Dynamic Studies of Thermoformed Embedded Printed Electronics Using Micro-CT

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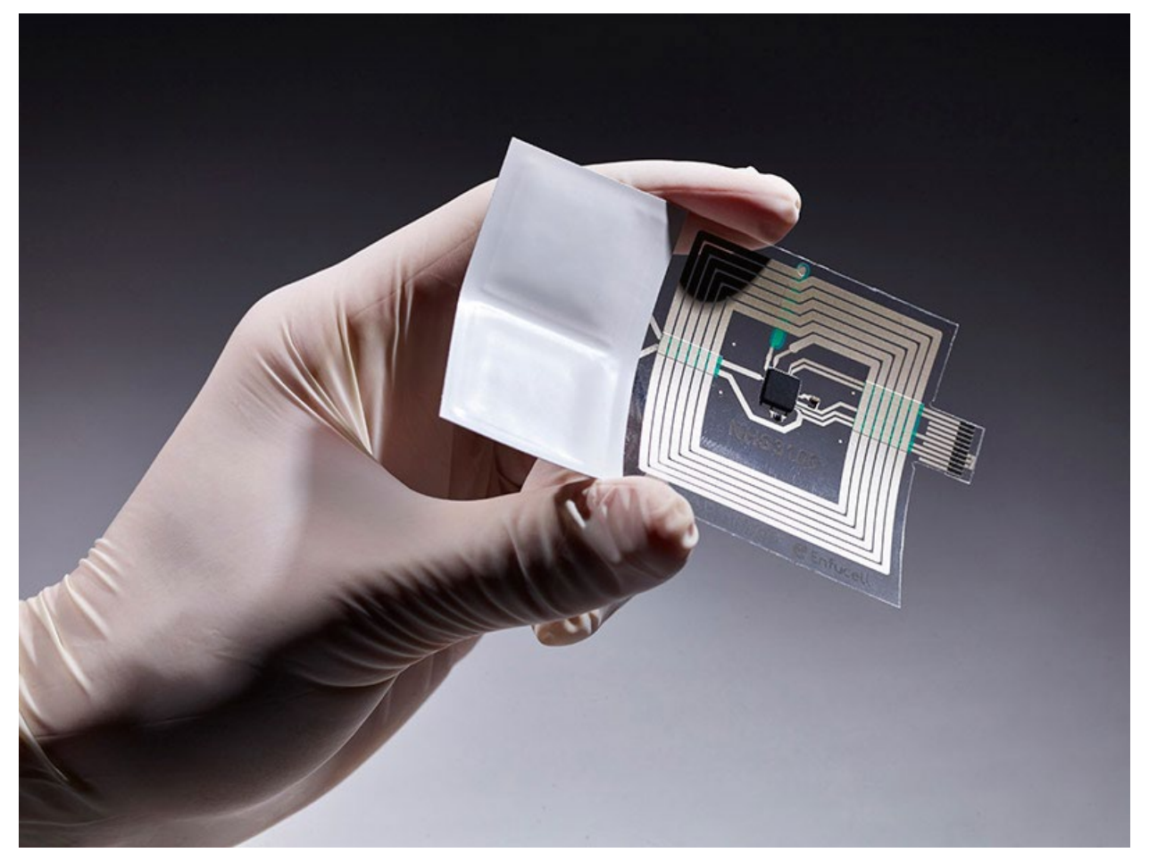
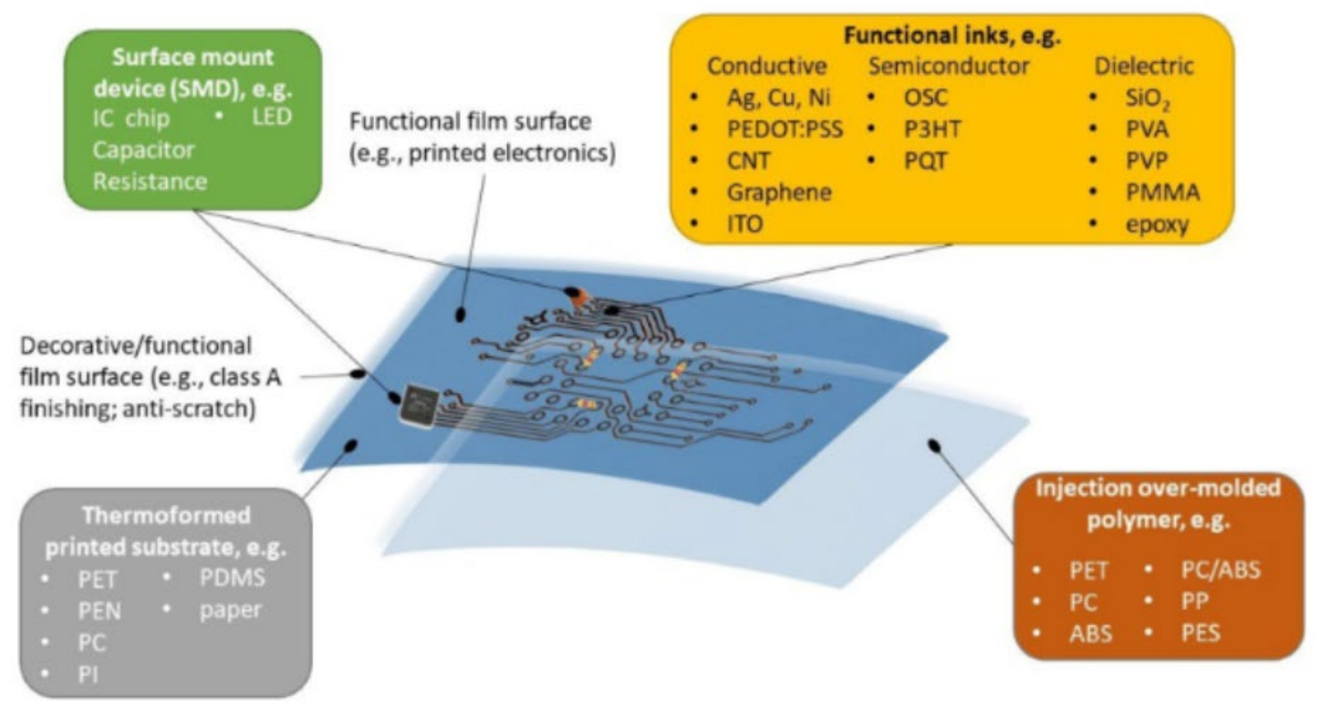
Abstract

- In-Mold Electronics (IME) integrate circuits directly into the shape of the product during manufacturing, reducing assembly and enabling lightweight, smart designs.
- During thermoforming, printed functional inks (e.g., conductive inks) experience heat, pressure, and stretching, causing cracking or loss of electrical performance.
- The strain mechanics governing the deformation, damage evolution, and electrical integrity of printed conductive features is not well understood in the literature.
- The long-term goal of this project is to develop a new paradigm for studying strain related processing of inks during thermoforming steps using Dynamic in situ Micro-Computed Tomography.
- As a first step, preliminary experiments are being conducted using static micro-CT analysis.
- These experiments establish the experimental setup needed for future dynamic in-situ micro-CT studies of IME manufacturing.
- Understanding these internal micro-deformations and adhesion changes will enable the development of novel design principles.

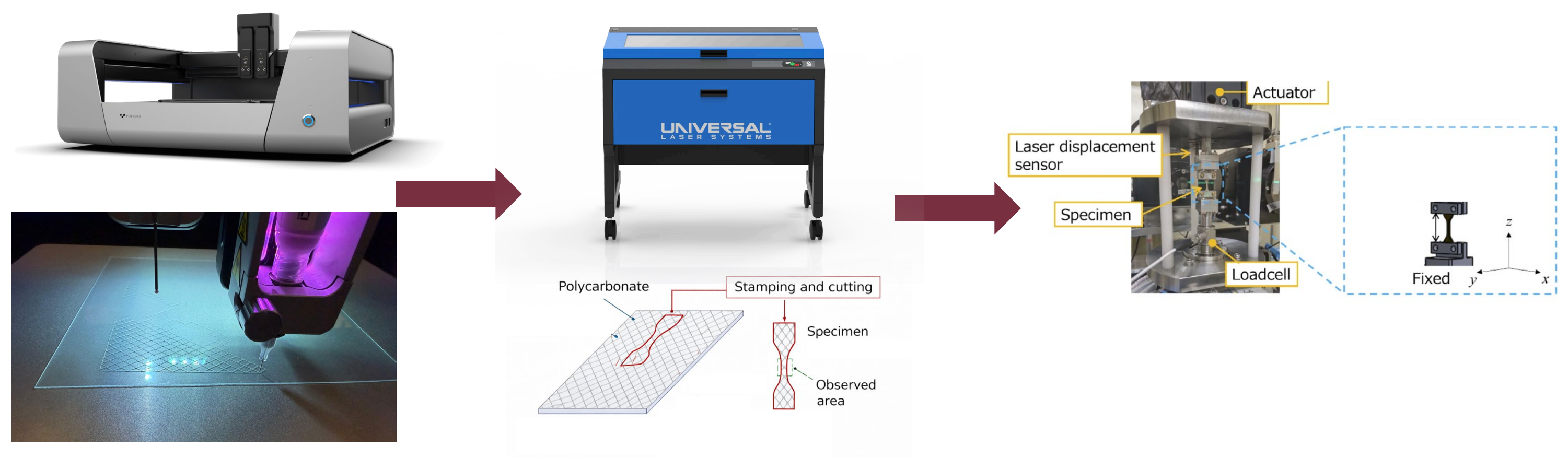




Introduction

- In-Mold Electronics (IME) integrates functional electronics into a product's structure, creating 3D objects with embedded circuitry [1].
- IME replaces traditional electronics mounted on rigid PCBs, enabling lighter and thinner designs.
- Applications span automotive (HMI panels), consumer electronics (wearables, smart appliances), healthcare (monitoring patches), and aerospace (weight-saving panels).
- IME is critical for industrial engineering: reduces weight (up to 70%) and thickness (up to 90%) while supporting structural electronics [2].
- Research gap: Internal deformation, damage, and electrical integrity of printed conductive features during thermoforming are not well understood.

Current Work (Preliminary Study)



Procedure:
- Thermogravimetric Analysis (TGA) was performed to characterize the thermal behavior of the material.
- A hatch pattern was designed using SolidWorks.
- The hatch design was printed onto a polycarbonate sheet using FS0142 Flexible Silver conductive Ink and the Voltera Printer.
- Dog-bone specimens were cut from the polycarbonate sheet using the VersaLaser cutter, following standard geometry used for tensile property evaluation.
- Tensile testing was performed inside a micro-CT system to observe deformation during loading.

Preliminary Results

A graph with the TGA analysis and tensile testing results will be added here

TGA Analysis:
- Material stable up to ___ °C; onset of decomposition at ___ °C.
- Confirms suitability for thermoforming temperature range.

Tensile Testing (Dog-Bone Specimens):
- Elongation up to ___% before first micro-cracks appear in ink.
- Stress-strain curves show elastic region, yield point, and failure onset.
- Adhesion strength of ink to substrate measured; regions of delamination observed.

Importance / Insights:
- Confirms substrates and inks survive processing temperatures.
- Provides baseline mechanical behavior and failure locations for comparison in dynamic imaging.
- Identifies regions prone to cracking or delamination for targeted study.

Next steps:
- Transfer samples to Devan stage for combined tensile + dynamic micro-CT imaging.

Future Work

A figure of the experimental workflow for the future work will be added here.

Dynamic In Situ Imaging:
- Transfer samples to the Devan stage inside the micro-CT scanner.
- Apply tensile or thermoforming loads while continuously imaging the internal structure.
- Track real-time micro-deformations, adhesion changes, and crack formation.

Geometry Studies:
- Prepare multiple samples with different mold geometries.
- Thermoform each sample while imaging to see how topography affects strain distribution.
- Compare deformation and failure locations across patterns and shapes.

Material & Ink Testing:
- Deposit silver and copper inks on various flexible polymer substrates (PET, PTFE, PC).
- Perform dynamic imaging to evaluate mechanical and adhesion performance.

Quantitative Analysis:
- Measure strain, deformation, and adhesion from micro-CT data.
- Correlate these metrics with electrical performance.
- Develop predictive models for ink behavior during thermoforming.

Conclusion

- Preliminary TGA and tensile tests confirm that the substrate and inks can withstand thermoforming temperatures and mechanical loads.
- Micro-CT imaging of dog-bone specimens provides insight into internal micro-deformations and adhesion behavior.
- Hatch pattern design influences strain distribution and potential failure locations.
- Setup testing with the tensile stage ensures compatibility for future dynamic in situ experiments.
- This preliminary work establishes a baseline for real-time dynamic imaging, guiding future studies on robust in-mold electronics fabrication.

Resources

[1] F. Hong, L. Tendera, C. Myant, and D. Boyle, "Vacuum-Formed 3D Printed Electronics: Fabrication of Thin, Rigid and Free-Form Interactive Surfaces," SN Comput. Sci., vol. 3, no. 4, p. 275, May 2022, doi: 10.1007/s42979-022-01174-1.

[2] T. Simula, P. Niskala, M. Heikkinen, and O. Rusanen, "Component Packages for IMSETM (Injection Molded Structural Electronics)," in 2018 IMAPS Nordic Conference on Microelectronics Packaging (NordPac), Oulu: IEEE, Jun. 2018, pp. 50–54. doi: 10.23919/NORDPAC.2018.8423845.