2.5D Smart Objects
Using Thermoplastic Stretchable Interconnects

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IMEC - CMST

Who we are
• Research group part of the imec BAN-group and part of Ghent University.
• Located at the Technologiepark in Ghent, Belgium.
• Own staff 55 researchers.

What we do
• Enabling technologies for **flexible and stretchable electronics**.
• Polymer photonics.
• Display technology.
• In close collaboration with **leading industrial partners** along the value chain.
IMEC - CMST

Ultra Thin Chip Packaging

Smart Wireless Tags
- radio chip
- humidity sensor
- micro controller
- antenna

Smart Contact Lens
Introduction

- Traditional electronics

Flat silicon wafer & chips

Rigid boards (PCB)

Rigid electronic components
Introduction

- Traditional electronics
  - Rigid boards
  - Flexible foils
Introduction

- Traditional electronics
  - Flexible foils
    - Dynamic, mechanical deformable elements
    - Reduce weight
    - Compactness
Next generation of smart devices requires integration of form and function!
Introduction

3D MID

- Thin copper layers.
- Vendor lock-in.
- Complex 3D assembly process required.

Flex Rigid

- Increased mounting complexity.
- Multi-layer
Introduction

Current methods are complex and have a high setup cost.

A better solution towards 2.5D free-form electronics?
Requirements:

- Use standard industrial equipment (avoid vendor lock-in),
- Standard SMT components,
- High temperature lead-free solder,
- High thermal and electrical conductivity,
- Integration in thermoplastic polymers (e.g. PC/ABS),
- Multi-layer interconnects,
- Free-form 2.5D shapes.
Introduction

- Thermoplastic parts shrink after high temperature steps.
- Changes in interconnect length during fabrication.
- Most plastics can’t withstand high-temperature reflow soldering.

Stretchable Interconnects

- “Light” version: No large cyclic elongation changes necessary.
- Encapsulation doesn’t need to be stretchable.
- Deformation using thermoforming becomes possible.
Introduction

Our approach:

- **Functional islands**, interconnected with **meander-shaped interconnects**.
- Based on existing **polyimide flexible circuit technology**.
SMI principle

- Temporary carrier to produce stretchable circuit:
  - Harsh PCB style steps (e.g. soldering) done in absence of embedding polymer.
  - High dimensional stability.
Introduction

1. Plastic film is heated past its glass transition temperature.

2. Forming tool is pushed upward against the plastic film.

3. Film is drawn against the forming tool using a vacuum.

4. Part cools down and retains shape; Forming tool is removed.
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Fabrication

- Circuit Board Production
- Assembly
- Encapsulation

- Carrier Board Preparation
- Remove Excess FCB Material
- Thermoforming

- Placement of Circuit on Carrier Board
- Definition of Meanders and Islands
- Trimming
Fabrication Process Flow

1. Flexible Circuit Board Application
2. Meander & Island Structuring
3. Component Assembly
4. Circuit Transfer Through Lamination

5. Peel Circuit from Carrier Board
6. Laminate Remaining Layers
7. Heat to Glass Transition Temperature
8. Vacuum Forming
Fabrication
Circuit Board Production

- Polyimide-based Flexible Circuit Boards (FCBs)
  (e.g. DuPont Pyralux, UBE UPISEL, ShengYi SF305, …)
  - Supplier independence,
  - Most standard features available (e.g. multi-layer, ENIG plating, …),
  - Assembly of components using SAC305 possible.

- Other FCB materials
  (e.g. copper on PET)
  also possible.

- Typically 18 µm Cu + 50 µm PI.
- Panelization possible.
Fabrication
Carrier Board Preparation

- Carrier Board Requirements:
  - High temperature stability (> 250 °C),
  - High dimensional stability,
  - Low adhesion to thermoplastic elastomers,
  - Temporary pressure sensitive adhesive.

- Adhesive: Taconic TacSil Tape FH20LB
  - Carrier tape for FCB assembly.
  - Highly reusable for high temperature steps. (> 500 cycles)
  - Glass fiber mesh coated with PTFE.
  - Available on rolls of varying widths.

Silicone based adhesives on rigid substrate.
Fabrication
Carrier Board Preparation

- Rigid substrate: FR-4
  - Easily available for most PCB manufacturers.
  - Cheaper variants (e.g. CEM-3) are possible.
  - Carrier tape can be removed to reuse the board.

- Preparation of Carrier Board:
  - Roll laminate PSA on FR-4 board.
  - Vacuum press cycle to remove trapped air.
  - Pre-bake in reflow oven using SAC305 profile.
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Fabrication
FCB Placement

- FCB is placed on carrier board using roller.
  - Minimizes air trapped between adhesive and flex foil.
  - Use minimal force to avoid stretching the FCB.

- FCB size does not have to equal carrier board size.

- Vacuum press step at this point is possible:
  - Completely removes trapped air.
  - Important for certain designs (e.g. very thin foils).
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Fabrication Outline Definition

- Outline of meanders and islands needs to be defined.
  - Cut through polyimide layer without damaging carrier board.
  - Precise alignment with circuit necessary.

- Laser cutting:
  - Available at many PCB manufacturers.
  - Optical alignment using etched fiducials.
  - Very high accuracy.
  - Ideal for small quantities of varying designs.
  - Fast systems are available. (> 20 cm/s)
  - Rinse using IPA after cutting to remove debris.
Fabrication Outline Definition

- Critical parameter: distance between outline and copper.
  - Increase in distance leads to higher yields.
  - Decrease in distance increases stretchability.

- Punching is an alternative for higher volumes.
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Fabrication Residue Removal

- Remove FCB material between islands and meanders.
- Ease of removal depends on design.
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Fabrication Assembly

- Assembly using lead-free high temperature solder (SAC305).
- Preference for no-clean flux.
  - Cleaning can damage or delaminate meanders.
  - Residue has no noticeable impact in rest of the process.
- Flat carrier board allows standard process flow:
  - Stencil print solder paste,
  - Pick-and-place components,
  - Reflow soldering.
  (e.g. IR, hot air, vapour phase, …)
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Fabrication Encapsulation

- Encapsulation using vacuum press.
  - Available at most PCB manufacturers.
  - Low cost compared to alternatives. (e.g. over-molding)

- Thermoplastic elastomers are excellent adhesive layers:
  - Available for several temperature ranges,
  - Good adhesion to a wide range of materials,
  - Excellent step conformation.

- Multiple materials available:
  - Thermoplastic polyurethane (TPU)
  - Ethylene Vinyl-Acetate (EVA)
  - …
Fabrication
Encapsulation

- Lamination of non-flat surfaces?
  - Components are highest features.
  - High forces can easily break fragile components.

- Rogers BISCO Foam HT-870 as press pad.
  - Silicone foam rubber,
  - Allows lamination of high aspect ratio components.
  - Stable up to 200 °C.
  - Avoids custom vacuum press tooling.

- Laminate TPE on-top of circuit.

Equal pressure distribution necessary
Fabrication Encapsulation
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Fabrication Encapsulation

- Removal of carrier board
  - Adhesion between TPE and circuit > Adhesion between circuit and carrier
  - Most TPEs have very low to no adhesion to the silicone PSA.

- Carrier board can be peeled off.

- Repeat same procedure to laminate rigid thermoplastics sheets to the TPE film.

- Top rigid sheet can be laminated at same time as first TPE film.

- Symmetric laminates desirable.
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Fabrication
Thermoforming

- Multiple processes available. (e.g. vacuum forming)
  - All based on same principle (see introduction),
  - Forming temperature range: 140 – 200 °C

- No machine modifications required.

- Alignment of sheet vs. tool is important.
Fabrication
Vacuum Forming
Fabrication

Trimming

- Cut off edges used for clamping during thermoforming.
- Normally done using punching or routing.
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Example Devices
Mini LED Dome

Out-of-plane buckling due to shrinkage and stretching of thermoplastic materials after forming.
Example Devices
Mini LED Dome

- Integrates ten 0603 LEDs in 5 parallel chains.
- Formed over half 50 mm sphere.
- Power supply connection on outer ring.
Example Devices
Connector Integration
Example Devices
Ghent Light Festival Demonstrator

- Thirty five mid power LEDs formed over elliptical tool.
- Devices tested under real world conditions.
Example Devices
Ghent Light Festival Demonstrator
Example Devices
Ghent Light Festival Demonstrator
Summary

- Method to integrate circuit in thermoplastics.
- Based on flexible circuit technology.
- Stretchable meander interconnect necessary.
- Advantages:
  - Processing on flat substrate.
  - No vendor lock-in.
  - Avoids 3D MID pitfall of 3D assembly.
  - Thick PCB grade copper allows for power applications.
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