Direct writing of Liquid Metals for Printed Electronics

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Low melting point metal alloys, also known as liquid metals (LMs), are becoming a focal point for printed electronics applications due to their high electrical and thermal conductivity and flexibility under mechanical stress, which makes them interesting for stretchable electronics and enables self-healing. The LMs are fluid and ductile at room temperature or near it, and can therefore be easily shaped. In spite of their fluidic nature, LMs suffer from one significant disadvantage: their combination of viscosity, surface tension, and density makes them difficult to print with inkjet printing or any other standard direct writing method.
We have developed a versatile glass capillary-based direct-write method for printing LMs such as eutectic gallium alloys, which also enables the fabrication of various fully printed devices. We have demonstrated planar as well as 3D printing of Galinstan (an eutectic alloy of gallium, indium and tin) lines. Further, we have also fabricated and analysed the electrical behaviour of interconnect wires, resistors, p-n diodes and transistors fabricated by combination of LM and other functional materials deposited with the same and other printing methods. [1] The result demonstrated working p - n diodes with an ON / OFF ratio of 10^5, as well as fully printed transistors with ON currents in tens of mA and tunable resistors that can be further encapsulated in PMMA to keep them structurally intact on mechanical stress without sacrificing conductivity.

With only one technology for processing various inks, the device functionality is enhanced, while the fabrication process is streamlined and simplified. This approach demonstrates the enormous potential of liquid metal printing, which is far more than its conventional use as interconnects in printed electronics. Our vision is to use these fully printed devices in the future to build fully printed, flexible, wearable sensors and devices.

[1] N. Hussain, T. Fu, G. Marques, C. Das, T. Scherer, U. Bog, L. Berner, I. Wacker, R. R. Schröder, J. Aghassi-Hagmann, and M. Hirtz, Advanced Materials Technologies **6**, (2021).

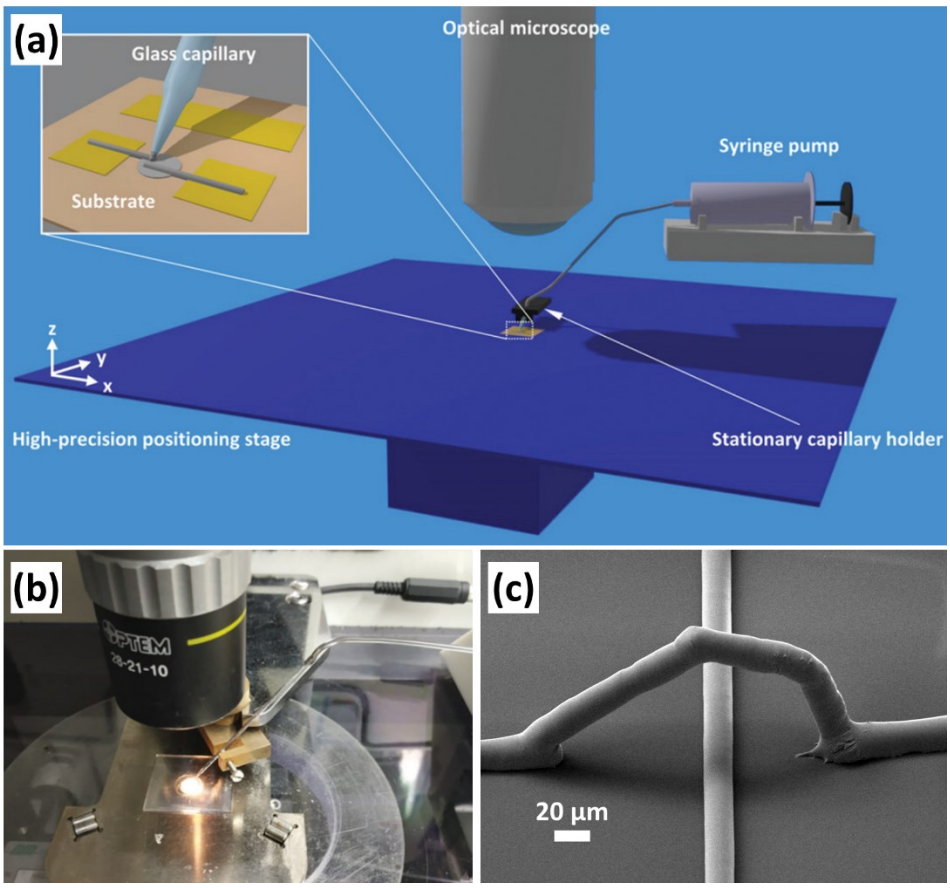

Figure 1: Direct writing setup and print results (a) A schematics of a printing setup featuring a high-precision positioning stage which provides movement in in x, y, and z directions, an optical microscope for monitoring, and a capillary holder connected to a syringe pump for controlled flow of liquid metal ink. (b) Actual image of the setup. (c) SEM image showing the 3D arch structure of a Galinstan line over a previously printed line. (Reproduced from [1])