Fabrication of Stretchable Transparent Conductors Using Nano-Accordion Structures

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The ability to engineer materials that are simultaneously conductive, stretchable, and transparent is difficult, and can lead to emerging applications in flexible displays, wearable electronics, conformable sensors and actuators. Nanomaterials are an attractive candidate for making flexible transparent electronics as they provide the ability to engineer electrical, mechanical and optical properties independently. The geometry based approach to enable stretchable conductors involves using thin rigid micro-scale wavy geometry [1] and 2D nanomesh [2] on an elastomeric substrate. Another approach is focused on making use of nanomaterials such graphene [3] and carbon nanotubes [4] to fabricate a composite stretchable material. These techniques have successfully demonstrated stretchable transparent conductors, but due to the random nature of fabrication process, it is difficult to design and control the electrical, mechanical, and optical properties individually.

In this work, we present an alternative approach to design and fabricate a nanostructured material that is simultaneously conductive, stretchable, and transparent. This approach involves improving the stretchability of Al-doped-ZnO (AZO)/ZnO thin films facilitated by accordion-fold geometry, maintaining conductivity and transparency simultaneously. The fabrication approach combines nanolithography to generate a periodic grating template and atomic layer deposition (ALD) [5] for conformal coating, and is illustrated in Figure 1. This ability to systematically design the nano-accordion structure results in controllable multifunctional response across mechanical, electrical, and optical domains.

The fabricated 30 nm thick ZnO nano-accordion structure using this technique can be stretched to 51% strain without any systematic failure, which is two orders of magnitude improvement over planer film. We will present a detailed numerical and analytical analysis of the dependence of stretchability of nano-accordion structure on its geometrical parameter (h^3/t) as shown in Figure 2(b), where h and t are height and thickness of nano-accordion respectively. The resistance of nano-accordion samples depends on tensile strain and this relationship is illustrated in Figure 2(c). We will also present the effect of bending on the electrical performance of nano-accordion samples and effect of nano-accordion thickness on optical transmission.

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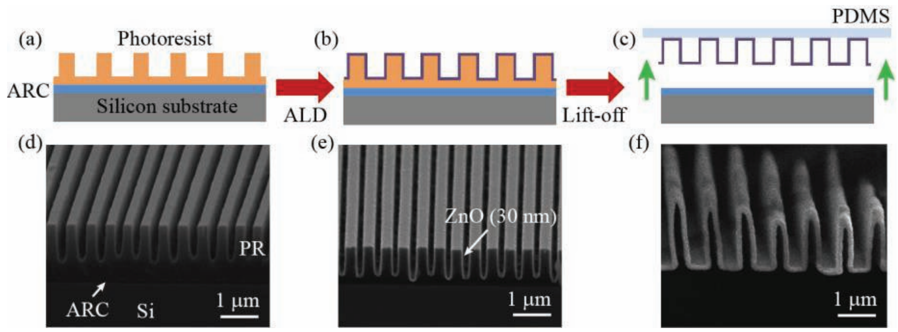

Figure 1. (a) Photoresist template patterned with 500 nm period using interference lithography. (b) Deposition of ZnO/AZO thin film on photoresist template and structure lift-off and transfer to PDMS. (d)-(e) SEM images for corresponding fabrication step.

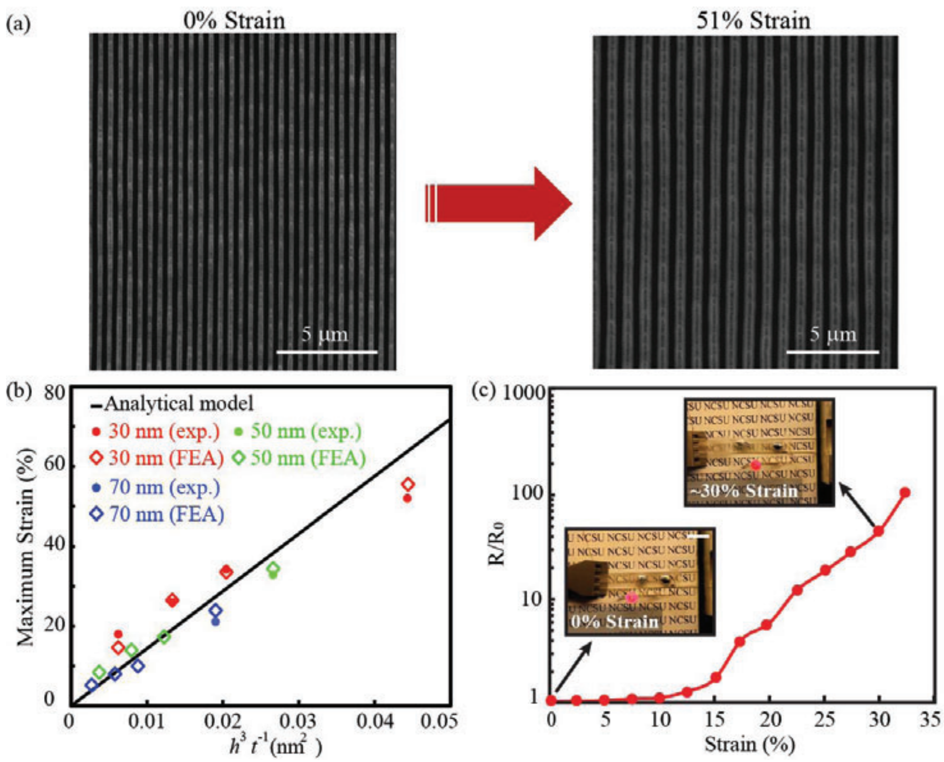

Figure 2. (a) Tensile loading of nano-accordion structure. No systematic failure till 51% strain. (b) Relationship of maximum stretchability of nano-accordion structure with the normalized geometric parameter h^3/t using the analytical model, FEA, and experimental data. (c) Electrical characterization of 50 nm AZO nano-accordion structure. Relative resistance versus strain in static loading. Optical images show the AZO nano-accordion sample as a stretchable transparent conductor at 0% and ~30% strain.

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