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RESEARCH HIGHLIGHT

Seeing is believing: a versatile new approach to optically transparent electrodes

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Although materials having both excellent optical transparency and electrical conductivity at first seem counterintuitive, such substances are essential to a myriad of modern technologies. Applications for transparent conductors include electrodes for LCD, OLED and other displays, touch screens, electromagnetic interference shielding, transparent heaters (for example, automotive windshields), and photovoltaic cells.[1] For many applications, mechanical flexibility, as on plastic substrates, is also desirable for versatile form factors, impact resistance, roll-to-roll manufacture, product functionality and light weight. For many applications, the oxides of heavy post-transition metals, such as tin-doped indium oxide (ITO) or, to a lesser extent, related oxides, have traditionally served this purpose.[1] However, the cost of ITO is sensitive to fluctuating indium prices, electrical conductivity is not optimum, ITO is corroded in many environments, polycrystalline ITO coatings on plastic are brittle and less conductive, and ITO films are grown by capital-intensive sputtering processes.[1] A key issue in vapor-phase coating processes is the percentage of material actually transferred to the substrate, and for ITO this process has been heavily optimized for high yields. Other approaches to transparent conductive films utilize conducting polymers,[2] metallic carbon nanotubes,[3] graphene[3] and metallic nanowire/nanoparticle networks[4] (one variant is now commercial; http://www.cimananotech.com/). These latter methods all yield flexible films on plastic at low growth temperatures. Nevertheless, few rival the combined transparency/conductivity of the best ITO films, and all are materials-specific, meaning that conductive films are restricted to a single material.

In a recent *Nature Nanotechnology* Letter, Professor Yi Cui of Stanford University and his team report a versatile, materials-general approach for depositing transparent conducting networks based on novel ‘nanotroughs.’[5] As shown in Figure 1a, networks of long polymer fibers are produced by electrospinning, with the densities and fiber dimensions controlled by the electrospinning conditions. Next, the fibers are coated with any number of materials (for example, metals, alloys, silicon, ITO etc.) using low pressure vapor deposition (for example, sputtering, electron beam evaporation). Because of the line-of-sight directionality, the fibers are coated only on one side. Subsequent dissolution of the polymer leaves dense interconnected networks of nanotroughs (Figure 1b). These networks can be applied to diverse substrates, including paper, plastic and textiles, to yield strong, mechanically flexible structures (Figure 1c). For metallic networks such as those of copper, silver, gold, the optical and electrical properties rival or exceed those of the best ITO on glass, yet are flexible and stretchable. An interesting optical characteristic of the metallic troughs is that the cross-sections are reduced in comparison to those of flat nanowires, and simulations show that the nanotroughs exhibit ‘light-focusing’ characteristics that may be useful in solar cells and photodetectors.

Regarding scale-up, a future issue to be addressed is the yield of material deposited on the polymer networks.

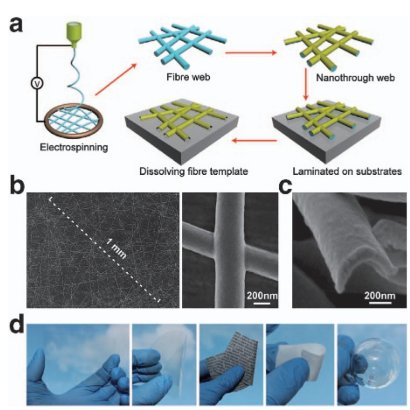

Figure 1 Fabrication and transfer-to-substrate process for nanotrough networks. (**a**) Polymer fiber webs are first deposited by electrospinning. The webs are then line-of-sight coated with various materials from the vapor phase, the polymer portion of the web is dissolved, and the resulting nanotrough networks are transferred to substrates. (**b**) Plan-view scanning electron microscopy images of gold-based nanotrough networks (left), a junction between two nanotroughs (right). (**c**) Cross-sectional view showing nanotrough curvature. (**d**) Transfer of gold nanotrough networks to glass, polyethyleneterphthalate, paper, textile and curved glass substrates (left to right). Adapted from Cui and Coworkers.[5]

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