Imperceptive and breathable microneedle-metal mesh electronic skin for reliable, long-term, and high-fidelity surface biopotential monitoring

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Electronic skins (e-skins), engineered to be compliant and biocompatible with human skin, have emerged as an ideal platform for integrating the biological world into information networks. [1] Among various e-skin detections, surface biopotentials play a crucial role in assessing physical functions, diagnosing diseases and human-machine interfaces. To ensure reliable, long-term, and high-fidelity surface biopotential monitoring, maintaining a consistently robust, conformal, and comfortable interface between the e-skin and human skin is essential. Unfortunately, current commercial and medical electrodes fall short in meeting these requirements. They often require skin pre-treatment, can cause discomfort and irritation, face challenges with signal degradation over time, and have limitations in terms of sweat permeation, skin adhesiveness, and flexibility. Addressing these challenges is crucial for advancing biopotential monitoring technology and expanding its potential applications.

Herein, a microneedle-metal mesh e-skin (MMES) is designed to effectively solve these problems. Figure 1 shows the schematics of microneedle-metal mesh electrodes fabrication strategy. The entire fabrication process can be divided into three distinct parts. The first part involves the creation of microneedle structures using UV-based nanoimprint lithography and magnetron sputtering. The second part focuses on developing metal-mesh structures using photolithographic patterning. The third part employs the step-up galvanostatic electrodeposition method to fabricate the microneedle-metal mesh electrodes.

The metal mesh patterns in MMES contribute to enhancing various physical properties such as mechanical adaptability, flexibility, and breathability, thereby enhancing robust electromechanical skin interface. Meanwhile, the microneedle array in MMES is optimized to directly overcome the barrier of skin surface, increase the effective contact area, eliminate time-consuming skin preparation, and then provide mechanical interlocking for robust integration and anti-motion artifacts, resulting in a higher signal-to-noise ratio and lower skin contact impedance. The structure of MMES is shown in Figure 2 and Figure 3. It is expected to have a broad impact on applications requiring reliable, long-term, and precise surface biopotential monitoring.

[1] Yang, Jun Chang, et al. "Electronic skin: recent progress and future prospects for skin-attachable devices for health monitoring, robotics, and prosthetics." *Advanced Materials* 31.48 (2019): 1904765.

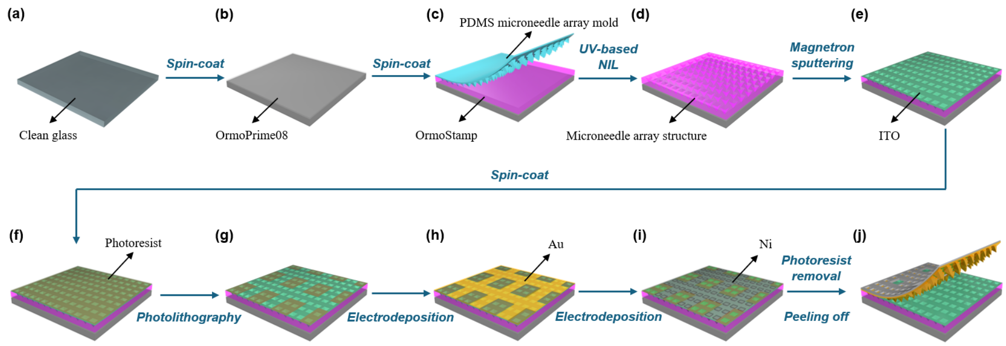

Figure 1: Schematics of microneedle-metal mesh electrodes fabrication strategy.

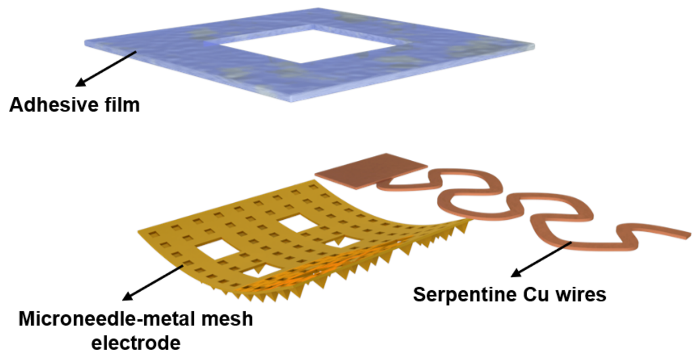

Figure 2: Schematics of MMES structure.

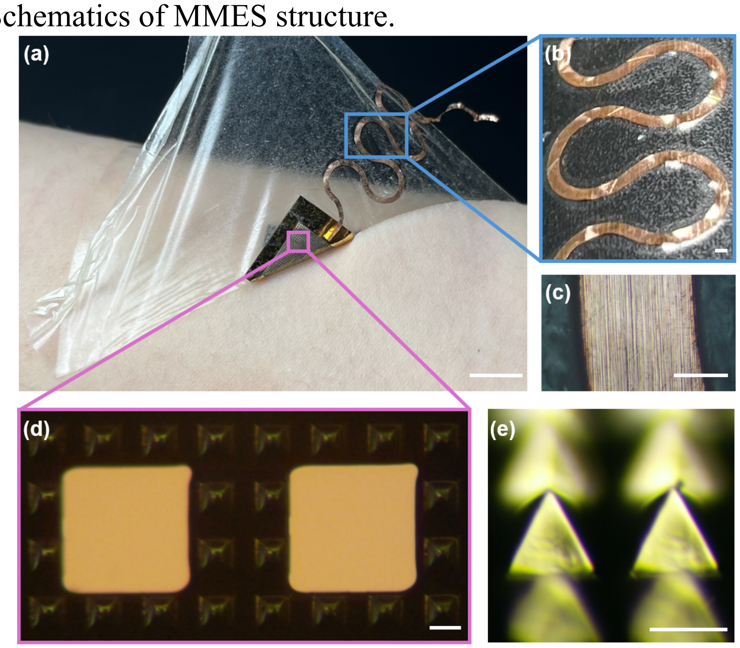

Figure 3: MMES is laminated on human skin. (a) Optical image of the MMES adhered to the human skin. Scale bar, 1.5 cm. (b) Optical image of the serpentine Cu wire connecting the electrode to the signal-receiving device (Cu wire is attached to black cardstock with 3M transparent film). Scale bar, 1 mm. (c) A magnified microscopic view of the Cu connecting wire. Scale bar, 0.5 mm. (d) Microscopic photograph of the metal mesh structure with the high-density microneedle array (microscope backlighting). Scale bar, 50 μm. (e) A magnified microscopic view of the high-density microneedles. Scale bar, 50 μm.