Digitally Printed Hybrid Stretchable Circuits for Wearable Bioelectronics

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Introduction

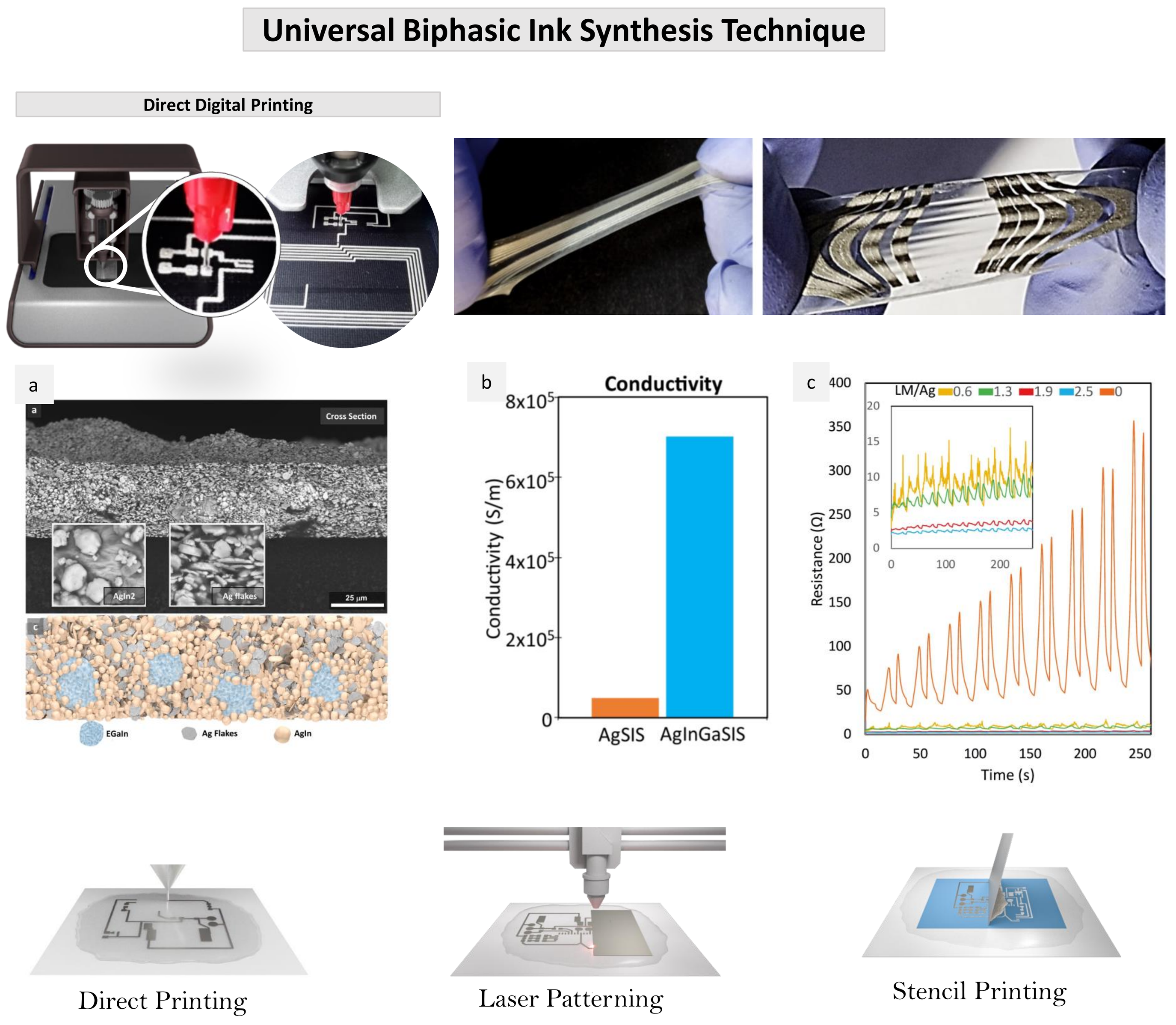
The field of soft and stretchable electronics has received increasing attention during the last few years. This is due to its applications in wearable and implantable bioelectronics for health and performance monitoring, smart garments, e-skins for robotics, entertainment, and human machine interfaces.

Among the materials that are used for fabrication of soft and stretchable circuits, Eutectic Gallium Indium (EGaIn) Liquid Metal (LM) is the most promising conductor, as it combines high electrical conductivity, fluidic deformability, self-healing properties, and low electromechanical coupling and low hysteresis when subject to mechanical strain. However, fabrication of liquid metal based circuits is challenging, due to the underlying problems on deposition and patterning of liquid metals, which often requires preparation of stencils and molds. Moreover, integration of solid-state microchips into soft-matter, and stretchable printed electronics has been one of the biggest challenges against their scalable fabrication.

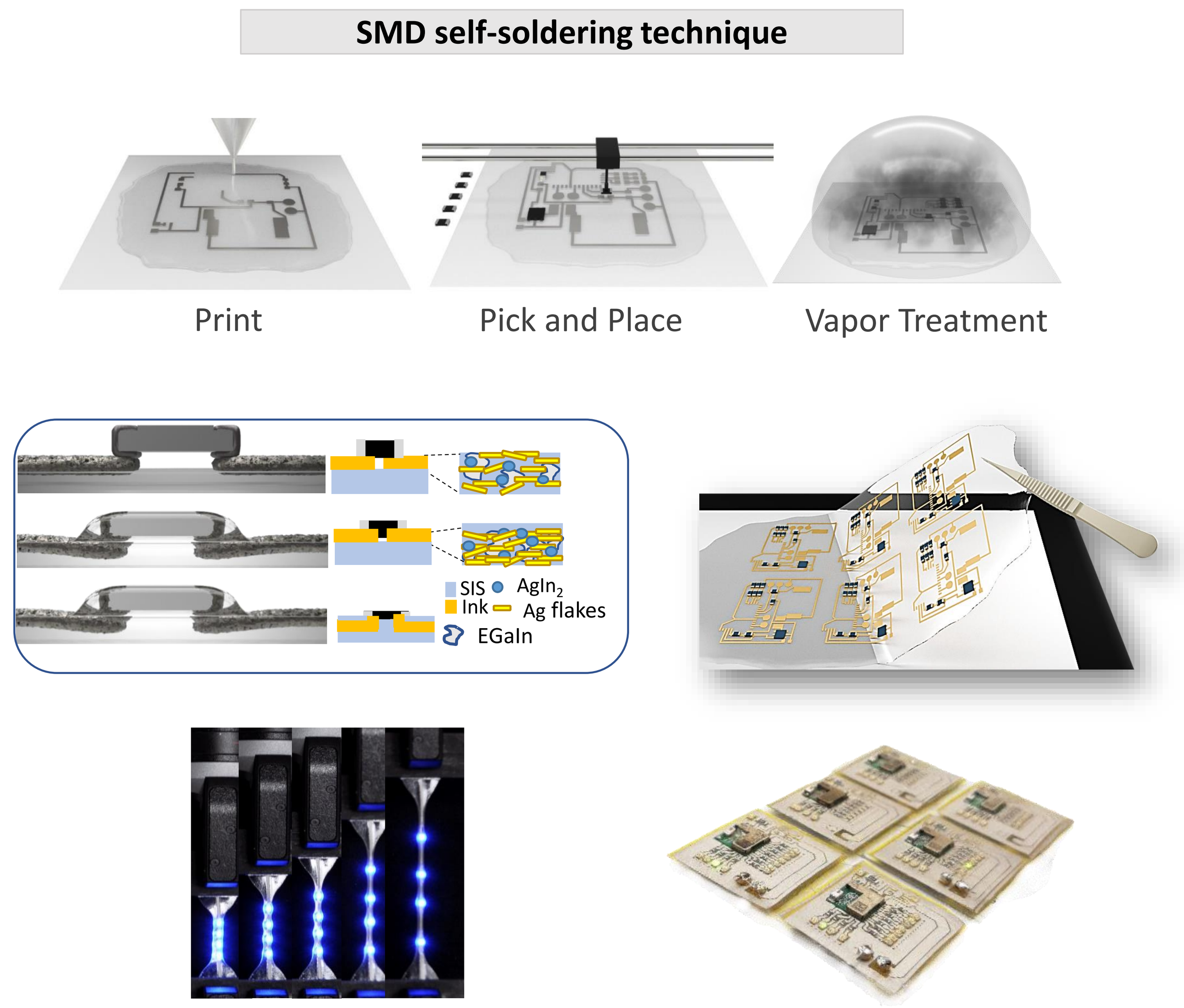
Contribution

- Synthesis of a printable biphasic liquid metal based composite (Ag-In-Ga ink), which allowed for the first time digital printing of stretchable circuits, through an accessible extrusion printer. [1]
- A facile technique for autonomous self-soldering, self-healing, and self-encapsulation of printed stretchable circuits, that allowed for the first time, integration of silicon chips into stretchable circuits at the room temperature, and in a single step, with record breaking maximum strain tolerance values. [2]
- Demonstrations of several applications of e-skin and e-textiles circuits for wearable biomonitoring, including a multi-electrode e-textile belt for lung and bladder monitoring through electrical impedance tomography (EIT), and Functional Electrical Stimulation (FES), and integrated hybrid circuits with multiple strain sensors and integrated microchips for mechanical sensing.

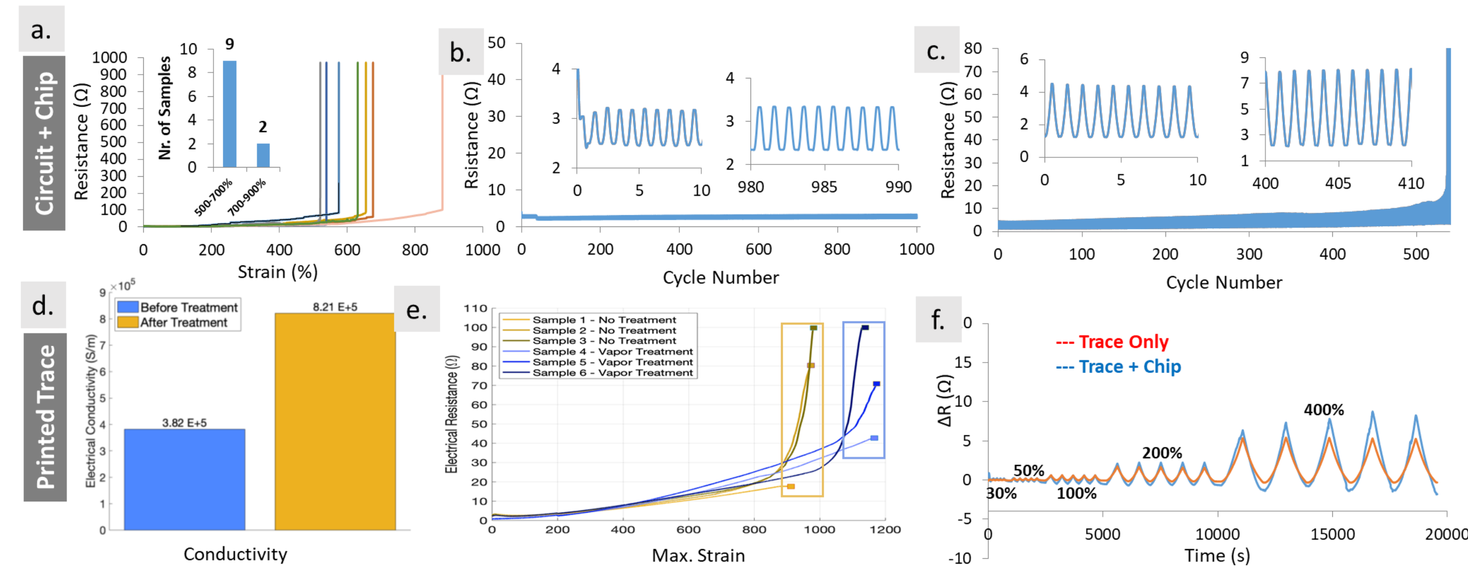
Results



- Bi-phasic Ag-EGaIn ink that demonstrates high electrical conductivity (7.02×10^5 S/m), extreme stretchability (max. strain >1000%), and low electromechanical gauge factor (GF).
- Unlike liquid metals, this ink can be extruded and printed with high resolution with low-cost extrusion printers.
- Ag-In-Ga material system exhibits an exceptional combination of fluid-like deformability.

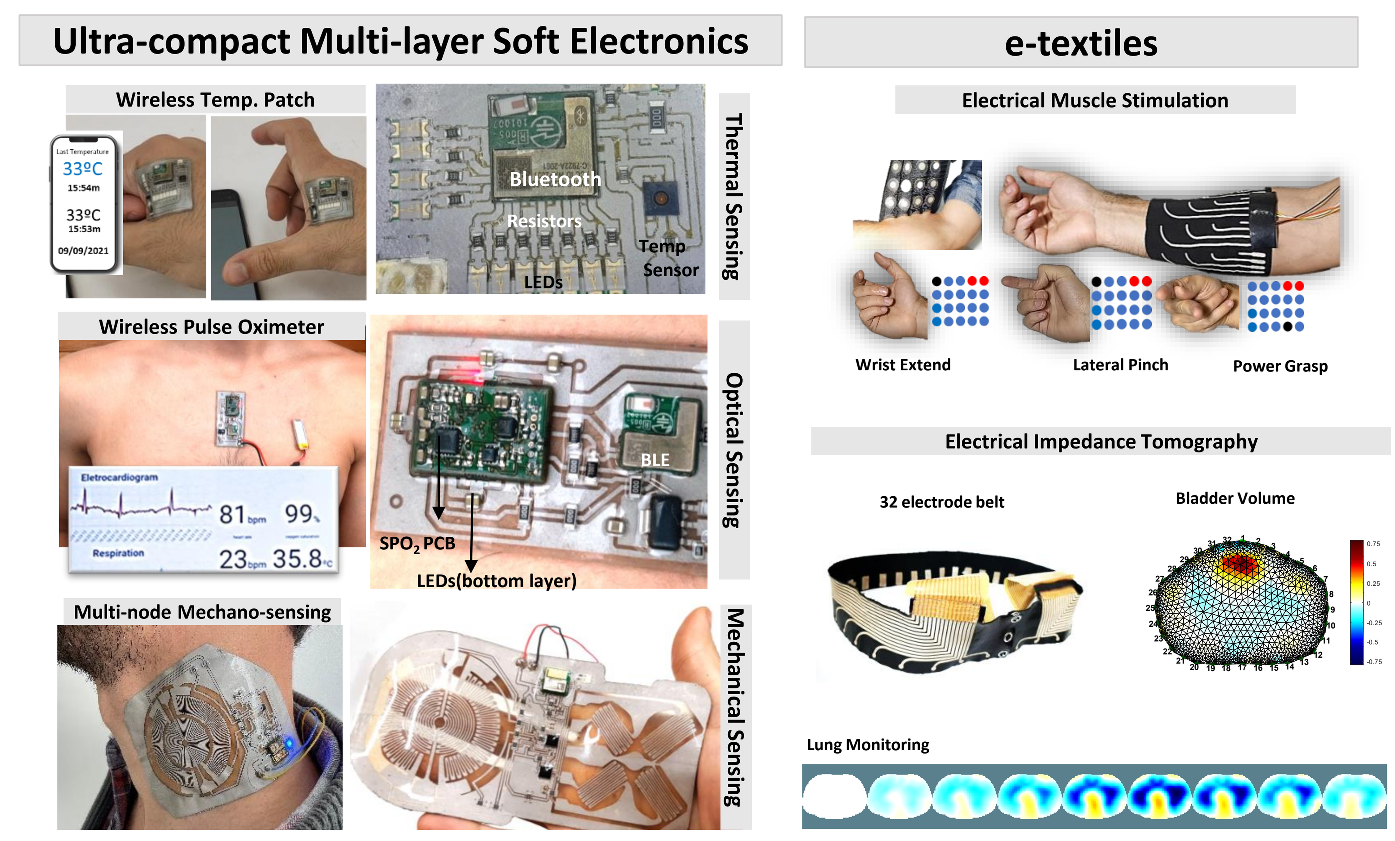


Pol-Gel [2], a simple technique for self-soldering, self-encapsulation, and self-healing of the circuits, which is an important step toward low cost, scalable, and rapid fabrication of hybrid microchip-integrated ultra-stretchable circuits. This is performed by triggering a Polymer-Gel transition in physically cross-linked block copolymers that are present in the ink, by exposing the circuits to the solvent vapor. This results in maximum strain tolerance of >500% for chip-integrated soft circuits, which is at least 5x higher than the previous works.



- Maximum strain of >500% prior to electrical failure, a stable behavior for 1000 cycles of 100% strain, and 500 cycles of 400% strain.
- The average electrical conductivity of the samples after the toluene vapor exposure was increased from 3.8×10^5 to 8.21×10^5 S/m,.

Applications



References

[1] Lopes, Pedro Alhais; Fernandes, Daniel Félix; Silva, André F.; Marques, Daniel Green; de Almeida, Aníbal T.; Majidi, Carmel; Tavakoli, Mahmoud. "**Bi-Phasic Ag-In-Ga-Embedded Elastomer Inks for Digitally Printed, Ultra-Stretchable, Multi-layer Electronics**". ACS Applied Materials & Interfaces (**2021**).
[2] Lopes, Pedro Alhais; Santos, Bruno C.; de Almeida, Anibal T.; Tavakoli, Mahmoud. "**Reversible polymer-gel transition for ultra-stretchable chip-integrated circuits through self-soldering and self-coating and self-healing**". Nature Communications (**2021**).
[3] Lopes, Pedro Alhais; Paisana, Hugo; De Almeida, Anibal T.; Majidi, Carmel; Tavakoli, Mahmoud. "**Hydroprinted Electronics: UltrathinStretchable Ag–In–Ga E-Skin for Bioelectronics and Human–Machine Interaction**". ACS Applied Materials & Interfaces (**2018**).