Nanoscale metallic resistors in soft polymers

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Progress in bio-compatible materials and manufacturing technologies has enabled soft and integrated sensing platforms to provide analytic and diagnostic tools for biological cells[1]. Thereby, single cell mechanical analysis can provide critical information into the disease progress and therapy[2]. As an example, the mechanical behavior of single platelets has been investigated on soft hydrogel substrates using optical imaging[3]. However, the underlying high-resolution optical measurement is time consuming and not scalable. Thus, electrical sensing technologies and platforms that can analyze many cells in parallel are of interest in order to produce clinically relevant and statistically significant datasets. Considering the size of biological cells (e.g. blood platelet diameter of ~2-3μm), nanolithography techniques, such as electron-beam lithography, should be utilized for such nanoscale (or submicron-scale) sensing element fabrication. Moreover, the fabricated nanosensors are preferably embedded into soft polymers to more closely mimic the natural environment of the cells.

Towards the goal of a soft, arrayed sensing platform for cell analysis, this paper presents a fabrication method based on nanoscale metallic resistors using electron-beam lithography and a transfer process to soft polymeric substrates (Figure 1). The technique uses a standard lift-off process with PMMA electron beam resist on a layer of Parylene C and polyacrylic acid (PAA) on a supporting silicon substrate to pattern the gold nanostructures. The patterned resistive elements are then encapsulated with PDMS and separated from the silicon substrate by immersing them in water. PAA is water soluble and, thus, serves as a sacrificial layer enabling the transfer of the metallic nanostructures to the PDMS layer. The additional Parylene C film aids the liftoff process and protects the nanostructures during the transfer process. Finally, the Parylene C layer is removed by oxygen plasma. Using this process, gold resistors with 100 nm features sizes have been successfully embedded into soft (~1.3 MPa) PDMS films (Figure 2). The electrical performance of the metallic nanoscale resistors embedded into soft polymers was verified by measuring their I-V characteristic (Figure 3).

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[1] Alrifaiy et al., Polymers, Vol. 4, No. 3, p 1349-1398, (2012)
[2] Polacheck & Chen, Nature Methods, Vol. 13, No. 5, p 415-423, (2016)
[3] Myers et al., Nature Materials, Vol. 16, No. 2, p 230-235, (2017)

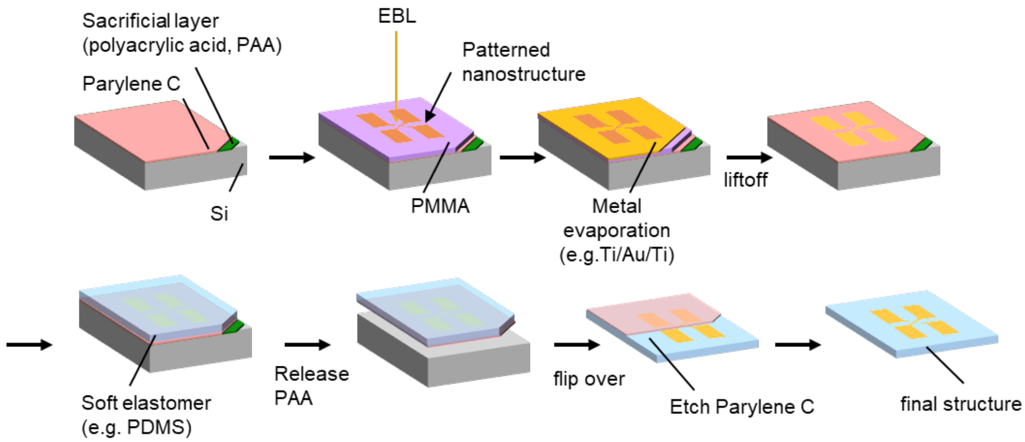

Figure 1: Process flow for patterning metallic nanostructures and transferring them from a silicon substrate to a soft PDMS film.

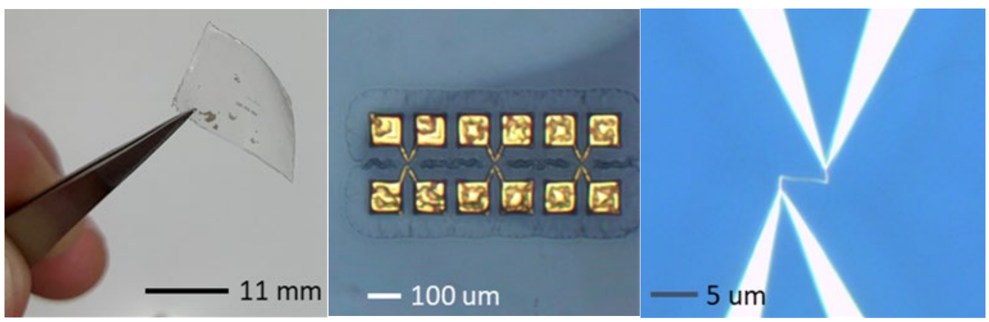

Figure 2: a) Fabricated metal resistors in PDMS being held by tweezers b) three resistive devices with 100 micron probe pads for 4-point measurement c) single leg 100 nm resistor.

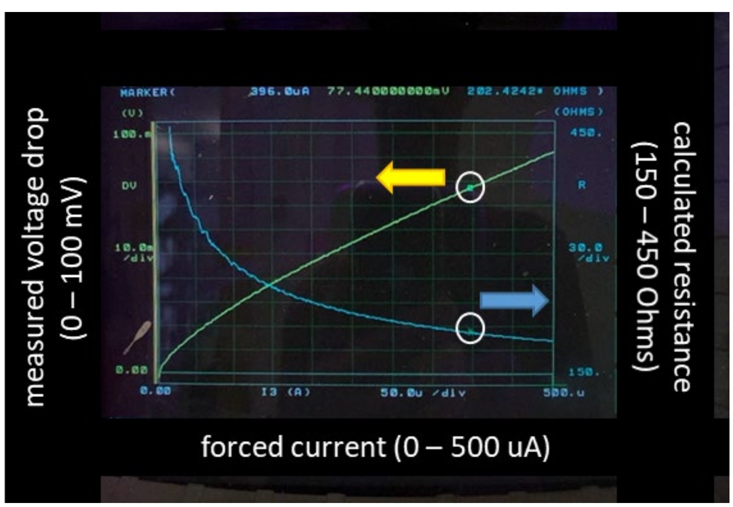

Figure 3: Four point measurement I-V characteristic of resistor in Fig 2c with approx. 200 Ohm resistance.