Scalable Manufacturing of Stretchable Electronic Devices based Biphasic Liquid Metal Stamp

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***Abstract*—A Stretchable electronic device is required for real-time health monitoring and to fabricate stretchable conductor, liquid metal interconnect technology has been researched. They make it possible to incorporate electronic components for various applications, and these electronic devices can endure repeated bending and stretching without experiencing any damage. The proposed approach suggests an adhesive, conductive biphasic liquid metal ink and a multiple times stamp printing process. By designing an inkpad for stamp printing, this method enable high-resolution printing of flexible devices with excellent performance, and scalability.**

BACKGROUND

Stretchable electronics is emerging technology for various applications, including wearable devices, and human-machine interfaces, which is allowing them to conform to irregular and curvilinear human body that is required durability and reliability [1]. In order to functionalize stretchable devices, unlike rigid conductive materials, liquid metal is a proper solution due to its liquid state in room temperature, high conductivity, high stretchability, and good biocompatibility [2,3]. However, the fluidic nature of liquid metal has challenges of leakage leading to its poor reliability, particularly in situations involving stretching or compression. As a result, liquid metal has to modify its state for printing on substrates [4].

In this research, we suggest an adhesive, conductive biphasic liquid metal ink and implementing multiple times stamp printing process that can directly print flexible devices several times. Firstly, to improve adhesion, liquid metal nanoparticle is sintered at 600 ℃ creating a thick solid oxide layer that stick to various substrates. Biphasic liquid metal made by thermal sintering can be used as ink for stamp printing of conductive patterns. Secondly, the stamp was designed to enable multiple times printing of biphasic liquid metal ink to prevent disposable inkpad for scalable manufacturing. Lastly, in our printing process, the mask is removed when printing conductive patterns, thereby reduce substrate damage, and minimize particle waste.

MATERIALS AND METHODS

Biphasic LM (liquid metal) inkpad is fabricated as shown in Fig. 1. 363mg of eGaIn alloy is sonicated with 4ml ethanol and sonicating at an amplitude of 30 μm for 60 min using a tip sonicator. For uniform dispersion, a glass vial with LM nanoparticle was mixed using a vortex mixer for 1min. Si wafer was placed under the desired mask design, and to make LM film, LM nanoparticle was sprayed slowly onto a Si wafer substrate using a commercial spray gun. After spray deposition, the printed LM nanoparticle film went through thermal sintering in a furnace at 600 ℃ for 30 min and cooled at room temperature. The inkpad of the stamp which is imprinted by biphasic LM can press and print multiple printing to enable scalable manufacturing. The stamping process of printing biphasic LM is shown in Fig. 2. In the point of printing, the stamping process means transferring biphasic LM ink onto a target surface directly and aligning to substrate easily. By biphasic LM stamp, we can print on various substrates such as *PDMS, TPU, and VHB tape. Also, with a thick coating of biphasic LM particle on the inkpad (~100 μm), it is possible to print the desired pattern several times. We tested *10 samples of biphasic LM stamp and the average number of prints that each stamp could produce was three (Fig. 3).

Resistance of Biphasic LM was measured using a four-point probe, after being pressed by stamp to a VHB tape in 2 × 1 cm rectangular pattern. Average thicknesses of stamped pattern were calculated *~100 μ m. Initial conductivity of the biphasic LM was calculated as $2\times10^{5} S/m$. For electromechanical properties, a dog-bone pattern was used by stamping biphasic LM onto VHB and PDMS substrates. Electrical connections were connected by copper tape on each end of the pattern's edge. We measured resistance change of the biphasic LM traces during strain. The relative resistance at 100% strain on VHB was *doubel.

*For the 'BLISS' micro-LED array, 0805 LEDs were put through the printed pattern on the PDMS substrate with no adhesive glue (Fig. 4). The substrate was aligned on position and pressed by the biphasic LM stamp with gentle pressure in the vertical direction for 5 seconds. The patterns on the substrate were encapsulated by PDMS and the LED array was stretched to 100% strain and then compressed by hand.

In summary, our approach enables an improved adhesion with the use of conductive biphasic LM particle and employs the stamp printing process to print and align easily with high resolution, excellent performance, scalability, and reliability. The stamping process makes the manufacturing of stretchable electronic devices rapid, and allows for easy customization.

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Fig. 1. Biphasic particle fabrication & Characteristics of biphasic particle

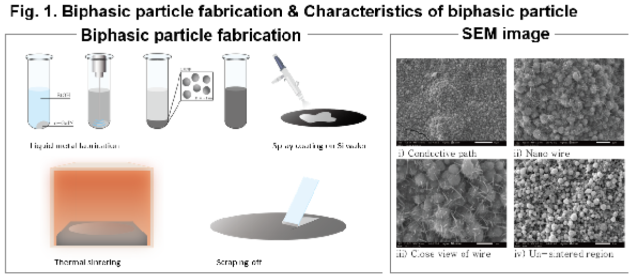
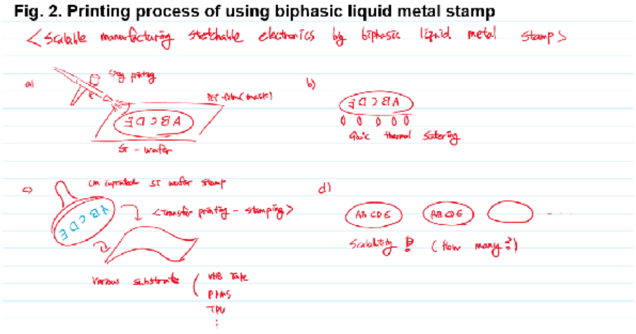


Fig. 2. Printing process of using biphasic liquid metal stamp



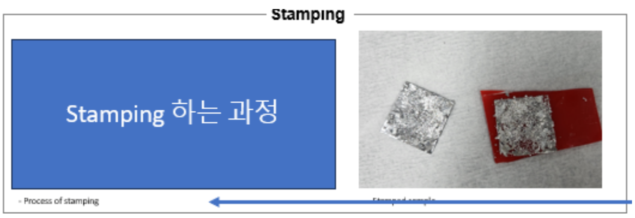


Fig 3. Stamping process and sample of stamped

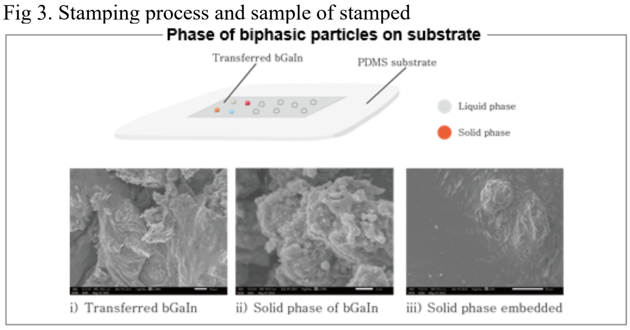


Fig 4. Phase of biphasic particle on substrate

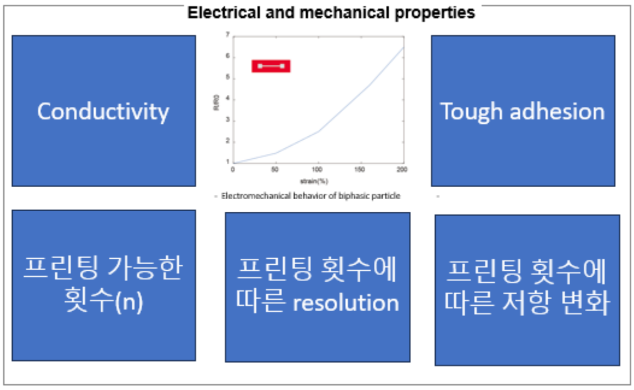


Fig 5. Electromechanical properties

❖ **Micro-LED array**

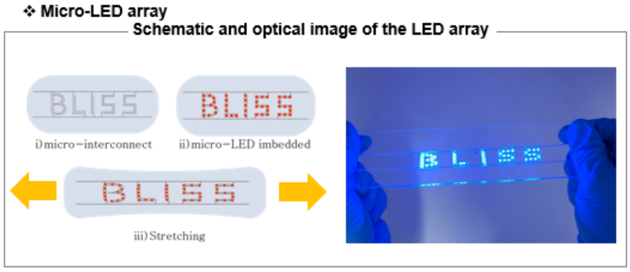


Fig 6. Schematic and optical image of the LED array