# Organic and Printed Electronics

*Dr. Danick Briand – EPFL*

*Prof. Vivek Subramanian – EPFL*

# OPE course content and schedule

| Dates | Lectures | Lecturers |
|---|---|---|
| 20.02 | **Introduction** | D. Briand |
| 27.02 | **Physics of printing I** | V. Subramanian |
| 06.03 | **Physics of printing II** | V. Subramanian |
| 13.03 | **Materials for large area electronics** | V. Subramanian |
| 20.03 | **Thin film transistors fundamentals** | V. Subramanian |
| 27.03 | **Thin film transistors devices & Circuits** | V. Subramanian |
| 03.04 | **Organic light emitting diodes** | V. Subramanian |
| 10.04 | **Solar cells** | V. Subramanian |
| 17.04 | **Flexible and printed sensors** | D. Briand |
| 01.05 | **Energy storage & Encapsulation** | D. Briand |
| 08.05 | **Integration & Smart Systems** | D. Briand |
| 15.05 | **Sustainable electronics** | D. Briand |
| 22.05 | **Case study** | D. Briand |

# LESSON 10 – HETEROGENEOUS INTEGRATION AND SMART SYSTEMS

*Dr. Danick Briand*

**Reference book 2nd Ed. on OPE: Chapter 11**

# Objectives and content

## Objectives

- Overview of different techniques to assemble components on polymeric foil

## Content

- What is Hybrid printed electronics: Motivations and challenges
- Techniques to assemble silicon components on polymeric foils
- Techniques to assemble foil based components on polymeric foils
- Some examples of integration

# L.A.M.: what has been realised so far?

**(Opto) Electronic devices:**
- Diodes;
- Transistors + circuitry;
- OLEDs;
- Solar cells.


RLC circuits (CSEM)

**Sensors and microsystems**


Memory (Thin Film)

**Electric discrete components:**
- Wirings (connections);
- Resistors;
- Capacitors;
- Inductors;
- Antennas

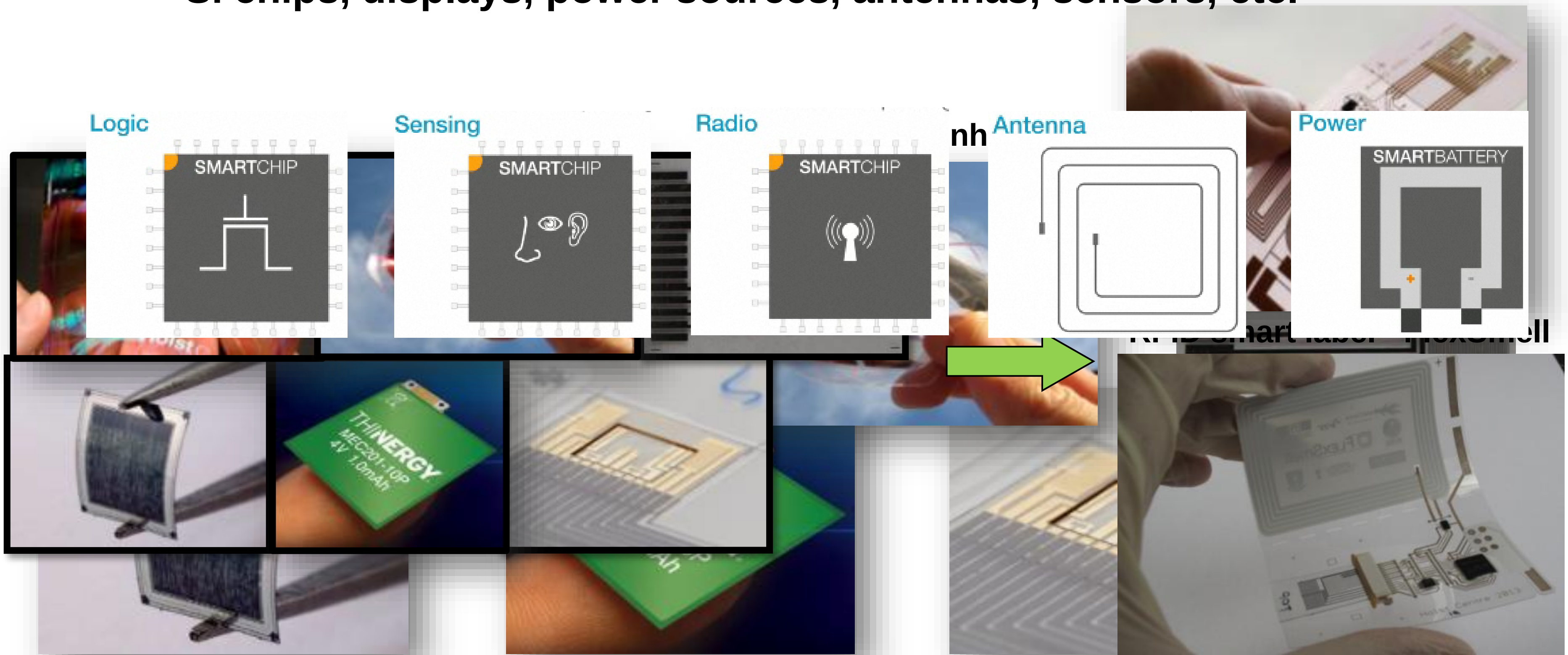
**Memory devices**

**Energy storage:** batteries and supercapacitors

SoftBattery® printed

# Towards smart sensing systems

- **Systems-in-foil integration**
  - **Si chips, displays, power sources, antennas, sensors, etc.**




IMS-CHIPS | Thinergy | SAMLAB/Holst Centre | RFID smart label - FlexSmell

- **Required developments:**
  - **Cost-effective assembling processes compatible with large area processing (S2S, R2R) + low T°C (PET substrate)**
  - **Mechanically robust electrical interconnections (2D and 3D)**

# Motivations

- **Hybrid Electronics:**

  A combination of printed circuitry, thin-film electronics and classical silicon-based components

**To combine the benefits of flexible and printed electronics on foil and silicon technologies**

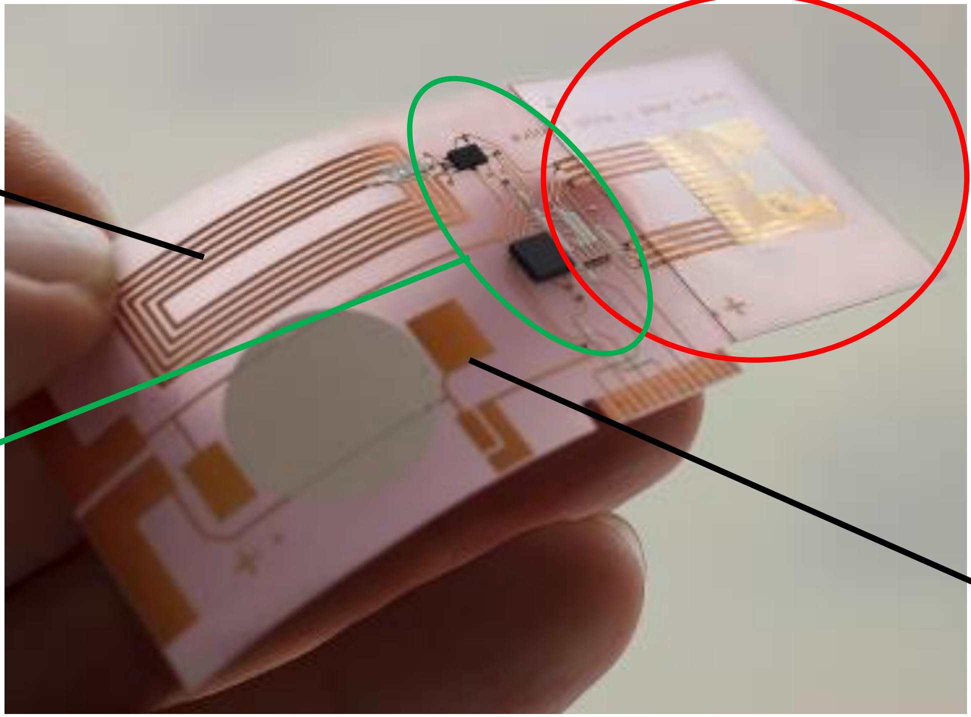
# Motivations

## Systems-in-Foil (SiF): integration

- Smart sensing RFID label

interconnected foils

printed antenna



Si chips

printed PCBs

**Two types of components to assemble: Foils & Silicon / Discrete components**

**From EPFL-LMTS in collaboration with Holst Center (NL)**

# Basic process flow for hybrid systems

- $1^{st}$: Printing of components
- $2^{nd}$: Assembling with other components

- For a R2R process or conventional printing process: more suited to print before assembling silicon chips
- Using digital printing: one could always consider to print with silicon chips already on the foil

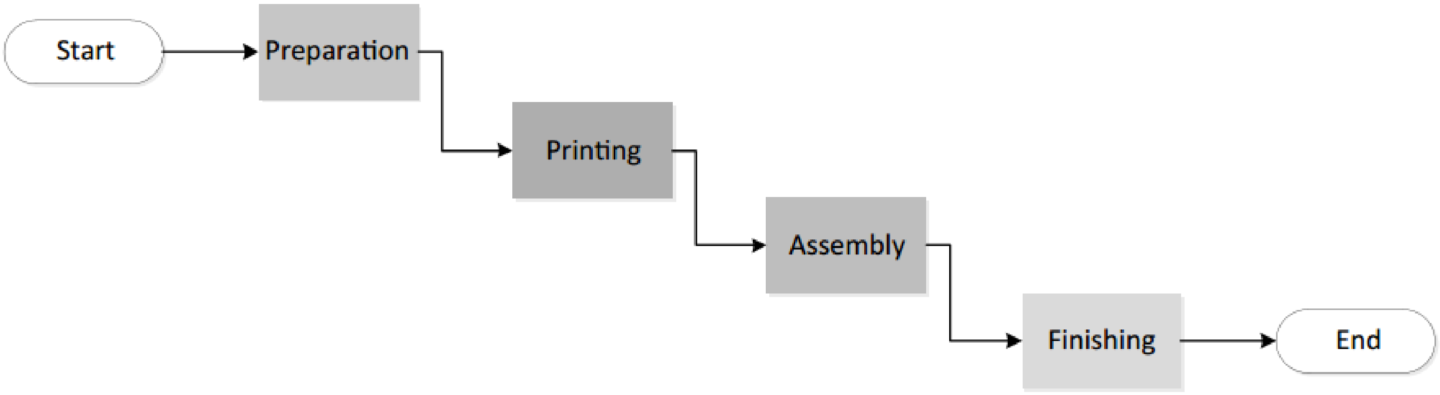



**Figure 11.1** Schematic representation of the sets of processes typical for hybrid printed electronics.

# Basic process flow for hybrid systems

More details for a system with one printed Ag layer (PCB + antenna) and one silicon RFID chip for instance.

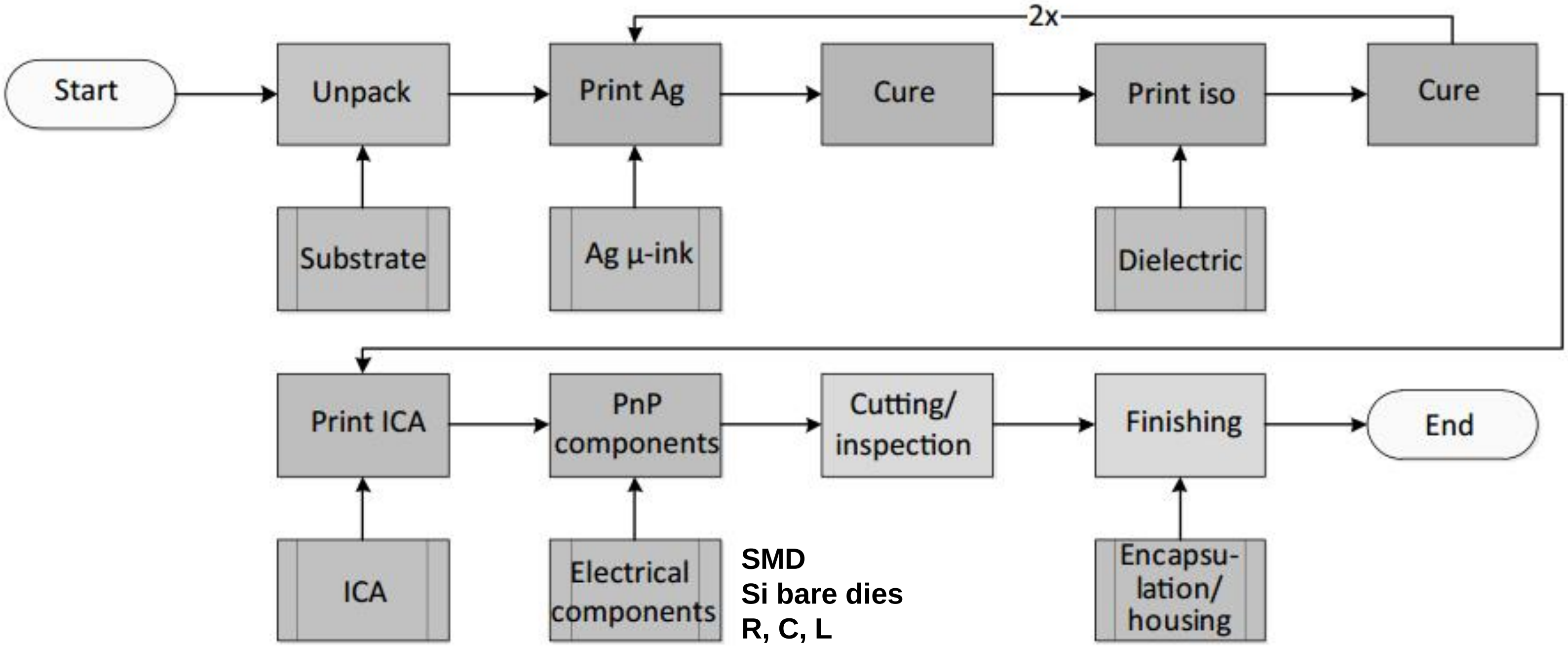



**Figure 11.2** Schematic representation of a generic process flow for a hybrid printed electronics product.

**ICA: Isotropic Conductive Adhesive**
**PnP: Pick and Place**
**SMD: Surface Mount Device**

# Challenges

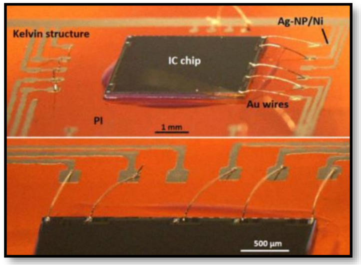
- Tranferring silicon components involve pick and place processes, with adhesive patterning, alignment, application of pressure  and temperature for mechanical fixation/electrical connection
- Soldering temperature, for instance of SnAgCu, not compatible with most polymeric foil (temperature resistant polyimide is ok)
- Maintening the flexibility of the system: minimise number of SMD components, bendable assemblies, use of thin bare Si dies (flip-chip)
- Reliability of the assembling: mechanically, electrically, chemically

**Alternative processes are required**:

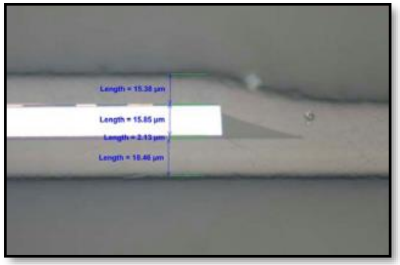
- Assembling techniques that can follow high volume/speed manufacturing
- Cost-effective, materials and process wise

# Silicon chips on foil

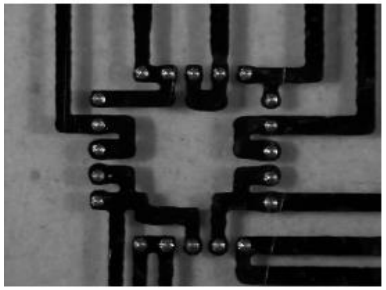
- **Wire bonding**
- **Photolithography + evaporation**
- **Soldering (on Polyimide)**
- **Printing onto chip**
- **ICA**
- **ACA/ACF**



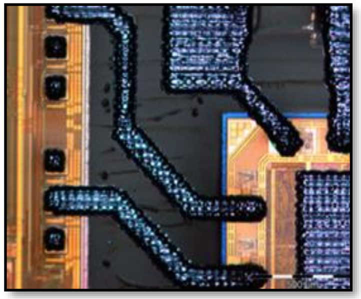

IEEE Tras. Dev. Mat. 5 (2), 2005



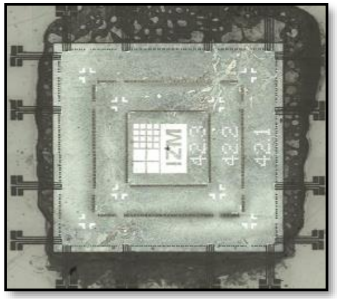
IEEE Tras. Dev. Mat. 5 (2), 2005



From Holst Center



IEEE Tras. Dev. Mat. 5 (2), 2005



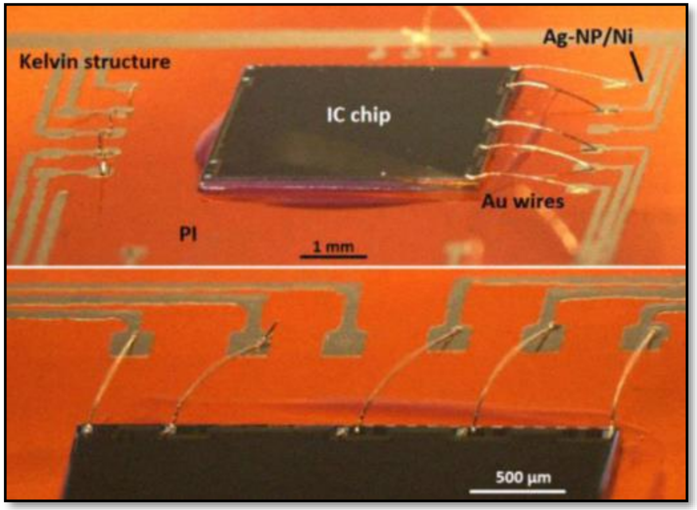
IEEE Tras. Dev. Mat. 5 (2), 2005

**ICA: Isotropic conductive adhesive (paste)**

**ACA: Anisotropic conductive adhesive (paste)** **ACF: Anisotropic Conductive Film (sheet)**

# Silicon chips on foil

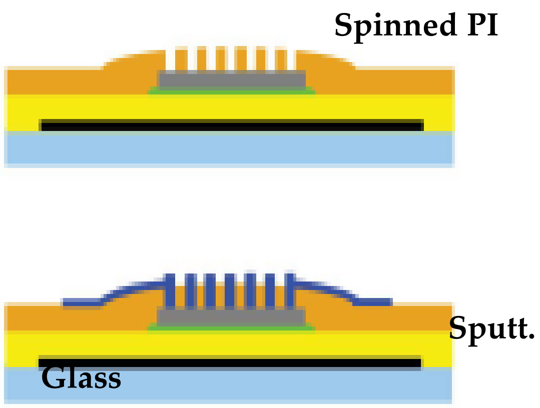
- **Wire bonding**
  - **Has been demonstrated on Polyimide foil (gold or other plating needed) but can be difficult to implement (adhesion and nature of the contact pad, foil substrate deforms during bonding)**
  - **Not adapted for production, only for small volumes and limited to Polyimide, but soldering is the established method on Polyimide (used in the FlexPCB industry)**

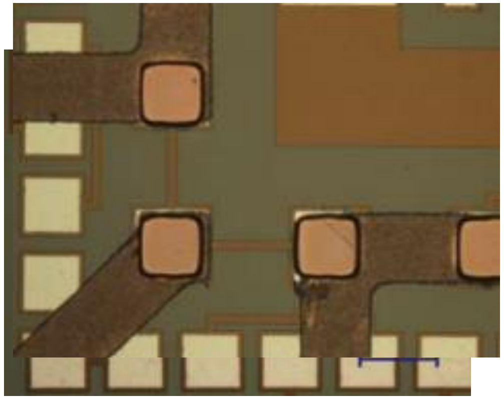



IEEE Tras. Dev. Mat. 5 (2), 2005

# Silicon chips on foil

- **Photolithography**
  - **Spin coating of a photosensitive layer over the silicon chip**
  - **Metallisation using vacuum process (evaporation or sputtering)**



Gent Univ. / imec

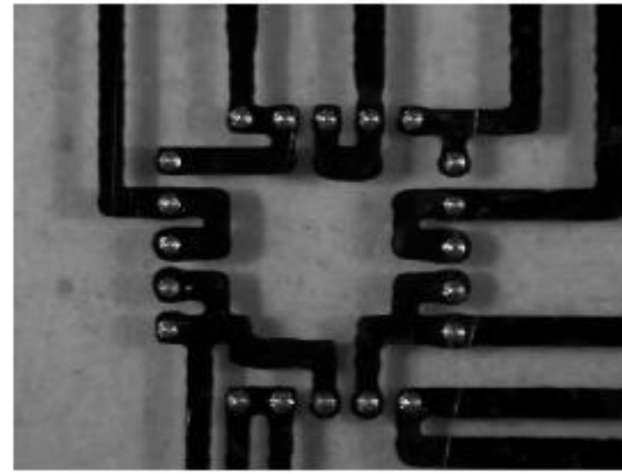
# Silicon chips on foil

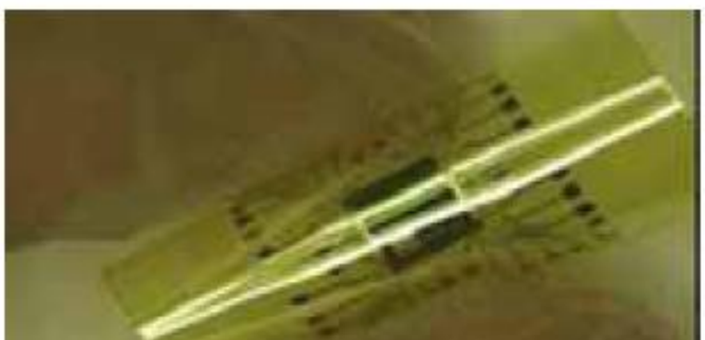
Holst Centre

- **Flip chip on printed PCB on PI using soldering**

**Current research:**

- further development of Si flip chip on flex
  → decrease pitch size to below 50 μm using novel, low cost circuitry-making concept
  → decrease chip thickness to 10 μm
  → increase number of I/O connections to 50
- develop stretchable 'printed circuit board'
- evaluate reliability
- optimize product (adhesive/design)





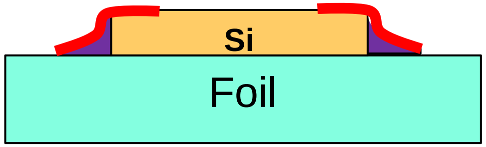
Embedded 25 micron thick chip between 2 polyimide layers, resulting in 60 micron thick package (cooperation IMEC/UGent)

**Recently in 2019 a company won an award for soldering/fixing on PET**

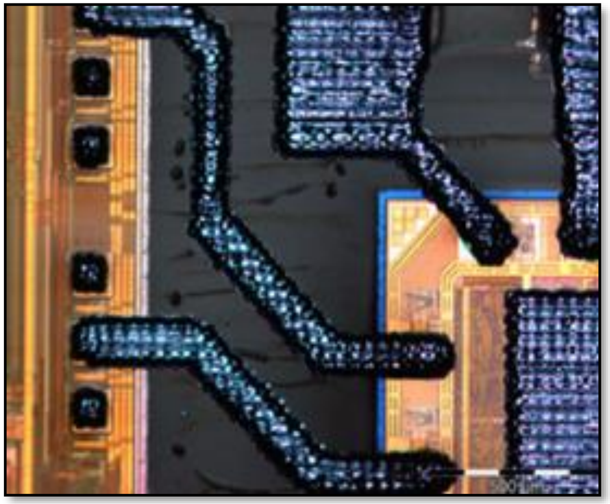
# Silicon chips on foil

- **Printing on silicon chips**
  - **Main challenge is linked to covering the step**
  - **Covering steps with Inkjet printing is not easy: one solution is to «soften» the edges by printing a polymeric layer around the chip**
  - **Aerosol Jet provides better results (inclined nozzle), but low throughput (array of nozzles limited to a few)**
  - **Chip thinning to reduce the step height / embedding the chip in cavity made in the foil**

Decrease the stepness




Inkjet



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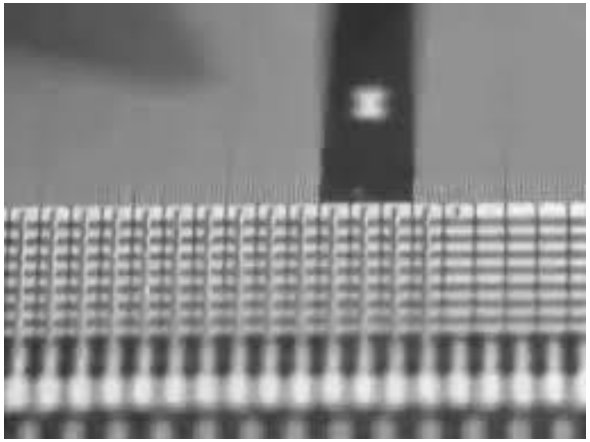
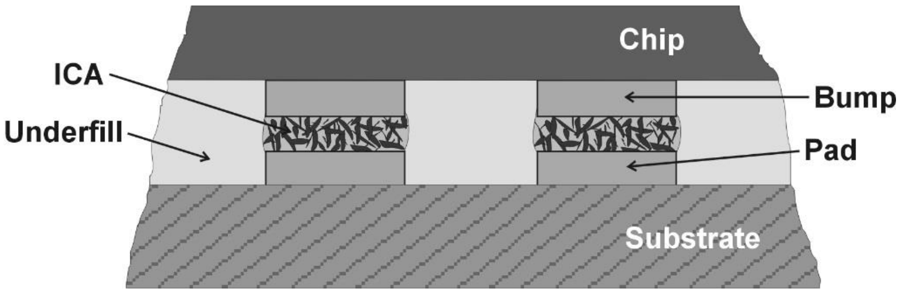


Aerosol jet

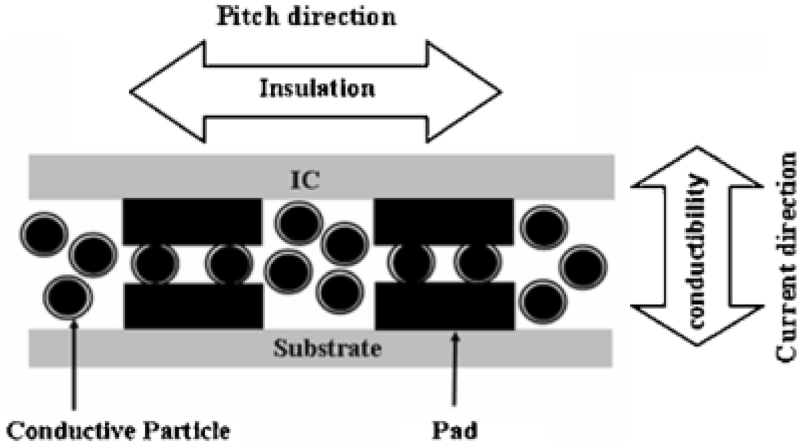
# Electrically conductive adhesives

- Isotropic conductive adhesive (ICA) "low cost"
  - Filler particles (i.e. Ag) + adhesive polymer resin (epoxy, etc.)
  - Conductivity in all directions (high volume fraction 25-30 %)
  - Confinement of paste required (resolution → vias dimensions)
- Anisotropic conductive adhesive (ACA) "high cost"
  - Filler particles: i.e. Ni / Au + adhesive polymer resin
  - Conductivity in z-direction only (low volume fraction 3-15 %)
  - Fine pitch assembly

Cross-section



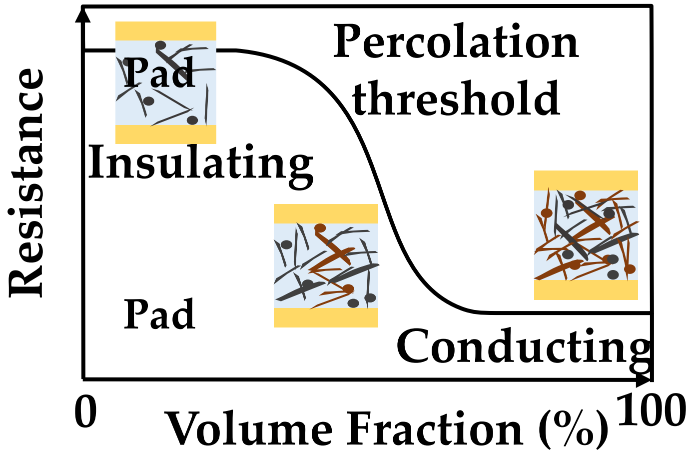

[Frisk, Laura, Finland]

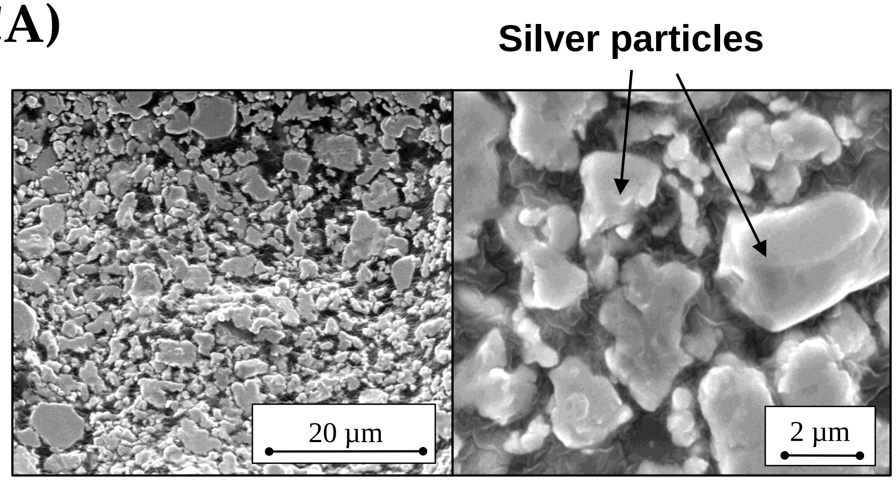



[Chao-Ming L, et al., 2005]

# Electrically conductive adhesives cured at low temperature

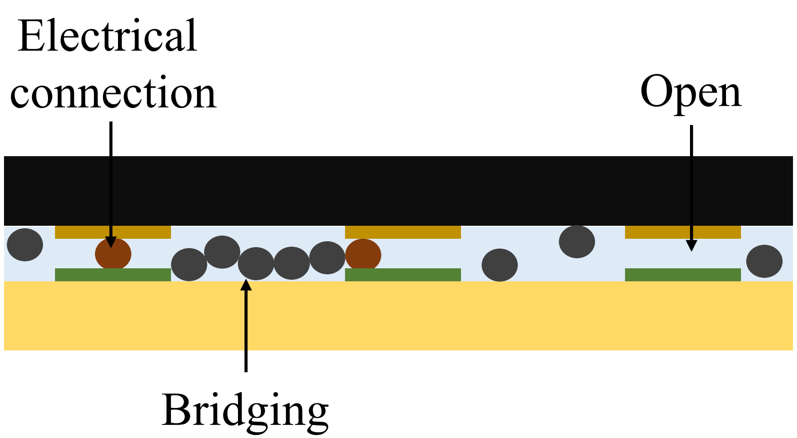
- **Isotropic conductive adhesive (ICA)**



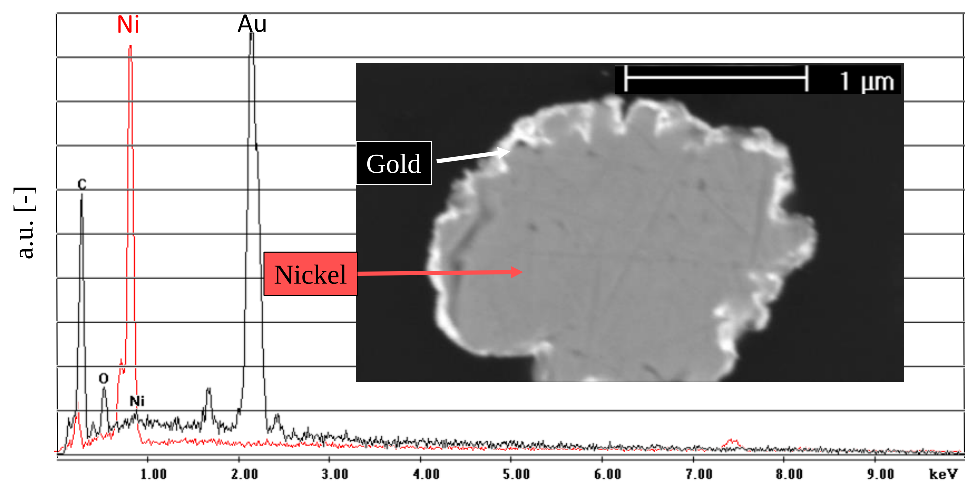




CE 3103WLV

- **Anisotropic conductive adhesive (ACA)**

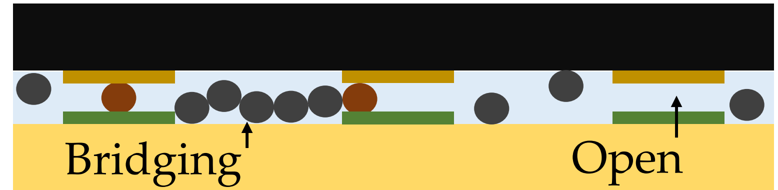



AC365

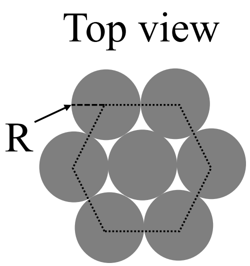


# ACA probability of failure

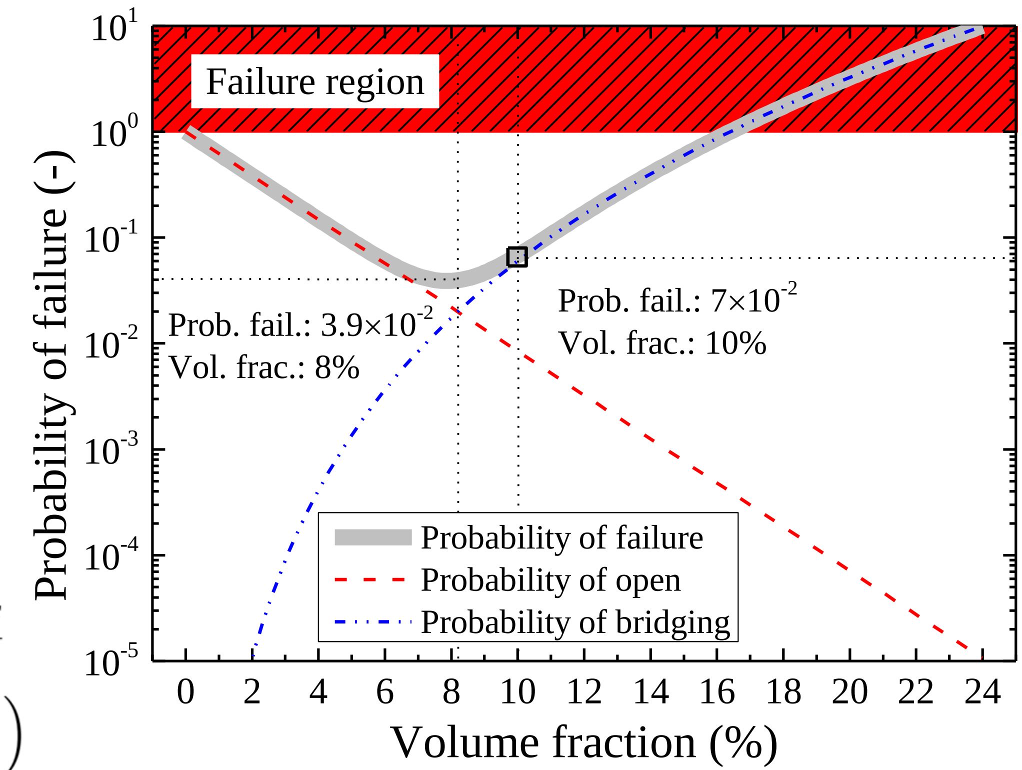
- $P_{failure} = P_{open} \cup P_{bridging}$



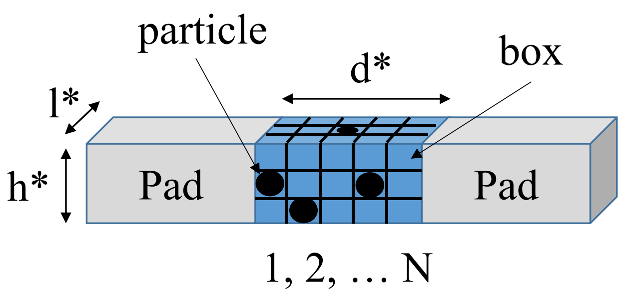

- $P_{open}$ **(Poisson's distribution)**




$$P(0) = e^{\frac{3 \cdot VF \cdot A_{ele}}{2\pi \cdot R^2}}$$




- $P_{bridging}$ **(Box model)**




$$\mu_2 = \frac{6VF}{\pi}$$

$$\sum_{i_1=1}^{l^*}\sum_{i_2=1}^{l^*}\sum_{j_1=1}^{h^*}\sum_{j_2=1}^{h*}\left(\mu_2^{dist}+\mu_2^{dist+1}+\ldots+\mu_2^{d^*h^*l^*}\right)$$

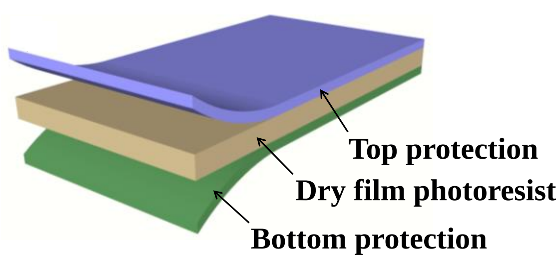
**IEEE Tras. Dev. Mat. 5 (2), 2005**

**A. Vásquez Quintero et al., J. Micro. Engi., 110, (2013)**

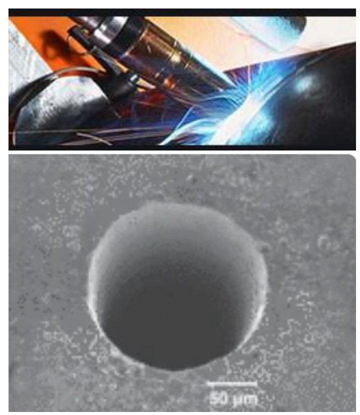
# Dry film adhesive for ICA confinement

- **Foil adhesive with cavities patterned by laser etching to confine the ICA for small pitch between the contact pads on the Si chip (to avoid short-cuts)**
- **Dry (sheets or roll) format**
  - **Double side adhesive with protective foils**
  - **flexible & large area**
  - **no wet chemistry**
  - **lamination  by applying pressure and temperature**

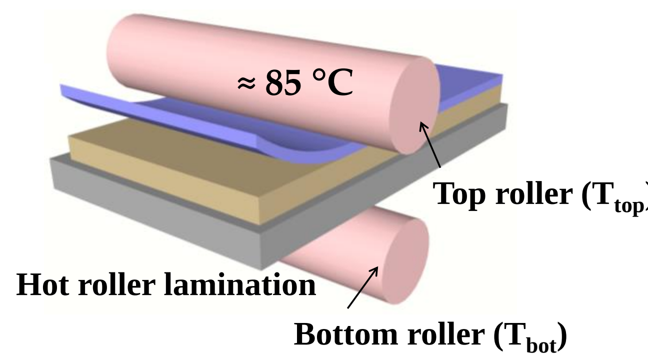
**Adhesive foil**




**Excimer laser micromachining**




**Lamination**

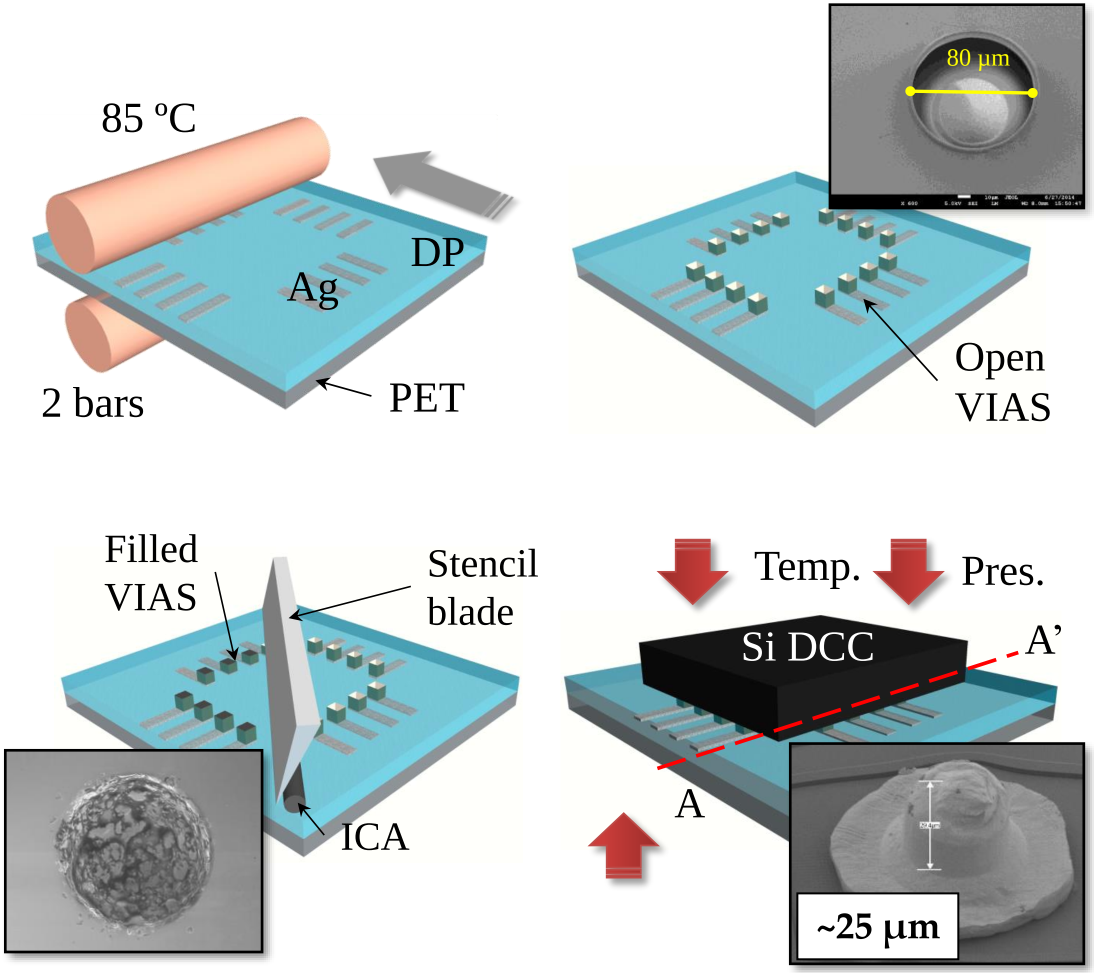


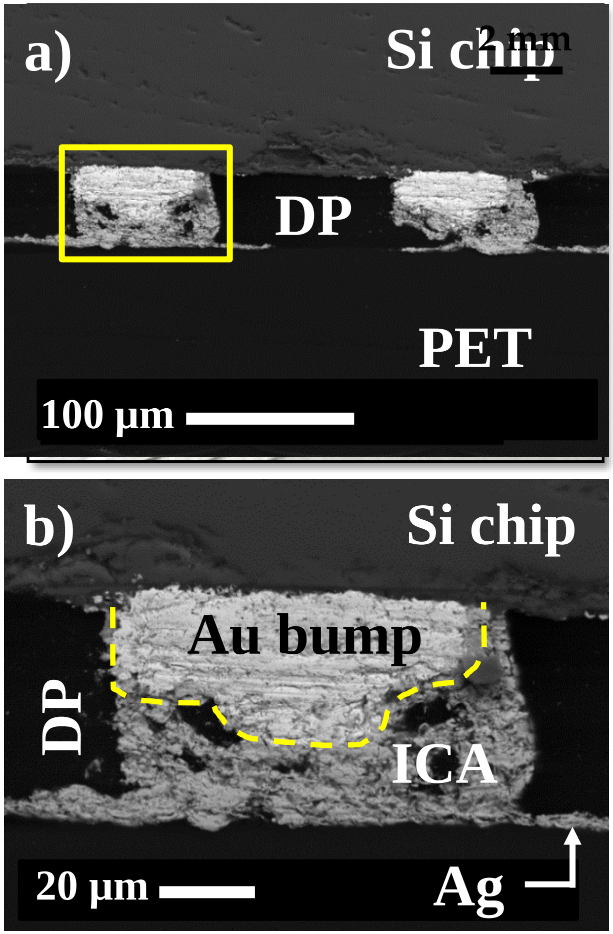

- **Process flow compatible with temperature sensitive foils, ie PET**

# Silicon chips on foil: ICA

**Low temperature integration methods (85°C) + fine pitch**

- Thinned silicon chips flip chip to Foil with Au bumps



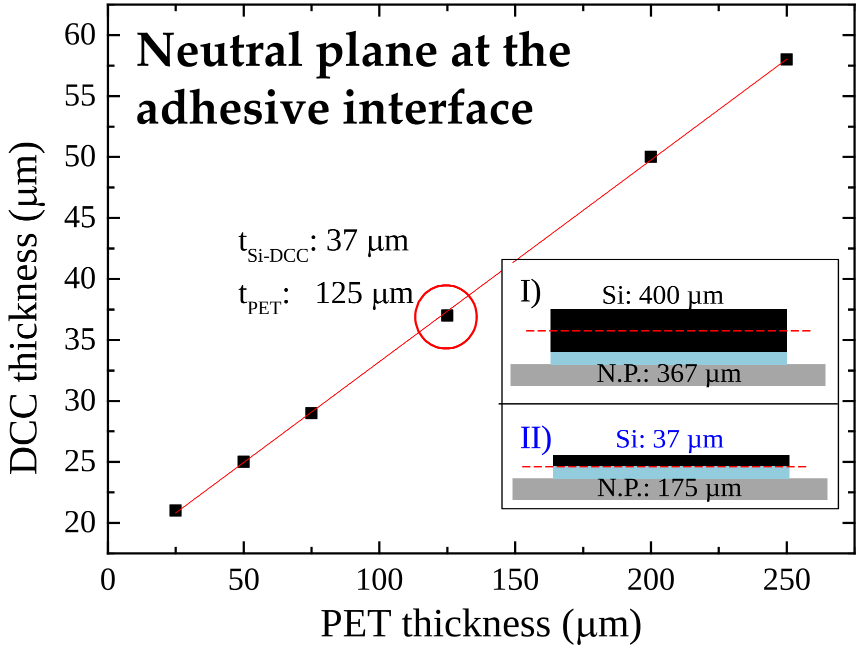




A. Vásquez Quintero et al.,
J. Micromech. Microeng., (2014)

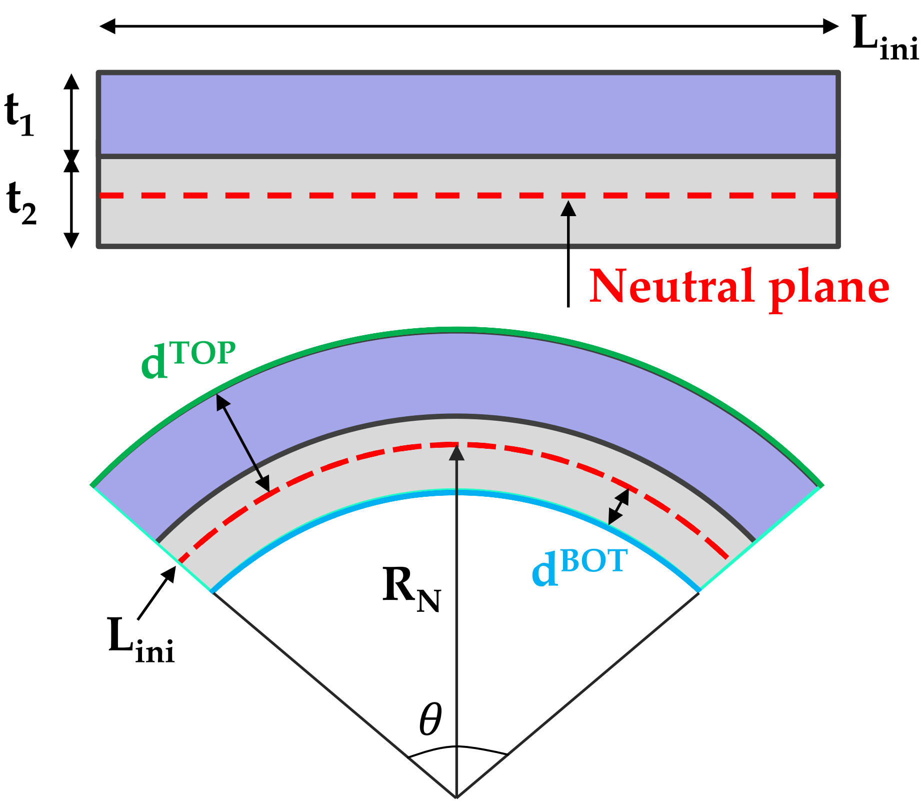
# Thinned bare Si chips with ICA for enhanced flexibility

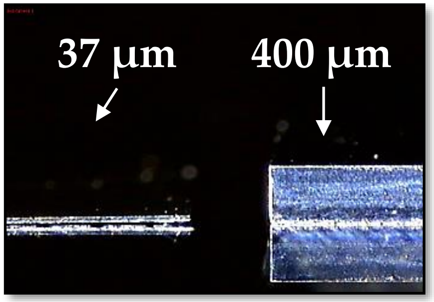
**Low temperature integration methods (85°C) + fine pitch**

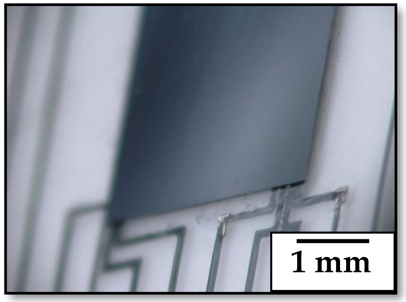
- Thinned silicon chips for flexibility: assembling design for neutral plane at the interface




$$y_N = \frac{\sum_{i=1}^{n} E_i A_i h_i}{\sum_{i=1}^{n} E_i A_i}$$



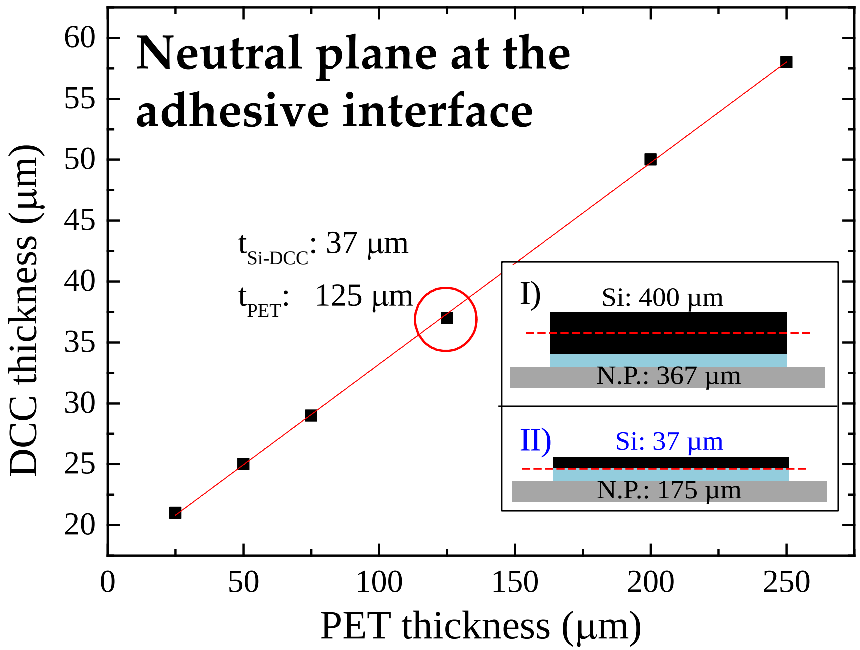



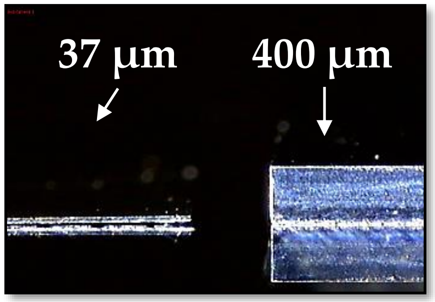

A. Vásquez Quintero et al., J. Micromech. Microeng., (2014)

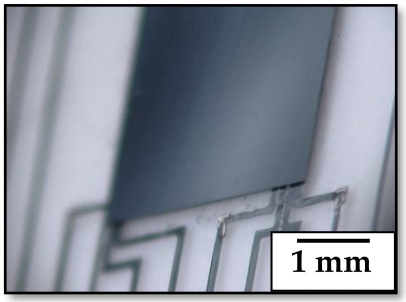
# Silicon chips on foil: ICA

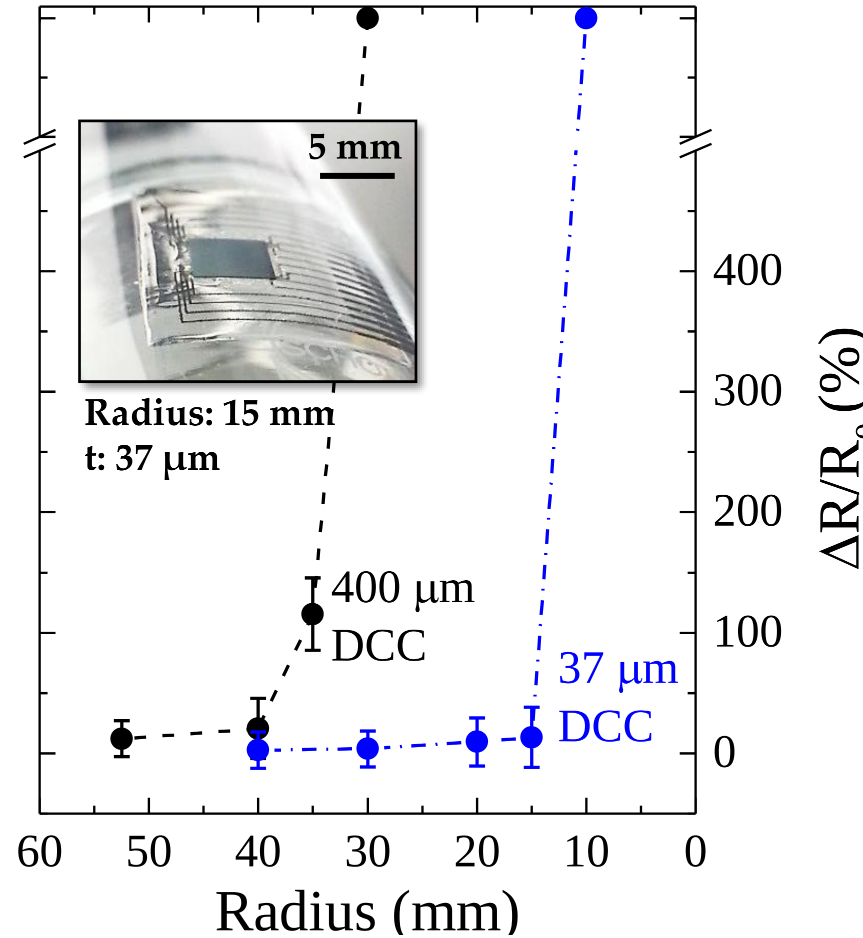
## Low temperature integration methods (85°C) + fine pitch

- Thinned silicon chips for flexibility: assembling design for neutral plane at the interface



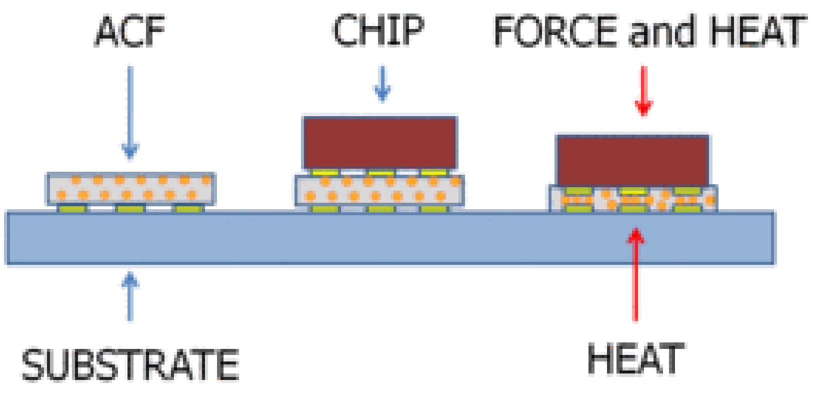




A. Vásquez Quintero et al.,
J. Micromech. Microeng., (2014)

# Silicon chips on foil: ACA / ACF

**Low temperature integration method**

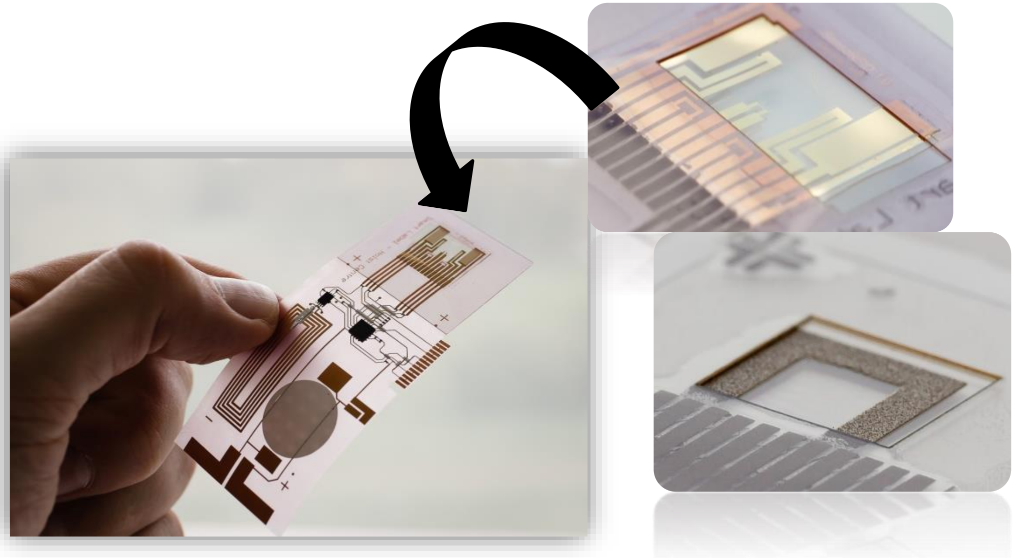
- In the form of liquid paste to be dispenses or dry film that can be laminated
- Specific temperature profile (typical up to 120°C with given ramps and plateau)
- Bonding temperature, temperature profile, and time determine bonding strength, electrical conduction, residual stress



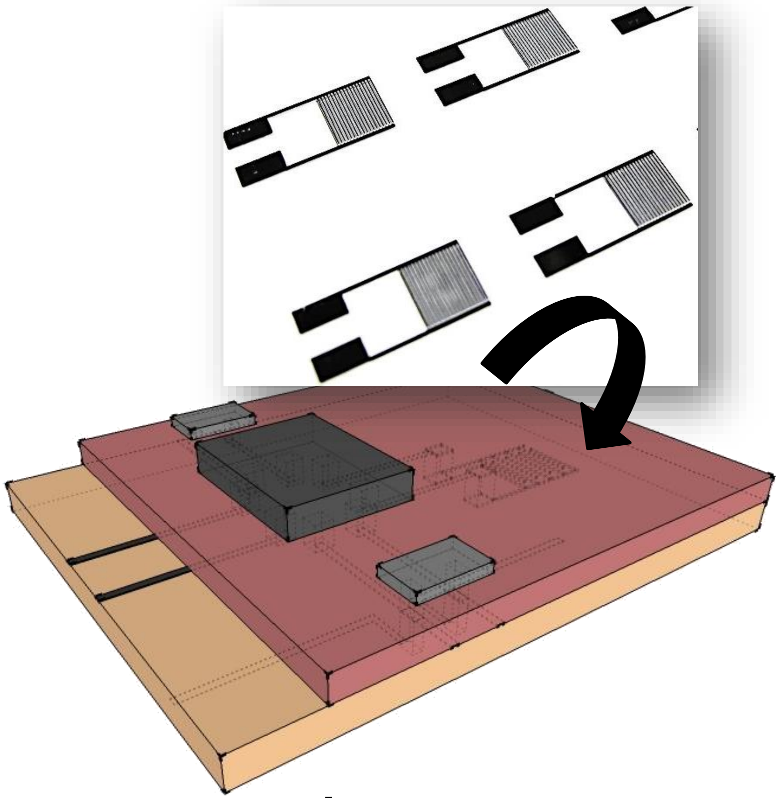

- Thinned silicon chips for flexibility: assembling design for <u>neutral plane</u> at the interface

# Foil integration strategies

**Foil-to-Foil (F2F)** — **VS** — **One foil (1F)**



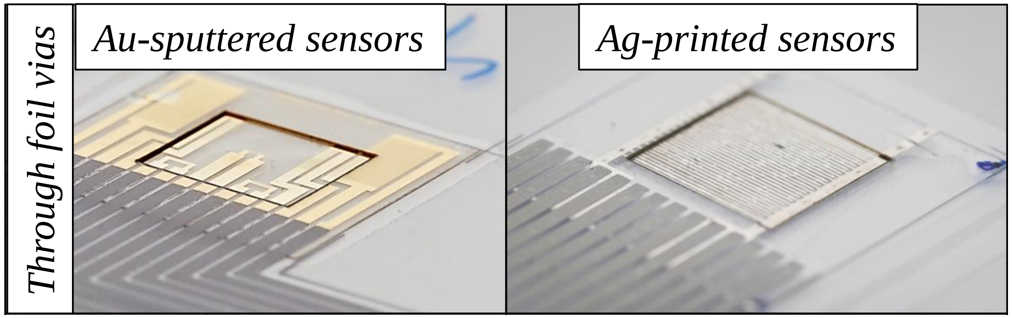
- **Increase system versatility**
- **Accelerate design feedback-loop**
- **Increase fabrication yield**
- **Overcome compatibility issues**



- **Less process steps**
- **Mature process flow**

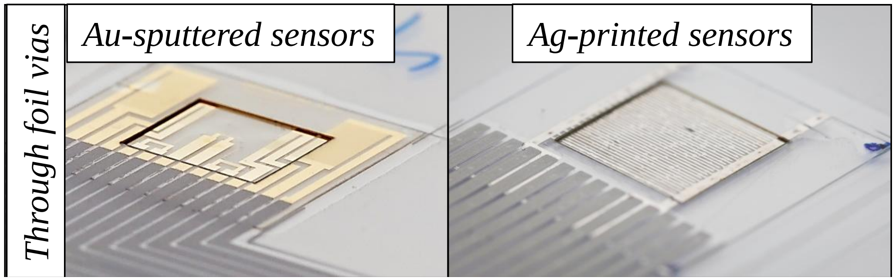
# Interconnection techniques

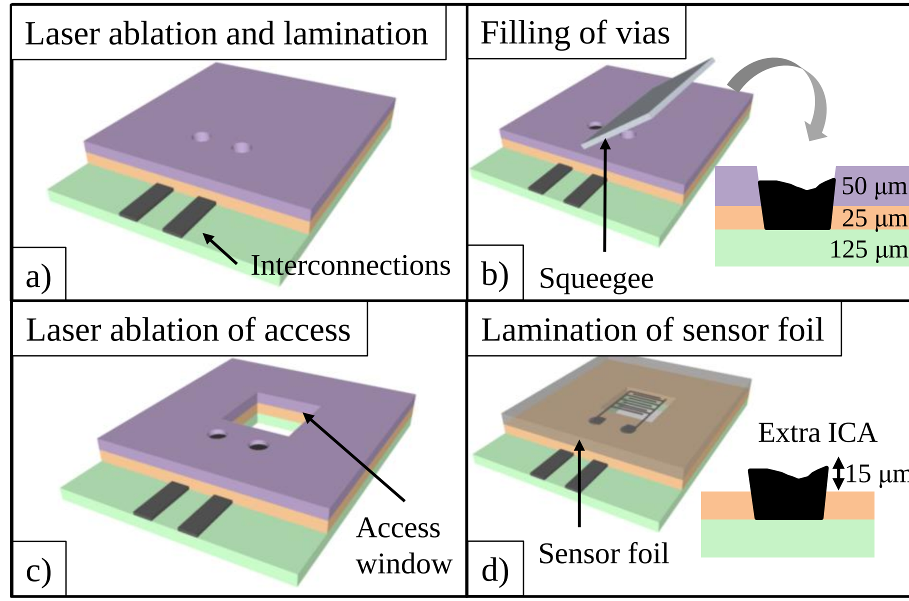
1. **Through foil vias (TFV)**
   - **Laser-ablated vias (180µm) through PSA – pressure sensitive adhesive**
   - **Screen-printing of ICA to fill the vias**
   - **Curing (time depends on temperature): not optimum for high throughput**
2. **Anisotropic conductive adhesive (ACA) (higher cost at the moment)**
   - **Stencil-printed ACA (mechanical and electrical connection)**
   - **Thermodebonder curing (pressure and temperature/120°C, with specific profile for short time)**



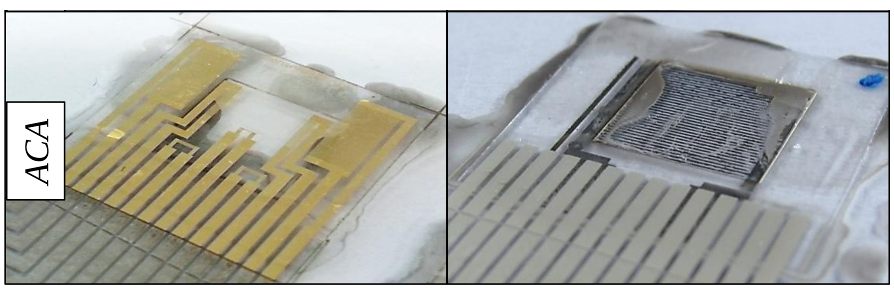
# Foil-to-foil integration: TFV vs. ACA

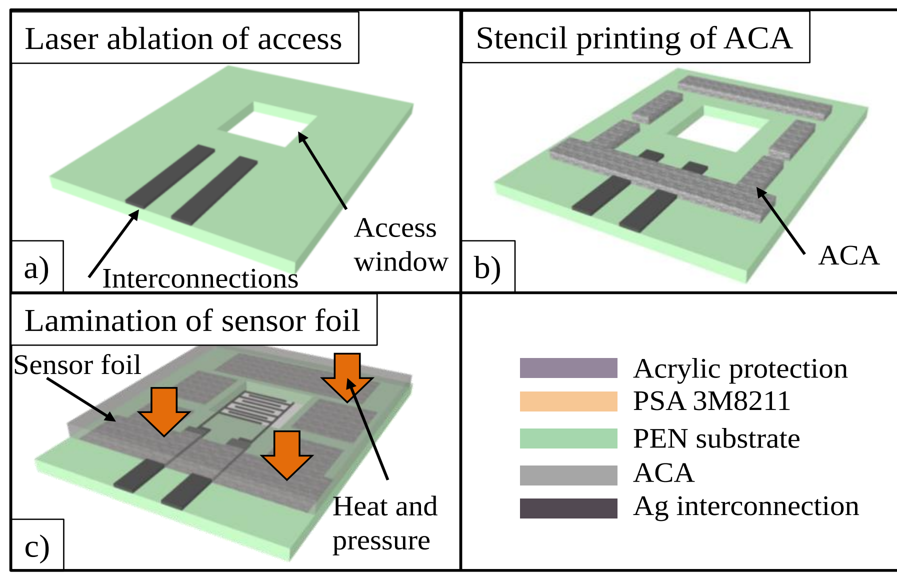
- Through foil vias (TFV)



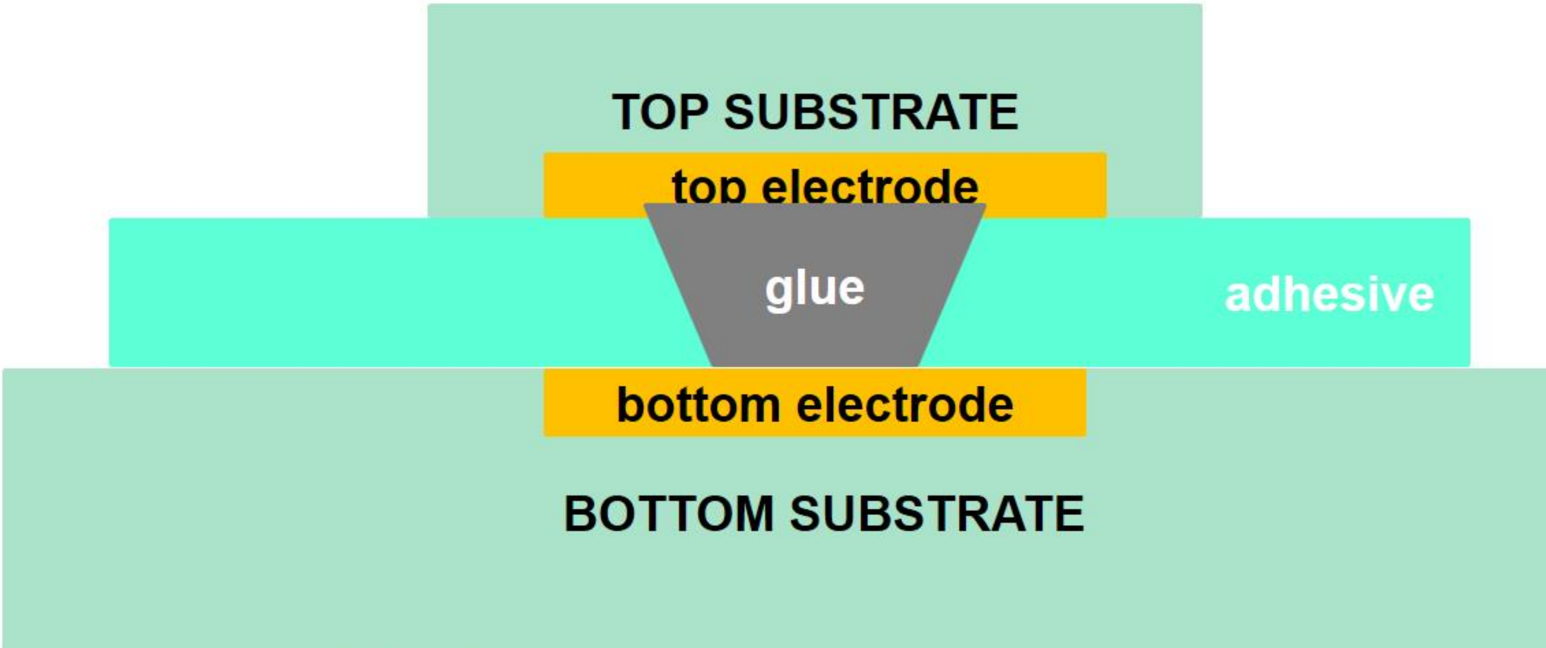

- Anisotropic conductive adhesive (ACA)



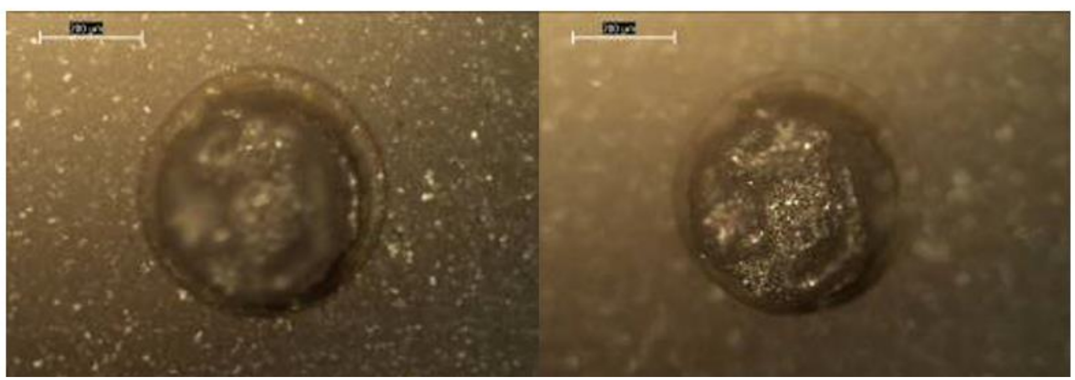




**A Vásquez Quintero et al. Micro. Eng.**

# Foil-to-foil: Laser ablated TFVs




Filled vias



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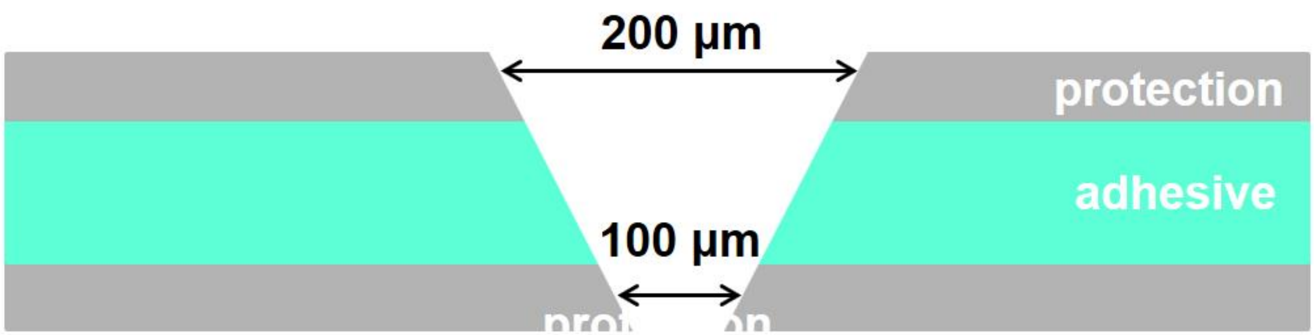


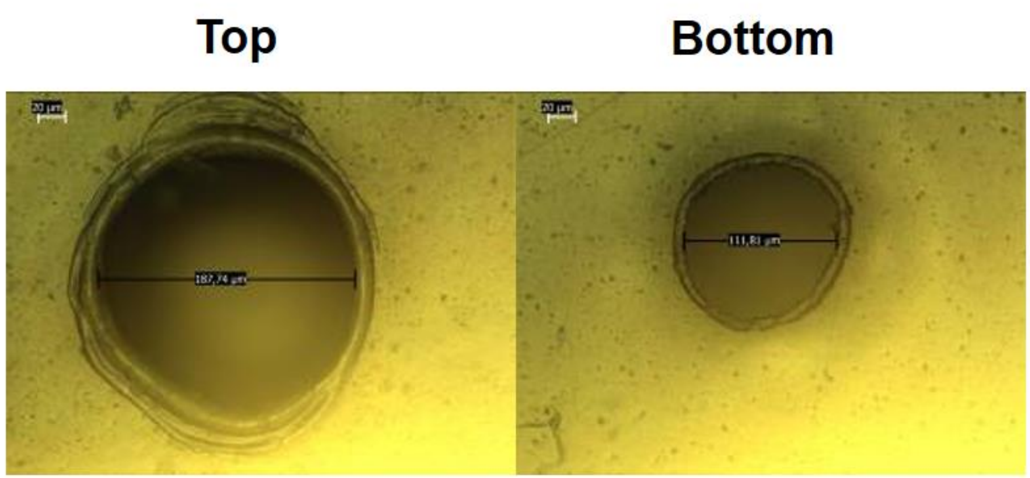

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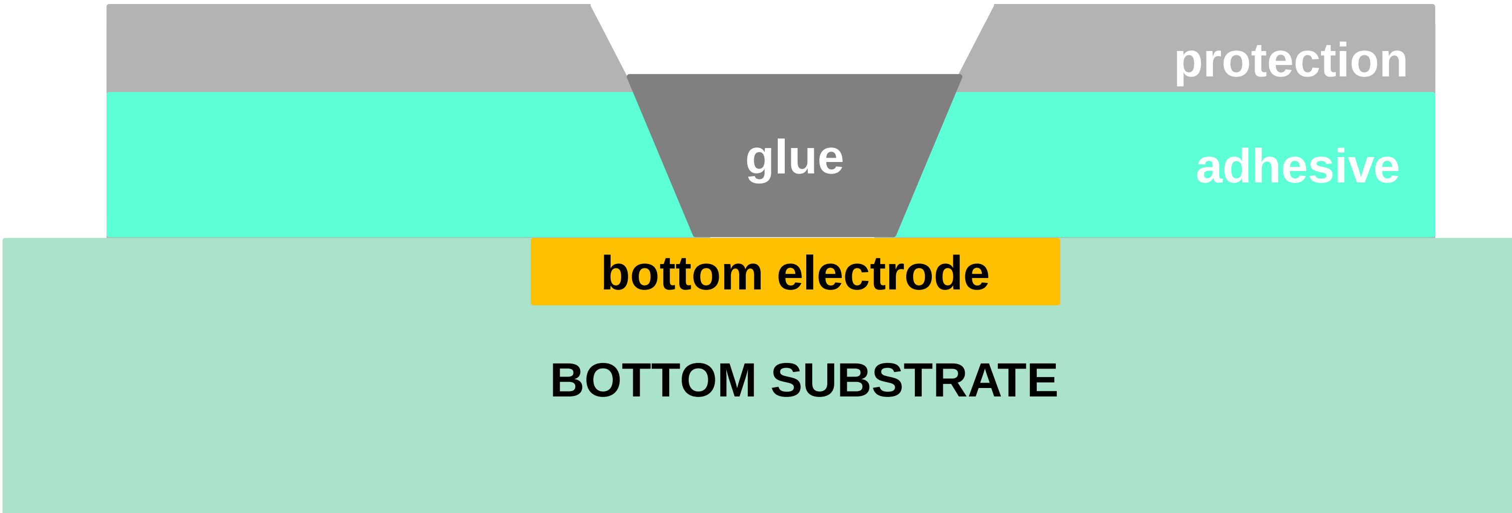


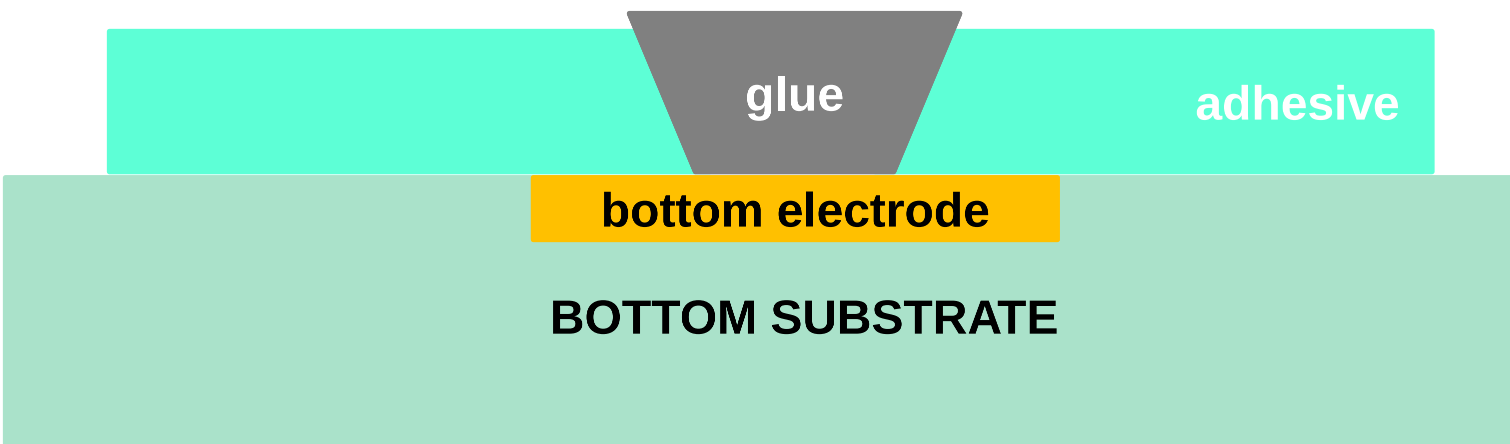

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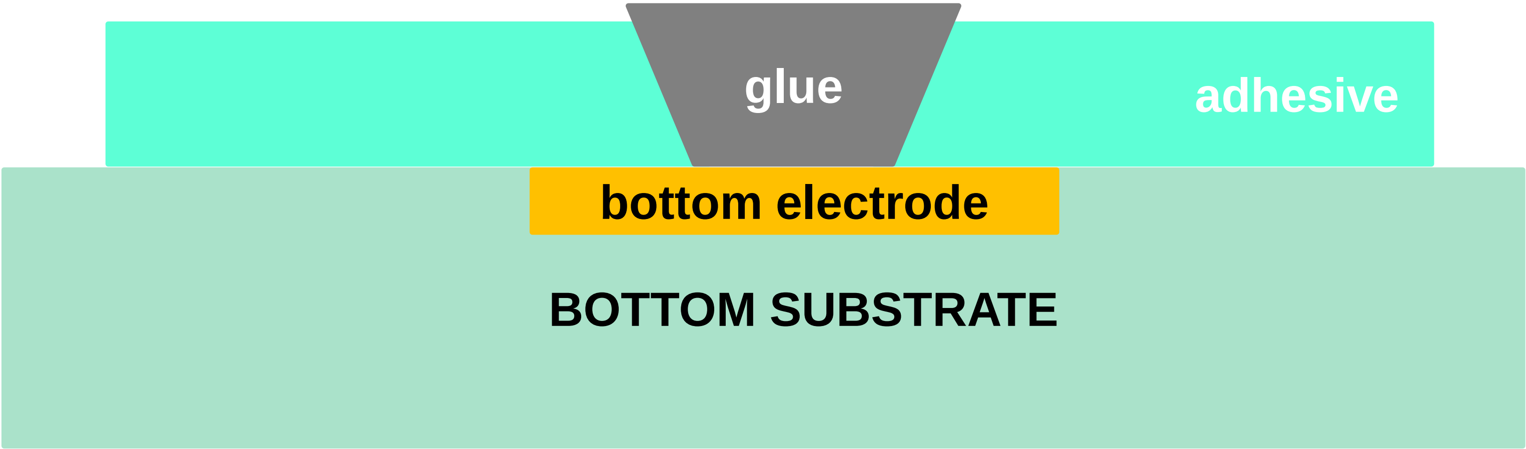
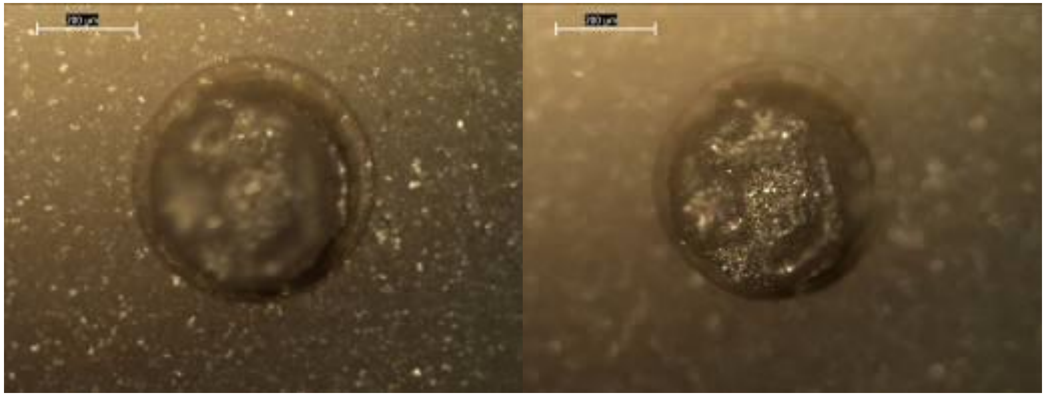
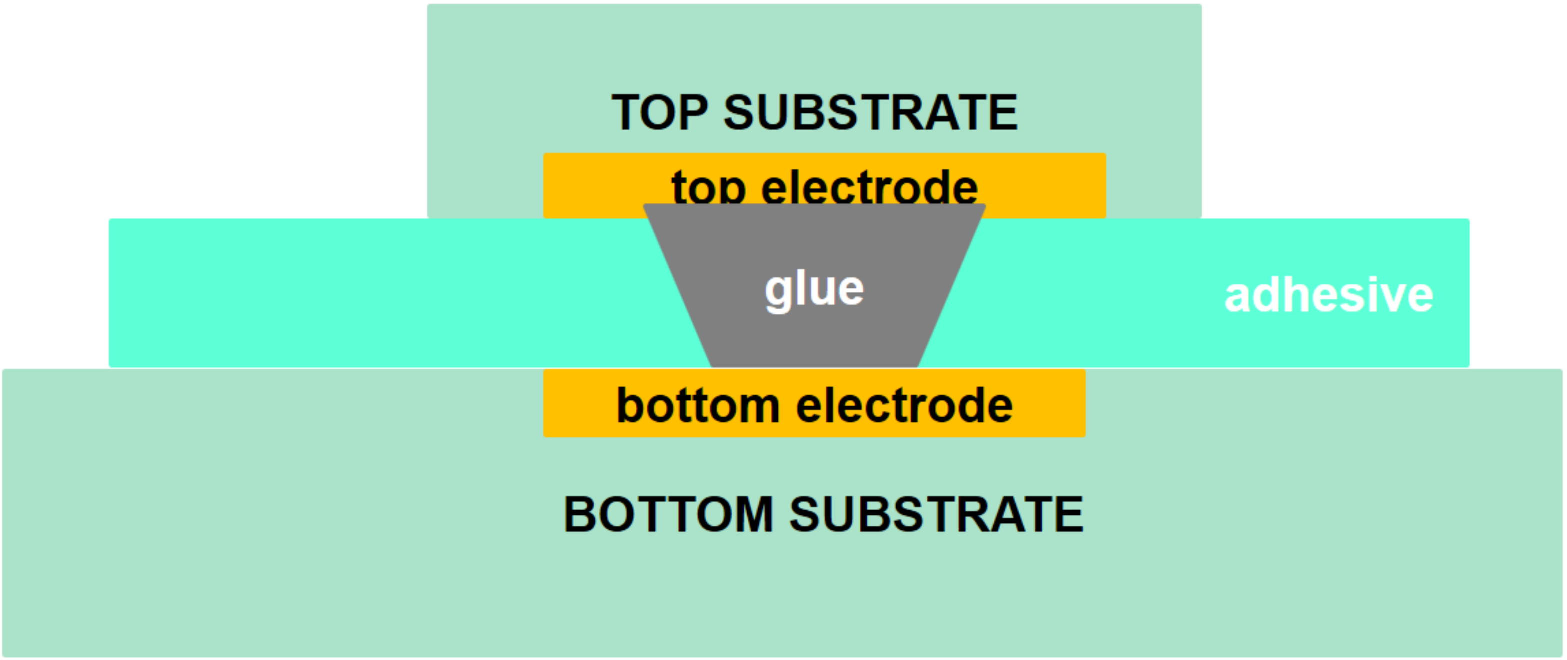



**Filled vias**

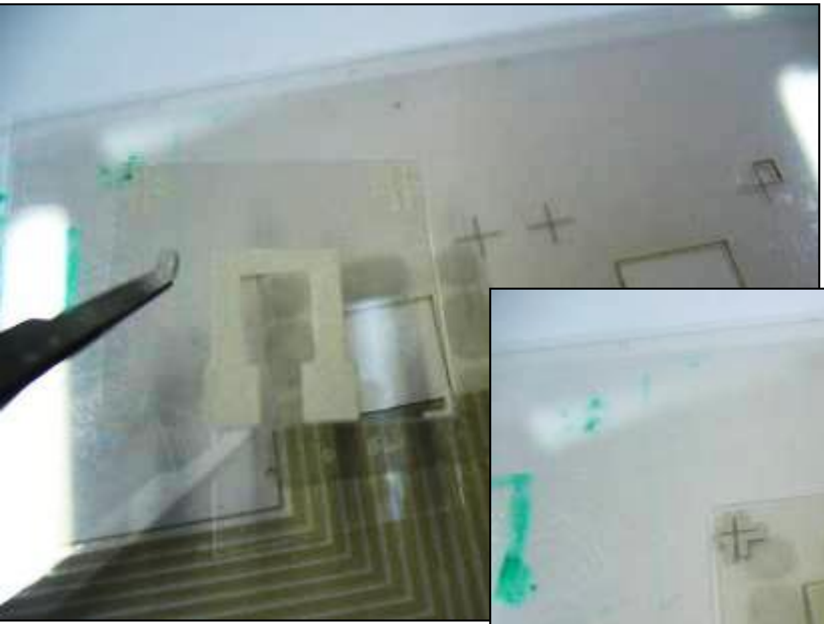


# Foil-to-foil: Laser ablated TFVs

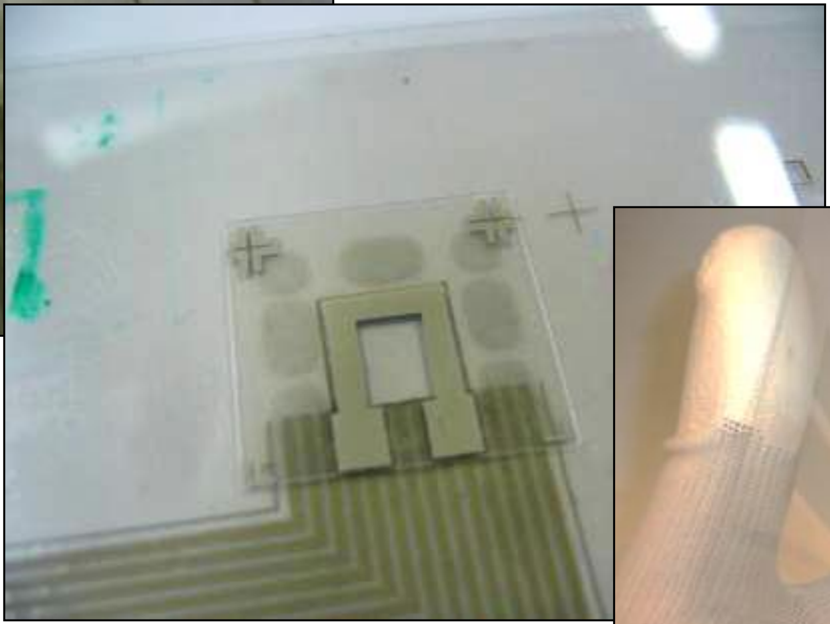


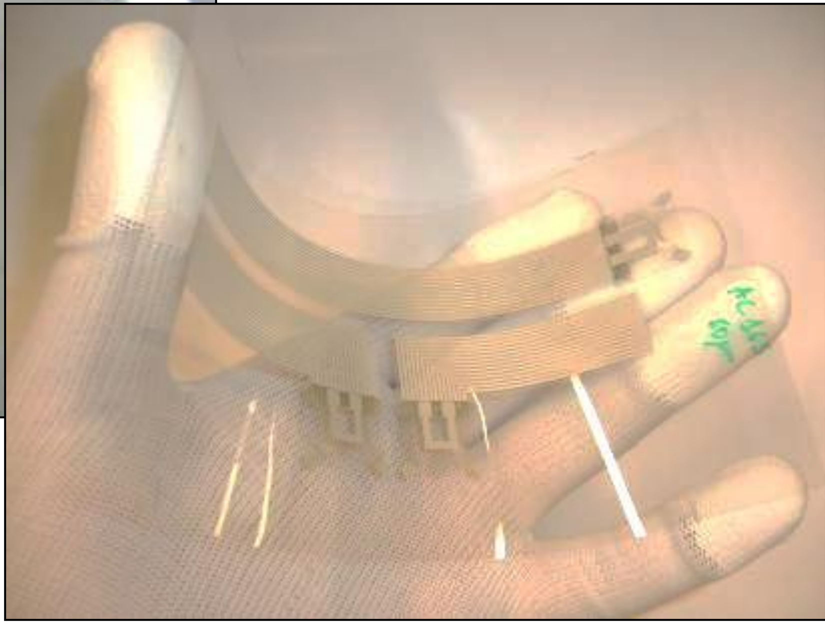

**Heat + pressure**

# Foil-to-foil (ACA)



**Anisotropic conductive adhesive approach**



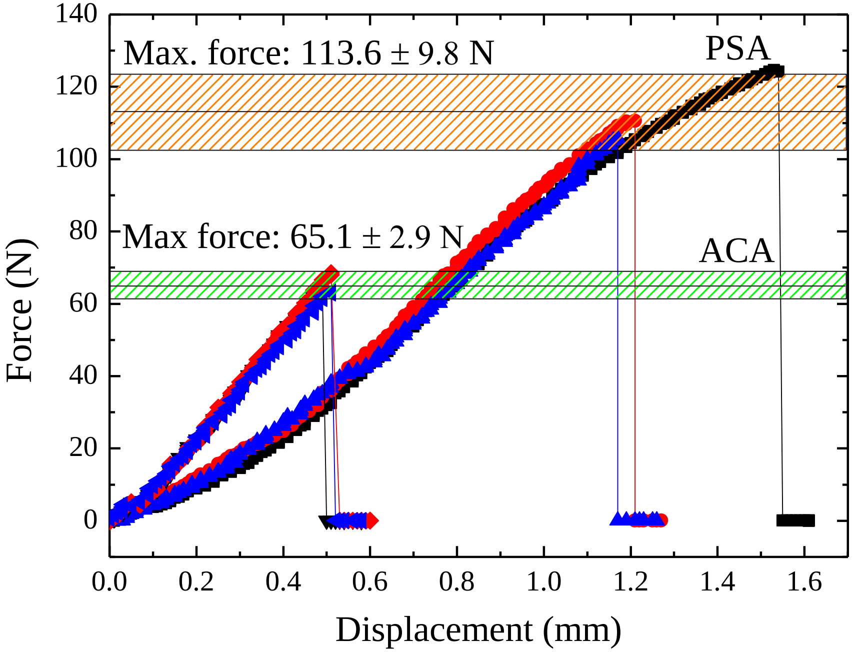


**Collaboration with Holst Center (NL)**

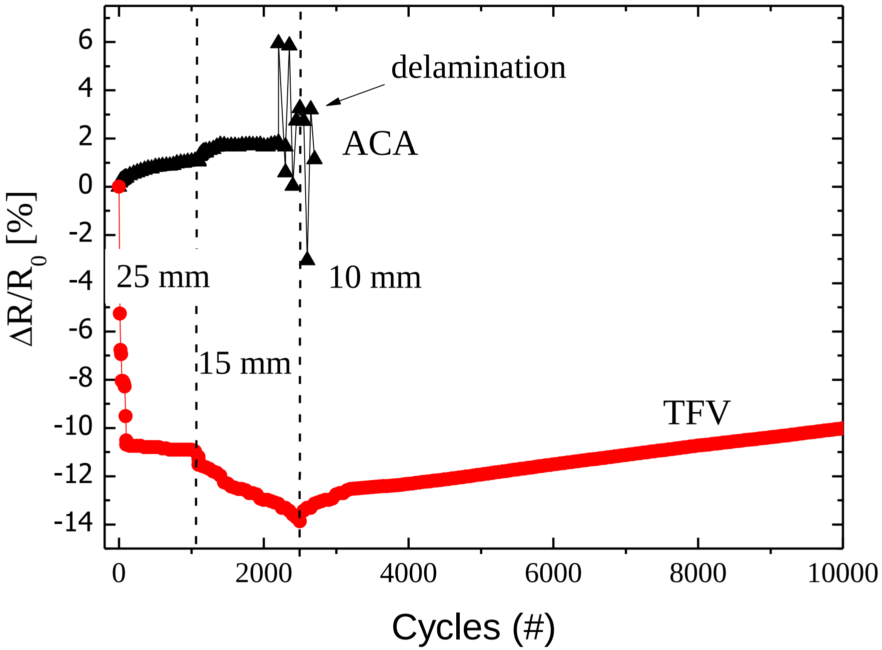
**A. Vasquez Quintero et al., Presented at LOPE-C 2012**

# Foil-to-foil integration: TFV vs. ACA

## Adhesion shear tests




## Bending tests

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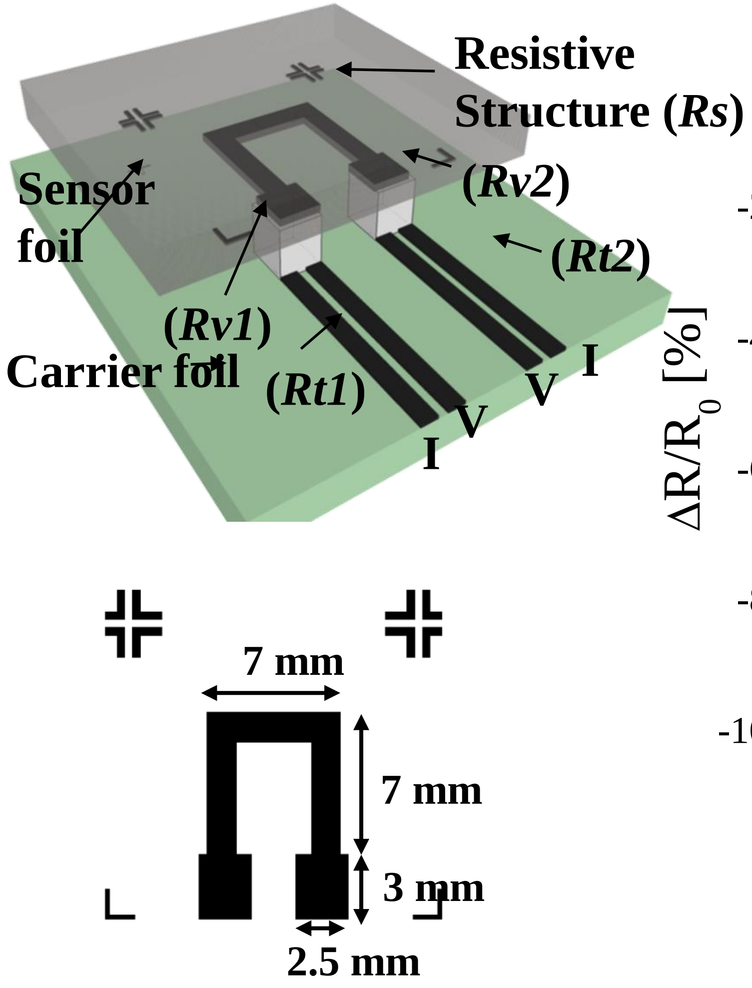
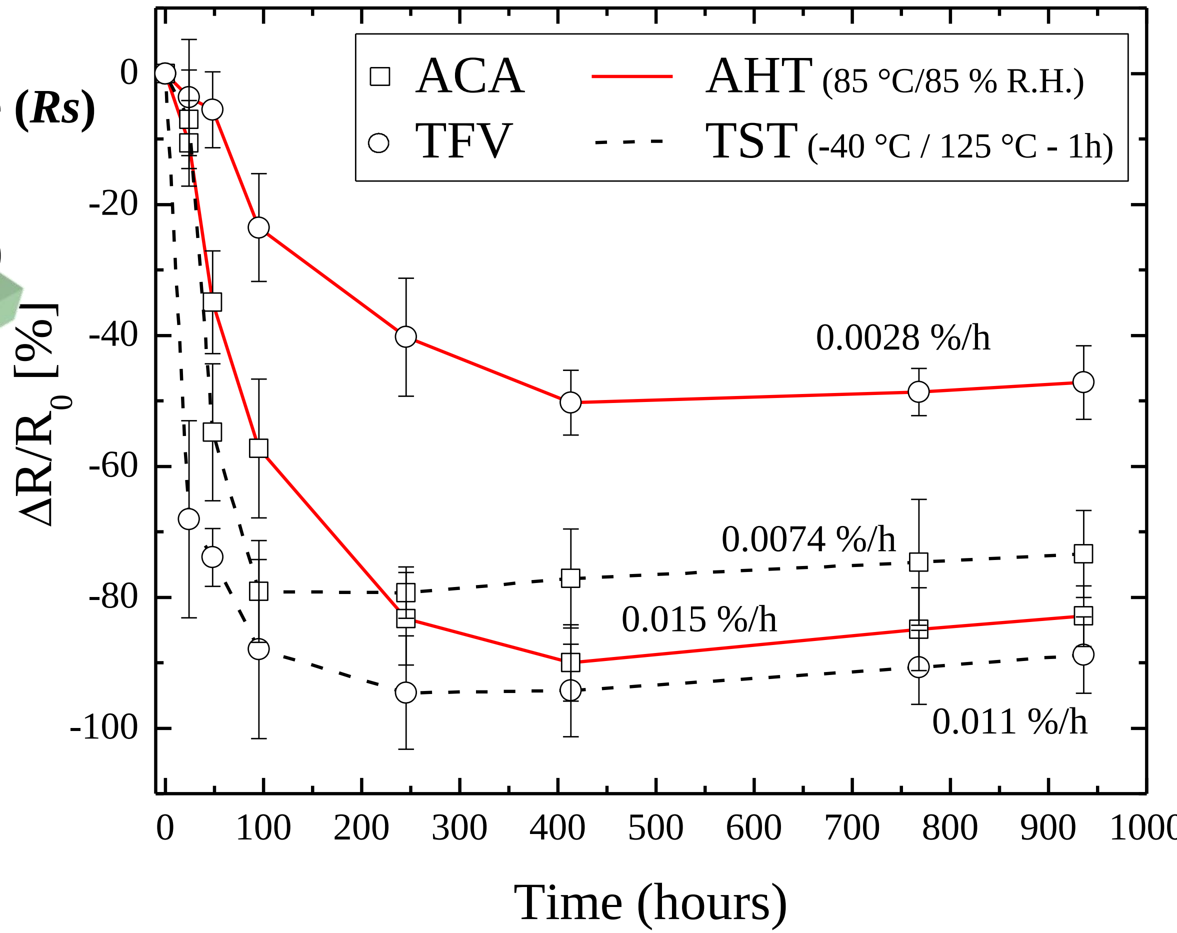
## Enviromental aging tests

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**For mechanical stability and protection against moisture:**

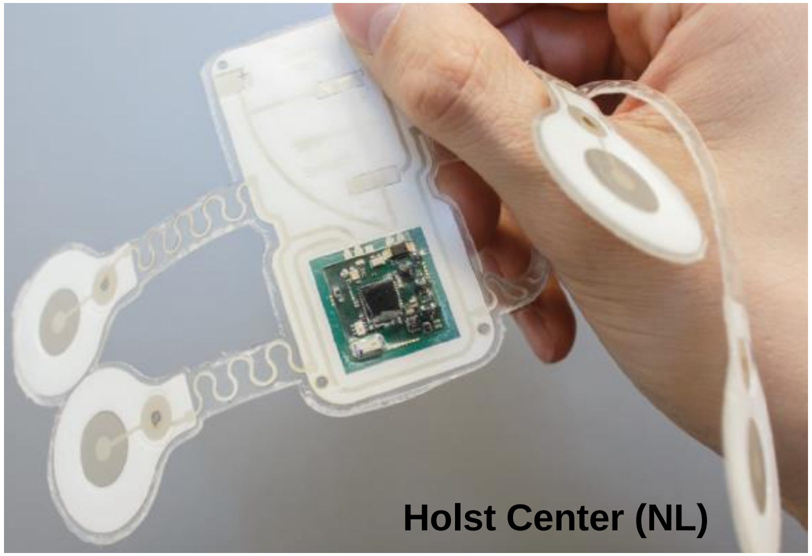
- Spray coating of polymeric protective layer
- Lamination with thermoplastic materials such as thermoplastic polyurethanes gives thin flexible systems
- Wearable electronics: silicones (hydrophobic and very flexible) are common encapsulating materials. Silicones are typically casted or molded

Main issues:

- Temperature and adhesion

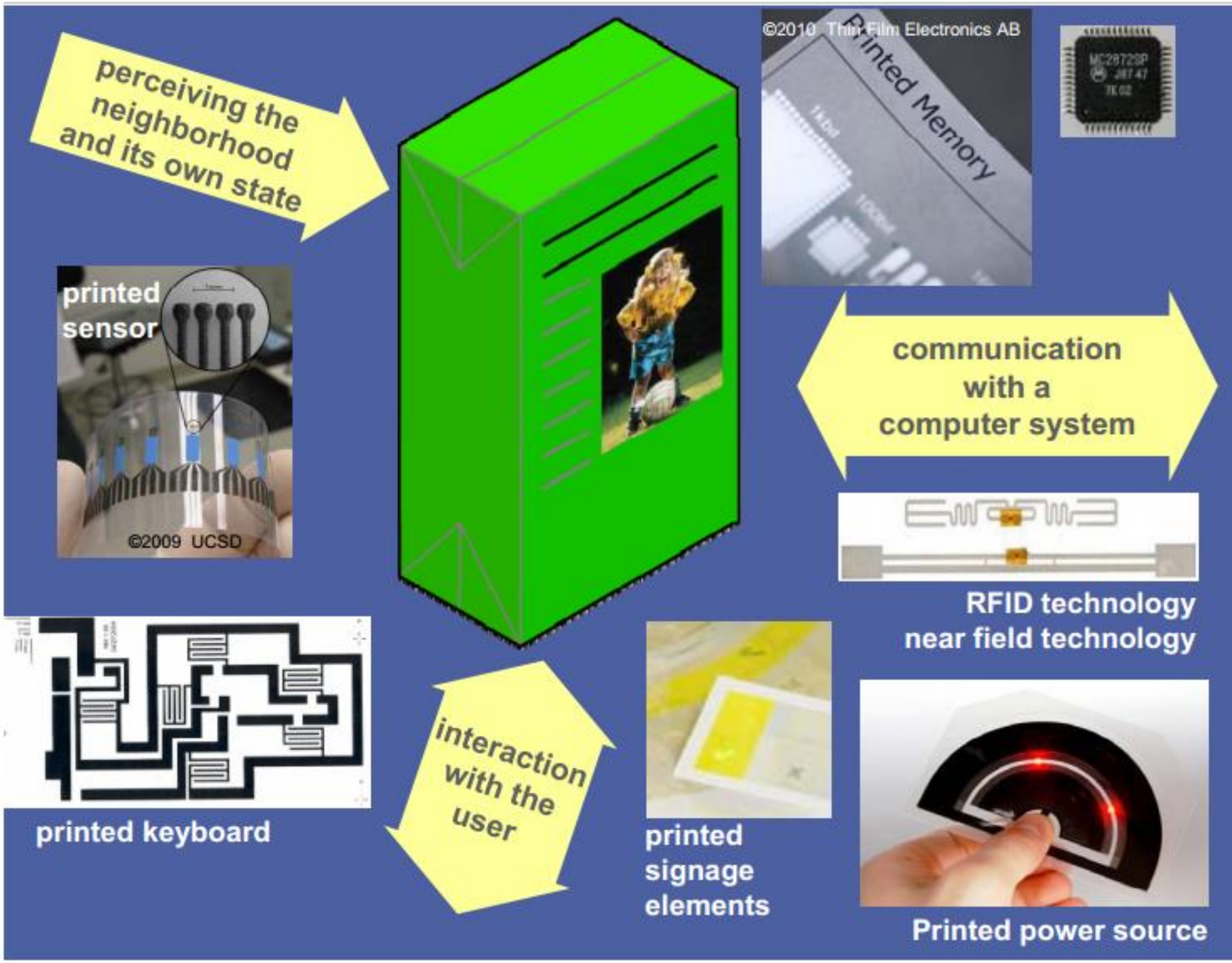
**Dicing / shaping:**

- Blade cutting possible
- Mainly laser etching especially if rounded shapes




health patch encapsulated with thermoplastic polyurethane

# OPE smart systems




**Memory**
- Thin film memories
- Printed memories

**Silicon electronics**
- Communication protocol
- Measurement functionality

**Digital logic**
- Organic FETs
- Electrolytic transistors
- High frequency rectifiers
- Power amplifiers

**Sensors**
- Pressure sensors
- **Keyboards**

**Display**
- Electrochromic
- Electrophoretic (e-ink)
- EL
- OLED

**Power sources**
- Batteries
- Solar cells
- Fuel cells

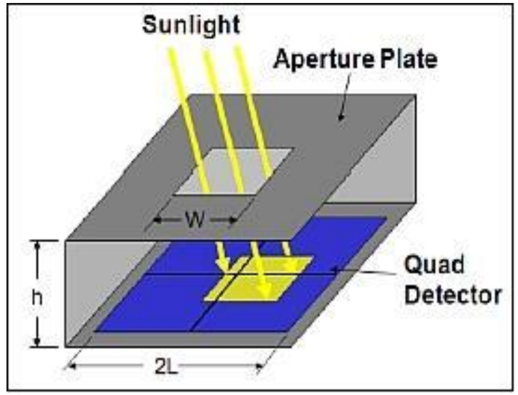
**Passive components**

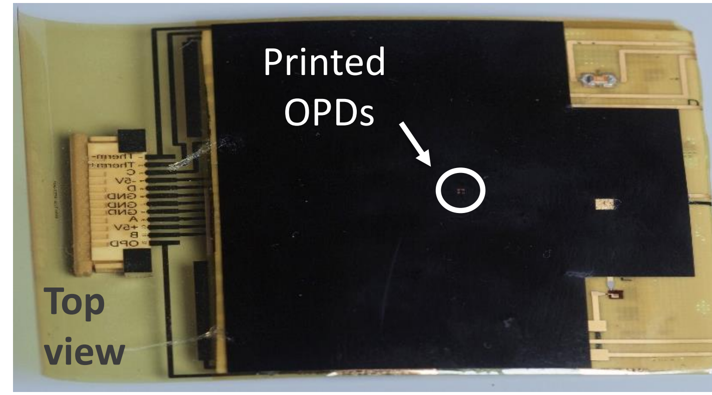
**Antennae**
- UHF & microwave dipoles

**From R. Baumann, TU-Chemnitz**

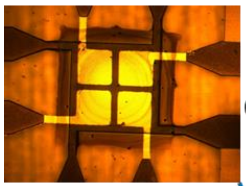
# Hybrid smart photodetector system

**Image credit:**
**The Aerospace Corporation**



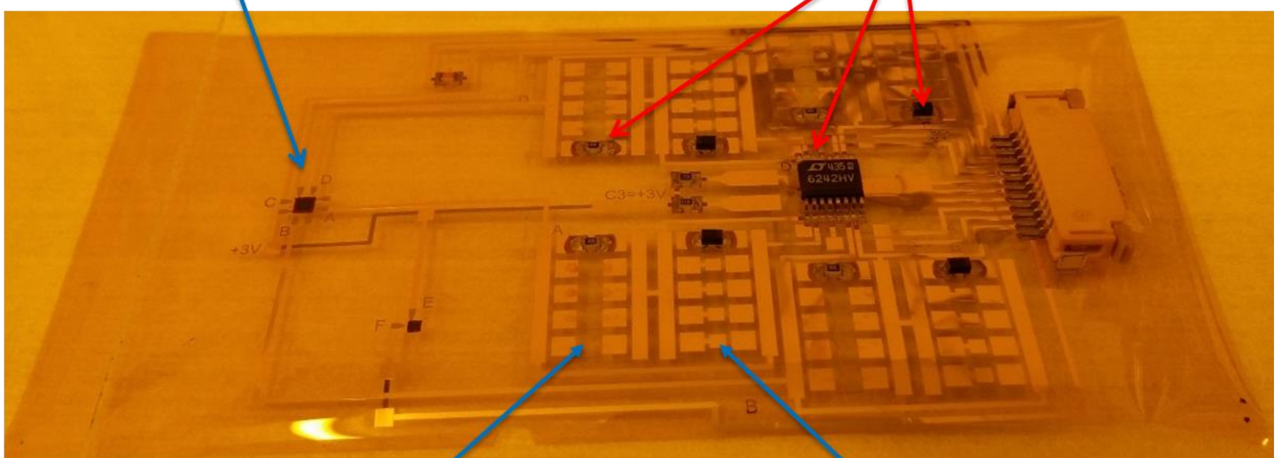



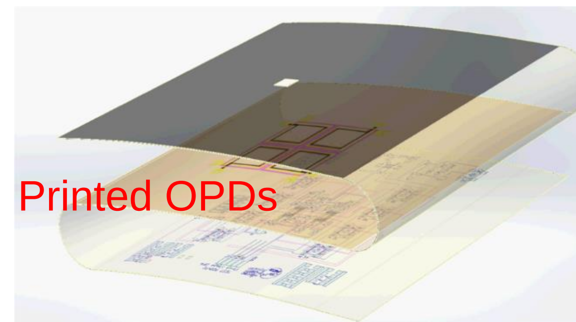

Folded module



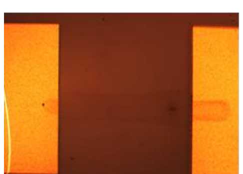
Printed
quad sensor

SMDs



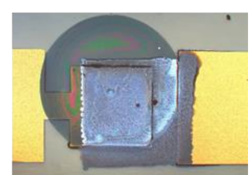



Printed passive
components and SMDs



Printed
resistors

Printed
capacitors

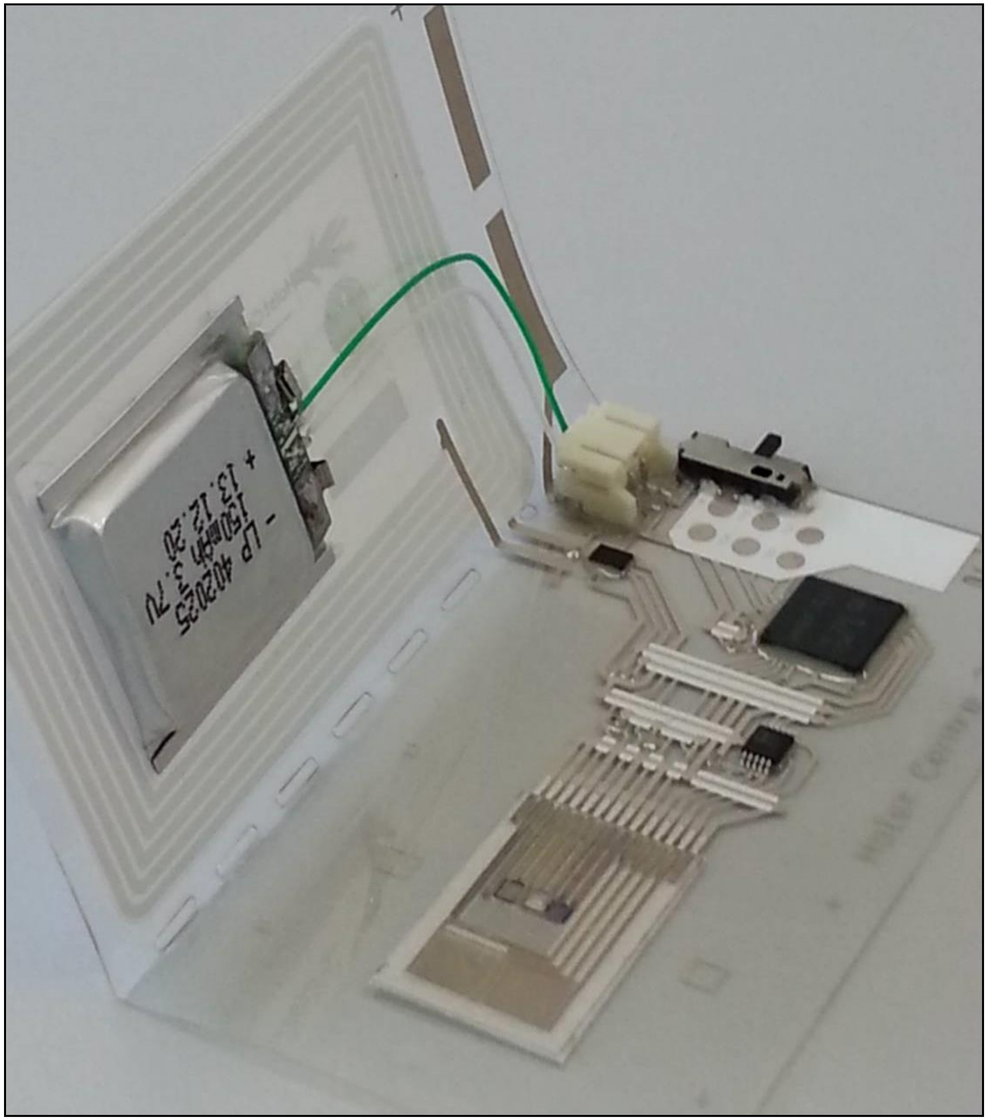


# Hybrid smart sensing RFID label

**Reverse engineering case study for the last session**

**Instructions are available on the moodle**

**TO BE DONE AT HOME**




**EU project FlexSmell**

# In-mold electronics

- **Inserting thermoformed printed electronics into a product without using a standard printed circuit board**

– Flexible circuit printing, surface mounting electronic components, thermoforming, in-mold labeling and injection molding.

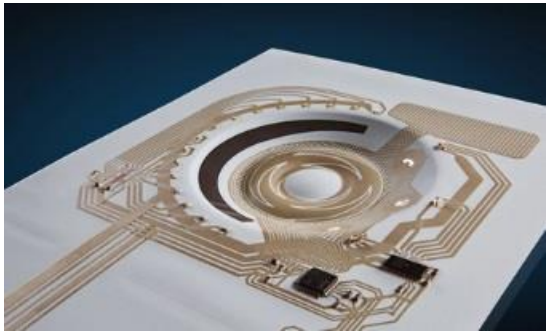
– TactoTek starts with in-mold labeling (IML) material. Decoration, if desired, is printed, followed by conductive circuitry, printed touch controls and/or printed antennas.

– Electronic components are mounted using standard high speed pick-and-place machinery.

– Electronics can be as simple as LEDs or as complex as microprocessors and are affixed to the IML using specialized adhesives able to withstand the temperature and pressure associated with injection molding.

**Molding materials**

High pressure, high temperature plastics such as polycarbonate (PC), acrylic (PMMA), acrylonitrile butadiene styrene (ABS), and for flexible designs, thermoplastic polyurethane (TPU)



TactoTek

# In-mold electronics

- **Inserting thermoformed printed electronics into a product without using a printed circuit board**

**Building blocks** at Tactotec

Circuitry—printed flexible circuitry and wiring harness

Lighting—single/multi-color indicators, ambient lighting, logo/branding, animated lighting

Controls—printed capacitive touch controls molded into plastic surfaces

Sensors—ambient light, impact, stress, proximity, accelerometer

Antennas—NFC, Bluetooth/WLAN antenna

Integrated Circuits—MCU, BLE

TactoTek

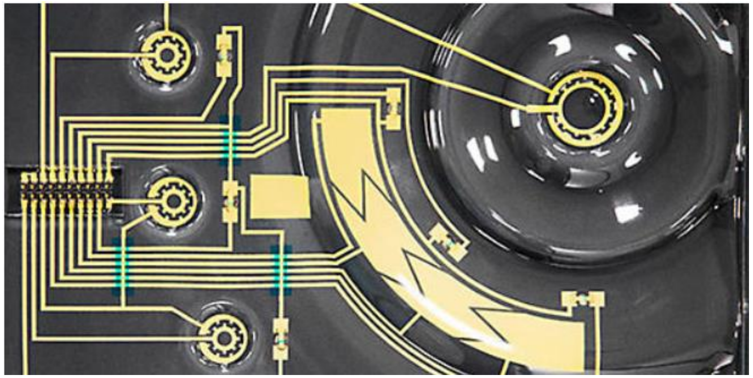
- **Inserting the electronics into a product without using a printed circuit board, a module, or even a system-in-package**

**More than 70% lighter**
Buttons and wires account for most of the weight in conventional switches. In-Mold Electronic Technology eliminates them both.

**Up to 30% less cost**
With fewer parts and manufacturing steps, In-Mold Electronic Technology makes production simpler and more efficient than even before.

**Part assembly time cut by 40%**
Assembly is a single-connection, “snap-on” process, significantly reducing assembly time while increasing reliability and enhancing ease of service.

**New design freedom**
Your ideas are no longer constrained by the need to conform to bulky circuitry. Capacitive LED switches can now be arrayed anywhere, in virtually any shape.



Dupont & Holst center: Center console in vehicules:
- Stretchable silver ink on thermoformed polymer
- 1.5 mm thick with injection molded polymer

# Some questions

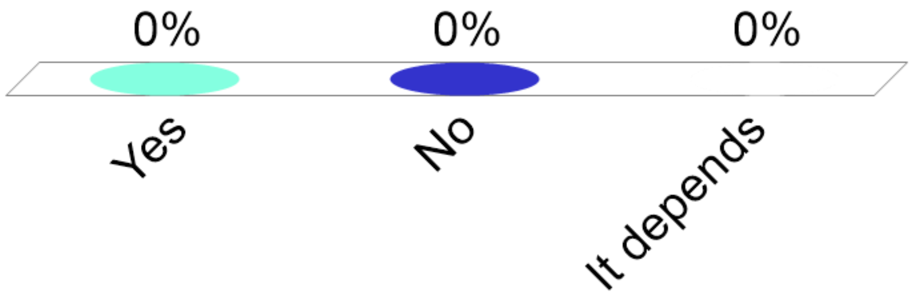
- Hybrid printed electronics vs. all printed
  - Advantages, drawbacks, status
  - Typical proces flow
- Methods for integration with a focus on ICA and ACA
  - Silicon to foil
  - Foil to Foil
- Finishing / Encapsulation: coatings and lamination
- Process flow for making RFID tag without and with sensors (i.e. linked to the case study)

# Q1: Can we call hybrid printed electronics an OLED component integrating sputtered or evaporated Ba or Ca cathode ?

A. Yes

B. No

C. It depends



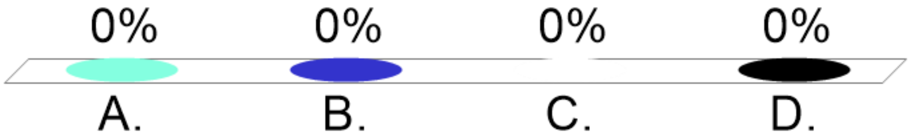
# Q2: What is a typical size for contact pads on a CMOS chip?

A. 500 um to 1 mm

B. 250-500 um

C. 100-250 um

D. 25-100 um



# Q3: Which of the following methods are adequate to interconnect electrically silicon bare chips to a PET foil PCB ?

A. **Isotropic conductive adhesive**

B. **Soldering**

C. **Inkjet printing**

D. **Wire bonding**

E. **Anisotropic conductive**