Large-area stretchable microsystems; potential for food packaging applications

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Functionality in Si: technological success story of 20\textsuperscript{th} century

And continuing....

Calculating power or memory per Si area

Diverse functionality: MEMS, Si photonics, high voltage transistors,...

Apple iPhone 5

Accelerometer
Gyroscope
Magnetometer
xMP CMOS camera
GPS
....
....however, not matched by the evolution in packaging & interconnect technology

Mainly still rigid or rigid-flex boards with bulky components mounted on top

Apple iPhone 5

Standard flex with standard surface mount devices (SMD)
Increasing demand for wearable, implantable, ‘ambient’ electronics and sensor systems

→ Requires drastically novel form factors to replace the classic PCB
→ Requires ultra-thin and conformal electronics

→ Electronics that can be deformed into any shape, elastically or 1 time
Outline

CMST?

Stretchable large-area microsystems

Stretchable low-cost optical gas sensors

Stretchable membranes
CMST; Centre for Micro Systems Technology

Department of ELIS (Electronics and Information Systems),
Faculty of Engineering and Architecture, Ghent University

~55 people, strongly project driven research, active in 17EU projects

CMST is an associated lab of imec, an intl. R&D centre on nano-electronics centered in Leuven, and one of the Flemish SOC’s (Strategisch Onderzoeks Centrum)
CMST participates in several of imec’s Industrial Affiliation Programs (IIAP)

CMST participates in several of the research programs of Holst Centre

CMST is a member of e-poly,
The centre for advanced polymer based microsystems and applications

UGent IRF consortium of 8 complementary research groups active in the field of polymer based microsystems (technology and applications)

Research Valorisation Manager; Frederik Leys
‘Microsystems technology’ is a very broad domain...

Focus of CMST is on

Packaging and opto-electric interconnect technology platforms to make **flexible or stretchable microsystem solutions**
Processing @ Technologiepark Zwijnaarde

700m² cleanroom, 0 2004
Class 100, 1000 and 10,000
Currently run @ full capacity
Outline

CMST?

Stretchable large-area Microsystems

Stretchable low cost optical gas sensors

Stretchable membranes
Vision and approach towards stretchable electronics

- Start from off-the-shelf sensors and electronic components
- Assemble components on small flexible PCBs → ‘functional islands’
- Interconnect functional islands by stretchable wiring
- Embed the entire system double-sided in an elastic polymer foil, such as PDMS
Vision and approach towards stretchable electronics

Two-fold research focus:

Technology to make the islands
- ultra-thin / as flexible as possible
- smaller area / higher component density
- low-cost

Technology to make a reliable stretchable matrix of the flexible islands
Vision and approach towards stretchable electronics

Technology to make a reliable stretchable matrix of the flexible islands
Stretchability

Cu, (or Au, Ag,..) are intrinsically not, or very little stretchable

→ How to obtain stretchable interconnections

1) without changes in conductivity during stretch/release
2) which are reliable → integration in eg textile implies many stretch/release operations during use + significant pressures during washing etc.

1) Without changes in conductivity

Pattern Cu interconnection lines in meandering shape

→ 2D springs, in-plane of PCB
2) **Reliable stretchable interconnections**

Simulations show that ‘horse shoe ’shaped meander is optimal geometry.

Stresses during elongation are locally too high.

Multi-track horse shoe meander
2) **Reliable** stretchable interconnections

Crack propagation can be postponed by introducing a supporting meandering polymer material underneath the Cu

- Au meanders
- Poly-imid supporting layer
- Width 200um
2) **Reliable** stretchable interconnections

Smooth stretch-flex transition is essential
Reliability tests: cyclic stretching incl. impact of moisture, temperature, etc.
Process flow
(compatible with standard PCB processing! → ‘lab-to-fab’ ongoing)
Double sided embedding in stretchable polymer, for instance PDMS

System completely embedded in stretchable material

Remove carrier

Top embedding

Bottom embedding

Removal of molds
Infant respiratory activity monitoring
(in collaboration with Verhaert, FP6 ‘Stella’)

Polyimide
Copper
Soldermask
Flexible island

Temporary flex connector

Respiration sensor connections

Buzzer connections

Smooth flex-stretch transition

Embedded in Dow Corning Sylgard 186
Vision and approach towards stretchable electronics

Technology to make the islands
- ultra-thin / as flexible as possible
- smaller area / higher component density
- low-cost
Towards optimised functional islands

**Ultra –thin / as flexible as possible**
Bare chip die is between 300 and 700micron thick, but all functionality is contained in thin top layer → can we work with bare and ‘thinned down’ dies?

**Smaller area / higher component density**
Can we stack components in 3 dimensions, reducing the island area?

**Low-cost**
Standard chip package is up to 50% of the chip cost → can we think of other packaging concepts?

Standard poly-imid substrate material is up to 10x more expensive than eg PET → can we switch to other substrate materials?
UTCP : ultra-thin chip package

1) Bare dies are thinned down to 20 micron (using CMST proprietary process)

Works for commercial off-the-shelf components!
← e.g. Texas Instruments micro controller

+ below ~30micron, Si dies become flexible

2) Thinned dies are packaged in between two 20 μm thin flexible polyimide layers
UTCP: ultra-thin chip package

3) Wire bonding to lead frame is replaced by contact vias and metallisation and plating

- Laser-pattern contact vias to chip contacts (metal bumps required on die (Ni/Au))
- Metallisation Interconnect layer, lithography and plating
- + release from carrier
UTCP integration on/in flex PCB

UTCP can be solder assembled as Surface Mount Device on flex PCB

UTCP can be laminated between two flexible circuit boards

→ other components can be assembled on top
   → 3D integration
   → smaller surface area

~ 50um
Comparison UTCP vs. standard flex technology

3D integration of TI microcontroller
Low-cost? → From lab to fab

UTCP: LAP (Large Area Production) necessary to be cost-effective

Lab: single die, placed in center of substrate, die alignment not critical

Fab: multiple dies, distributed over large substrate, alignment accuracy ≈ die bond pad size
Multiple dies per panel @ HighTec (Switzerland)

- Use of semi-automatic Palomar Pick & Place machine
- Example: 150mm (6”) square glass, with 180 positions per panel for UTCP EEPROM chip

Finished UTCP panel (56 chips placed)

Detail (central part)
Low-cost? → Switch to PEN, PET, Polyurethane,…

In close collaboration with Holst Centre, System-in-Foil program

Smart label, incl. Moisture & T-sensor transceiver

See the Holst presentation on printed electronics for more details
Towards optimised functional islands

Ultra –thin / as flexible as possible
Bare chip die is between 300 and 700micron thick, but all functionality is contained in thin top layer → can we ‘thin down’ chips? YES

Smaller area / higher component density
Can we stack components in 3 dimensions, reducing the island area? YES

Low-cost
Standard chip package is up to 50% of the chip cost → can we think of other packaging concepts? YES

Standard poly-imid substrate material is up to 10x more expensive than eg PET → can we switch to other substrate materials? YES
UTCP combined with stretchable interconnects
Interest in using biopolymers / biodegradable systems → route to reducing electronic waste

Inductive link, driving a LED, embedded in PDMS

Same Inductive link, embedded in PCL (Polycaprolactone) = biodegradable polymer
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Stretchable membranes
Polymer based waveguides

Silica fibre

SOI wave guide (IBM)

In polymer materials (low-cost)
Towards polymer based *stretchable* optical waveguides

- Micro-moulding in capillaries (MIMIC)
  - Bonding of 2 PDMS layers forming covered channels
  - Applying a drop of liquid core material at the inlet
  - Curing the core material when the channels are filled

Optical PDMS, with higher refractive index
Example of full polymer based optical system

Stretchable up to 30%, without significant loss
How can we use polymer waveguides as gas sensors?

1) Mix a gas-sensitive fluorescent dye in the cladding material before the MIMIC step

2) Remove cladding of the waveguide-array on one side (use air as cladding)

   \[ \text{core exposed to air} \rightarrow \text{gas can diffuse into the waveguide core (porous PDMS)} \]

3) Measure the change in fluorescence of the dyes due to the interaction with the gas
Gas sensor using core of polymer waveguide as gas-sensitive volume
Initial results using toluene: significant response via change in fluorescence!

Set-up

Fluorescence vs toluene concentration
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Stretchable membranes
Porous biocompatible polymer films

Patented method to make very thin (< 20um) porous polymer films

Applications a.o. in designing elastic bioreactors:
HEPSTEM (IWT-SBO, 2009-2013)
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