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In-Mold Electronics with Biosourced and Biodegradable Polymers

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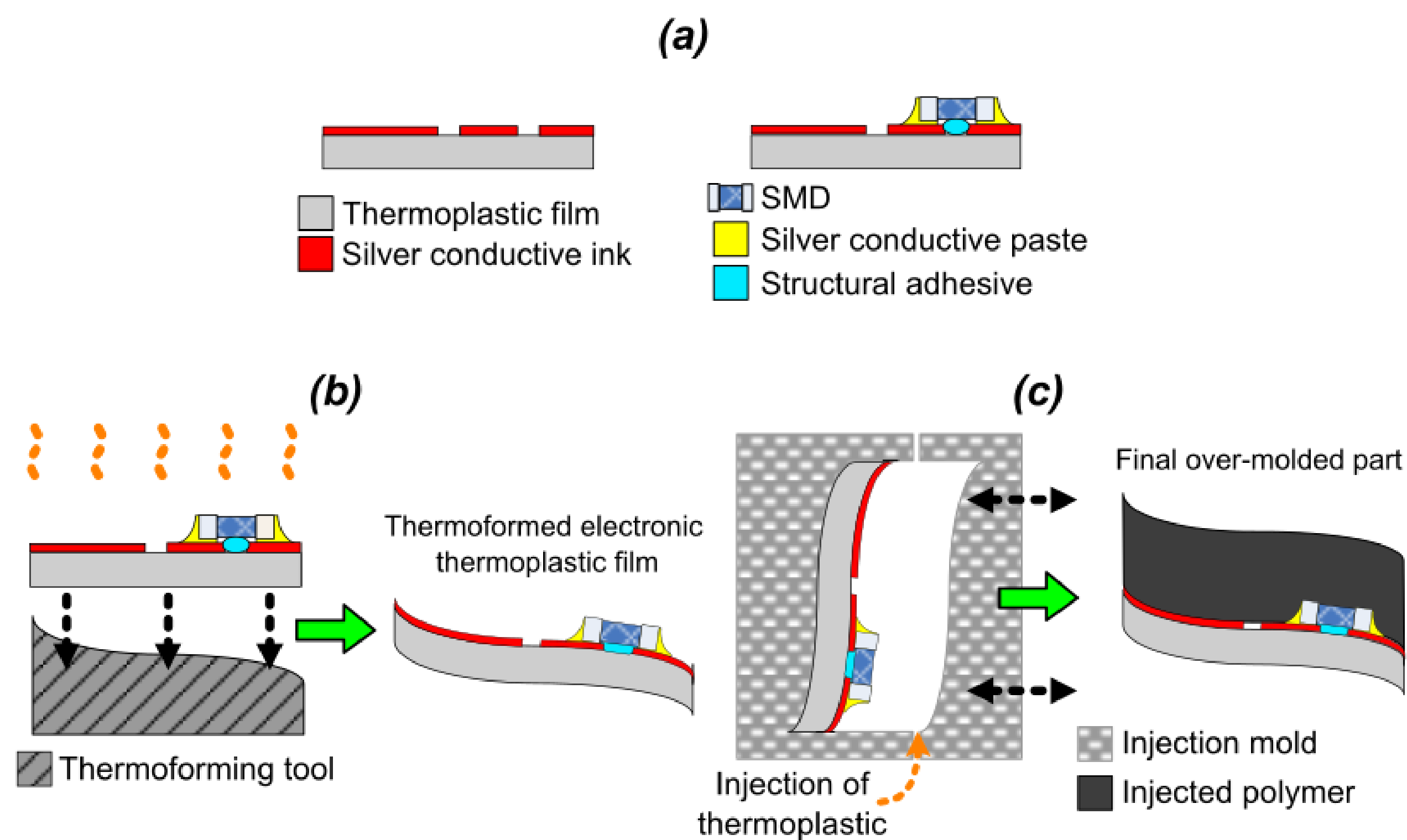
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In-Mold Electronics : principle and materials

- In-Mold Electronics (IME) is a 3D plastronic technology combining the plastics processing field with electronics.



- Process in three main steps:
 - Screen printing (ink deposition on a polymer film) + electronic components (SMD) pasting
 - Thermoforming (substrate shaping from 2D to 3D through heating)
 - Overmolding by injection.

- PolyCarbonate (PC), petroleum-based, reference material in IME

Polymer substrate characterization

- Polymer of interest: PolyLactic acid (PLA 300 μm)
- Biosourced and biodegradable, for the manufacturing of more sustainable IME devices

PLA1, PLA2: pellets Ingeo 2003D and 3251D from NatureWorks LLC
 PC1, PC2: Makrofol DE 1-1 films and pellets 2405 from Covestro

- Applications in signal electronics and HMI (Human-Machine Interface)

Properties	PLA1	PLA2	PC1	PC2
Tg (°C)	55	59	150	144
Tm (°C)	151	171	/	/
Td (°C)	310	310	454	454
Elongation at break (%)	3.9	/	128.7	/
Impact resistance (kJ/m ²)	/	1.7 (1J) (notched)	/	8.9 (15J) (notched)
Surface roughness Sa (μm)	0.37	/	0.19	/
Surface energy (mN/m)	38	46	46	47

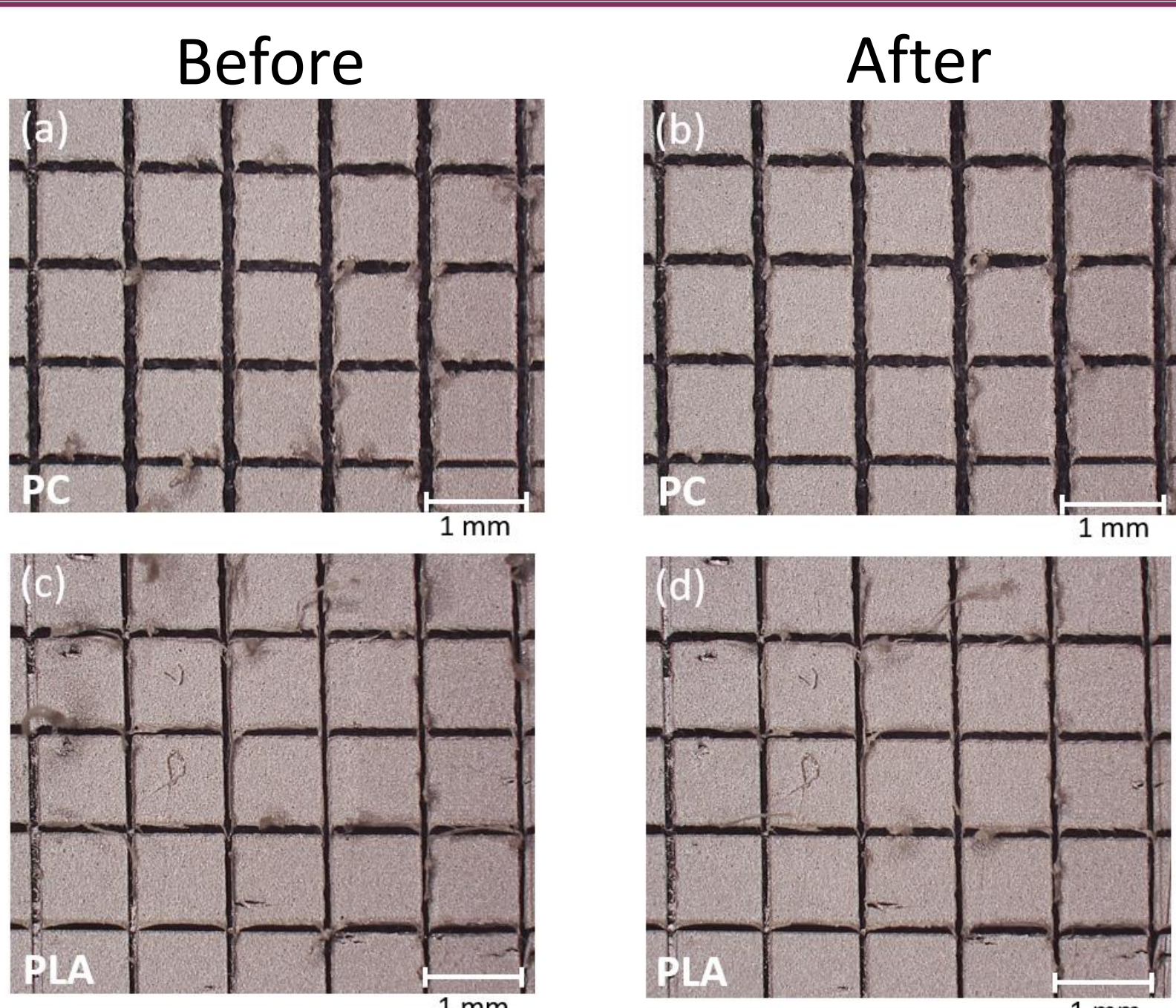
PLA not thermally and mechanically as good as PC:

- Low Tg (60°C) → necessary to adapt and optimize the process and the choice of application to this limitation.
- Minimal elongation at break (less than 5%) and impact resistance (just 2 kJ/m²) rather unfavorable to IME as such.

Surface roughness minimal and surface energy around 40-45 mN/m: the polymer wettability can influence the adhesion of conductive ink and electronic components in screen printing. → advantageous properties similar to PC.

Characterization toward an electrical circuit

Adhesion of ME603 conductive ink



- Standardized cross-cut test (ISO 2409, scotch test).

- Great adhesion on PLA1 and PC1 substrates
 Classification 0 = Edges of the cuts smooth and no squares of the lattice detached.

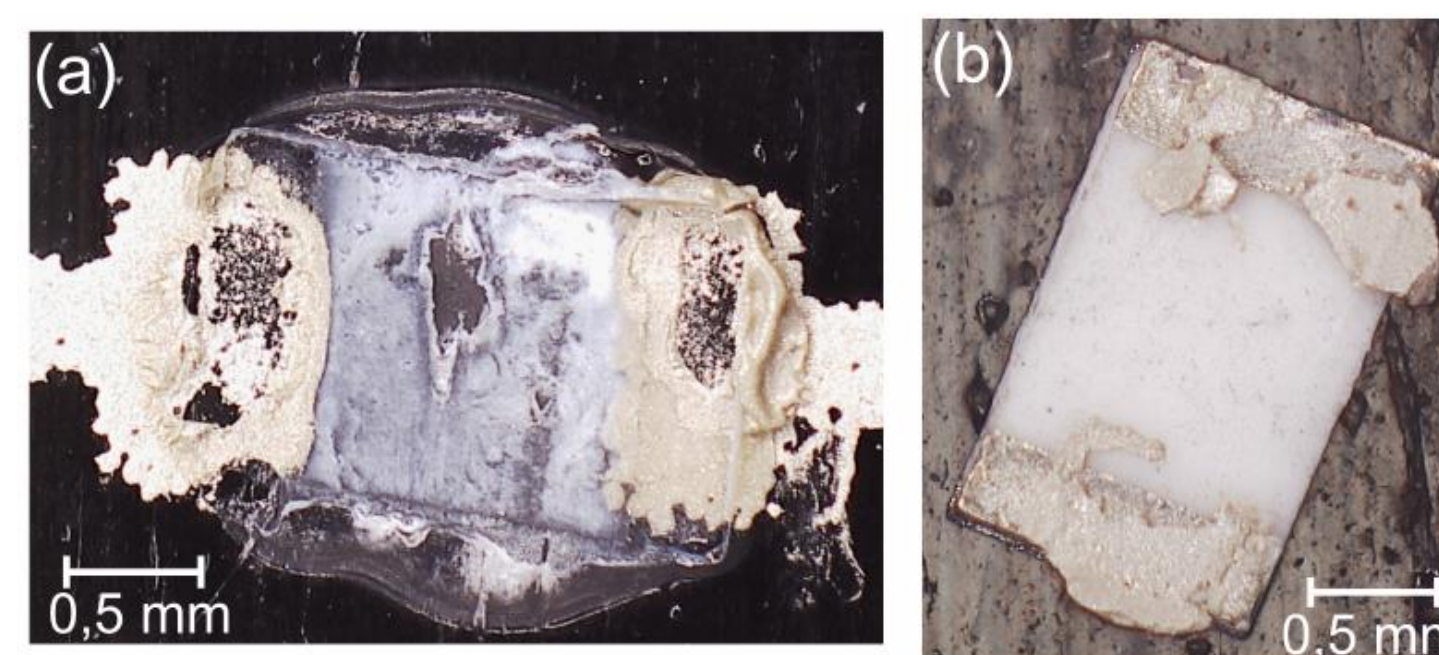
Drying ME603 and ME902 on PLA1 : 55°C – 2h30

Adhesion of SMDs

- ME902 conductive paste + ethyl cyanoacrylate
- Shear testing of SMD on ME603 traces

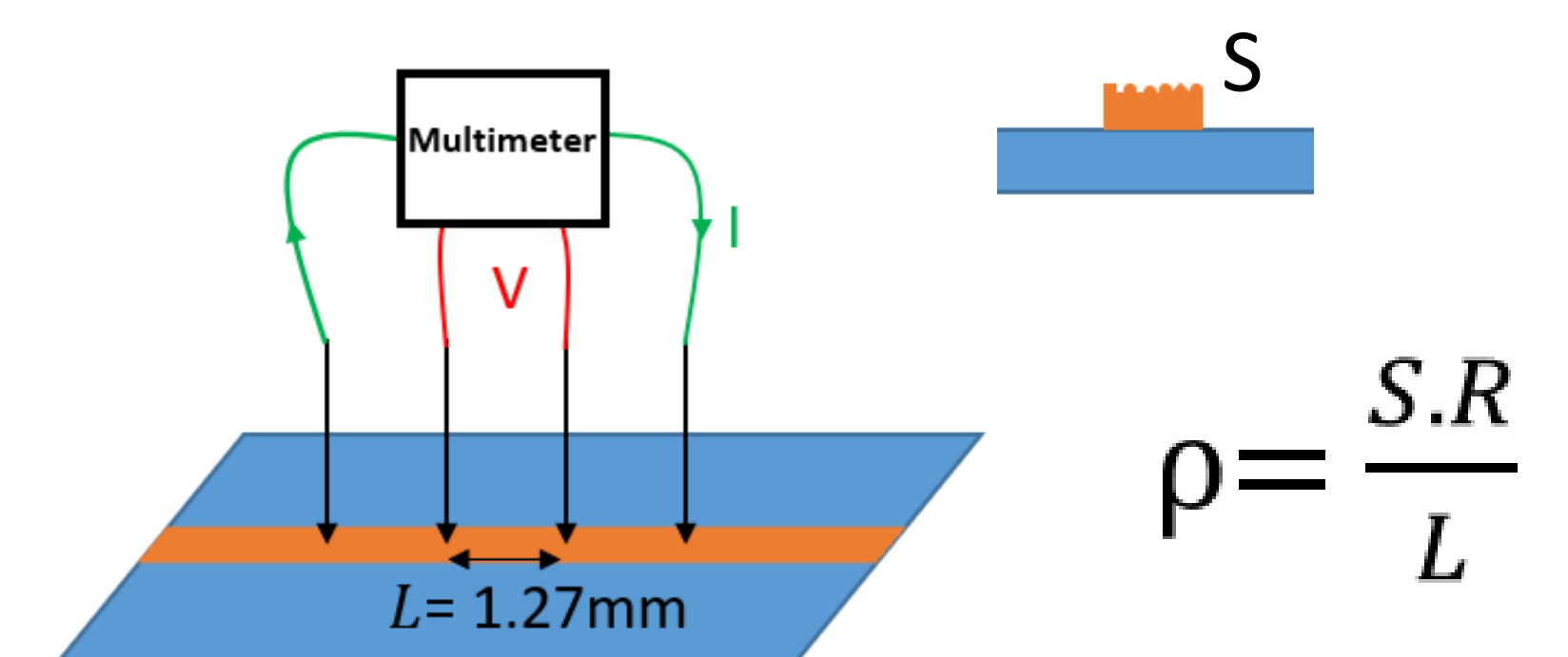
	Drying conditions	Shear stress (N/mm ²)
ME902 on PC1 (ref)	120°C – 20 min	7.68
ME902 on PC1	55°C – 2h30	2.76
ME902 on PLA1	55°C – 2h30	1.80
ME902 + cyano on PC1	55°C – 2h30	8.67
ME902 + cyano on PLA1	55°C – 2h30	9.10

- Fracture surface = in ME902 paste layer
- Adhesion decrease with drying temperature decrease



Resistivity of ME603 ink

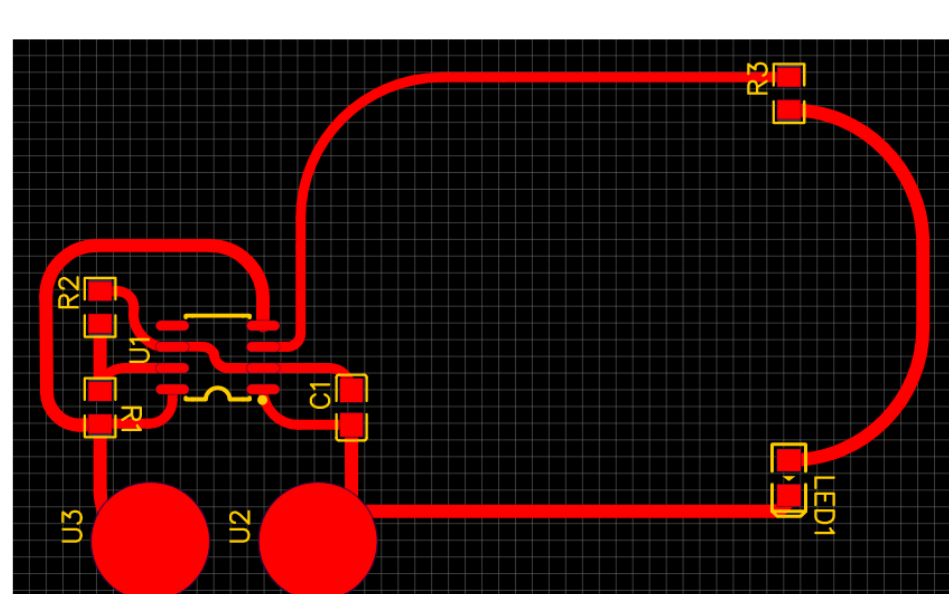
- Resistance measurements with four-point probes method and cross-sectional area S with confocal profilometer



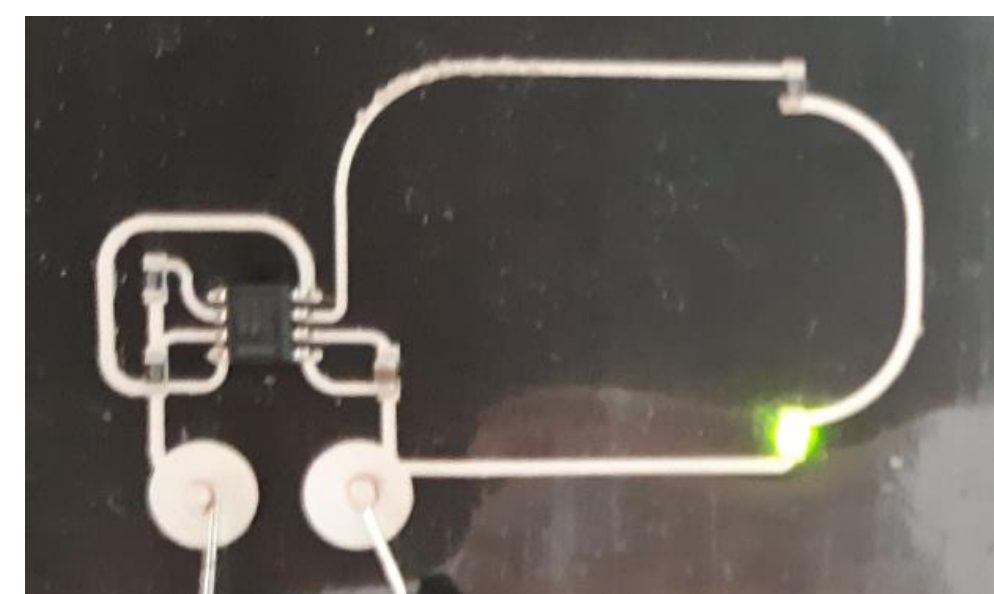
	ME603 on PC1 (120°C – 20 min)	ME603 on PLA1 (55°C – 2h30)
Resistivity (μΩ.cm)	31 – 54	290 – 300

- Higher resistivity on PLA1 than on PC1 (55°C vs. 120°C) → Loss in conductivity on PLA1
 ➤ Good enough to operate a simple electronic circuit

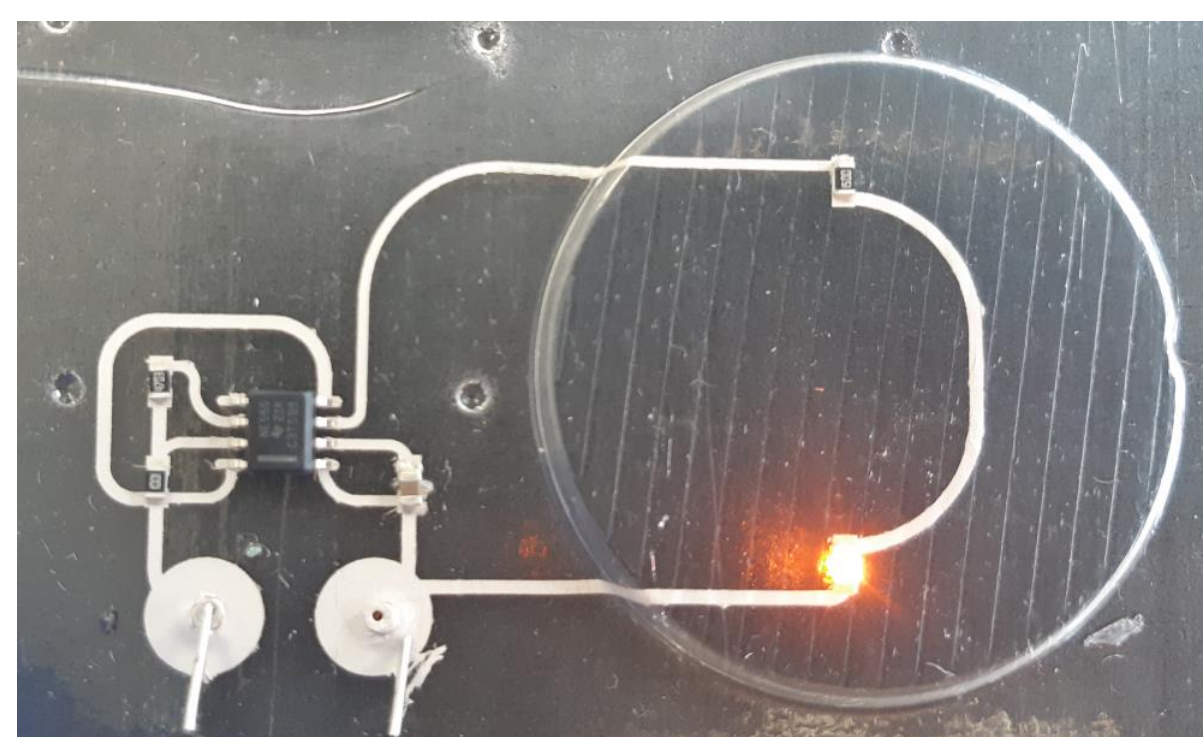
Proof of concept



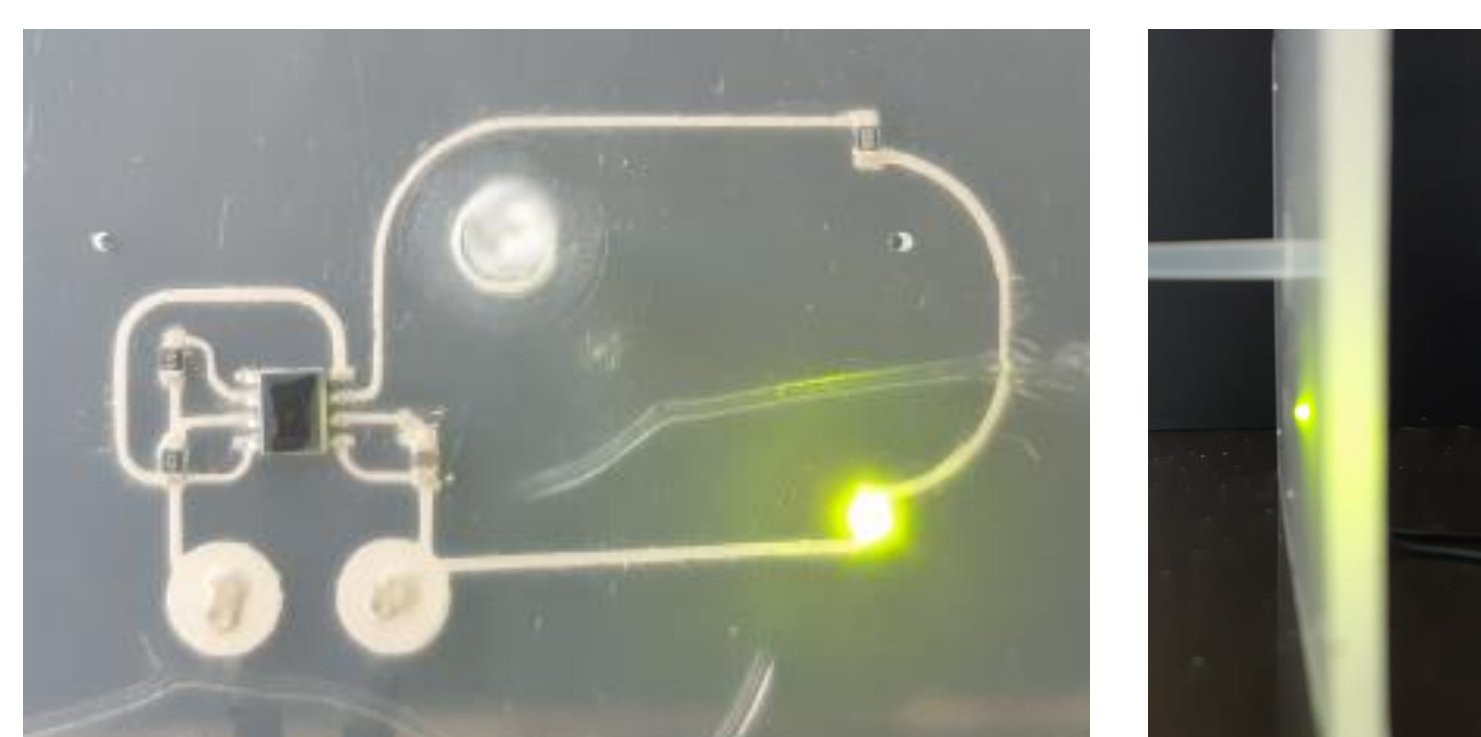
NE555 IC timer
 3 resistors
 1 capacitor
 1 LED



After screen printing + SMD pasting



After thermoforming



After overmolding by injection

Conclusion

- The feasibility of IME on PLA was demonstrated:
 - ✓ The electronic circuit is well encapsulated
 - ✓ The performances of the conductive ink is sufficient for our applications (signal electronics) and the ink and SMD adhesion is excellent
 - ✓ The mechanical properties of the proof of concept in PLA remain interesting
 - ✓ The ink conductivity can be improved → photonic curing

- C. Goument *et al.* In-Mold Electronics on Poly(Lactic Acid): towards a more sustainable mass production of plastronic devices. *Int J Adv Manuf Technol* (2023). <https://doi.org/10.1007/s00170-023-10878-4>

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