Nanoscale Strain Gauges on Flexible Polymer Substrates

D. K. Brown[1,2], I. Lodhi[1], B. Haile[1], O. Brand[1,2]
[1]School of Electrical and Computer Engineering, [2]Institute for Electronics and Nanotechnology, Georgia Institute of Technology Atlanta, GA
devin.brown@gatech.edu

D. R. Myers, W. A. Lam
Department of Pediatrics, Division of Pediatric Hematology/Oncology, Emory University School of Medicine, Wallace H. Coulter Department of Biomedical Engineering, Georgia Institute of Technology, Atlanta, GA

Cell forces have been connected to pathologies ranging from excessive bleeding to cancer, but due to their inherent heterogeneity, measurements on many cells are needed to gain an accurate understanding of the biophysical behaviors. Existing technologies to measure cell forces are very slow, typically relying on the analysis of light microscopy images[1]. Non-optical techniques, such as nanometer-scale strain gauges located underneath the cells would allow for real-time single-cell force measurements with improved spatial resolution. Moreover, arrays of such strain gauges could enable high-throughput mechanical measurements of large cell populations. Our previous work reported fabrication of nanoscale strain gauges on flexible polydimethylsiloxane (PDMS) substrate using a transfer process with a polyacrylic acid sacrificial layer and a parylene C capping layer[2]. That process was limited by the oxygen plasma etch removal of the parylene C capping layer causing residue on the probe pads and damage to the nanoscale structures.

This work improves on those results by using a transfer process with a sacrificial aluminum layer and no capping layer[3]. This allows for more reliable 4-point electrical probing and the demonstration of transduction of mechanical strain to electrical resistance change. To the best of our knowledge, these strain gauges exhibit the smallest lateral dimensions known to be made on a flexible and soft polymer substrate. Optical (Figure 1) and electron microscopy (Figure 2) images show the successful transfer of the strain gauges with 100 nm width, with three different resistor patterns. The nanoscale strain gauges were characterized using a probe station and fixtures with varying radius of curvature to create a controlled compressive strain ε_x, resulting in a reduction in resistance (Figures 3 and 4). Figure 3 compares the measured resistance change of type-1 resistors with the resistance change simulated using COMSOL as a function of the PDMS surface strain. The measured resistance changes are similar to the simulated response. Finally, Figure 4 compares measured resistance changes as a function of surface strain for all three resistor patterns. As expected, the straight type-3 resistors exhibit a larger sensitivity compared to the serpentine type-1 and type-2 devices.

---

[1] D. R. Myers et al., Nat Mater, vol. 16, no. 2, pp. 230-235, Feb 2017.
[2] D.K. Brown et al., EIPBN 2019 Conference, May 2019.
[3] E. K. W. Tan et al., Sci Rep, vol. 8, Apr 26 2018.

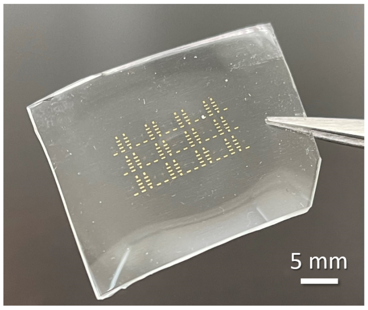

Figure 1: PDMS substrate with 0.85 mm thickness and 28 x 35 mm area, with 144 Au nanoscale strain gauges, each with four point probe pads.

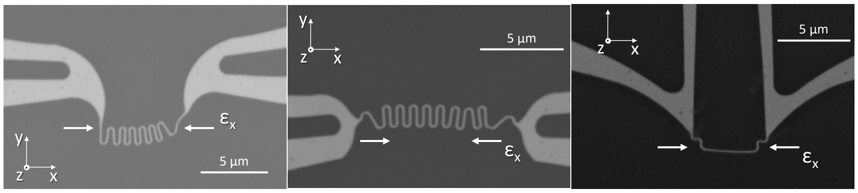

Figure 2: SEM images of 100 nm line width type-1 (left), type-2 (middle), and type-3 (right) resistors on PDMS.

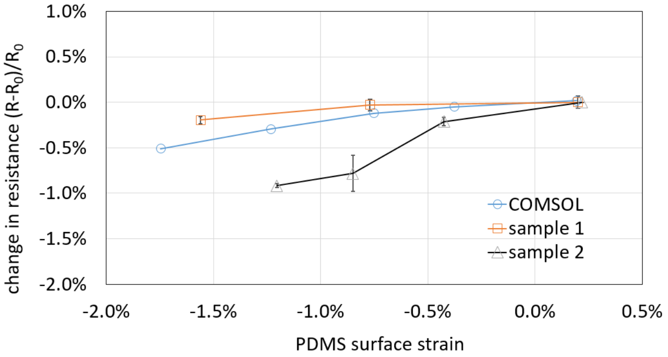

Figure 3: Measured and simulated relative resistance change of type-1 resistors versus PDMS surface strain.

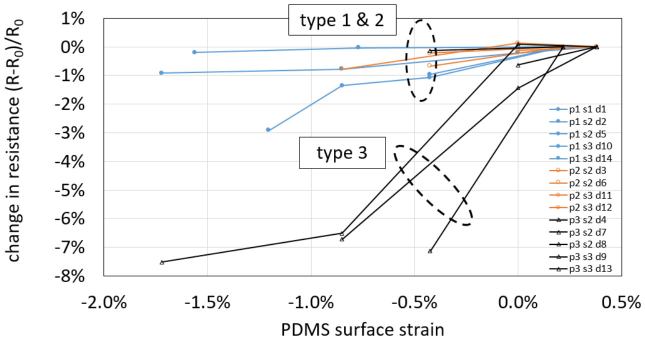

Figure 4: Measured relative resistance change of all pattern types (p1,p2,p3) versus PDMS surface strain on three different samples (s1,s2,s3) for 15 unique devices (d1-d15).