Flexible Electronic Systems

Ran Liu

School of Information Science and Technology

Four Campuses

Fudan was founded in 1905

Medical School merged in April 2000

Fudan University

- **29 schools and departments, such as School of Humanities, School of Life Science, School of Economics, School of Information Science and Technology, and School of Medicine, etc.**
- **11 Fudan affiliated hospitals**
- **2346 faculty members (over 1500 professors and associate professors)**
- **Total number of students: 47504**
  - **Full-time students: 27088**

    Undergraduate Students: 13237

    Graduate Student: 13851

    Foreign Students: 3805
  - **Part-time and Online Education: 16611**

School of Information Science & Technology

- **Five Departments:**
  - **Dept. of Electronic Engineering**
  - **Dept. of Microelectronics**
  - **Dept. of Communication Science and Engineering**
  - **Dept. of Optical Science and Engineering**
  - **Dept. of Light Sources and Illuminating Engineering**

- **One Research Institute/School:**
  - **School of Microelectronics**

International Advisory Committee



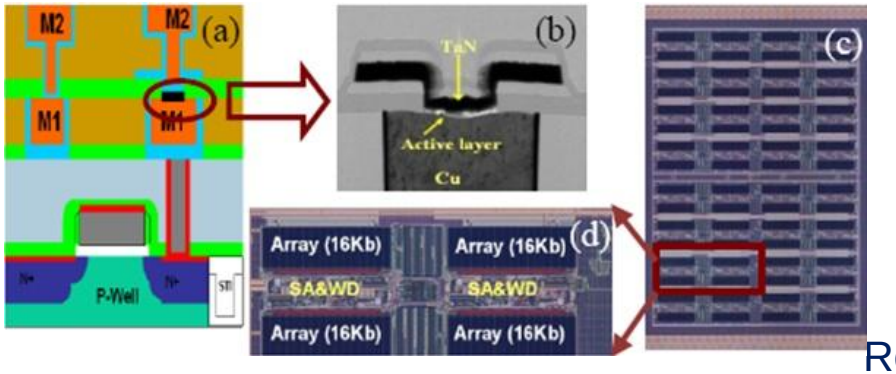




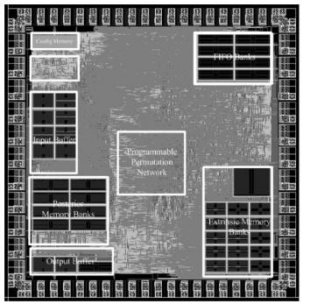



Microelectronic Technology

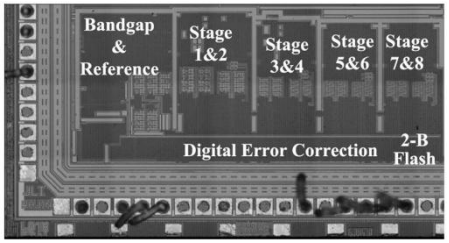
- SOC/IC Design
- IC CAD & Test
- Devices & Processing
- Micro/nano Systems



1Mb RRAM test chip worldwide in Logic Tech

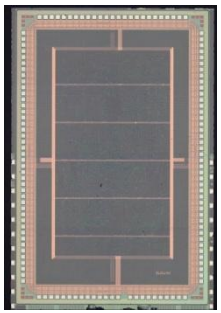


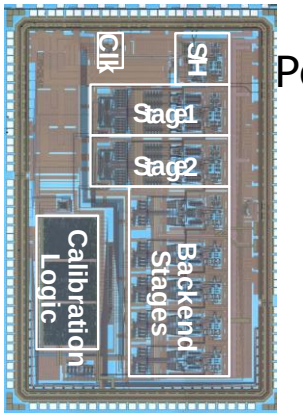
Reconfigurable LDPC Decoder for Flexi-Mode Applications



Low-Power Pipeline ADC for Video Application

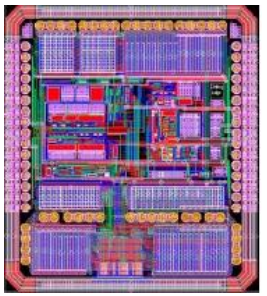
MIMO system for high-speed Wireless communication

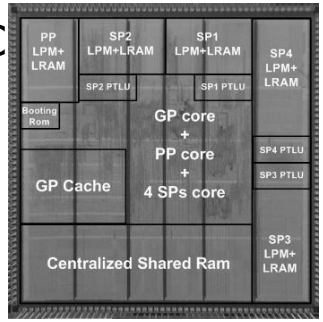




High performance ADC for LTE/IMT-A systems

Power Management IC





Heterogeneous Multi-Core Platform for Security SoC

Si Electronics Process Lab

Flexible Electronics Process Lab

3D printer

Aerosol Jet printer

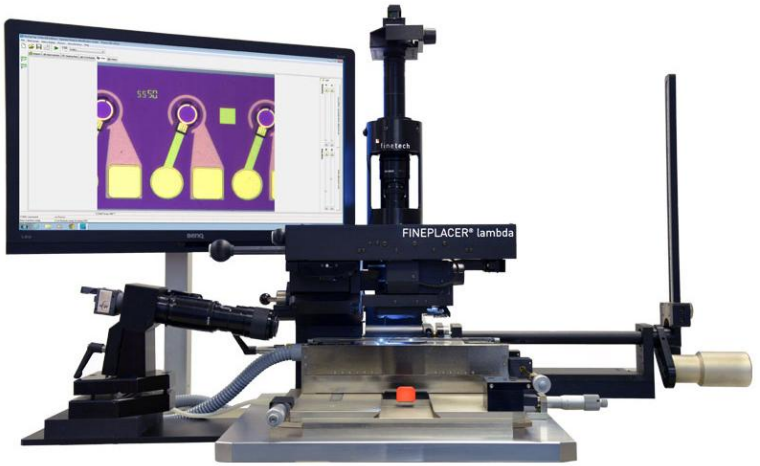
3D laser writer

Nanoimprint system

Flexible Electronics Process Lab

Optolaser bonding system

Flexible processing system



flexible sub-micron bonder

Flexible Electronics Process Lab

Temperature & Humidity Chamber

Desktop SEM

Transport property measurement

Photo Electrochemical Workstations

Flexible Electronics Process Lab

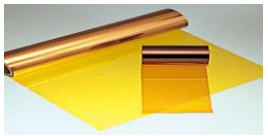
- Flexible substrate Magnetron sputtering system
- High vacuum evaporation deposition system
- Critical Point Dryer
- Wire bonding system
- High precision scribing system
- Roll to roll electrode deposition system

Printed Electronics

Functional Inks

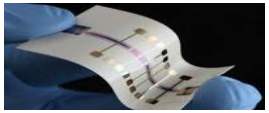
- Dielectrical
- Conductive
  - Conducting Organic
  - Metal-Based
- Semiconductive

Flexible Substrates



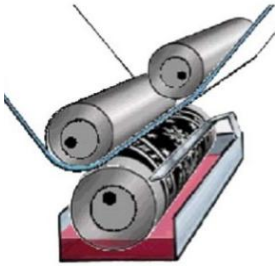
Plastic

Paper

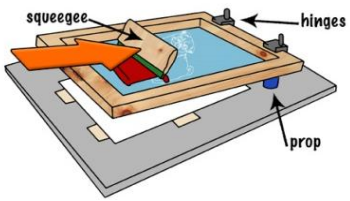


Textile

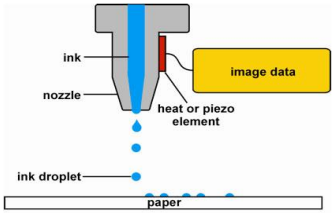
Examples of Printing Techniques



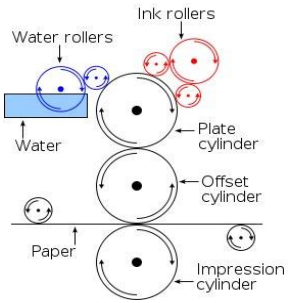
Gravure



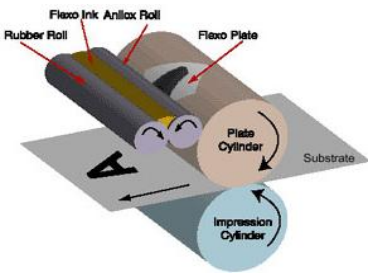
Screen



Inkjet



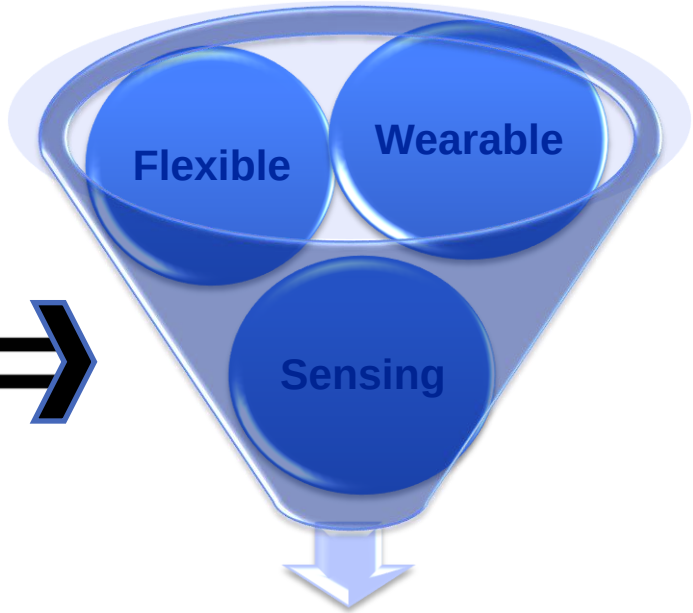
Offset

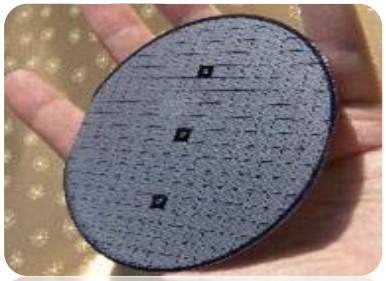


Flexo

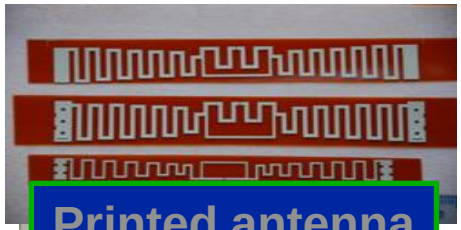
Silicon VS Printed Electronics

Printed Electronics	Silicon Electronics
Flexible	Short switching times
Large area &	High performance
Low cost per area	**Low cost per function**
Long switching time	Small areas
Low integration dens	Rigid substrates
Low stability	Sophisticated fabrication



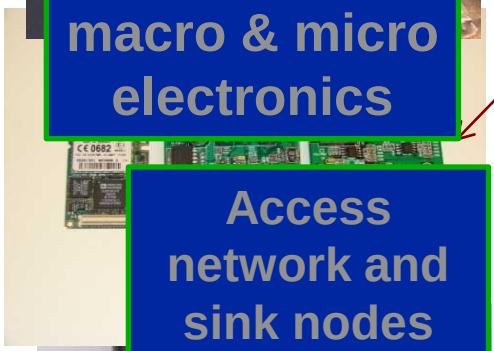


Flexible Intelligent Systems



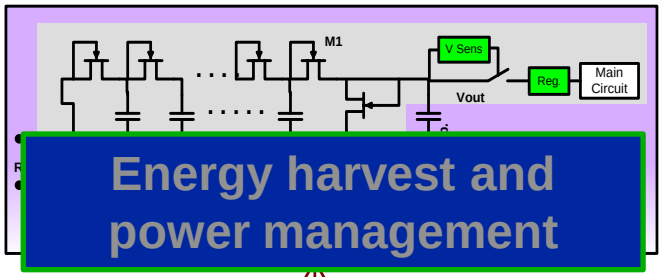
Printed antenna

Integration of macro & micro electronics

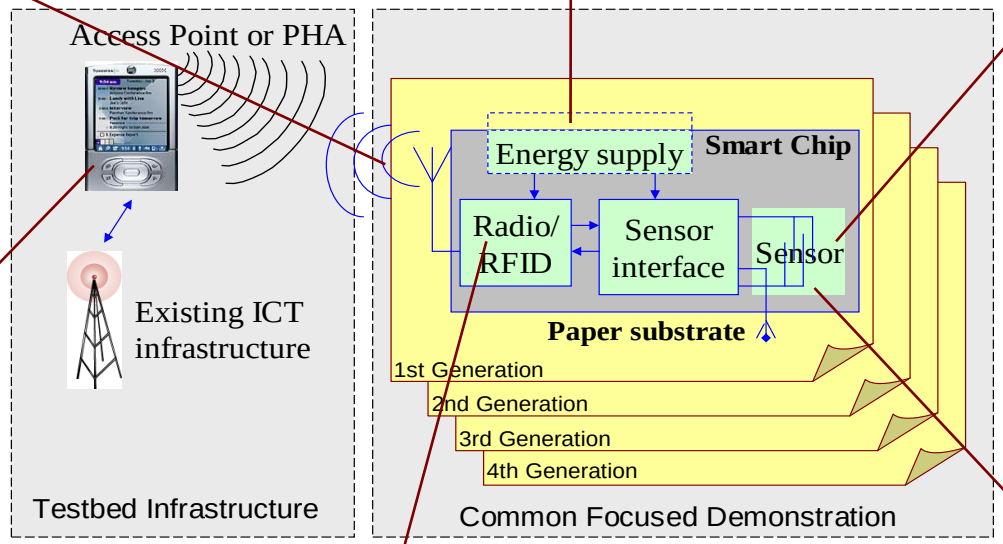


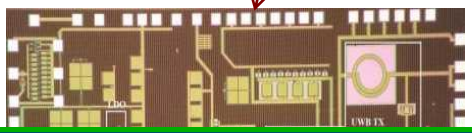
Access network and sink nodes

Applications: i-pack Medical/health

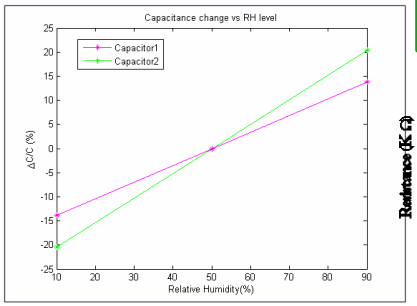


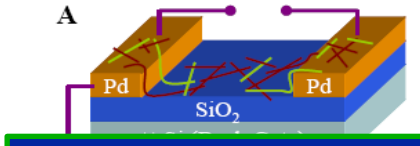
Energy harvest and power management



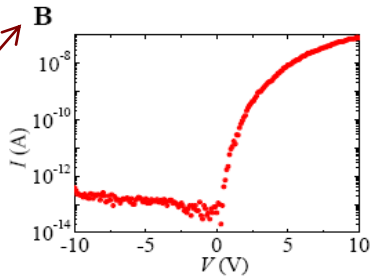


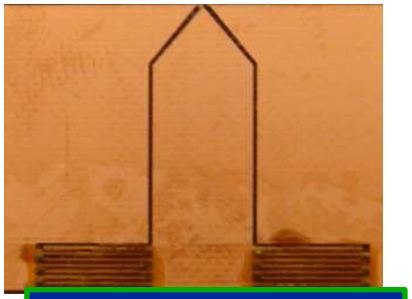
Ultralow power short distance wireless communication



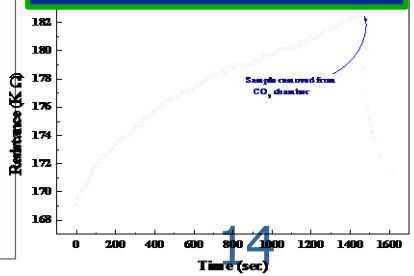


Printed TFT, RFID

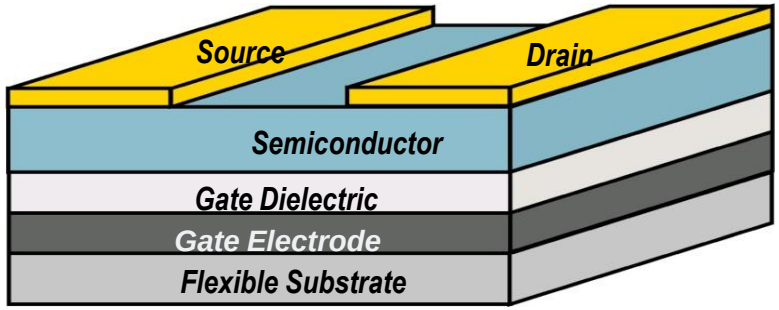




Printed sensor



Printed TFTs



Schematic structure of a back-gated thin-film transistor (TFT) on a flexible substrate

	Advantages	Challenges
Polymer TFTs	• Light-weight • Flexibility • Solution processablity • Ultra Low-cost	• Low Carrier Mobility • Poor Air Stability
CNT TFTs	• Flexibility • High Carrier Mobility • High Current Capacity	• Difficulty in Dispersion • Limitation in Processability

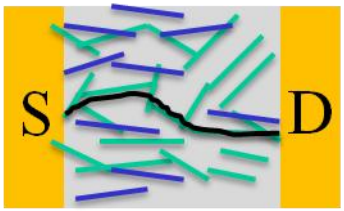
Nature Communication（2014）， IEEE EDL

CNT based TFT

CNT disperse

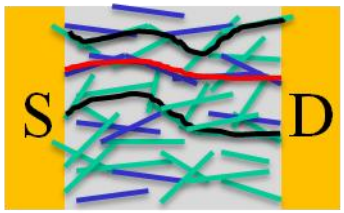
Agglomeration of SWCNTs in solvent

s- vs. m-SWCNT



Only s-SWCNT percolation

Low I_{on} **Large I_{on}/I_{off}**



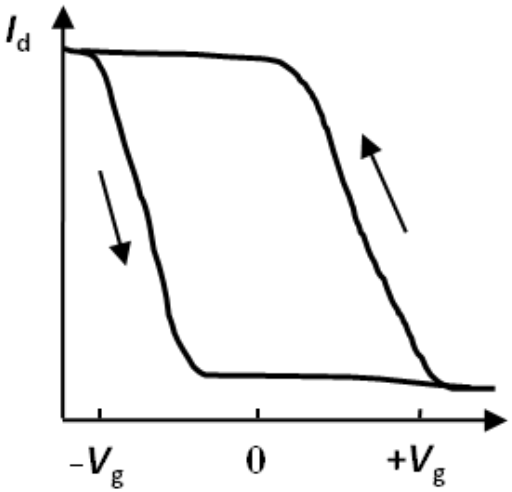
Both s- and m-SWCNT percolation

High I_{on} **Small I_{on}/I_{off}**

s-SWCNT

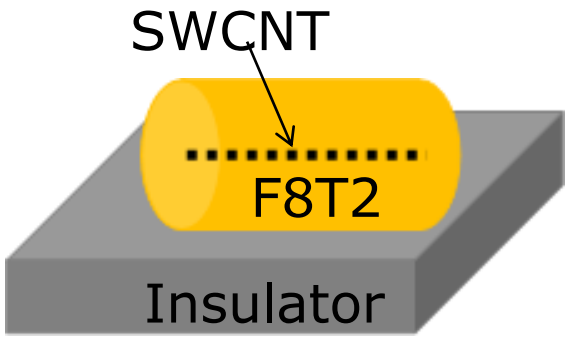
m-SWCNT

Significant hysterisis

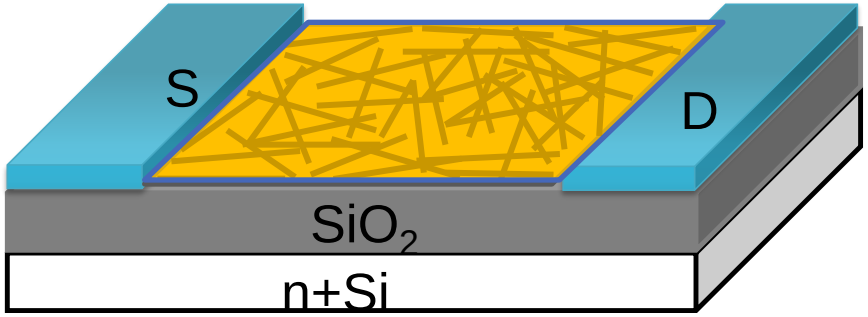


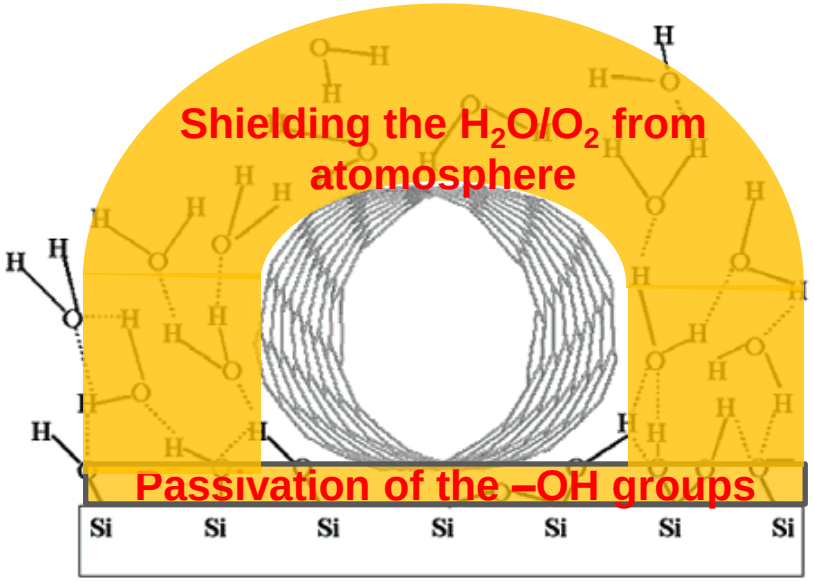
- **Instability in device operation**
- **Misinterpretation of device behavior**

CNT/polymer TFT



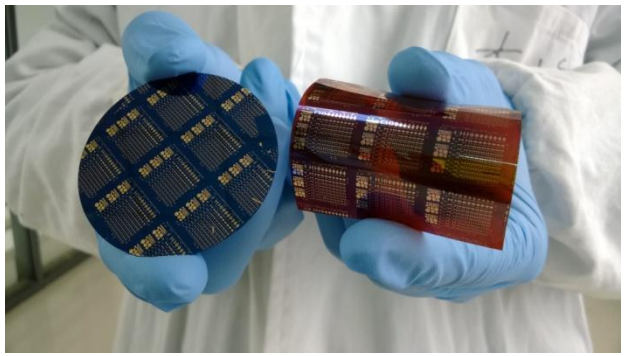
A composite structure with SWCNTs being fully wrapped by polymers

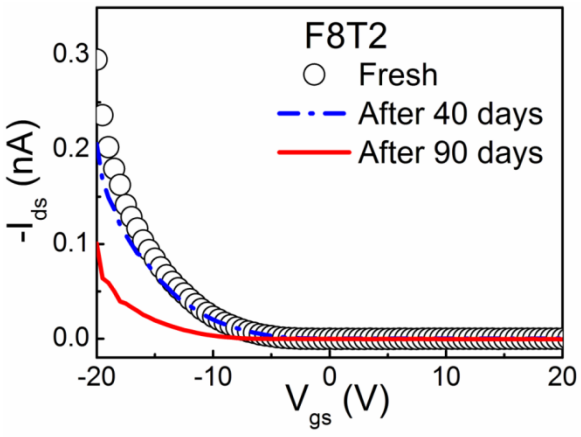


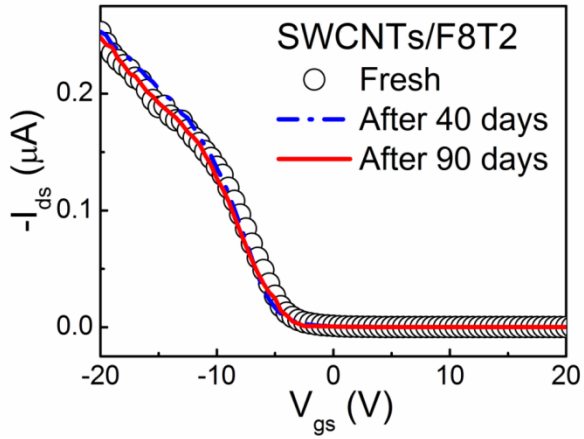


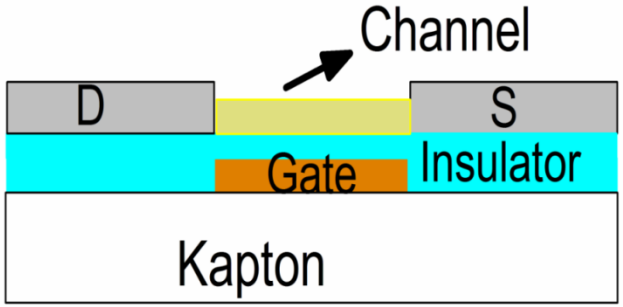
Source of hysteresis for TFTs with SiO_2 as dielectric:
(1) SiO_2 surface bounded water (≡SiOH groups)
(2) H_2O/O_2 in the ambient atomosphere

Printed TFT circuits on flexible substrates







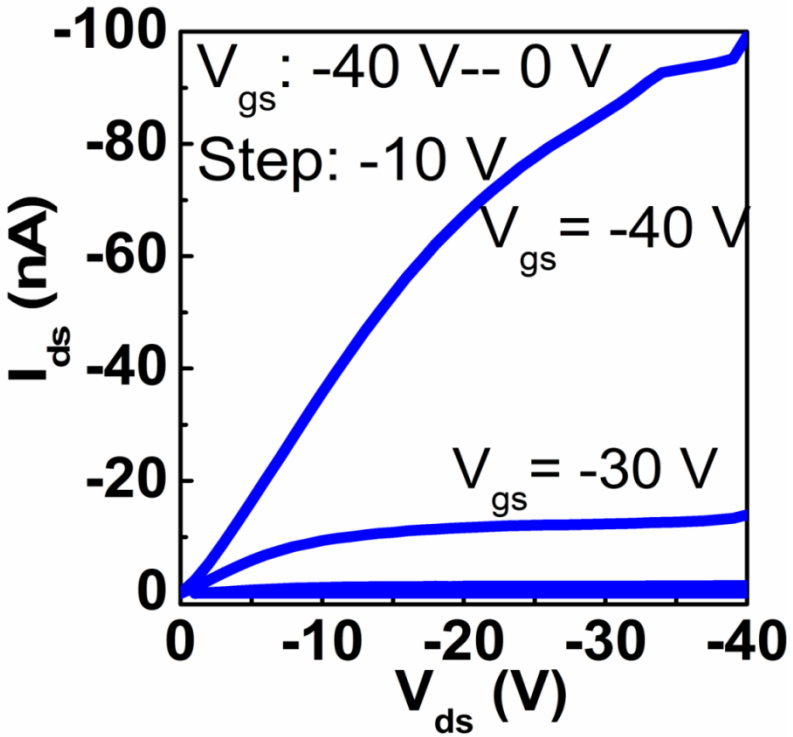


Channel: SWCNTs/ F8T2 by IJP

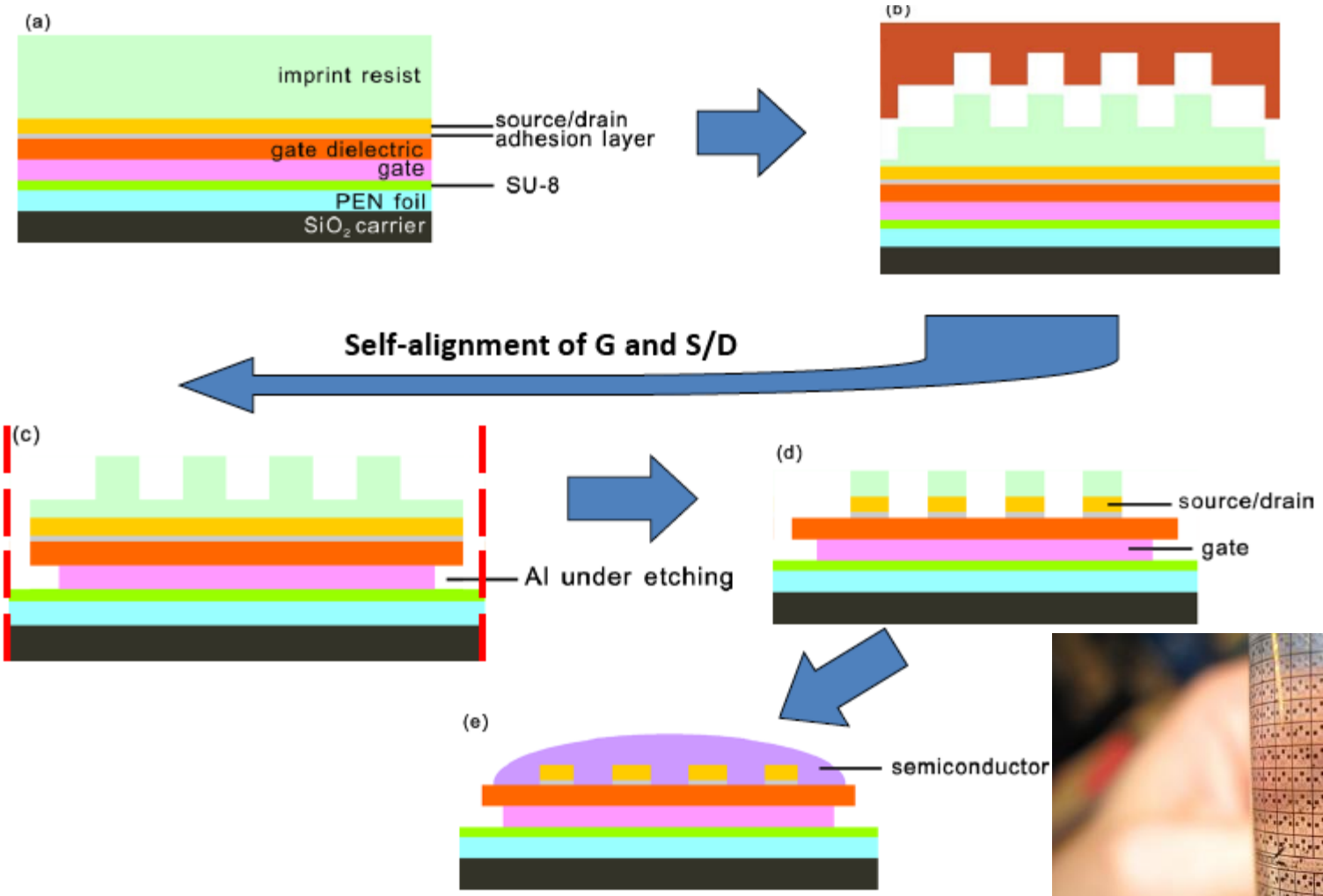
S/D: Ag by IJP

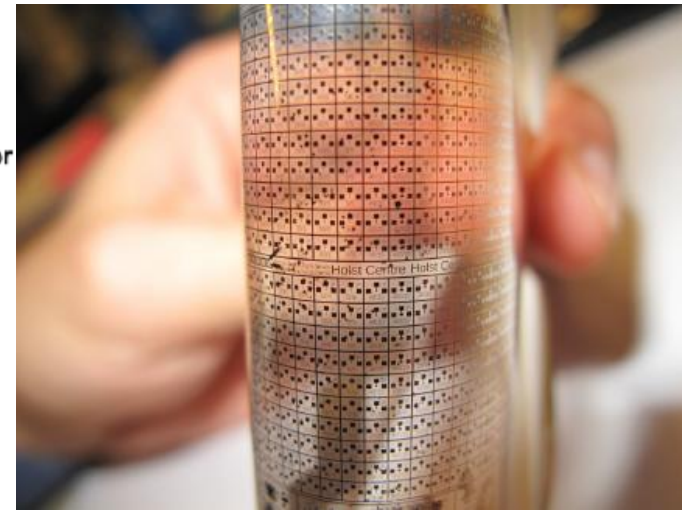
Gate Insulator: Al_2O_3 by ALD

Gate:Au by E-beam Evaporation



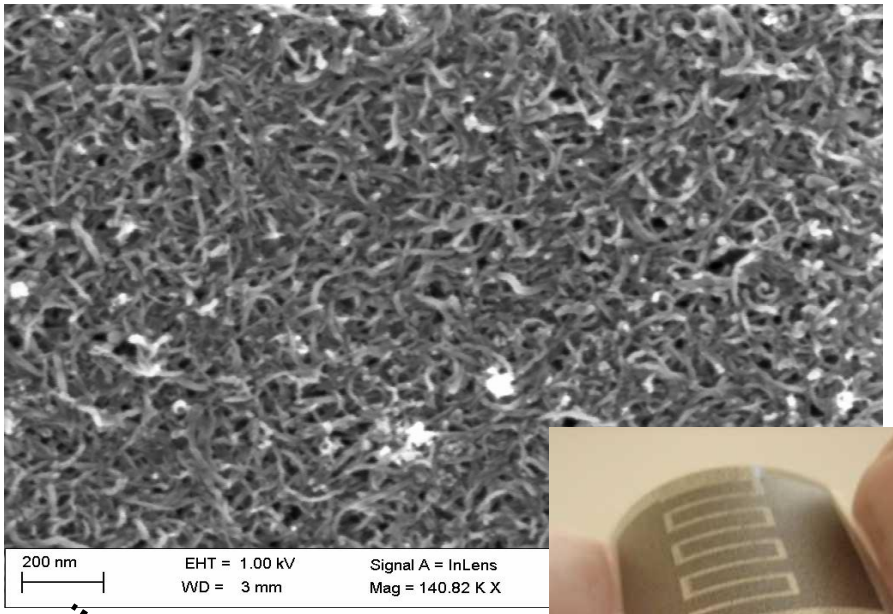
Nanoimprinted TFTs on flexible substrates

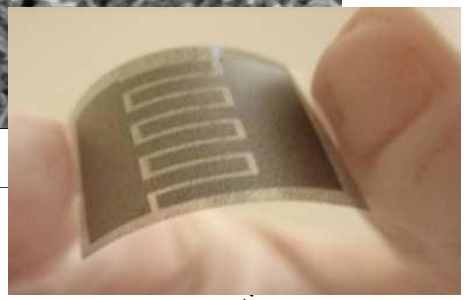


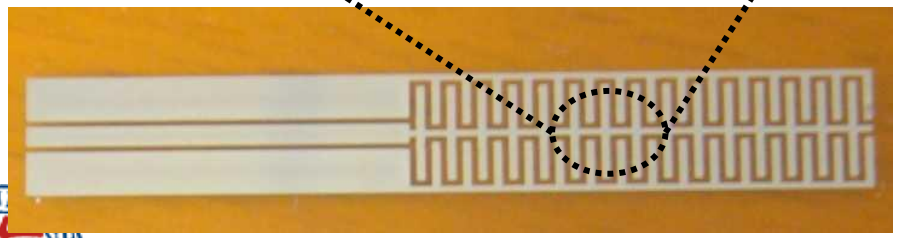


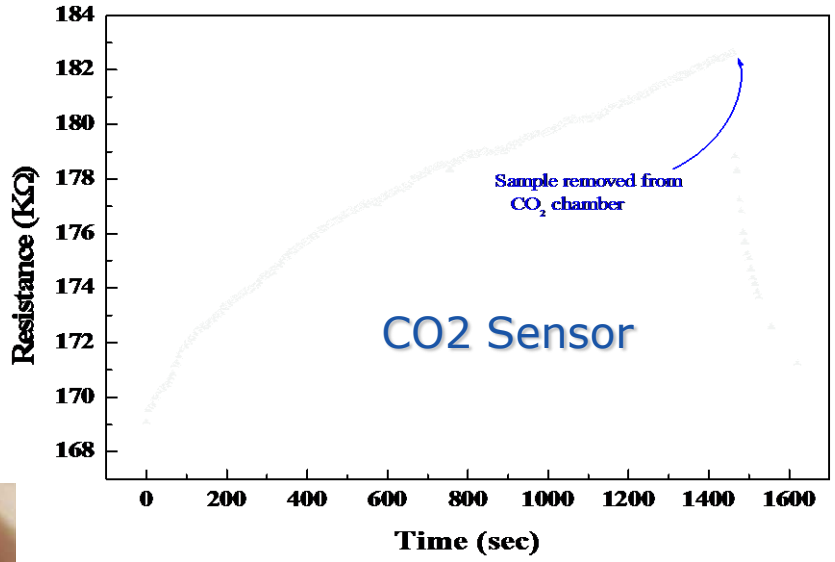
Yiheng Chen, Chalmers University

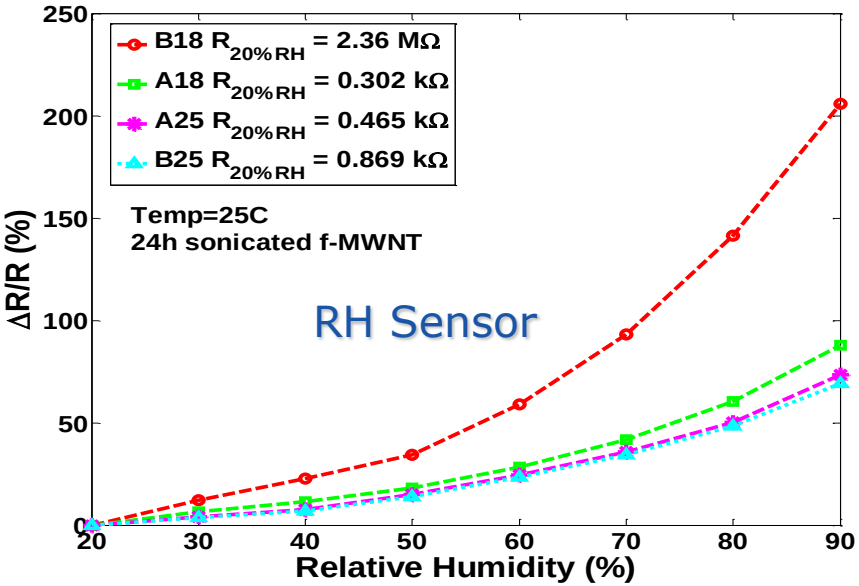
Printed Sensors





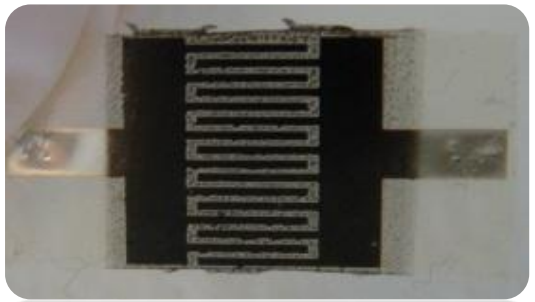




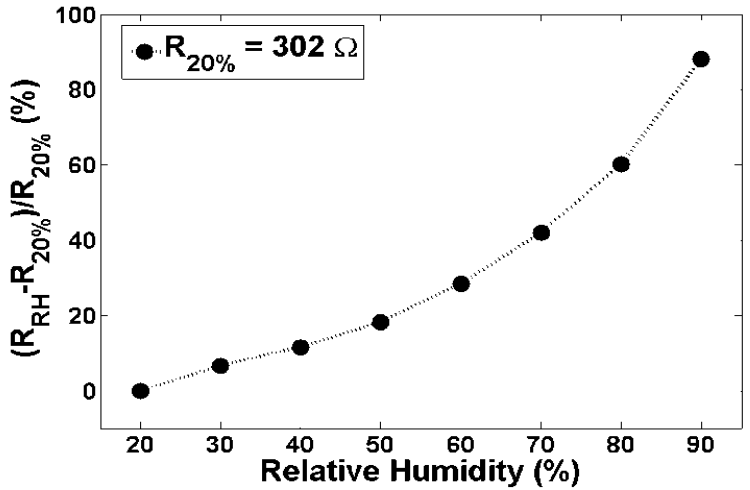


Printed Humidity Sensor

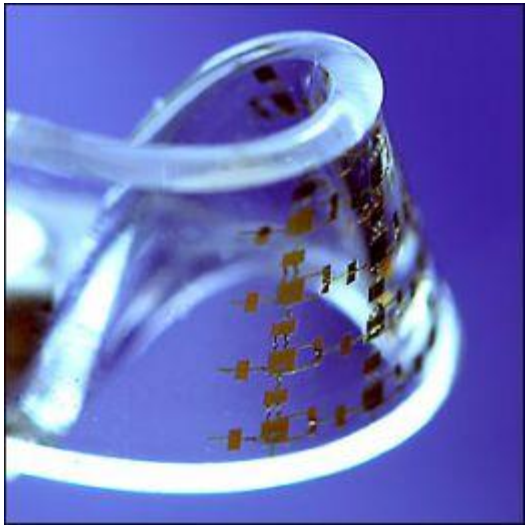
- Resistive humidity sensor
  - Inkjet printed interdigital electrodes
  - Functionalized Multi-Walled Carbon Nanotubes (f-MWCNTs)

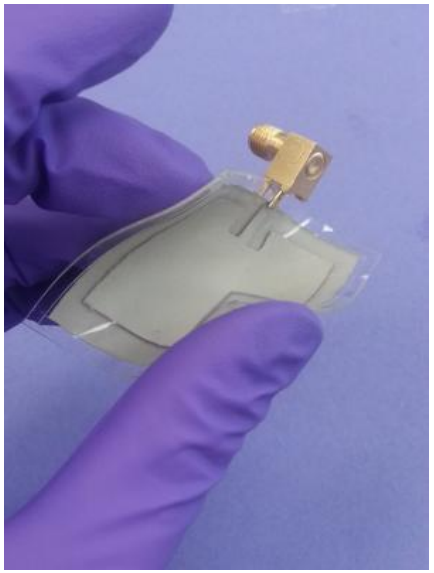


- DC resistance varies under different RH levels.

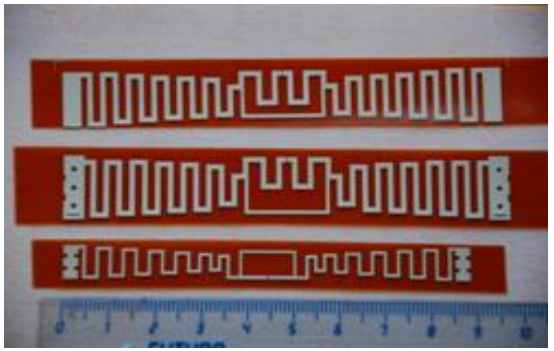


Flexible Antenna

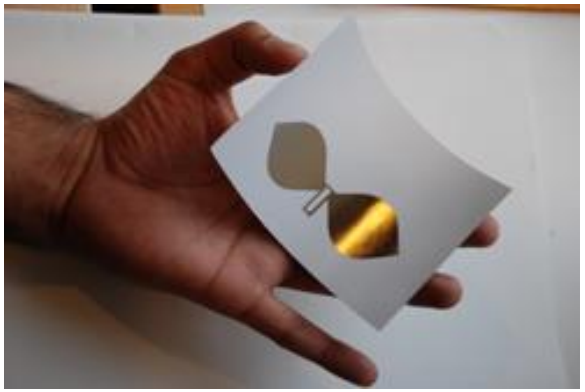




RFID, anti-counterfeiting
One-time use protection
Printed antenna (UHF, UWB)

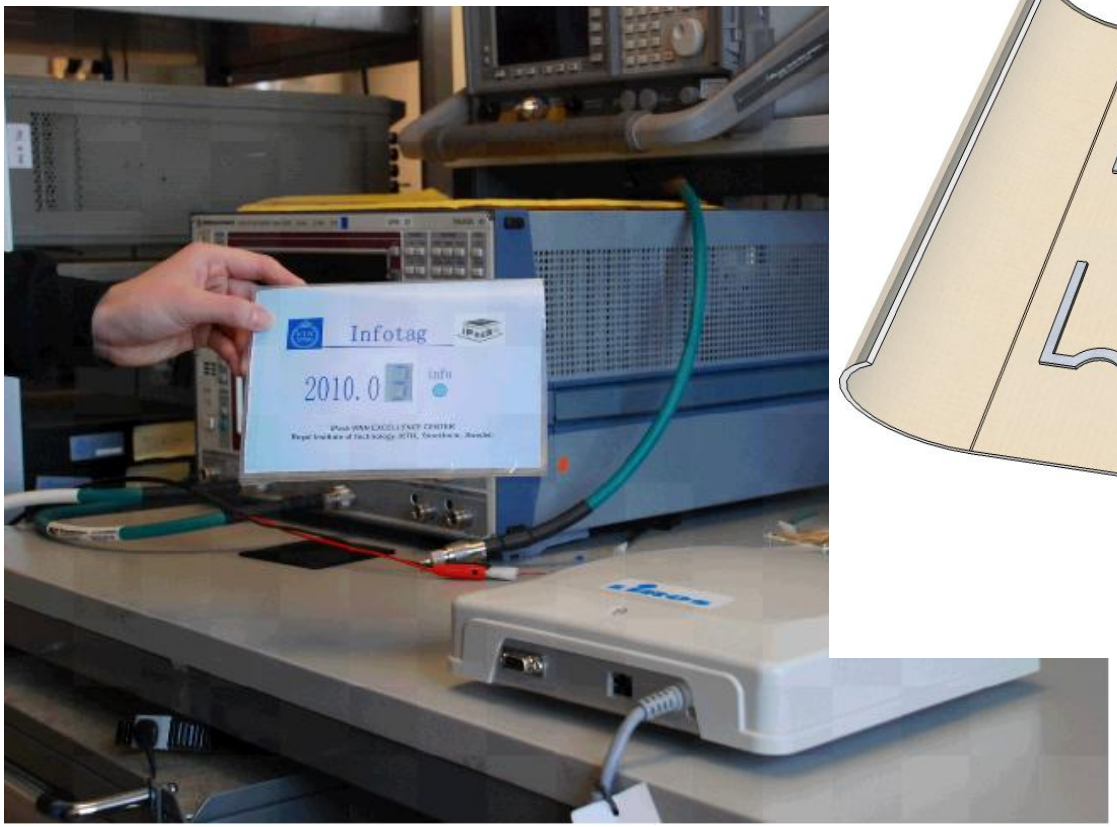


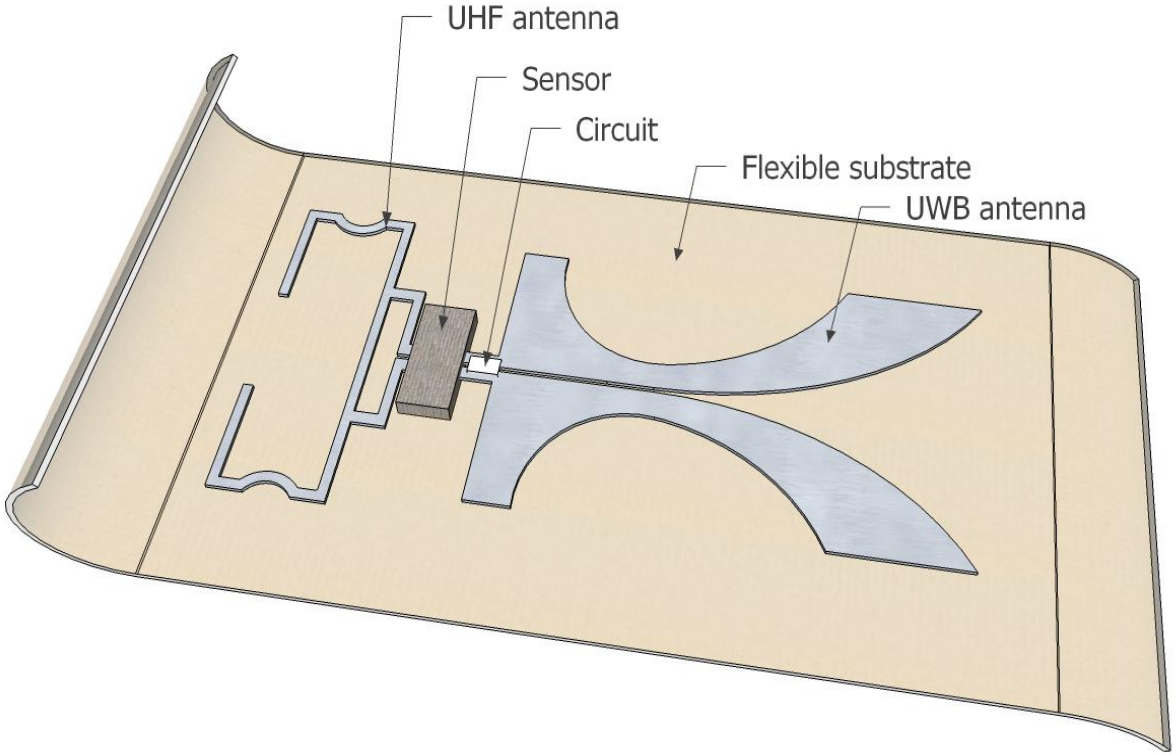
Robust UHF Antennas with low ink consumption and high gain



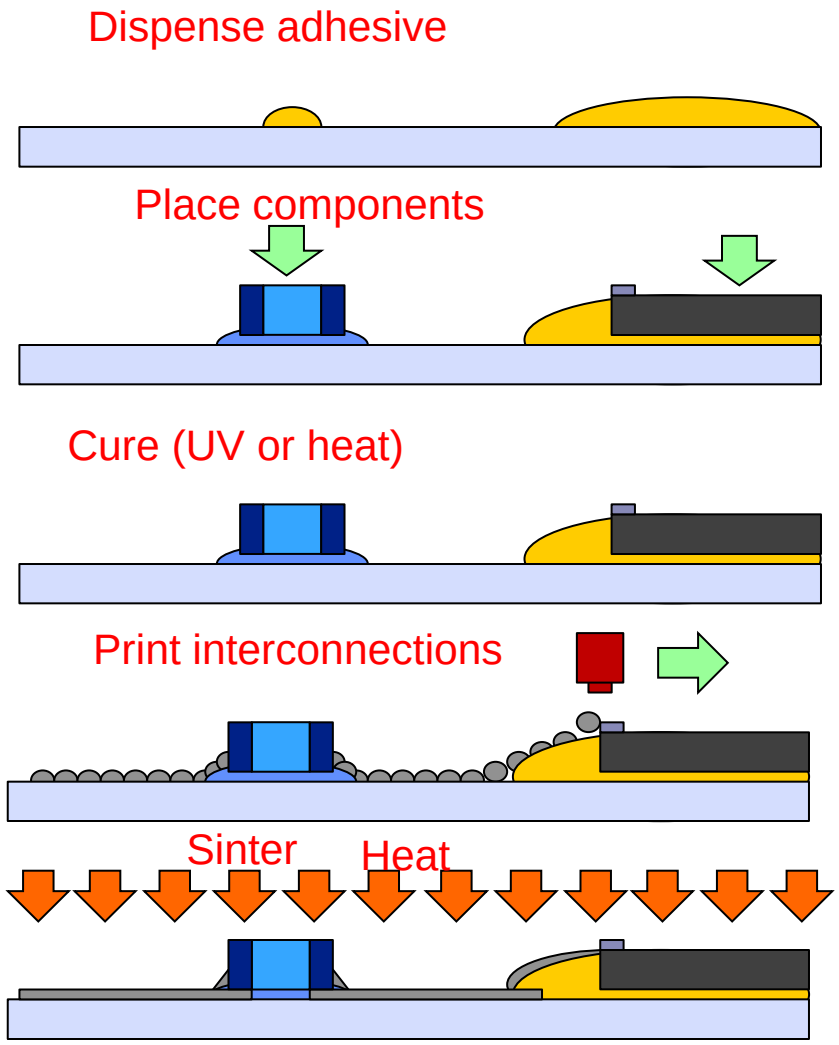
Quadrate Bowtie Antenna for UHF RFID Band

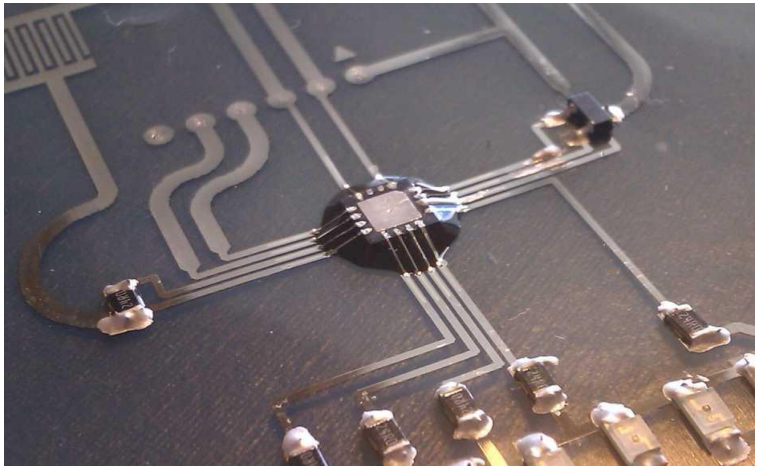
InfoTag - Intelligent RFID with Paper Display





Integration of Si chips with printed electronics

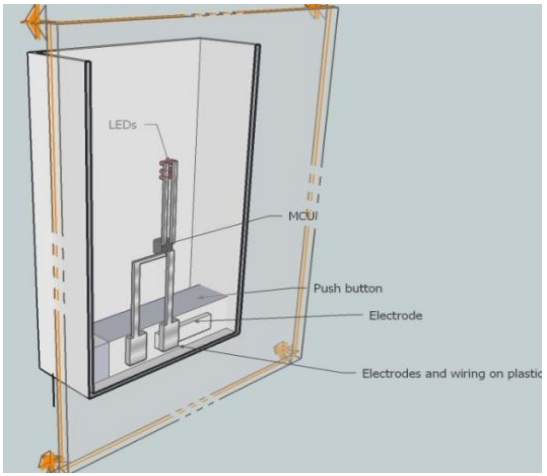




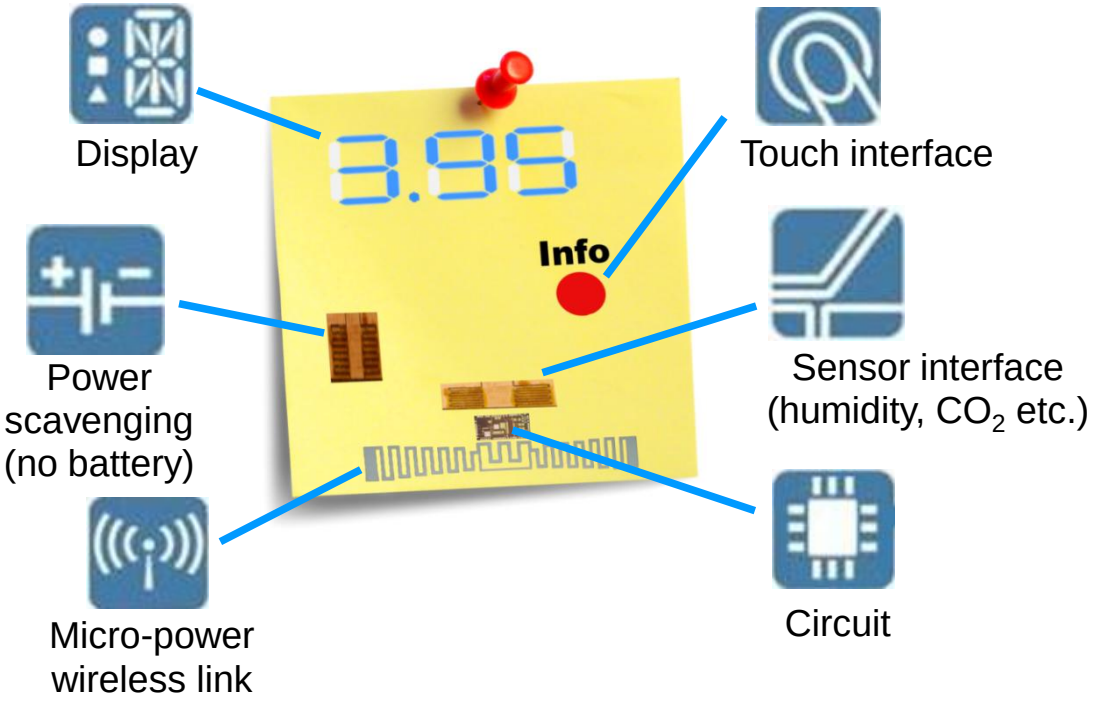
Xie, L.; Yang, G.; Mantysalo, M.; Xu, L.-L.; Jonsson, F.; Zheng, L.-R., "Heterogeneous Integration of Bio-Sensing System-on-Chip and Printed Electronics," IEEE Journal on Emerging and Selected Topics in Circuits and Systems, vol.2, no.4, pp.672-682, Dec. 2012.

Intelligent Packaging

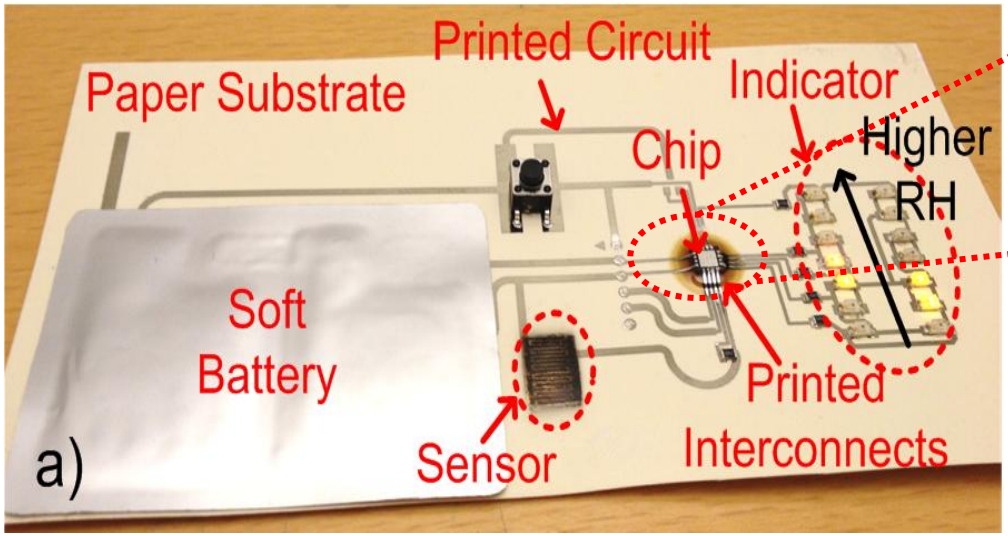
- Item-Level Tracking and Quality Control
  - Sense, Interact, Inform
  - Data processing, Communication

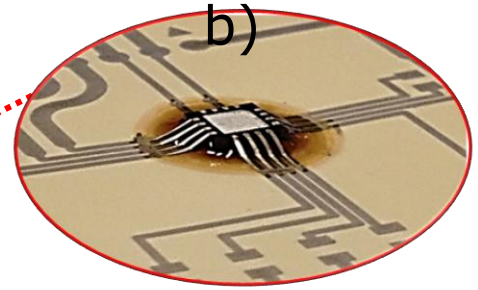


- Price sensitive -- Paper Substrates
  - Flexible
  - Low-cost
  - 'Green'



Paper-Based Sensor Card

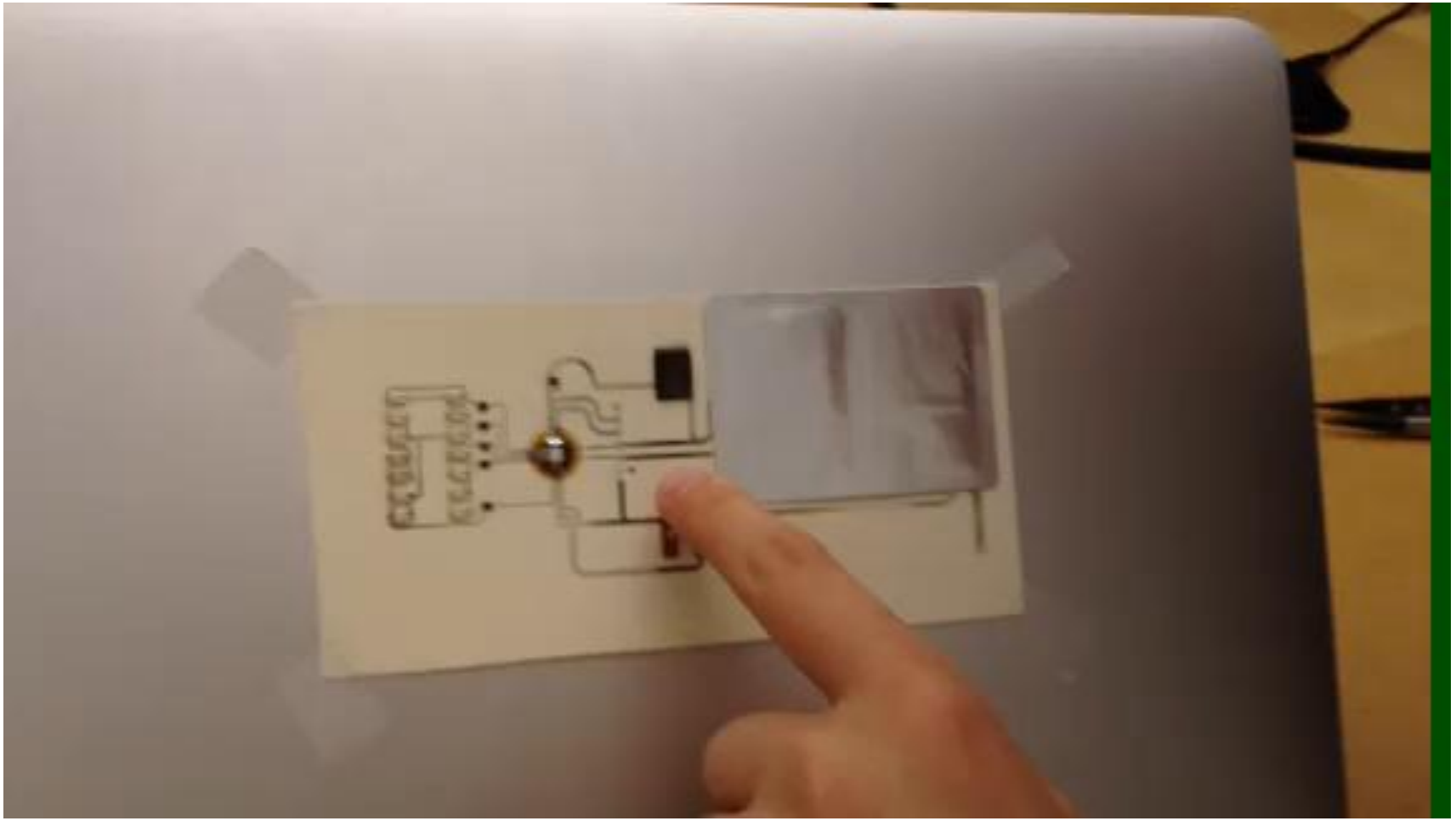




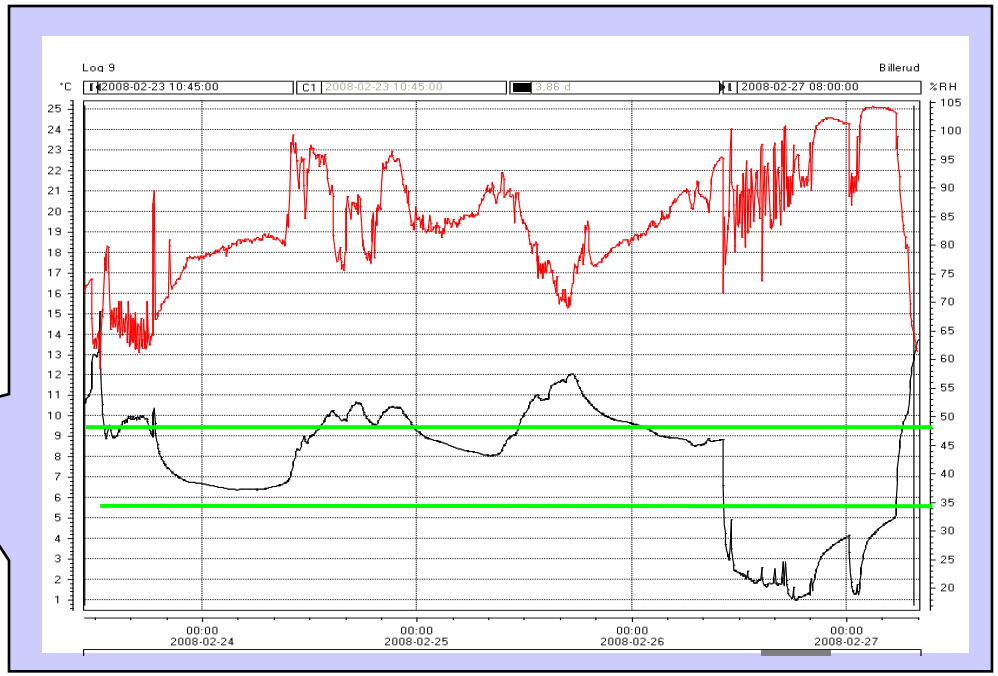
- Paper
  - Flexible
  - Low-cost
- Sensor & LEDs
  - Intelligent
  - Interaction
- MCU
  - Detect
  - Process

Li Xie, Yi Feng, etc "Electrical and Mechanical Reliability Evaluation of Paper-Based Hybrid Sensor System for Smart Packaging Application," Sensors Journal, IEEE vol.13, no.10, pp.3948,3956, Oct. 2013.

Paper-Based Sensor Card

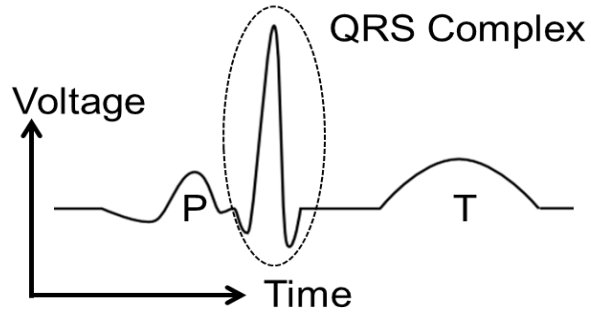


Intelligent packaging devices



Intelligent IoT tags integrated with temperature, humility, CO2 sensors.

Pervasive Healthcare Devices



Electrocardiogram (ECG)

Holter Monitoring System

Seamless monitoring:

Long term, real time, continuous, unobtrusive, anytime & any status.

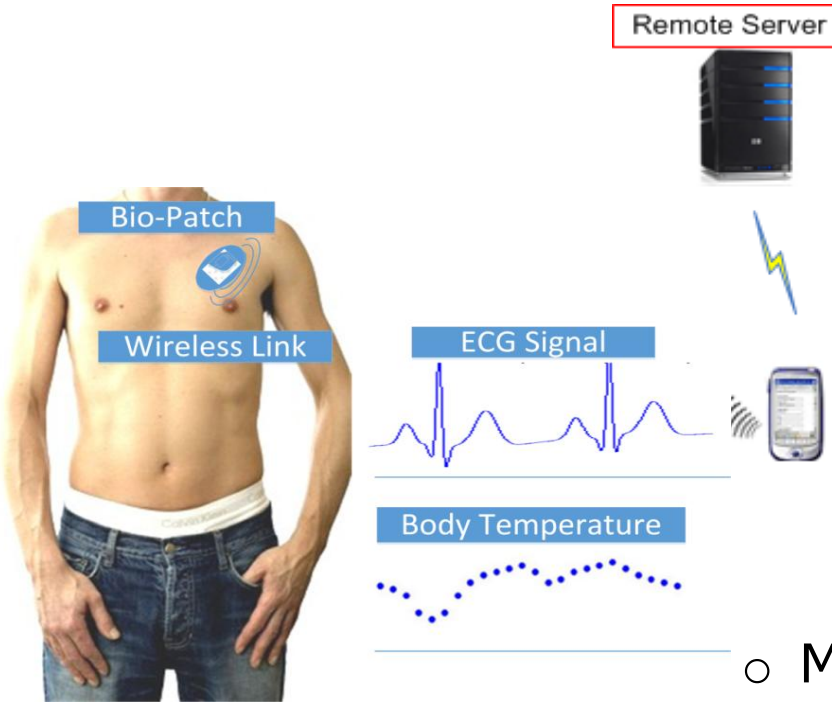
Conventional Healthcare Devices

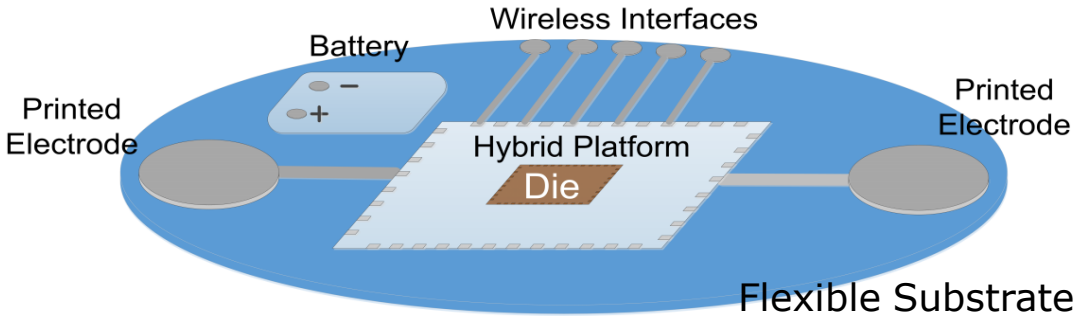
- Large physical size
- Tangled wires

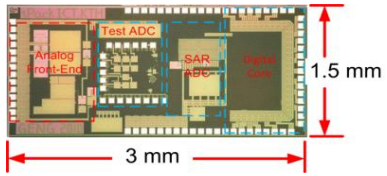
Next-Generation Healthcare Devices

- Comfort
- Small, lightweight, thin.
- Long battery life

Architecture of Bio-Patch







Key Technologies:

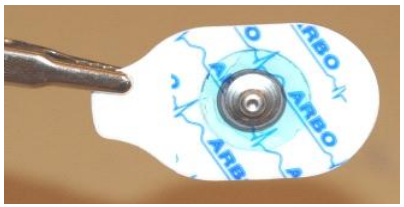
- Mixed-signal System-on-Chip (SoC)
- Inkjet Printed Electrodes
- Heterogeneous Integration

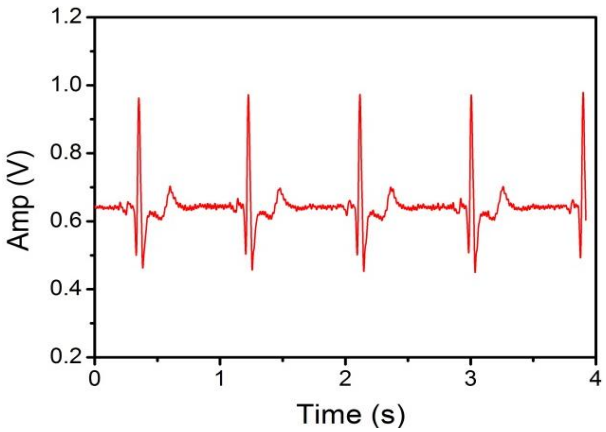
Architecture of Bio-Patch with an application scenario of ECG measurement

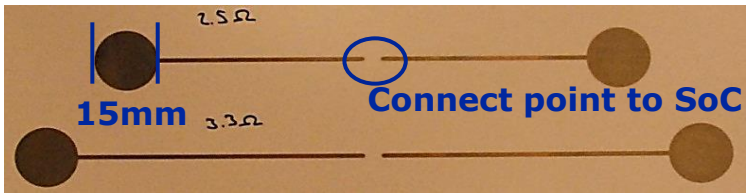
Inkjet-printed ECG electrodes

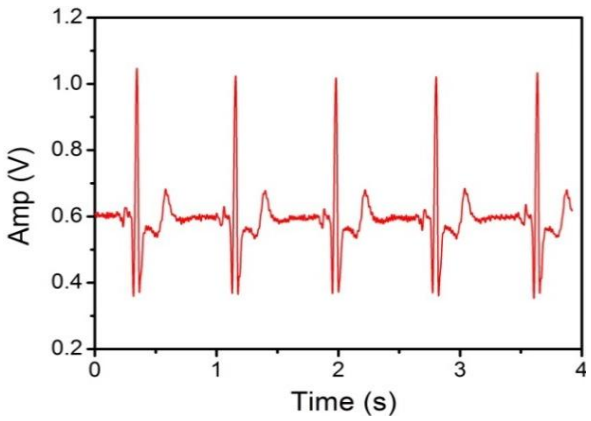
Conventional wet electrode:
- Signal degradation due to dehydration;
- Gel may cause irritation.

Inkjet printed dry electrode:
- Cost effective
- ‘Green’
- Easy to customize



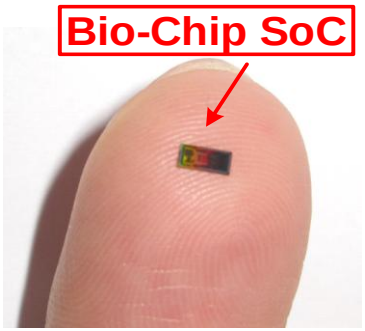




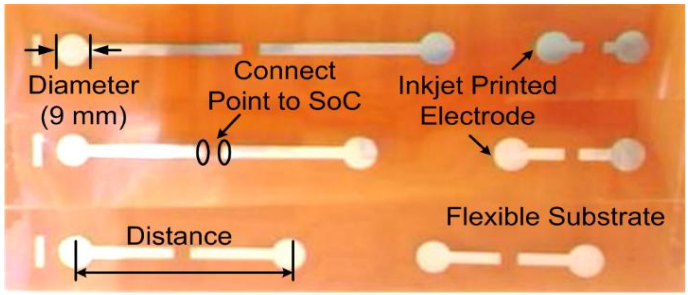


System miniaturization

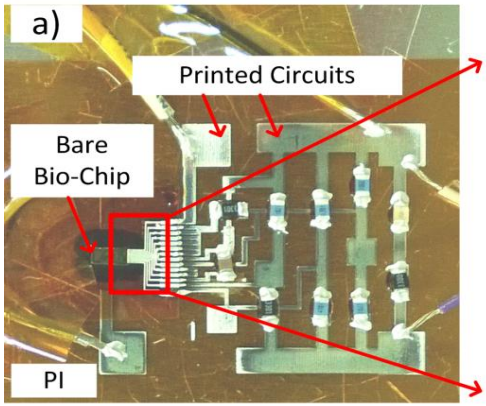
- System-on-Chip

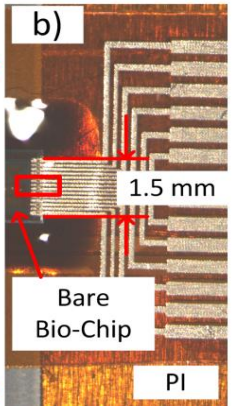


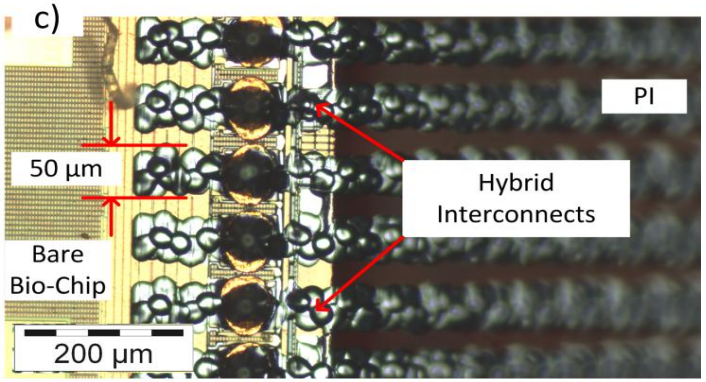
- Optimized electrode size:



- Bare-die integration: 65 µm pad size and 90 µm pitch

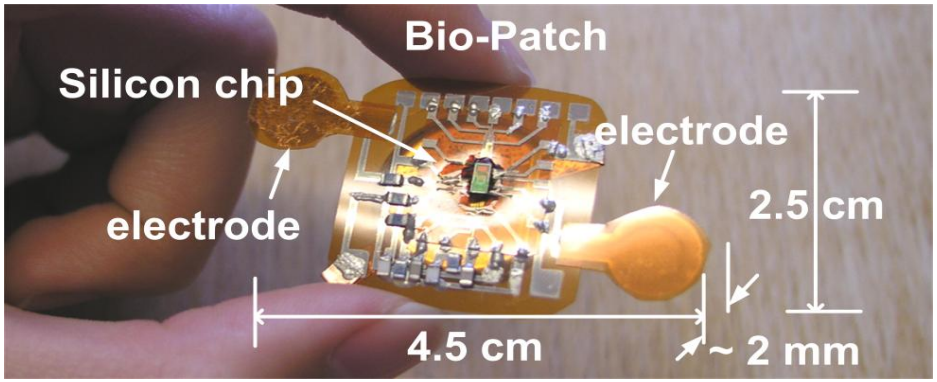


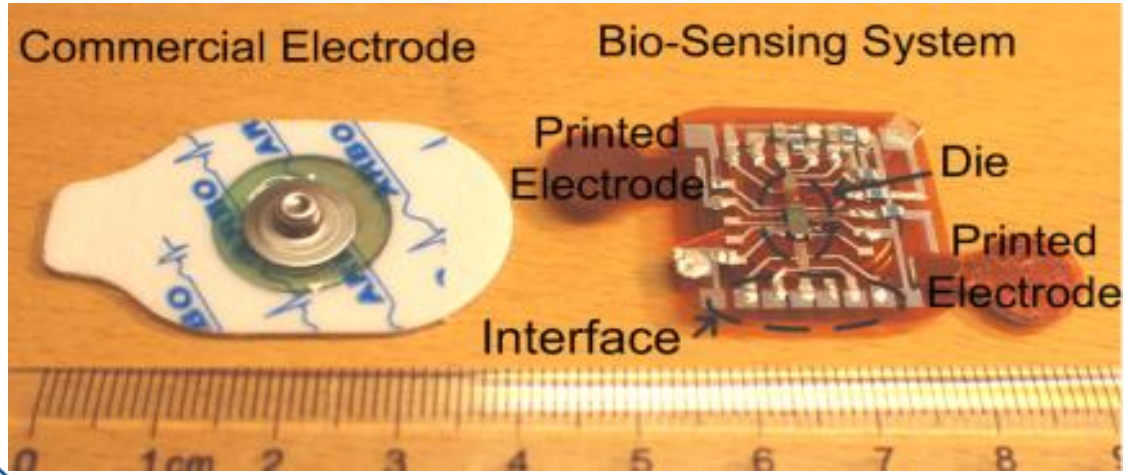




Wearable Bio-Patch

Flexible Electrodes + Bio-Sensing Chipset





Features:

- User comfort:
  - Flexible substrate
- Long battery life
  - Low-power IC
- Small size:
  - Optimized electrode
  - Single chip solution
  - Inkjet printing


Thank you!