsulation at wafer level by glass frit bonding of a glass cover wafer is applied.

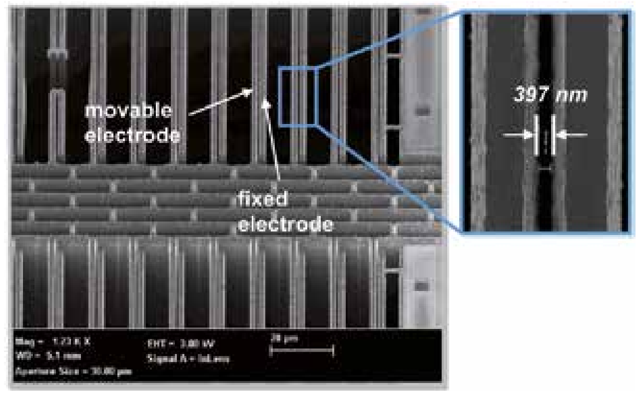


Fig. 4: SEM image of the comb electrodes with reduced gap

The simulations have been conducted using Agilent ADS software. It provides the capability to include technology specific libraries containing semiconductor device models and to perform a simulation of electronics and mechanical behavior. We expect 130 pA mixer output current at 10 mV mixer input voltage according to the simulation.

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MICRO- AND NANOELECTRONICS / BACK-END OF LINE

The business unit „Micro- and Nanoelectronics / Back-end of Line“ focuses on three main fields of activity:

- Materials, processes, and technologies for micro- und nanoelectronics with emphasis on back-end of line
- 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

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 a more holistic approach. Strong interactions between technology, material science, as well as modeling and simulation are necessary to face these challenges. At Fraunhofer ENAS close meshed interrelations have been established between the specific fields of activity within the past years.

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 “.

Markets and branches - relevant to this business field, 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

Chemicals and material manufacturers

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

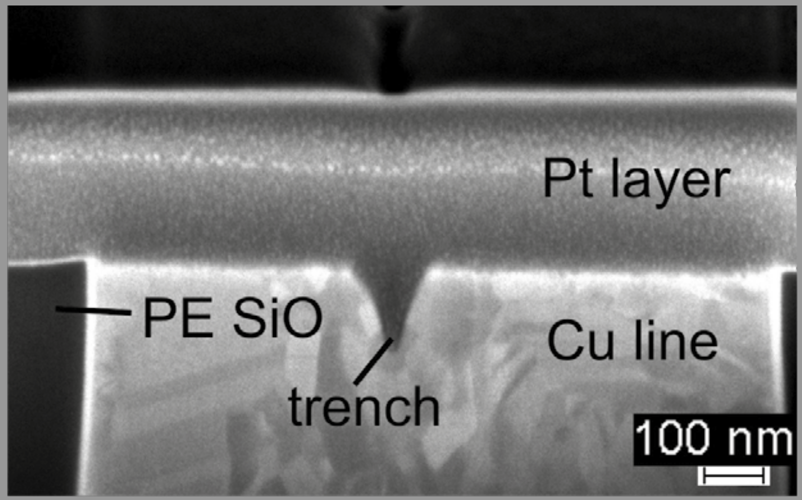
Further activities within the business unit are determined by the international semiconductor roadmap (ITRS) as well as by the global trends “Beyond CMOS“ and “More than Moore“.

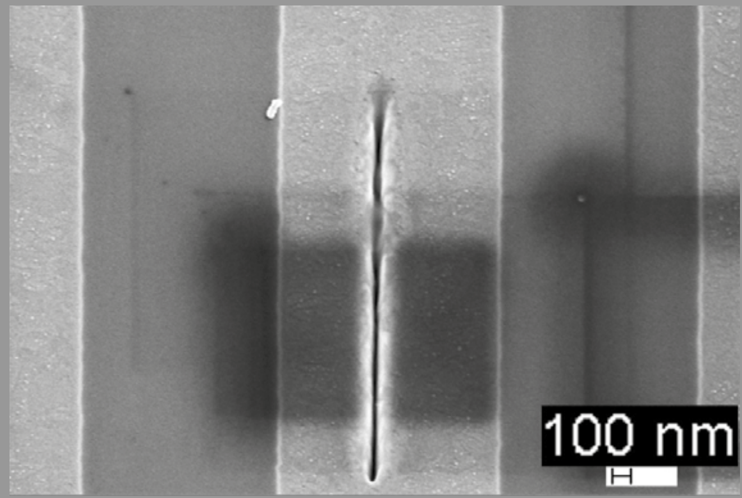
Within leading edge micro and nanoelectronics, emphasis will be on dielectrics as well as metallization and barriers, e.g.:

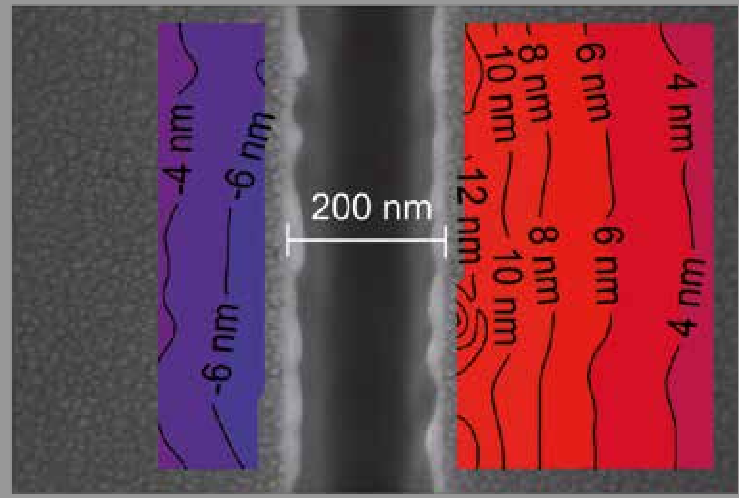
- Ultra-low-k-materials ($k = 2.0 – 2.3$), deposited by CVD- or spin-on-technologies
- Alternative ultra-low-k-approaches, e.g. airgaps ($k < 1.3$)
- Ultra thin CVD- and ALD-barriers
- Self forming barriers
- Airgap-compatible barriers and barriers for copper layers with extremely low resistivity

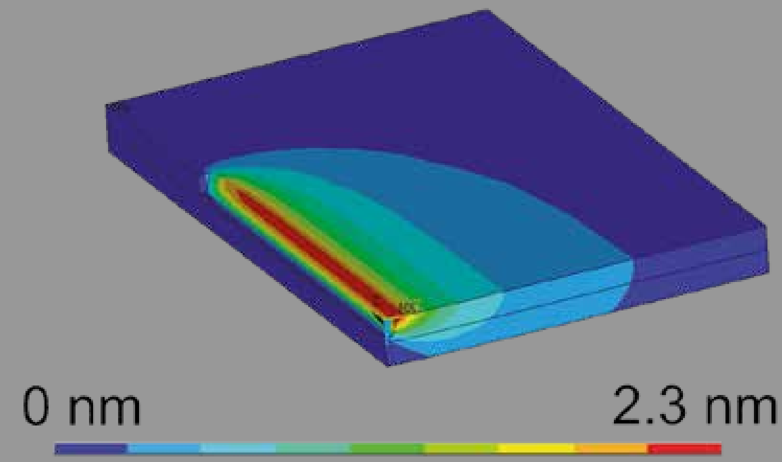
Beyond CMOS is characterized by new designs and materials, like carbon nano tubes (CNTs). Fraunhofer ENAS has started basic research in that field in close cooperation with the Center for Microtechnologies at Chemnitz University of Technology. Bringing this research to an application is an important goal for the coming 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 in MEMS/NEMS-applications is aimed for.









IMPROVING RELIABILITY OF BEOL STACKS BY A DEEPER UNDERSTANDING OF MATERIAL AND PROCESS INDUCED STRESSES

Ramona Ecke, Dietmar Vogel

The ongoing miniaturization and introduction of new and additional materials in integrated circuits accompanied by enhanced complexity and heterogeneity cause an increasing number of potential failure sites. Beside the increasing number of failure sites also the behavior of well-known failure mechanisms can change or new failure mechanisms can be introduced. This leads to reliability concerns whereas reliability is an important requirement for all applications of integrated circuits.

The biggest part of improvement in IC products was provided by material and technology developments. Meeting all requirements for further scaling and reliability an interaction between wafer technology, material science modeling, simulation and design is becoming increasingly important. The business segment "Micro and Nanoelectronics / Back End of Line" joins all these competencies focused on interconnect systems.

An important risk factor is residual stress in multi-layered thin films like in the interconnect system leading to delamination, cracking and extrusion. Stresses are caused by the manufacturing process especially by multiple layering of different materials and thermal cycling during deposition or patterning. The determination of these residual stresses by means of finite element simulation is problematic due to the large amount of process steps. Numerous physical and chemical influences by processes have to be considered, which is hindered by partly unknown material properties and behavior of thin layer. Modeling and simulation relies on material databases, where basic material properties, e.g. Young modulus or electrical resistivity, are provided. Unfortunately, values from databases often don't correlate well with the properties of deposited layers. Namely, properties of thin layers differ strongly from properties of bulk material and are highly influenced by the specific deposition process, i.e. by temperature, plasma power, used precursors and gases etc., and not at least by the surrounding materials. Therefore, more realistic material values have to be determined as input for qualified modeling and simulation of interconnect architectures.

Accurate stress measurement, especially in patterned multi-film stacks and with spatial resolution, can help to calibrate the modeling and simulation. That is why new stress measurement methods with high spatial resolution are being developed at Fraunhofer ENAS, in strong interaction with material and process development and integration issues. One of those methods is the fibDAC stress relief technique, which allows submicron spatial resolution. Ion milling of tiny trenches causes local stress relief deformations, captured by digital image correlation (DIC) on micrographs picked up before and after milling. The measurement process can be realized in standard FIB equipment. An in-house developed software code allows effective and fast comparison of the measured stress relief with the predicted one from finite element simulation. As a result stresses at the trench milling position can be determined. The tool can be applied to basically most of materials, including nano-crystalline and amorphous phases, where x-ray diffraction methods fail.

The Figures above depict a trench cross section prepared after stress measurement in a Cu line. Furthermore, a typical stress relief displacement field nearby the trench middle is shown. Displacements of a few nanometers only are caused by stress release milling and detected by DIC analysis on high magnification SEM images. A finite element simulation for the near trench displacements are given for illustration as well.

A careful validation of the fibDAC stress relief technique preceded its application. Simple specimens of non-patterned SiN layers deposited by PECVD were used and the obtained results were compared with established stress measurement methods. For example, wafer bow and microRaman spectroscopy were chosen for this cross-checking. Because stress relief is a function of material stress as well as of elastic material properties, nanoindentation for the determination of the Young's moduli of the film material was incorporated. Both bow and fibDAC stress relief measurements provided a stress value spread less than 10 %. This spread originates from stress variation over the wafer and from the measurement error. Within this maximum 10 % error bar bow and stress relief stresses coincided.

The fibDAC stress relief method is being applied to local stress measurements in arrays of adjacent parallel metal lines (width 1.0 µm and 1.6 µm with inter-line spacing of 1.2 µm), which clearly exceeds the capabilities of the bow measurement and standard x-ray diffraction technique. Samples are prepared in different ways to examine the influence of the surrounding dielectric material or annealing steps after Cu-ECD on the local stress. Currently, PECVD SiO2 and SiCOH are used as dielectric material with accordant dielectric barriers SiN and SiC. Afterwards, the investigations should be widened to further low-k materials. Treatments after Cu-ECD are also studied, like the influence of temperature anneal, self anneal or stress measurement just after deposition and Cu-CMP. The high spatial resolution of the fibDAC technique even allowed separate stress measurement in the Cu metal and in the dielectric gap, respectively. For example, measurements performed after barrier / Cu deposition and CMP finish revealed for PE-SiO_2 dielectrics a major tensile stress in the dielectrics and a moderate compressive stress for Cu lines in the direction normal to the line. This stress level occurred within 24 … 36 hours after CMP finishing.

The systematical investigation of contribution of materials and processes to a local stresses by the fibDAC stress release technique leads to a better understanding of residual stresses in multi stacks. The results help to understand local stress development in detail. The results will be incorporated in predictive modeling and simulation for multilayer stacks to reach higher accuracy.

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) and the state of objects (Condition Monitoring). 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 in 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 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 data acquisition. Electronic components, that are necessary for the RF technology and sensor systems, are supplied by industrial partners.

In the field of application-specific antennas, the intention is to analyze the dielectric environment of the material to be marked during the lifetime in advance and to include the results in the design of the RFID solution. In addition, beyond printing technology work is carried out in the field of antenna design in the ultra high frequency (UHF) and super high frequency (SHF) range and for matters of electro magnetic compatibility.

In order to bring together elements printed with silicon based chips in terms of a hybrid solution there is a strong cooperation with the core competences "Interconnect Technologies" and "System Integration Technologies" as well as with the business unit "Micro and Nano Electronics / 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 non-rigid, 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 6 volts.

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 label
- 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 electro mechanical 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 are another aspect of this sub business unit. 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 Fraunhofer ENAS offers the following services

- System Design and Modeling
- Technology development
- Manufacturing of prototypes with specific technologies
- System Test
- Development of applications

THE EUROPEAN CLEAN SKY PROGRAM: AIMS FOR GREENER AERONAUTICS

Martin Schüller, Eberhard Kaulfersch, Sven Rzepka

Introduction

The Clean Sky Joint Technology Initiative (JTI) [1] is an innovative 7 years program that will radically improve the impact of air transport on the environment while strengthening and securing aeronautics industry's competitiveness. It is one of the largest European research projects ever with the purpose to achieve, to demonstrate, and to validate technological breakthroughs to reach the main environmental goals of 50 % less CO_2, 80 % less NOX, and 50 % less noise emission by 2020. Combining the efforts of 86 organizations in 16 countries, Clean Sky is expected to lead the early introduction of new, radically green air transport products that will encourage the aviation world to make greener products to be brought into service sooner. The comprehensive set of Clean Sky demonstrators comprise smart structures and integrated advanced low-noise solutions, innovative concepts for active flow and load control as well as green design, manufacture, maintenance and recycling for airframe and systems.

Structure of Clean Sky

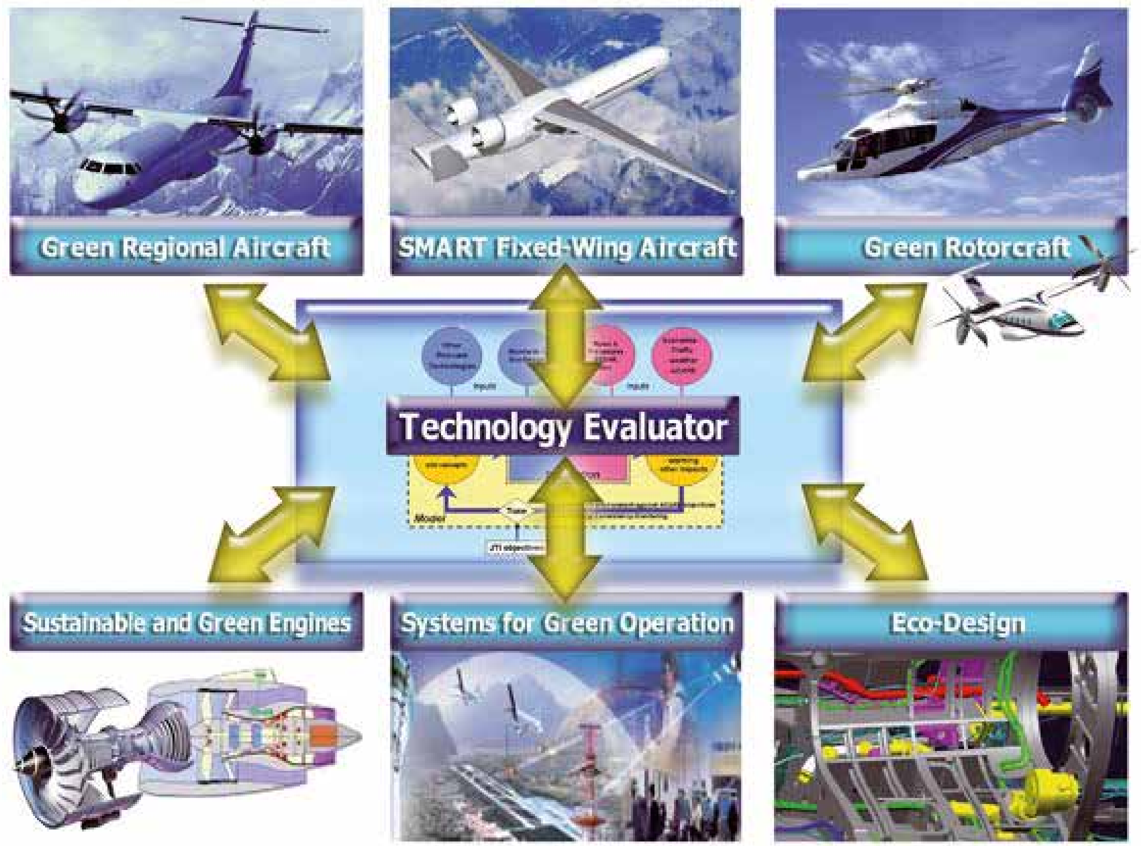
Worldwide, air transport is a keystone to further economic growth. At the same time, air transport is facing all the global economic and ecological challenges. The oil resources vanish and, in addition, global warming is a world-wide recognized issue. Therefore, carbon trading and ecologically motivated taxes are likely to increase. Thus, environmental friendliness of air traffic is of significant importance. Clean Sky will assess, design, build, and test many technological validation vehicles that will give the industry greener, more innovative aviation products. It is expected to yield green aircraft components, which generate less noise, lower the emissions, reduce the fuel consumption, and apply the environment protection principles at all levels of use: design, production, maintenance, overhaul, repair, and disposal. "Clean Sky" is structured in six Integrated Technology Demonstrators (ITD) [1], as shown in Fig. 1. The ITDs will deliver low weight technical solutions using advanced structures and materials, Configurations for low aerodynamic noise and the optimized integration of technologies developed in other ITDs.

ITD Smart Fixed Wing Aircraft (SFWA)

The SFWA aims to develop an all new »smart wing« design that makes use of passive and active flow and load control technologies and will help to reduce the drag of the wing in cruise as a means for reducing the medium- and long-range aircraft fuel burn and emissions by up to 20 % and noise by 5 to 10 dB. The Fraunhofer Institute for Electronic Nano Systems ENAS within the SFWA project is leading the task on development of fluidic actuators dedicated to flow control to be demonstrated in future aircraft wings. It contributes by design and analysis as well as manufacturing and reliability of closed-loop architecture for sensor-actuator interaction and actuators for innovative surfaces/ devices to form "smart" adaptive surfaces.

ITD ECO Design (EDA)

The ECO Design ITD is taking the total aircraft life cycle into consideration, consisting of the three distinctive phases: aircraft design and production, aircraft use and maintenance, aircraft withdrawal. Fraunhofer ENAS contributes in EDA to technical requirements, specifications for, and assessment of green technologies for new lead free solder materials and assembled electronic boards and electronics. Design guidelines with respect to avionics and reliability investigations of green avionics are its tasks within the life cycle assessment. In addition, Fraunhofer ENAS is developing a new approach of accelerated fatigue testing and modeling for organic and nano composite materials to be used in airframe structures for lowering the weight per load of the aircraft substantially. In EDS, Fraunhofer ENAS participates in choosing an appropriate model to evaluate network quality when introducing new power units (e.g. based on fuel cells). Requirements for assessment variables of the Electrical Network Analysis Model will be defined focusing on the linkage to the "ecolonomic" analysis.



ITD Systems for Green Operation (SGO)

The SGO ITD is improving the aircraft operation through increased energy efficiency due to better management of mission and trajectory. Technologies from this ITD are enablers of further improvements in environmental impacts at the vehicle level. Fraunhofer ENAS provides sensorics to the aircrafts' main and auxiliary energy generation and will participate in environmental testing campaigns.

ITD Green Regional Aircraft (GRA)

The objective of the Green Regional Aircraft - Low Weight Configuration is to validate and demonstrate the technologies, which fit best to the environmental goals set for the regional aircraft entering the market in the following years. In the frame of enabling new technologies, Fraunhofer ENAS is designing and providing patch antennas for wireless communication modules to be able to transmit the signals of several sensors. PoF (physics of failure) methods during the design phase are employed to ensure reliability and to meet the operational safety needs of future wireless solutions for distributed miniaturized sensor network (DMSN) under all avionic environmental conditions. In the Low Noise Configuration branch of GRA, design and manufacturing of fluidic actuators (synthetic jets) is the task of Fraunhofer ENAS. These actuators will be assessed and optimized by 3D wind tunnel.

The Technology Evaluator (TE)

The Technology Evaluator is an essential element of the Clean Sky project as it allows independent benchmarking of the achievements against the targets. It monitors the continuous progress made during the project runtime and shows it the stakeholders, internal and external entities. The TE also assesses the merit of complementary R&D activities performed in ITDs with regards to ACARE environmental objectives and serves a number of further objectives. Fraunhofer-Gesellschaft leads the TE effort globally assessing the "ecolonomic" impacts of Clean Sky.

Summary

The European air transport sector - comprising more than 130 airlines, operating across a network of over 450 airports with some 60 air navigation service providers and the manufacturing industry – is expressing an urgent need for environmentally compatible air traffic. The JTI Clean Sky is the consequent answer to these challenges as compiled in ACARE's vision 2020. The joint efforts of the private and public partnership 'Clean Sky' will culminate in functional technology demonstrators for each of the six ITDs that allow bringing the future aircraft to environmental friendliness.

References: www.Cleansky.eu

COOPERATION

FRAUNHOFER ENAS - COOPERATION WITH NATIONAL AND INTERNATIONAL UNIVERSITIES

National Cooperation

Interdisciplinary cooperation is the key for success. The Fraunhofer Institute for Electronic Nano Systems cooperates with the faculties of Electrical Engineering & Information Technology, Natural Sciences and Mechanical Engineering of the Chemnitz University of Technology. The cooperation aims at generating synergies between the basic research conducted at the Chemnitz University of Technology (CUT) and the more application-oriented research at the Fraunhofer ENAS.

The departments Multi Device Integration, System Packaging and Back-end of Line closely cooperate with the Center for Microtechnologies ZfM of the Chemnitz University of Technology. With the ZfM, its clean rooms and technological equipment, the faculty of Electrical Engineering & Information Technology possesses a special scientific operating unit. It is the basis for the production of prototypes and pilot-run series, for the development of technologies and materials as well as for the training of students, trainees and young researches in step with research and actual practice.

Furthermore, a very close collaboration exists between the department Micro Material Center and the Chair for Materials and Reliability of Microsystems which belongs also to the Center for Microtechnologies of the Chemnitz University of Technology. They cooperate in the fields of material characterization, simulation and experimental analytics.

Together with the ZfM 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 electro mechanical 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.

Printed functionalities are a relatively new research topic of the smart systems integration. Printing technologies are just well established at the Chair of Digital Printing and Imaging Technology of the faculty of Mechanical Engineering of the CUT. 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.

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. 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 Sendai in Japan is a very successful one. As a principal investigator Prof. Dr. Thomas Gessner got an own WPI research group belonging to the devision 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 CMOS-MEMS integration and the fabrication of nanostructures using self organizing and self assembling.

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 Microintegration and Reliability 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.

NANETT - NANO SYSTEM INTEGRATION NETWORK OF EXELLENCE

The research consortium nanett „nano system integration network of excellence" 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). Under the direction of the Chemnitz University of Technology and the Fraunhofer Institute for Electronic Nano Systems this multi disciplinary network of nine partners was formed to bring together their different competences in the field of applied nanotechnologies. Using the approach of combining the capabilities of several renowned scientific institutions enables international and domestic top level research on a competitive basis. 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.

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. To suit the scientific requirements of these highly interdisciplinary fields and due to huge invest costs for production and test equipment in the field of micro and nanotechnologies it is essential to use synergies created by collaborative work of different renowned research centers for successfully conducting competitive research and development.

Fields of research are:

Processes and technologies for nano scale material systems

- Application of quantum mechanical phenomena and effects of nano structures
- Patterning of nano structures in unconventional materials
- Characterization of magnetic properties

Micro-nano-integration

- Integration of nano structures with electromechanical functionalities
- System design and architecture of energy efficient sensor networks
- Technologies for autonomous sensor nodes

Nano materials

- Fabrication of functional nano composite materials
- Material integrated sensor functionality in lightweight structures
- Reliability of functional materials

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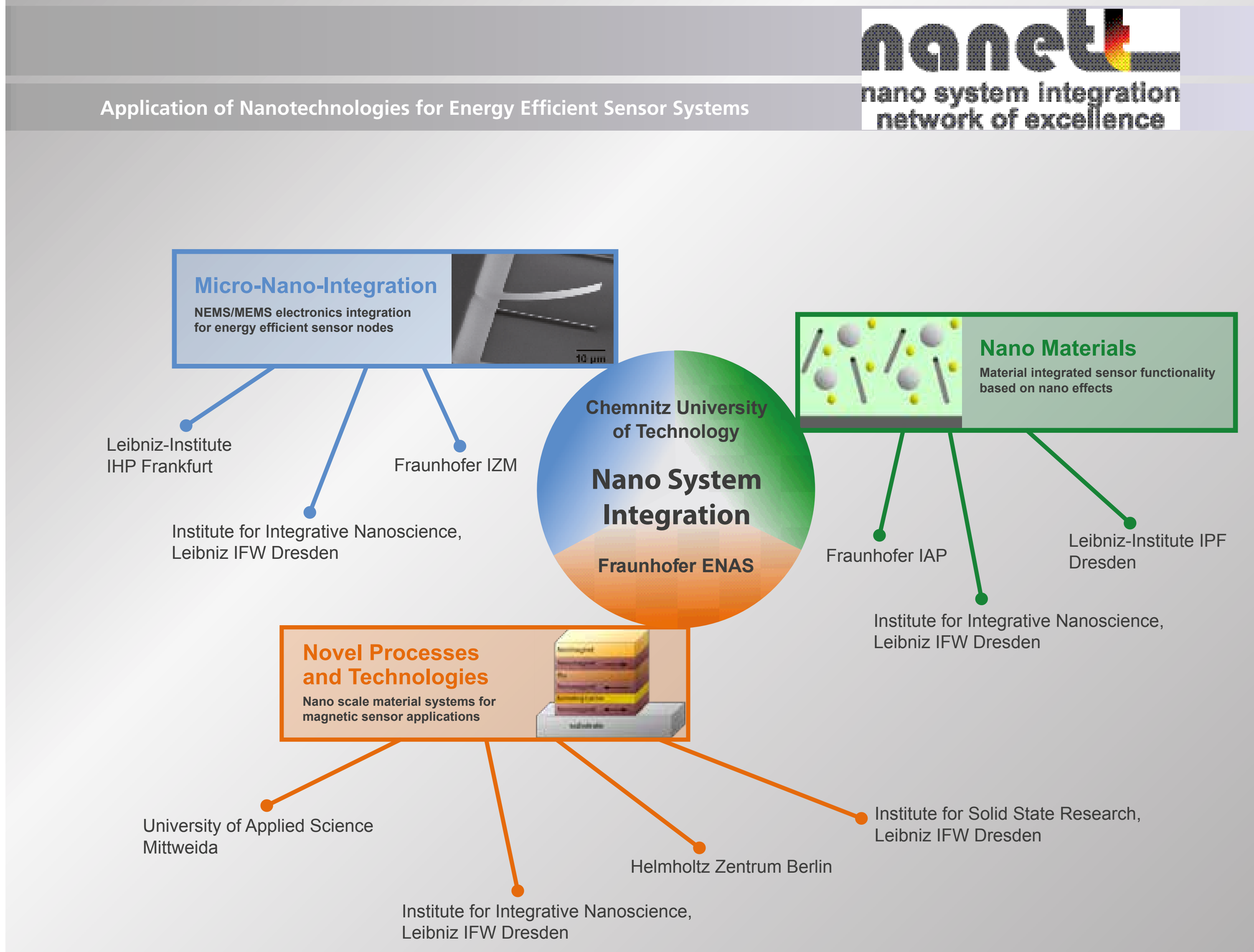
http://www.nanett.org/



INTERNATIONAL RESEARCH TRAINING GROUP

„Materials and Concepts for Advanced Interconnects"

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 for 4.5 years 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".

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 as the coordinator on the Chinese side and Prof. Thomas Gessner on the German side. A graduate school like this offers brilliant young PhD students the unique opportunity to complete their PhD work within 2.5 to 3 years in a multidisciplinary environment. Up to 14 PhD students of the German and 20 of the Chinese partner institutions, as well as a post-doctoral researcher at the Center for Microtechnologies are involved in the current 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 as well as new concepts for connecting the devices within integrated microelectronic circuits. Smaller contributions are being made in the field of device packaging and silicides for device fabrication. In this sense, the IRTG project is helping to solve problems currently encountered on the way to nanoelectronics.

Therefore, the research program of the IRTG concentrates on both applied and fundamental aspects, and treats the mid- and long-term issues of microelectronics metallization. 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.

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.

Summer School 2010

The 5th summer school of the IRTG 1215 was held from 26th March to 1st April 2010 in Chemnitz. This event was organized by the German partners under the direction of Prof. Thomas Gessner.

The summer school started with a social event. A guided sight seeing tour was planned to Freiberg, Saxony, for all members of the IRTG program. The Professors, tutors and PhD students visited the historic center of Freiberg and the Freiberg Cathedral "St. Marien". After lunch all participants attended "A mineralogical Journey around the World", which is the theme of the "Terra Mineralia", one of the largest mineral collections in the world provided by the Technische Universität Bergakademie Freiberg. Due to earlier exchanges (Mobility Period) of several PhD students between the Chinese and the German side, the event was accompanied by an active communication of all members.

On March 29th and 30th, 18 talks and 32 scientific posters were presented by the German and Chinese PhD students to show their status and progress of their diversified scientific work. Each oral presentation closed-up by questions from the audience. Moreover, the communication between the international participants was improved by the discussions at the posters and during tea breaks and meals on both days.

Finally, the summer school closed with the evaluation meeting on March 31st for all participants.

Evaluation meeting on March 31st

The proposal for the second period of the IRTG program was submitted to the German Research Foundation (DFG) in October 2009 including a detailed report of the first period. The new topic "Materials and Concepts for Advanced Interconnects and Nanostructures" combines both, activities related to "More Moore" as well as "More than Moore", correlating to the current trends in micro- and nanoelectronics. The proposal included 9 subprojects on the German and 11 subprojects on the Chinese side.

On May 31st the evaluation of the first period of the IRTG program took place at Chemnitz University of Technology. The members of the IRTG welcomed six evaluators from German universities and research institutions, two evaluators of the Chinese Ministry of Education (MoE) and four representatives of the German Research Foundation in Chemnitz.

The event was opened by Prof. Thomas Gessner, speaker of the International Research Training Group. He presented the activities and progress in the scientific program within the first four years. An overview of all Chinese activities as well as the Chinese scientific environment was given by Prof. Ran LIU from Fudan University in Shanghai and Prof. Di CHEN of Shanghai Jia Tong University. Additionally, two PhD students from each partner side presented their scientific work in detail. Moreover, a poster session was held, including 34 PhD presentations of all involved PhD students and postdocs. The second part of the day was reserved for extensive discussions of the evaluators and all members of the IRTG. The day ended with a reception in the hotel "Chemnitzer Hof" for all participants.

As the first period of the IRTG program achieved an "excellent research" rating and in July 2010 the second period of the IRTG program was approved by the German Research Foundation.

Statistics of the 1st IRTG period 04/2006 – 09/2010

Even though this program is the first of its kind at the Chemnitz University of Technology, it was quickly well-established and successfully operating since April 2006.

Within 4.5 years of the first period, one autumn and four summer schools of several days duration were held in Germany and China. More than 20 PhD students were exchanged from the German to the Chinese side and vice versa for about 3 months each. As a result of the strong collaboration of all partner institutions, round about 10 joint publications and more than 150 publications in total resulted from the scientific work in the IRTG. On the German side, 10 PhD students finished their PhD or submitted their thesis within the first period. The over-all gender ratio of the German PhD students was about 35 % female.

For further information please visit our webpage:
http://www.zfm.tu-chemnitz.de/irtg/

Photo:
right page: PhD students of the second period of the IRTG program

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

The Gessner group at the Advanced Institute of Materials Research of the World Premier International Research Center (WPI-AIMR) at the Tohoku University in Sendai/Japan

In 2007 the Japanese Government has created so called World Premier International Research Center (WPI) at five excellent universities with the goal to promote outstanding, international visible research. This activity is comparable with the German Exzellenzinitiative. In this framework Professor Gessner has been invited as a Principal Investigator (PI) from the WPI-AIMR (World Premier International Research Center Initiative – Advanced Institute for Materials Research) of Tohoku University. The group has been build up since the end of 2008. It now consists of 3 permanent stuff members and several visiting scientists and students. The group is managed by Prof. Yu-Ching Lin since November 2008. Within the WPI-AIMR there is close fusion research going on with the group of Professor Esashi and other research groups.

In 2010 mainly three research topics have been focused on in Gessner Group:

Metallic glass as a material for semiconductor wafer bonding

Metallic glassy material exhibits a certain viscosity while at the supercooled liquid region, but this viscosity is not low enough to allow free flow of the material over large distances. The supercooled region and therefore the temperature range in which the material exhibits its soft status, can be tailor made by designing the composition of the metallic glasses. Metallic glasses have fundamentally glassy structure and exhibit a Newtonian viscous flow in the supercooled liquid region which is between the glass transition temperature (Tg) and crystallization temperature (Tx). The atomic configuration could easily rearrange in the supercooled liquid state results in nice interdiffusion. The plastic fluidity performs superior wettability which improves interfacial integrity and achieves homogeneous bonding results. Unlike conventional crystallized metallic materials, the amorphous metallic structure is unstable thus diffusion phenomenon is even active at the temperature much lower than its melting temperature (Tm), which leads to low-temperature bonding. The polymer-like viscous fluidity in the supercooled liquid region helps wetting, easy diffusion and also increases tolerance of bonding surface roughness. As a MEMS bonding material, metallic glass is like a mixture of eutectic bonding alloy and glass frit. Bonding is done by applying a temperature above the glass transition temperature, thus by selecting a proper kind of metallic glass material, low temperature bonding is possible.

Nanoporous metals

Low temperature bonding, which prevents damage of the sensitive chips, has become a crucial issue of wafer level packaging and 3D integration. On the other hand, nanostructured materials have drawn much attention in recent years because of their high surface to volume ratio. Among nanostructured materials, nanoporous ones with large porosity can be used for functional applications such as catalysis, separation, purifications and sensing. Porosity in nanoscale also indicates a highly reactive surface which makes it possible to be a promising candidate for bonding process to reduce the bonding temperature. In this research, nanoporous gold structures with heat treatment were successfully fabricated. Furthermore, nanoporous gold for bonding at temperatures below 250 °C is demonstrated as well. The nanoporous structures are made in a two step process. First an Au-Sn alloy is formed through electroplating which uses sputtered Au/Cr film as a seed layer. After electroplating, the samples are annealed at different temperatures. The second step is chemical dealloying. 60 % HNO_3 is used to dissolve the Sn component of the alloy. After dealloying, the nanoporous gold structure with annealing at 70 °C is successfully fabricated.

MEMS actuators made from metallic glass

One of the main advantages of metallic glass is its high mechanical strength. So it is possible to create micro structures, with much better mechanical parameters that silicon based MEMS. One such example is an optical micro mirror. By using metallic glass as material for the rotational springs, it is possible to reach far higher mechanical movement angle compared to crystalline materials.

The basic structure of the micro mirror is still made by silicon. The springs are created from a sputtered layer of thin film metallic glass (TMG) that has been subsequently structured by etching.

Visting scientists of the Gessner group

Marco Haubold worked as visiting scientist form March 17th to April 5th, 2010, in the GI3 Lab Prof. Thomas GESSNER at ESASHI laboratory. The main objective of the short period research stay at WPI-AIMR in Tohoku University was the accomplishment of basic experiments for a laser assisted bonding process of substrates, used in MEMS fabrication. The main advantages of affecting just a very small region with the laser radiation and the locally limited raise of temperature therefore, are unique opportunities in means of applicable materials for MEMS production and structure design. Basing on silicon-glass direct bonding, tests have been performed in order to evaluate an adequate process window (e.g. wave length, output power, focus depth, repetition rate). After a training period at common laser tools by the laboratory's staff, several test runs were performed with prebonded samples with altered parameter sets, aiming on the enhancement of the mechanical stability. The achieved bond was subsequently characterized by pull testing and scanning electron microscopy (SEM), providing a good comparison for the different experiments. The results showed almost no increase of bonding strength for low energy levels, whereas significant changes could be induced at the touching interfaces at certain high output powers, resulting in a partly high bonding strength. Samples treated by these settings got destroyed during the characterization, proving the potential of bonding technique without an additional intermediate layer. The tests provide a basis of further investigations.

In addition to the experimental intention, the trip was used to participate in the WPI workshop from March 25th to March 27th. The author therefore used the opportunity to present his results of a former research project at WPI-AIMR "Bonding Investigations of oxidized Silicon Substrates with Metal-based Intermediate Layers" during the poster session.

A last purpose of the research trip describes the extension of the scientific exchange between the Fraunhofer ENAS and the WPI-AIMR in Tohoku University. Therefore it is envisaged to join a project of the European Community in order to strengthen the collaboration and expand the joint high level research.

More information about the Gessner group are published at the webpage: http://www.wpi-aimr.tohoku.ac.jp/gessner_labo/

COOPERATION WITH UNIVERSITIES AND RESEARCH INSTITUTES (SELECTION)

ACREO, Kista, Sweden
Aix-Marseille Universite, CNRS IM2NP, Marseille, France

CEA-LETI, Grenoble, France
CEA-Liten Grenoble, France
Centrum für intelligente Sensorik Erfurt e.V., Erfurt Germany
Chemnitz University of Technology, Chemnitz, Germany
Chongqing University, Chongqing, China

Deutsches Zentrum für Luft- und Raumfahrt e.V., Institut für Kommunikation und Navigation, Wessling, Germany

École Nationale Supérieure des Mines de St-Étienne, France
ESISAR, Institut Polytechnique De Grenoble, Groupe INP Grenoble, Valence, France
ETH Zurich, Switzerland

Femto-ST, Besançon, Frankreich
Forschungszentrum Rossendorf, Germany
Fraunhofer CNT, Dresden, Germany
Fraunhofer EMFT, Munich, Germany
Fraunhofer IAP, Golm, Germany
Fraunhofer IBMT, Potsdam, Germany
Fraunhofer IISB, Erlangen, Germany
Fraunhofer IMPS, Dresden, Germany
Fraunhofer ISIT, Itzehoe, Germany
Fraunhofer IWM, Halle, Germany
Fraunhofer IWS, 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
Fundacao Centros de Referencia em Tecnologias Inovadoras – CERTI, Florianopolis, Brazil

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

Holst Center, Eindhoven, The Netherlands

IMEC, Leuven, Belgium
Institut für Solarenergieforschung Hameln-Emmerthal, Germany

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

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

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

Massachusetts Institute of Technology, Cambridge/Boston, USA
Max-Planck-Institut (MPI) für Mikrostrukturphysik, Halle, Germany
Mid Sweden University, Sweden

Royal Institute of Technology, Stockholm, Sweden

Shanghai Jiao Tong University, Shanghai, China
Sunchon National University, Sunchon, Korea
Tohoku University, Sendai, Japan

TSINGHUA University, Beijing, China
Technische Universität Dresden, Germany

Universidade Federal de Pernambuco, Recife, Brazil
Universität Paderborn, Institut für Elektrotechnik und Informationstechnik, Fachgebiet Sensorik, Paderborn, Germany
Université de Rouen, ESIGELEC, Saint-Etienne du Rouvray Cedex, France
University of Applied Siences Mittweida (FH), Laser Application Center, Germany
University of California, Berkley, USA
University of Nevada, Reno, USA
University of Nice-Sophia Antipolis, France
University Paris Diderot, France
University of Tokyo, Research Center for Advanced Science & Technology (RCAST), Tokyo, Japan

VTT Technical Research Centre, Finland

Westsächsische Hochschule Zwickau (FH), Zwickau, Germany

Xiamen University, Xiamen, China

SMART SYSTEMS CAMPUS CHEMNITZ

The Smart Systems Campus Chemnitz is an innovative network with expertise in micro and nano technologies as well as in smart systems integration. This technology park provides renowned scientific and technical centers with the entrepreneurial spirit and business acumen and an economic boost at a location where everything is on the spot. A close integration 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 Integrative Lightweigth Technology (ZIL)
- Fraunhofer Institute for Electronic Nano Systems ENAS
- Start-up building
- Business Park.

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 Structures Engineering GmbH
- SiMetrics GmbH
- saXXocon GmbH
- BiFlow Systems GmbH.

The campus not only opens doors for young entrepreneurs in the start-up building, but expanding companies can also make use of neighbouring space on a business park. Micro-systems technology oriented companies can set up in business in line with their requirements on an area measuring up to 7 hectares.

The first company, which has built its own building there, i is the 3D-Micromac AG which develops and manufactures highly efficient and innovative machines for laser micro machining.

smart systems campus
TechnoPark Chemnitz

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), USA
Alenia Aeronautics, Casoria, Italy
alpha-board gmbh, Berlin, Germany
AMTEC GmbH, Chemnitz, Germany
Arentz Optibelt, Höxter, Germany
austriamicrosystems AG, Unterpremstätten, Austria
AXUS Technologies, Chandler AZ, USA

Benteler Automobiltechnik GmbH, Paderborn. Germany
Berliner Nanotest and Design GmbH, Berlin, Germany
Boehringer, Ingelheim, Germany
Robert Bosch GmbH, Reutlingen & Stuttgart, Germany

CAD-FEM GmbH, Grafing, Germany
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, Germany
CST AG, Darmstadt, Germany

DBI – Gastechnologisches Institut gGmbH, Freiberg, Germany
DBI - Gas- und Umwelttechnik GmbH, Leipzig, Germany
DiscoEurope, Kirchheim, Germany
Drägerwerk AG & Co. KGaA, Lübeck, Germany
Diehl Hydrometer, Arnsbach, Germany

EADS Deutschland GmbH, Corporate Research Center Germany, Department Microsystems, Munich, Germany
EADS Innovation Works, Munich, Germany

EDC Electronic Design Center, Chemnitz, Germany
ELMOS Semiconductor AG, Dortmund, Germany
elprotek GmbH, Buchen, Germany
Endress und Hauser AG & Co. KG, Germany
Envia M GmbH, Halle, Germany
EPCOS AG, Germany
EV Group Europe & Asia/Pacific GmbH, St. Florian am Inn, Austria
Exalos AG, Schlieren, Switzerland

FACRI, Research Institute, Xi´an, China
FHR Anlagenbau GmbH, Ottendorf-Okrilla, Germany
First Sensor Technology GmbH, Berlin, Germany
Flexo-Print Bedienfelder GmbH, Salzkotten, Germany
Freiberger Compound Materials GmbH, Freiberg, Germany
Freudenberg Co. KG, 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
Gesellschaft für Prozeßrechnerprogrammierung mbH (GPP), Chemnitz, Germany
GLOBALFOUNDRIES, Dresden, Germany
Gyrooptics Company Ltd., St. Petersburg, Russia

Hella, Lippstadt, Germany
Helenic Aerospace Industry S.A., Schimatari, Greece
Hispano Suiza, Colombes (Paris), France
Hotoprint Elektronik GmbH & Co. KG - Leiterplatten, Lamspringe, Germany

IBM, Zurich, Switzerland
Inficon AG, Balzers, Liechtenstein

Infineon Technologies AG, Munich, Dresden and Warstein, Germany and Villach, Austria
InfraTec GmbH, Dresden, Germany
Intel, Sophia Antipolis, France

Jenoptik-LOT GmbH, Gera, Germany
Jenoptik Lasersystems, Jena, Germany
JUMATECH GmbH, Eckental, Germany

KSG Leiterplatten GmbH, Gornsdorf, Germany

LG Electronics, Korea

Magh und Boppert, Paderborn, Germany
Mallinckrodt Baker, Inc., Philipsburg NJ, USA
MELEXIS, Bevaix, Switzerland
memsfab GmbH, Chemnitz, Germany
Microelectronic Packaging Dresden GmbH, Dresden, Germany
Microtech GmbH, Gefell, Germany
Multitape GmbH, Büren-Ahden, Germany

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

Océ B.V., Venlo, The Netherlands
Optibelt GmbH, Höxter, Germany

Panasonic Plasma Display Labaratory, Inc., Highland, New York, USA
paragon AG, Delbrück, Germany
Physikalisch-Technische Bundesanstalt Braunschweig (PTB), Germany
Philips Applied Technologies, Eindhoven, The Netherlands
printechnologics GmbH, Chemnitz, Germany
ProTec Carrier Systems GmbH, Siegen, Germany
PVATePla AG, Feldkirchen, Germany

Rainer Euskirchen Büro-Design GmbH, Bielefeld, Germany
RF-Embedded GmbH, Stephanskirchen, Germany

Ricoh Company, Ltd., Yokohama, Japan
Roth & Rau AG, Hohenstein-Ernstthal, Germany
Roth & Rau Microsystems, Wüstenbrand, 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
Sedemat GmbH, Oelsnitz, Germany
Senseor, Sophia Antipolis, France
Sentech Instruments GmbH, Berlin, Germany
SICK AG, Waldkirch & Ottendorf-Okrilla, Germany
Sensitec GmbH, Lahnau, Germany
SF Automotive GmbH, Freiberg, Germany
Siegert TFT GmbH, Hermsdorf, Germany
Silicon Sensor International AG, Berlin, Germany
SMD-Production-Technology, Krefeld, Germany
SolviCore GmbH & Co. KG, Hanau, Germany
Solardynamik GmbH, Berlin, Germany
Sony Corp., Semiconductor Business Unit, Japan
ST Microelectronics, Crolles, France
Suss Microtec AG, Munich, Germany

Thales-Avionics, Valence and Orsay, France
Toyota, Japan
TQ-Systems GmbH, Chemnitz, Germany
Turboméca, Bordes, France

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

Vowalun GmbH, Treuen, Germany
VW Oelsnitz, Germany

Wincor-Nixdorf, Paderborn, Germany

ZMD AG, Dresden, Germany
Zuken GmbH, Hallbergmoos, Germany

Opening of the Fraunhoferstraße in Chemnitz:
The Directors of the Fraunhofer Institutes in Chemnitz – Prof. Dr. Thomas Geßner (left) from Fraunhofer ENAS and Prof. Dr. Raimund Neugebauer (right) from Fraunhofer IWU – with Petra Wesseler, the mayor of building coordination and city planning of Chemnitz.

EVENTS

EVENTS OF THE FRAUNHOFER ENAS

Fraunhofer ENAS opened its doors to the public and to partners to give an impression of the world of research

Chemnitz Workshop on Nanotechnology, Nanomaterials, Nanoreliability

In 2010 the Chemnitz workshops on Nanotechnology, Nanomaterials, Nanoreliability started managed by the department manager of the Micro Materials Center Chemnitz Prof. Bernd Michel. Each department had the chance to organize a special half day workshop with experts from industry and research.

The first workshop took place on January 22, 2010. The department System Packaging had invited Prof. Lin from the WPI at the Tohoku University Sendai and Dr. Knechtel X-FAB as well as Dr. Hauser from Robert Bosch GmbH.

It was followed by

- MEMS related workshop on March 15, 2010, organized by the department Multi Device Integration
- Nano structures have been in the focus on May 20, 2010, organized by Back-end of Line
- Reliability on September 23, 2010, organized by Micro Materials Center
- Near Field Scanning October 13, 2010, organized by Advanced System Engineering.

This series of workshops will be continued in 2011.

Day of Architecture

In 2010 several events took place in the new building of Fraunhofer ENAS. So the Saxon architectorial association took part at the nationwide Day of Architecture on June 26 and 27, 2010. As the attractive building of Fraunhofer ENAS had been finished only one year before there was a special possibility to visit Fraunhofer ENAS and to take part at a guided tour by the architect.

AMZ Campus

On November 11, 2010, the AMZ Campus was held at Fraunhofer ENAS. AMZ is the Saxon Automotive Supplier Network. It is AMZ's primary objective to initiate and accompany product and technological developments – from the initial idea to the start of mass production (SOP) – as well as to strengthen the sustainability of Saxon enterprises in the automotive supply industry. The departments of Fraunhofer ENAS have presented their work with the focus on automotive applications or applications for mechanical engineering.

Art Exhibitions „Sciences Meets Arts“

The Fraunhofer ENAS starts the series of art exhibitions under the titel „Sciences Meets Arts“ in 2010. Therefore, the Institute invites local painters to exhibit their paintings and printmaking in the building of Fraunhofer ENAS. The exhibitions started with the vernissage of Peter Kallfels, an local painter famous for working with a kind of etching technique. This first exhibition was opened for employees of Fraunhofer ENAS and the public from April to October. The final of this exhibition with Peter Kallfels marked a gallery talk with the painter, researchers and other interessted people.

From October 2010 on, the Fraunhofer ENAS shows printmaking and paintings of Christian Lang, a popular painter from Chemnitz. His works is characterized by a variety of printing techniques. This exhibition will be presented to April 2011.

In 2011, the series „Sciences Meets Arts“ will be continued.

Days of Industrial Culture

Within the Days of Industrial Culture in Chemnitz on September 10 to 12, 2010, at friday night, manufactoring companies and research institutes opened their doors to the public. Visitors had the chance to watch working machines and staff. Fraunhofer ENAS took part at this event. More than 200 visitors have been at Fraunhofer ENAS to learn more about microelectronics, micro sensors and smart systems.

Photos:
left page: Prof. Dr. Bernd Michel welcomes the attendees to the first Chemnitz Workshop
right page: (left) Prof. Dr. Thomas Gessner and Peter Kallfels at the vernissage of the first art exhibition in the building of Fraunhofer ENAS; (right) Christian Lang explains a printing technique to guests of the second vernissage of „Sciences Meets Arts“

Prof. Dr. Thomas Gessner and Prof. Dr. Stefan E. Schulz from Fraunhofer ENAS belongs to the organization committee of the Fifth National IT-Gipfel 2010 in Dresden

FRAUNHOFER ENAS AT EVENTS

In 2010 the Fraunhofer ENAS attended various events, conferences and trade fairs all around the world.

Smart Systems Integration SSI 2010 in Como, Italy

The fourth SMART SYSTEMS INTEGRATION, European Conference & Exhibition on Integration Issues of Miniaturized Systems – MEMS, MOEMS, ICs and Electronic Components, took place from 10 to 11 March 2010 in Como. More than 200 participants from 15 European countries, USA, Japan, China and Syria attended the conference, organized by Mesago, Fraunhofer ENAS and Fraunhofer IZM. In his welcome presentation the chairman of the conference Prof. Thomas Gessner pointed out: "The European distribution gave the evidence that smart systems integration is a big issue in Europe especially in Germany, Belgium, France, Netherlands, Italy and Spain."

The smart systems integration conference is part of the activities of EPoSS- the European Technology Platform on Smart Systems Integration.

The Smart Systems Integration Conference 2010 showed a snap shot of the European research work on this field. Within the EPoSS session best practise examples were demonstrated. The MEMUNITY workshop focused on test and parameter characterization of systems and components. The implementation of printed electronics and functionalities in smart systems was discussed together with OE-A in the session organic and printed electronics. Experts and scientists from industry and institutes addressed and discussed various aspects of smart systems integration starting from technology and reliability, via development of components and materials up to best practise examples.

Smart systems will be able to take over complex human perceptive and cognitive functions. Smart devices will frequently act unnoticeably in the background and intervene visibly only when human capabilities to act and to react are reduced or cease to exist. Examples for such smart systems and related integration challenges are object recognition devices for automated production systems or devices for monitoring the physical and mental condition of vehicle drivers. Second time best paper and best poster have been selected and awarded, sponsored by EPoSS and Fraunhofer ENAS.

6th Fraunhofer-Gesellschaft Symposium in Sendai, Japan

The Fraunhofer ENAS participated at the 6th Fraunhofer-Gesellschaft Symposium in December 2010. The City of Sendai and Fraunhofer-Gesellschaft have a cooperation agreement since 2004 and have just prolonged for further three years.

The Fraunhofer Symposium is an event which has already been well established. It is an event, which has been designed to give an overview about the latest developments in smart systems integration of micro electronics and micro system technologies. This event has attracted scientists and researchers from all over Germany and Japan. In 2010 Fraunhofer IZM, Fraunhofer IWS, Fraunhofer IZFP and Fraunhofer ENAS have presented recent developments in packaging, smart systems integration, nano science and reliability.

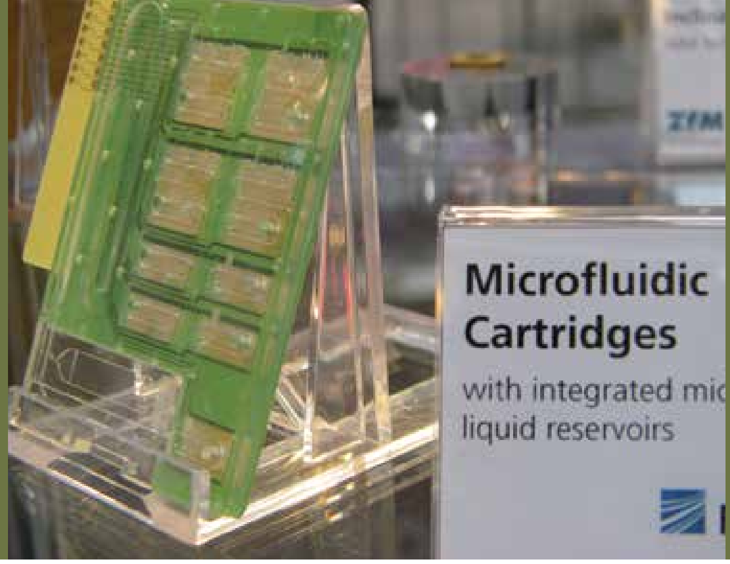
The day before the Sendai Micro Nano International Forum 2010, organized by Prof. Esashi took place.

Workshop nanett „nano system integration network of excellence" in Chemnitz, Germany

On November 9, 2010 the first workshop of the nano system integration network of excellence nanett was hold at the Chemnitz University of Technology. 120 participants took part at the event and got information on the research done within the last year. The partners of the network have shown their results in 10 talks and 26 posters.

Nanett is one of the successful initiatives of the second phase of the "Spitzenforschung und Innovation in den Neuen Ländern" program, funded by the Federal Ministry of Education and Research (BMBF).

Beside the four involved faculties of the Chemnitz University of Technology (Faculty of Electrical Engineering and Information Technology, Faculty of Natural Sciences, Faculty of Mechanical Engineering and Faculty of Computer Science) the University of Applied Sciences Mittweida, three Fraunhofer Institutes (Fraunhofer ENAS, Fraunhofer IZM and Fraunhofer IAP), three Institutions of the Leibniz Association (IHP, IFW and IPF) and the Helmholtz Zentrum Berlin (HZB) are linked in the nano system integration network of excellence.



Fraunhofer ENAS Trade Fair Activities 2010

In 2010 Fraunhofer ENAS presented its manifold activities at 19 tradeshows and exhibitions in Germany and abroad. Eight of these shows were parallel exhibitions during conferences. Fraunhofer ENAS took part in eight international trade fairs in Japan, China, USA, and Europe. Fraunhofer ENAS visited international trade fairs in China and the USA together with partners from the industry like GEMAC, Roth & Rau Microsystems GmbH, InfraTec Dresden GmbH and FHR Anlagenbau GmbH.

Since some years, the nano tech exhibition in Tokyo / Japan is the first fair of the year for Fraunhofer ENAS. In 2010, the institute showed research topics like bulk metallic glasses and low temperature bonding in cooperation with the Gessner group of the WPI-AMIR in Sendai/Japan.

Together with Roth & Rau Microsystems and Silicon Saxony, the institute visited the SEMICON China and gave an overview of sensor and system development in Saxony.

Medical analysis equipment was shown at the analytica in Munich in March 2010. The Fraunhofer-Gesellschaft presented its project ivD-Platform which offers services within the in-vitro-diagnostic market. Fraunhofer ENAS as one project partner exhibited a micro fluidic cartridge for point-of-care diagnostics. The analytica is an international trade fair for laboratory technology, analysis and biotechnology.

From April 19 to 23, 2010, the worldwide biggest industrial fair, the HANNOVER MESSE, took place in Germany. Fraunhofer ENAS presented integrated microsystems for condition monitoring in applications like an electronic seal, a RF ID label and two IR spectrometers. The institute was located at the "IVAM Produktmarkt" at the leading trade fair MicroNanoTec.

From 18 to 20 May the fair SENSOR+TEST with concurrent conferences took place in Nuremberg, Germany. The international trade fair for sensors, measuring and testing technologies showed a complete and interdisciplinary overview about the entire spectrum of measuring and testing systems expertise. Fraunhofer ENAS presented a contact-free wafer prober system working with a parameter-identification test for the first time.

In June 2010 Fraunhofer ENAS presented together with GEMAC and InfraTec Dresden current sensor systems at the Sensors expo and conference in Rosemont, Illinois, USA. This fair is one of the biggest and well-known events in the field of sensor. Besides, it is the only event in North America which was specialized on sensor and sensor integrated systems. The research partners showed an IR detector based on Fabry-Perot interferometer for gas analysis and inclination sensors

The Fraunhofer institutes working in the European CleanSky project shared one booth at the ILA Air Show Berlin in 2010. Here they presented the project progress and some results.

In the concurrent exhibition to the conferences of the NSTI Nanotech 2010, Fraunhofer ENAS showed R&D results in bonding and microelectronics in Anaheim / USA.

The second visited trade fair in Japan in 2010 was the exhibition Micromachine/MEMS in July in Tokyo. Fraunhofer ENAS demonstrated the operation of the IR detector developed together with InfraTec Dresden and presented several sensors like an ultra sonic transducer.

In October 2010 the SEMICON Europa took place in Dresden. As a member of the Fraunhofer Group Microelectronics the Fraunhofer ENAS showed a plasma chamber using with different equipment for plasma diagnostics. The institute demonstrated the research results in specific design of process plasmas.

The concurrent exhibition of the VDE-Kongess in Leipzig was the last exhibition Fraunhofer attended in 2010. The institute presented reliability and characterization methods applicable in automotive.

FRAUNHOFER ENAS PARTICIPATION IN TRADE FAIRS 2010

February		
	nano tech 2010 - International Nanotechnology Exhibition & Conference	Tokyo, Japan
March		
	SEMICON China	Shanghai, China
	SMART SYSTEMS INTEGRATION 2010 - European Conference & Exhibition	Como, Italy
	analytica - 21st International Trade Fair for Laboratory Technology, Analysis, Biotechnology and analytica Conference	Munich, Germany
April		
	Chongqing China Hi-Tech Fair	Chongqing, China
	HANNOVER MESSE 2010 - MicroTechnology	Hannover, Germany
May		
	Silicon Saxony Day	Dresden, Germany
	SENSOR+TEST 2010 - The Measurement Fair	Nuermberg, Germany
June		
	Sensors Expo & Conference	Rosemont, USA
	ILA Berlin Air Show 2010 - International Aerospace Exhibition and Conferences	Berlin, Germany
	Nanotech Conference & Expo 2011	Anaheim, USA
	Zulieferer Innovativ - 12th BAIKA Annual Congress	Ingolstadt, Germany
	SIT 2010 - Sächsische Industrie- und Technologiemesse	Chemnitz, Germany
July		
	Exhibition Micromachine/MEMS 2010	Tokyo, Japan
September		
	3rd NRW Nano-Conference 2010	Dortmund, Germany
October		
	SAME 2010 - 13th Edition of the Sophia Antipolis MicroElectronics Forum	Sophia Antipolis, France
	SEMICON Europa 2010	Dresden, Germany
	10. Chemnitzer Fachtagung Mikrosystemtechnik -Mikromechanik & Mikroelektronik-	Chemnitz, Germany
November		
	VDE-Kongress 2010	Leipzig, Germany

FACTS AND FIGURES

FRAUNHOFER ENAS IN FACTS
FRAUNHOFER ENAS IN ZAHLEN

Human Resources Development

Due to the increase of turnover, the staff level of Fraunhofer ENAS increased in 2010. Overall, 13 employees joined the team, bringing the total staff at Fraunhofer ENAS in Chemnitz and Paderborn to 91 at the end of 2010. Fraunhofer ENAS offers job training as micro technologist. Currently there are three trainees employed.

The institute also supports students with the opportunity to combine their studies with practical scientific work in the laboratories and offices of Fraunhofer ENAS. On an annual average 20 interns, undergraduates and students assistants were working.

The latter are proving to be a growing source for up-and-coming new scientists and technicians.

Financial Status, Equipment and Laboratory Investment

Within 2010 the turnover of the Fraunhofer ENAS was 7.6 million Euros. Contracts from German and international industry and trade associations reached just 2.8 million Euros, or in other words 36 per cent of the total turnover.

Own equipment investment of 1.6 million Euros was realized in 2010. Additionally, 5.2 million Euros have been invested as basic equipment for the new building and special financing.

Personalentwicklung

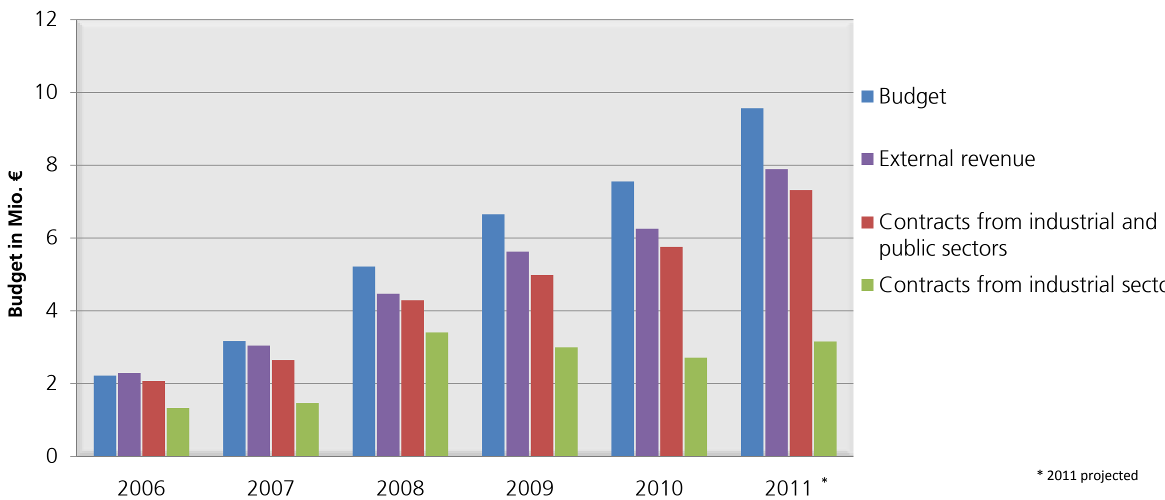
Basierend auf der Steigerung der Erträge erhöhte sich der Personalbestand des Fraunhofer ENAS 2010. Es wurden 13 Mitarbeiterinnen und Mitarbeiter eingestellt, sodass 91 Personen an den Fraunhofer ENAS Standorten Chemnitz und Paderborn zum Ende 2010 beschäftigt waren. Fraunhofer ENAS bildet seit 2009 Mikrotechnologen aus. Zurzeit befinden sich drei Mikrotechnologen in der Ausbildung.

Zusätzlich bietet das Institut Studentinnen und Studenten die Möglichkeit, ihr Studium mit praktischer wissenschaftlicher Arbeit in den Büros und Laboratorien des Fraunhofer ENAS zu kombinieren. Im Jahresdurchschnitt wurden 20 Praktikanten, Diplomanden und studentische Hilfskräfte betreut. Dieser Mitarbeiterstamm erweist sich in wachsendem Maße als Quelle für den Nachwuchs von Wissenschaftlern und Technikern.

Finanzielle Situation und Geräteinvestition

Im Jahr 2010 erzielte das Fraunhofer ENAS einen Umsatz von 7,6 Millionen Euro. Die Aufträge aus deutschen und internationalen Industrieunternehmen erreichten eine Summe von 2,8 Millionen Euro, was einem Umsatzanteil von ca. 36 % entspricht.

Die eigenen Geräteinvestitionen im vergangenen Jahr betrugen 1,6 Millionen Euro. Darüber hinaus wurden 5,2 Millionen Euro für die Erstausstattung des neuen Gebäudes bzw. Sonderfinanzierung investiert.



PATENTS

Title: Inertialer Wecker
Country: DE — Patent Number: 10 2010 060 906 .4
Date of Application: April 1, 2010

Title: Verfahren zum Test vom Mikrospiegeln
Country: DE — Patent Number: 10 2010 003 080.5
Date of Application: June 4, 2010

Title: Herstellung dünner Schichten von Kupferoxid und Kupfer mittels Atomic Layer Deposition
Country: PCT-US — Patent Number: 12/794,454
Date of Application: June 9, 2010

Title: Mikromechanisches Bauteil zum elektrisch gesteuerten Verbinden und Unterbrechen eines Signalpfades
Country: EP — Patent Number: EP10401078
Date of Application: July 9, 2010

Title: Abstimmbares Fabry-Perot-Filter und Verfahren zu seiner Herstellung
County: DE — Patent Number: 102010031206.1
Date of Application: August 25, 2010

Title: Herstellung dünner Schichten von Kupferoxid und Kupfer mittels Atomic Layer Deposition
County: EP — Patent Number: 08855886.1
Date of Application: October 07, 2010

Title: Verfahren und Vorrichtung zum Detektieren, Speichern und Auswerten von dynamischen Belastungen an mechanischen Bauteilen
Country: DE — Patent Number: 102010064237.1
Date of Application: Novembe 23, 2010

Title: Kapazitiver Inertialsensor mit Weckeinrichtung
Country: DE — Patent Number: 10 2010 060 906.4
Date of Application: November 24, 2010

Title: Mikrofluidisches System mit Temperierung
Country: DE — Patent Number:102010061911.6
Date of Application: November 24, 2010

Title: Flexibles mikrofluidisches System
Country: DE — Patent Number: 102010061910.8
Date of Application: November 24, 2010

Title: Fluidischer Aktor mit verformbarer Membran und langer Lagerfähigkeit
Country: DE — Patent Number: 102010061911.6
Date of Application: November 30, 2010

Title: Verfahren und Vorrichtung zum Messen, Regeln, Begrenzen und Protokollieren der Kräfte von Verbindungen der Fügetechnik mittels Kraftsensorik – "ForceDetector"
Country: DE — Patent Number: 10 2010 051 395.4
Date of Application: November 30, 2010

Title: Möbelbauteil für Stromversorgung
Country: DE| — Patent Number: 10 2010 047 579.3
Date of Application: December 28, 2010

AWARDS IN 2010

Best Poster Award for Printed Functionalities

Ralf Zichner, F. Siegel and Prof. Dr. Reinhard Baumann received the Best Poster Award of the International Conference on Flexible and Printed Electronics. They were awarded for a poster with the topic "Customized R2R Gravure Printed" at the conference in Hsinchu, Taiwan, on October 28.

Nikola Tesla Award

On 26 November 2010, the Serbian Minister for Diaspora Srdjan Sreckovic awarded the six winners of national awards for the work and efforts abroad. In the field of science and innovation Dr. Nenad Marjanovic has been awarded with the Tesla Prize. Dr. Nenad Marjanovic works as a scientist in the department Printed Functionalities of Fraunhofer ENAS.

Dr. Nenad Marjanovic belongs also to the management board of the company Plastic Electronic GmbH. He has good standing as a scientist. He is a doctor of engineering sciences and started his professional engagement in Serbia. He is author of numerous scientific papers and monographs.

The commission gave the following statement: Dr. Nenad Marjanovic contributes with his work and commitment to strengthen the intellectual diaspora network. He is supporting the development of organic electronics in Serbia by the long-term cooperation with the Vinca-Institute. Organic electronics will be one of the leading 21st century technologies.

Nikola Tesla (* 10 July 1856 in Smiljan, Serbia; † 7 January 1943 in New York, USA) was an inventor, mechanical engineer, and electrical engineer. He was an important contributor to the birth of commercial electricity, and is best known for his many revolutionary developments in the field of electromagnetism in the late 19th and early 20th centuries.

Schicke Ideen 2010

The network SAXEED awards promising business ideas of start-ups every year. In 2010, Dr. Jörg Nestler got the special prize "Schicke Ideen 2010" for his business concept "SmartFlow Systems". The idea combines low-cost fabrication of micro-fluidic devices with integrated, disposable micropumps and microvalves and will be realized in the new founded company Bi.Flow Systems GmbH.

CONFERRAL OF A DOCTORATE

PhD:	Stefan Leidich
Topic:	Entwicklung eines integrierten Mikroresonators für die kernmagnetische Resonanzspektroskopie kleinster Probenvolumen
Institution:	Chemnitz University of Technology

PhD:	Thomas Wächtler
Topic:	Films of Copper Oxide and Copper Grown by Atomic Layer Deposition for Applications in Metallization Systems of Microelectronic Devices
Institution:	Chemnitz University of Technology

PhD:	Saeideh Mohammadzadeh
Topic:	Electronic Transport Properties of Copper and Gold at Atomic Scale
Institution:	Chemnitz University of Technology

PhD:	Jörg Nestler
Topic:	Entwicklung integrierter mikrofluidischer Aktoren für den Einsatz in bioanalytischen Systemen
Institution:	Chemnitz University of Technology

LECTURES

Chemnitz University of Technology

Process and Equipment Simulation
Lecturers: Prof. Dr. T. Gessner, Dr. R. Streiter

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

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

Mikrotechnologie
Lecturers: Prof. Dr. T. Gessner, Dr. C. Kaufmann, Dr. A. Bertz

Microoptical Systems
Lecturer: Prof. Dr. T. Otto

Technology of Micro and Nano Systems
Lecturers: Prof. Dr. T. Gessner, Dr. K. Hiller

Technologien für Mikro- und Nanosysteme
Lecturers: Prof. Dr. T. Gessner, Dr. K. Hiller

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

Introduction to Finite Element Method,
in the lecture course Micro- & NanoReliability
Lecturer: Dr. S. Rzepka

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

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

Ausgabesysteme I - Druckausgabegeräte allgemein
Lecturer: Prof. Dr. R. R. Baumann

Ausgabesysteme II / Output Systems II- Druckausgabegeräte
Inkjet + Elektrofotografie
Lecturer: Prof. Dr. R. R. Baumann

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

Druckvorstufe I - Druckdatenaufbereitung
Lecturer: Prof. Dr. R. R. Baumann

Druckvorstufe II - Vertiefung Druckdatenaufbereitung
Lecturer: Prof. Dr. R. R. Baumann

Farbtheorie/Farbmetrik - farbliche Wirkung insb. von Druck-
produkten
Lecturer: Prof. Dr. R. R. Baumann

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

Output Systems II - Druckausgabegeräte Inkjet + Elektrofoto-
grafie
Lecturer: Prof. Dr. R. R. Baumann

Visuelle Wiedergabequalität - technische Beurteilung von
Druckausgaben
Lecturer: Prof. Dr. R. R. Baumann

Typografie und Gestaltung
Lecturer: Prof. Dr. R. R. Baumann

Lectures of International Research Training Group

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

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

Technische Universität Dresden

Master Course "Introduction to Finite Element Method"
Lecturer: Dr. S. Rzepka

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

University of Paderborn

Theorie und Anwendung von Phasenregelkreisen (PLL-Systeme)
Lecturers: Prof. Dr. U. Hilleringmann, 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 Siliziumsensoren
Lecturer: Prof. Dr. U. Hilleringmann

Halbleiterbauelemente
Lecturer: Prof. Dr. U. Hilleringmann

Halbleiterprozesstechnik
Lecturer: Prof. Dr. U. Hilleringmann

Mikrosystemtechnik
Lecturer: Prof. Dr. U. Hilleringmann

Seminar Sensortechnik
Lecturer: Prof. Dr. U. Hilleringmann

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, Leipzig, Germany	Prof. T. Gessner	member
Advanced Metallization Conference AMC, Sematech, USA	Prof. S. E. Schulz	member of the executive committee
Arnold Sommerfeld Gesellschaft zu Leipzig	Prof. B. Michel	scientific advisory board
Board of "KOWI", Service Partner for European R&D funding, Brussels, Belgium	Prof. T. Gessner	member
Conference on Safety and Security Systems in Europe	Prof. B. Michel	head of the conference committee
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
EPoSS (European Platform on Smart Systems Integration)	Prof. T. Gessner	member of the steering group
European Center for Micro- and Nanoreliability (EUCEMAN)	Prof. B. Michel	president
EURELNET	Prof. B. Michel	member of executive board
European Security Research and Innovation Forum (ESRIF)	Prof. B. Michel	representative of Germany
EuroSimE, Bourdeaux, France	Dr. R. Dudek	member conference committee
German Science Foundation	Prof. T. Gessner	referee
International Conference on R2R Printed Electronics (Asia)	Prof. R. R. Baumann	advisory committee
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
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
Materials Research Society (MRS)	Prof. R. R. Baumann Dr. A. Willert	member member
microsystems Technology Journal	Prof. B. Michel	editor-in-chief
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
Smart Systems Integration Conference	Prof. T. Gessner	conference chair
Smart Systems Integration Conference	Prof. T. Otto Prof. B. Michel Dr. C. Hedayat Dr. K. Hiller	member of program committee

MEMBERSHIPS OF FRAUNHOFER ENAS

- Silicon Saxony e.V.
- Cool Silicon e.V.
- International Association of Companies and Institutes in the Field of Microtechnology, Nanotechnology and Advanced Materials IVAM
- Nano Technology Center of Competence "Ultrathin Functional Films"
- European Center for Micro and Nano Reliability EUCEMAN
- European Platform on Smart Systems Integration EPoSS
- Organic Electronics Association OE-A
- Organic Electronics Saxony e.V. OES
- MEMS Industry Group™ in USA

PUBLICATIONS (SELECTION)

Books

Leidich, S.: Entwicklung eines integrierten Mikroresonators für die kernmagnetische Resonanzspektroskopie kleinster Probenvolumen. published by Universitätsverlag Chemnitz, 2010. ISBN 978-3-941003-14-9.

Waechtler, T.: Thin Films of Copper Oxide and Copper Grown by Atomic Layer Deposition for Applications in Metallization Systems of Microelectronic Devices. published by Universitätsverlag Chemnitz, 2010. ISBN 978-3-941003-17-0.

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