Flexible optoelectronic devices with metallic nanofiber transparent electrodes

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Organic light emitting diode (OLED) devices are receiving increasing interest from both industry and academia with the rise of flexible displays. To fabricate flexible OLED devices, one key issue is the fabrication of flexible transparent electrodes (TEs), which is a thin film layer with high optical conductance and desirable conductivity. For application in OLED devices, besides transmittance and conductivity, there are also additional requirements for the TEs, including cost-effective fabrication for industrial production, surface smoothness for device fabrication, and homogeneous conductivity for uniform light-emitting [1].

In this work, we report flexible OLED devices fabricated using template-grown metal nanofiber TEs through residual-layer-free nanoimprint and electrodeposition process, which address the aforementioned requirements. As shown in Figure 1, we first report the fabrication of the imprint mold, which is a flexible template with nanofiber extrusion network. A PMMA layer is first spin-coated on the Si wafer and followed by polymer nanofibers electrospun on it. Then, a Cr mask layer is evaporated on top, and the polymer fibers with the Cr above are lifted-off by proper solvent. After the exposed PMMA is selectively etched, the nanotrench network in the PMMA layer is duplicated into the OrmoStamp as the flexible imprint mold (Figure 1(h)).

Using the flexible imprint mold, TEs with metallic nanofibers can be fabricated through a solution-processed method, as shown in Figure 2(a-f). The nanofiber extrusion pattern originally on the imprint mold is first imprinted into the resist layer, which is spin-coated on a conductive glass. By optimization of processing parameters, i.e., resist thickness, imprinting pressure and temperature, a complementary nanotrench-pattern without residual resist can be obtained. Then, metallic nanofibers were electrodeposited in the nanotrenches. After removal of the imprint resist, the metallic nanofiber network is further transferred into thermoplastic substrates by thermal imprint. The fabricated flexible metallic nanofiber TE has the structure shown in Figure 2(h), and its morphology is characterized by scanning electron microscope (SEM) as shown in Figure 2(i). The fabricated TE has a relatively smooth surface with the metallic nanofibers fully embedded in the plastic substrates. Also, the typical line-width of the metallic fibers is smaller than 500 nm. With the flexible and flat TEs, flexible OLED devices can be fabricated by coating other layers on top, including hole transport layer, emissive layer, electron transport layer, and the metal cathode. Figure 2(j) shows the multilayer structure of the proposed flexible OLED. When applying external voltage, light can be emitted out from the transparent electrode side.

In summary, we propose a cost-effective method for flexible OLED devices with metallic nanofiber TEs. The flexible TEs are fabricated by a solution-based process with a three-step strategy that includes residual-layer-free imprint, electrodeposition and thermal imprint transfer. The metallic nanofibers typically has a linewidth of less than 500 nm, which provides the potential of small nonconductive gap while maintaining high transmittance. The small gaps results in relative uniform electrical field distribution for enhanced charge carrier injection and transportation, as well as uniform light-emitting comparing with electrodes with microscale metal mesh. With further investigation, this method is potential for mass production in industry.

1. Zeng, X.Y., et al., *A new transparent conductor: silver nanowire film buried at the surface of a transparent polymer.* Advanced Materials, 2010. **22**(40): p. 4484-4488.

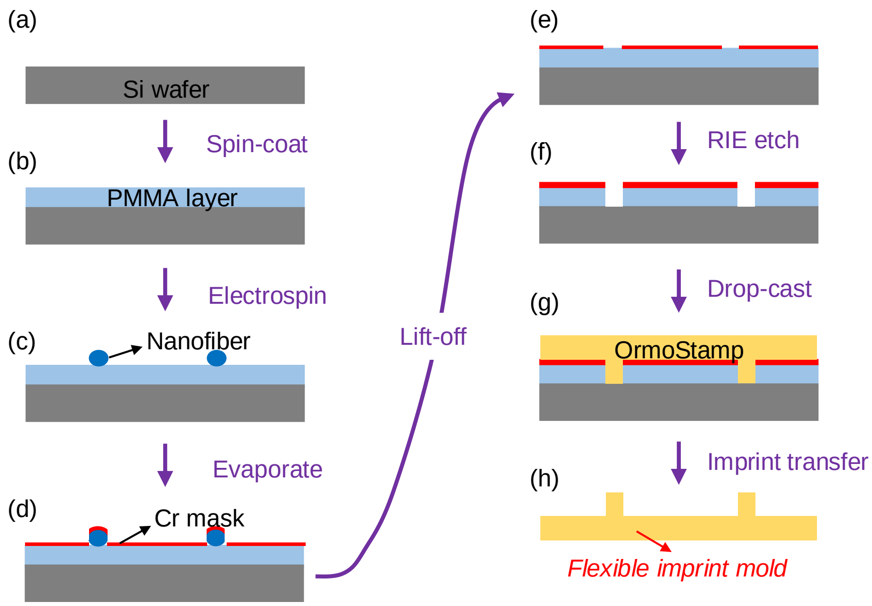

Figure 1. Schematic of the fabrication process of the flexible imprint mold with nanofiber extrusion network.

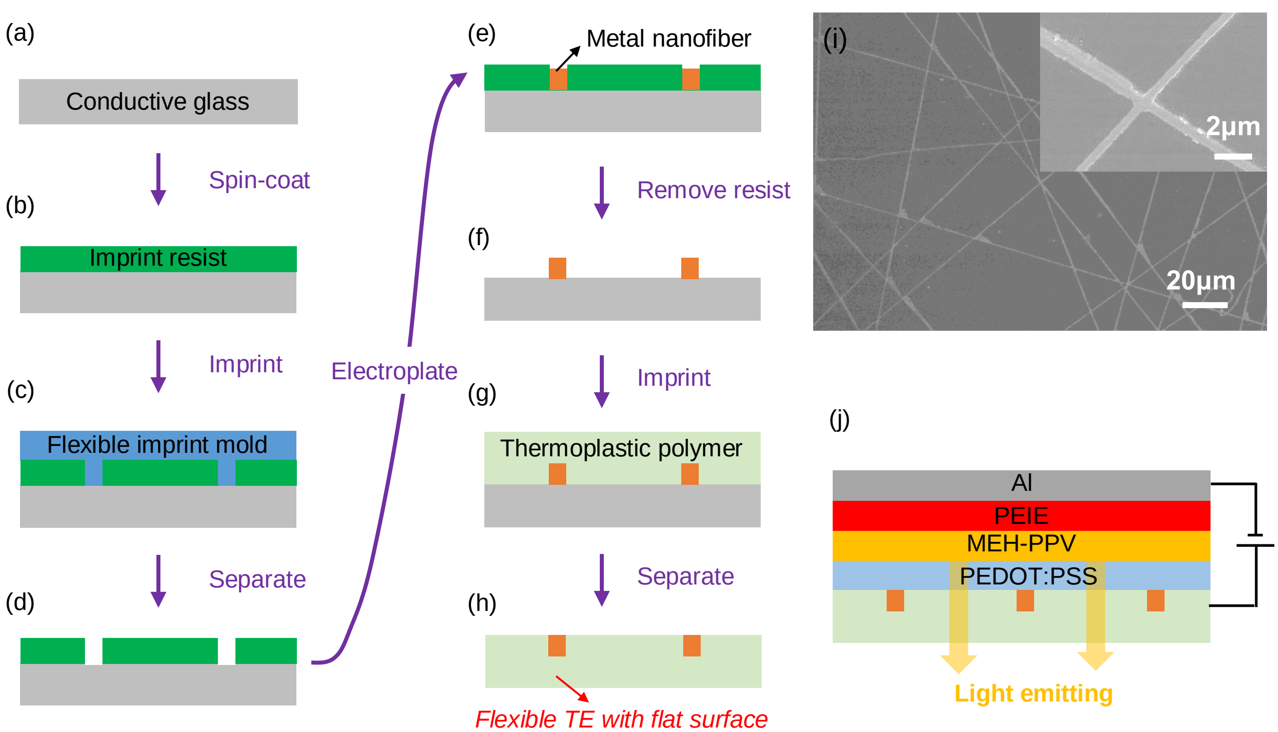

Figure 2. (a-h) Key steps of the fabrication of flexible transparent electrodes using a flexible imprint mold. The fabricated electrode has a flat surface with metal nanofiber network fully embedded in the plastic substrate. (i) SEM characterization of the metal nanofiber network embedded in a polymer substrate. The zoom-in view shows the linewidth of the metal nanofiber is approximately 400nm. (j) The multilayer structure of the flexible OLED based on our flat metal nanofiber transparent electrode.