Thin-Film Characterization on a Novel Wrinkled Elastomeric Substrate with Applications in Force Sensing

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Stretchable electronics have recently attracted attention for use in e-tattoos, e-skin, conformal pressure sensors, robotics, and a variety of other applications. A key challenge is to achieve conductive interconnects on top of elastomeric substrates that can withstand repeated stretch cycling without significant changes in resistance over time. Since interconnects change their electrical characteristics due to mechanical deformation, they can also be used as pressure/force sensors. To achieve this, intrinsically conductive polymers such as PEDOT:PSS, metal micro-/nanofiller doped silicones and epoxies, and other piezoresistive composites have been used[1]. However, pure metals have advantages such as high conductivity and the ability to be deposited as thin films. Since metals have a low elastic limit, patterns that can buckle out-of-plane (serpentines) or creating wrinkles[2] on the surface of elastic polymers have been employed to compensate for this. These techniques reduce cracking by allowing the metal to bend while the substrate stretches underneath it.

Thin-films of gold with the thickness of 25, 50, 100, and 150 nm have been sputter-coated on a novel elastomeric substrate, called Nanflx™. Nanflx™ has an adhesive surface while also creating wrinkles to allow metals to be deposited on stretchable substrates (UK Patent Application No. 1719697.3). Thin-film behavior is characterized using atomic force microscopy (AFM), optical microscopy, and resistance measurements. 100 µm and 2 mm thick substrates are compared. Fatigue, and crack propagation (See Fig. 1) are tracked for 1, 10, and 115 cycles of 0 to 7 N tensile stress. Indeed, the resistance for 100nm increases from 5.4 ohms by ~9% after 115 cycles. Surface wrinkling and roughness is higher with increasing thin-film thickness (See Fig. 2). Furthermore, the cracks in the metal can be tuned by stretching the device; this can be used to make strain gauges with an order of magnitude higher gauge factor than traditionally possible[3]. Fig. 3 demonstrates the fabrication process using a stencil as a shadow mask.

Force data from strain gauges alongside commercial products utilizing this technology will be presented. Scanning electron microscopy (SEM) micrographs of the cracks as well as real-time DR/R_0 (relative change in resistance) during the stretch cycles will also be displayed alongside hysteresis curves.

Tensile Strain Axis

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[3] Z. Liu, D. Qi, P. Guo, Y. Liu, B. Zhu, H. Yang, Y. Liu, B. Li, C. Zhang, J. Yu, B. Liedberg, and X. Chen, Adv. Mater. **27**, 6230 (2015).

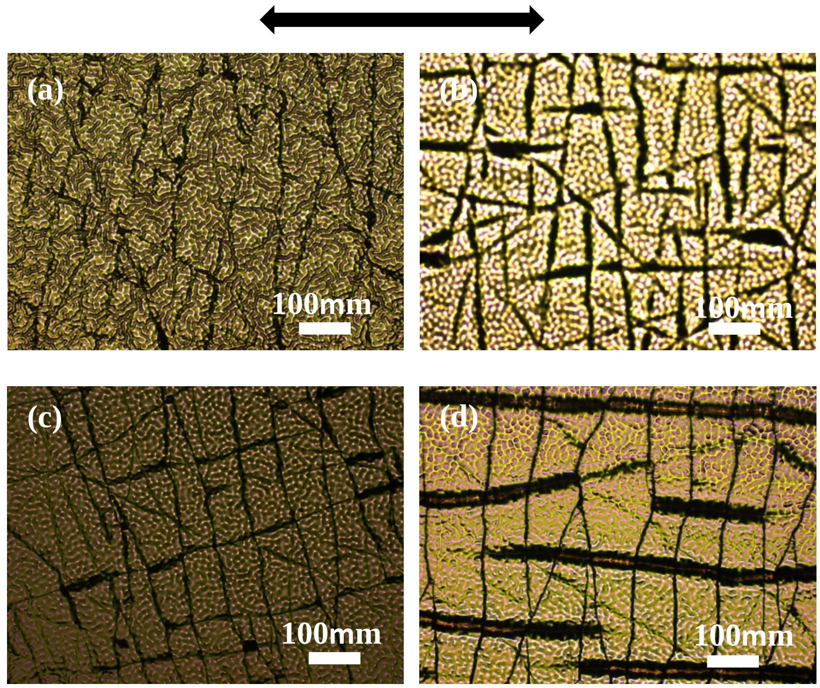

Figure 1: Optical micrographs of 100nm Au films sputtered on 2mm thick Nanflx™ substrates subjected to lateral tensile strain of 0-7N (a) unstrained after 1 cycle, (b) unstrained after 10 cycles, and (c) unstrained after 115 cycles. In (d) the substrate is under a strain of 30N which produces lateral buckling due to Poisson's ratio.

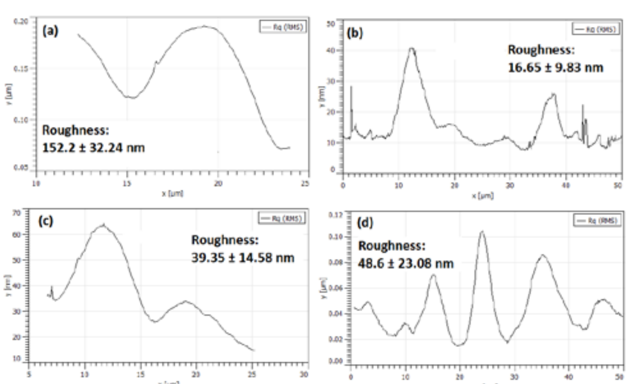

Figure 2: RMS surface profiles of Nanflx™ substrate plotted with an AFM for (a) the substrate without any metal, and (b) 25nm, (c) 50nm, and (d) 150nm thickness Au thin-films. Roughness is displayed for each plot. Thicker metal films lead to higher surface roughness and increased wrinkles.

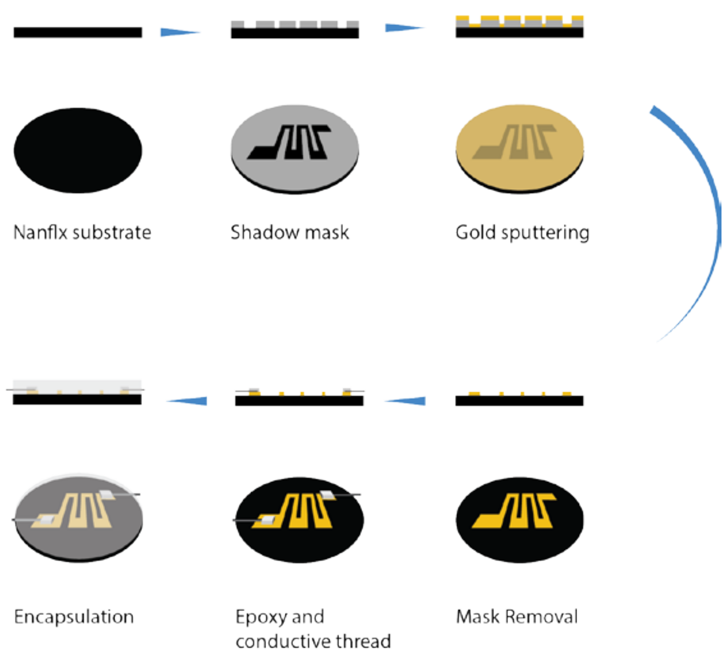

Figure 3: Fabrication process for making a strain gauge using the Nanflx™ substrate. The stencil shadow mask is made out of either vinyl or cellulose acetate. Gold is deposited and the mask peeled off after deposition. Suitable connections are made to wires using an Au-bonding epoxy before encapsulation with an elastomer.