Direct Laser Assembly of Organic Bioelectronics

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Statement of Purpose: Development of soft and conductive microstructures has become a hot topic in various research and technological areas, particularly organic bioelectronics [1, 2]. Among various fabrication techniques, two-photon polymerization (TPP) based on direct laser writing stands out due to its unique capability to fabricate 3D architectures from functional photosensitive resins in sub-micron resolution [3, 4]. In the realm of organic bioelectronics, incorporation of conductive fillers including graphene [5] and carbon nanotubes [6] in photosensitive resins has become a popular approach. However, low-level electrical conductivity of TPP-fabricated microstructures has remained a critical challenge. To surpass this limitation, here we introduce TPP-fabrication of highly conductive microstructures through direct incorporation of poly(3,4 ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS) in a TPP-compatible resin. These soft and conductive microstructures pave the way towards development of next-generation biomedical devices including minimally-invasive neural probes and wearable biosensors.

Methods: The developed resin consisted of 4 components: poly(ethylene glycol) acrylate (M_n=700) as the polymer crosslinker (72.5 wt.%), PEDOT:PSS 1.0 wt.% in H_2O as the conductive agent (0.5 wt.%), dimethyl sulfoxide (DMSO) as the miscible agent (25 wt.%), and ethyl (2,4,6-trimethylbenzoyl) phenylphosphinate (T-POL) as the photo-initiator (2 wt.%) (Figure 1-A). Microstructures were constructed on a coverslip through 3D movement of XYZ stages (Newport) and irradiation of 130 femtosecond pulses from an ultrafast Ti-Sapphire two-photon laser (MaiTai Deepsee, Spectra Physics), which crosslinked the resin at the laser focal point. Semiconductor device parameter analyzer (B1500A, Keysight) was used for electrical measurements. Scanning Electron Microscope (SEM) was employed to visualize the microstructures.

Results: To assess the electrical properties, TPP-fabricated micro-bridges with dimension of 265 µm × 10 µm × 10 µm (length × width × height) were fabricated, followed by performing current-voltage (I-V) measurement. It was demonstrated that direct incorporation of 0.5 wt% PEDOT:PSS in the resin remarkably increased the conductivity of microstructures over 10 orders of magnitude i.e. from 2.12 E-06 ± 1.21 E-06 S m^{-1} to 24600 ± 3260 S m^{-1} (n=3, AVG ± SD) (Figure 1-B). It is worth noting that the obtained conductivity value was almost three orders of magnitude higher than relevant works in the literature [7, 8], which is most likely due to formation of interconnected PEDOT:PSS branches in the microstructures.

Next, various microelectronic devices were designed, constructed, and characterized, including an array of resistors (Figure 2-C) and capacitors (Figure 2-D). I-V measurement revealed that the conductance of the resistor was 89.81 ± 5.72 µS (n=3, AVG ± SD) (Figure 2-E). Moreover, the capacitance of the capacitor was measured to be 259 pF from the hysteresis loop (Figure 1-F).

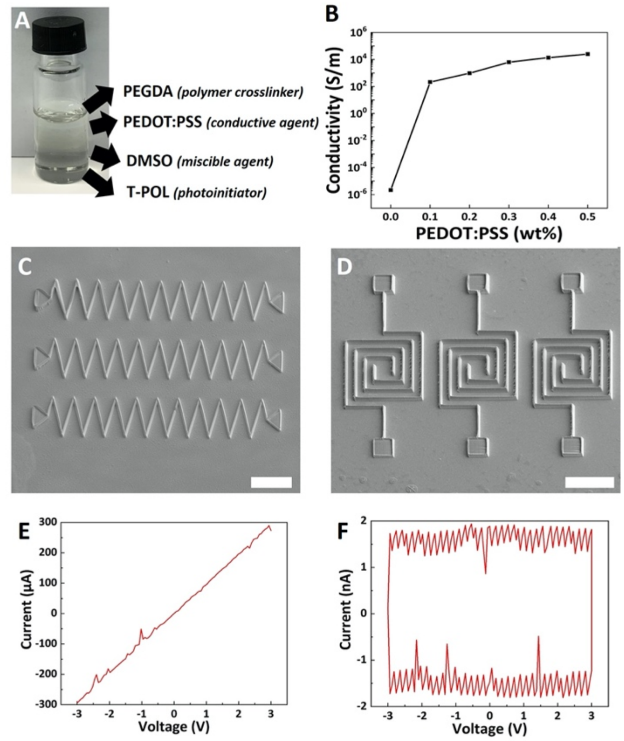

Figure 1 TPP-fabrication and characterization of conductive microstructures. A) Illustration of the ink components. B) Conductivity of the microstructures with respect to PEDOT:PSS concentration in the resin C-D) SEM micrographs of arrays of resistors and capacitors, respectively. E) I-V sweep of one resistor F) Hysteresis loop of a capacitor array (scan rate: 2 V s^{-1}). Scale bar in C and D is 50 µm.

Conclusions: In summary, we have developed a resin for fabrication of highly conductive microstructures via TPP lithography. Significant improvement of electrical conductivity by direct incorporation of PEDOT:PSS was demonstrated. Various microelectronic devices were fabricated and characterized. The outcome of this study can be greatly employed in a broad range of biomedical device applications.

References:

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