Stretchable Metal-mesh Transparent Electrodes Fabricated through a Solution-processed Approach

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Transparent conductive electrodes are essential components of many emerging electronic devices, such as smart phones, LED displays, and photovoltaics. Indium tin oxide (ITO) glass is the most popular commercially available TCEs in recent decades, which occupies 93% of the entire market in the year of 2013 with the sales of approximate $1.6 billion [1]. However, there are some intrinsic drawbacks of ITO glass as transparent conductive electrodes (TCEs), such as limited resources, high cost of fabrication and its brittleness [2]. With the rise of flexible and even stretchable electronic devices, recent research about TCEs is focused on seeking alternative TCEs with better flexibility, stretchability and durability as well as less expense compared to ITO glass.

In this study, we have applied a solution-processed method to fabricate flexible and stretchable TCEs as shown in Figure 1 (a). First of all, predesigned patterns are transferred to a photoresist layer spin-coated on an ITO glass substrate by photolithography. Then, the target metal is electroplated in the photoresist patterns to form the metal network. Next, the photoresist is dissolved off and PDMS is cast on the metal network. After the curing of PDMS, the metal network embedded in PDMS is peeled off to complete the fabrication of the stretchable TCE. To investigate on the performance of the stretchable TCEs, we measured the sheet resistance of the samples under different values of strain for four different patterns, including square grid, hexagonal grid, triangle grid and semicircle grid. Normalized resistance VS strain curves are represented in Figure 2, which shows that semicircle pattern exhibits the best performance in terms of stretchability with only about 2.5 times of initial sheet resistance under nearly 50% strain. Moreover, we also investigate the effect of varying metal thickness and varying PDMS Young's modulus on the stretchability of TCEs.

We further developed a template-based metal-mesh transparent electrode fabrication following the fabrication process in Figure 1. The process in Figure 1 shows a one-off method because the photoresist pattern is fully dissolved before the casting of PDMS. In our further development, we directly cast PDMS without the removal of photoresist. Metal grid structures can also be peeled off with cured PDMS, but it is standing on PDMS surface instead of being embedded in it. This method creates the reusability of photolithography patterns and the fabricated sample even exhibits better stretchability.

Our work reports a promising low-cost fabrication method for flexible and stretchable transparent electrodes. The whole processes are solution-based, making it possible for mass production. Our fabricated samples show desirable stretchability and uniformity. In our future study, we will further optimize the structures and materials for the stretchable transparent electrodes and develop practical applications based on this work.

1. K. Ghaggarzadeh, R.D., Transparent Conductive Films(TCF). Forecasts, Markets, Technologies (IDTechEx): p. 2014-2024.
2. Hecht, D.S., L. Hu, and G. Irvin, Emerging transparent electrodes based on thin films of carbon nanotubes, graphene, and metallic nanostructures. Advanced Materials, 2011. 23(13): p. 1482-1513.

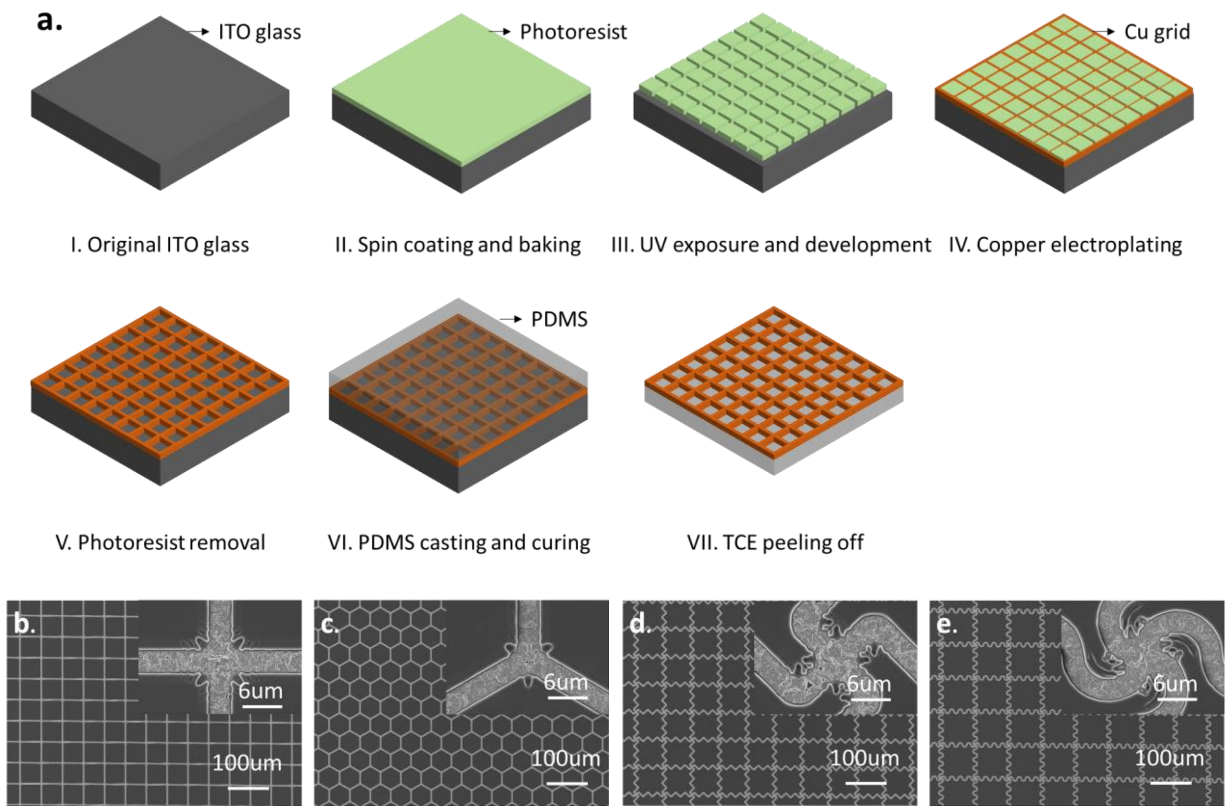

Figure 1. (a).Schematic diagram of fabricating flexible and stretchable TCEs. SEM pictures of samples after Fig.1 (a) Step.IV for four patterns, including square grid (b), hexagon grid (c), triangle grid (d), and semicircle grid (e).

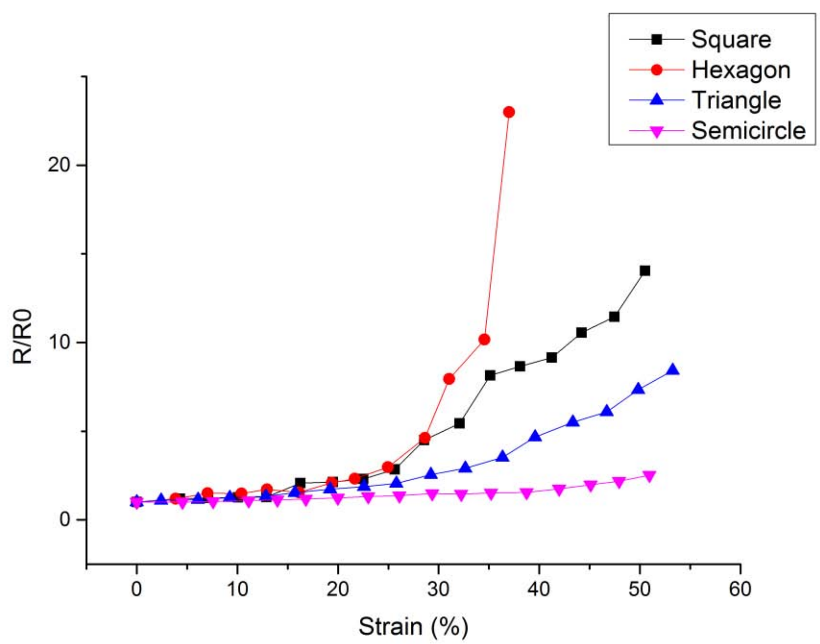

Figure 2. Normalized resistance VS strain curves for four different patterns.