SOFT LITHOGRAPHY COMPATIBLE FABRICATION OF PARALLEL ELECTRODES IN MICROFLUIDIC DEVICES

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ABSTRACT

This paper reports a fabrication process to integrate electrical sensors comprised of parallel electrodes into microfluidic devices that are manufactured using soft lithography. Our process facilitates placement of one of the electrodes over the plastic walls of the microfluidic channel, while leaving the counter-electrode on the glass substrate. With minimal fabrication complexity, our technique not only produces more uniform electric fields than conventional coplanar electrodes, but also is more suitable for the construction of complex electrical sensor networks in microfluidic devices due to greater layout flexibility.

KEYWORDS: Microfluidics, Coulter detection, Parallel electrodes, Soft lithography

INTRODUCTION

Electrical sensors are commonly integrated into microfluidic devices through micromachined surface electrodes to create integrated systems for applications such as counting, sizing, and electrical characterization of suspended micro/nanoparticles [1,2]. In most of these implementations, electrodes are placed on the floor of microfluidic channels in a coplanar arrangement using a self-aligned fabrication process compatible with soft lithography, while the use of parallel electrodes is limited because of the fabrication complexity. However, constricting electrodes to a plane not only leads to non-uniform electric fields affecting the sensor performance (Figure 1), but also complicates the design and scaling of multiplexed electrical sensor networks (i.e., the Microfluidic CODES system [3]), by requiring three different coplanar electrodes to be routed on the same plane leading to excessively long traces with high electrical resistance [4]. In this paper, we introduce a simple and robust fabrication method, compatible with soft lithography, to create parallel-electrode sensors in microfluidic devices.

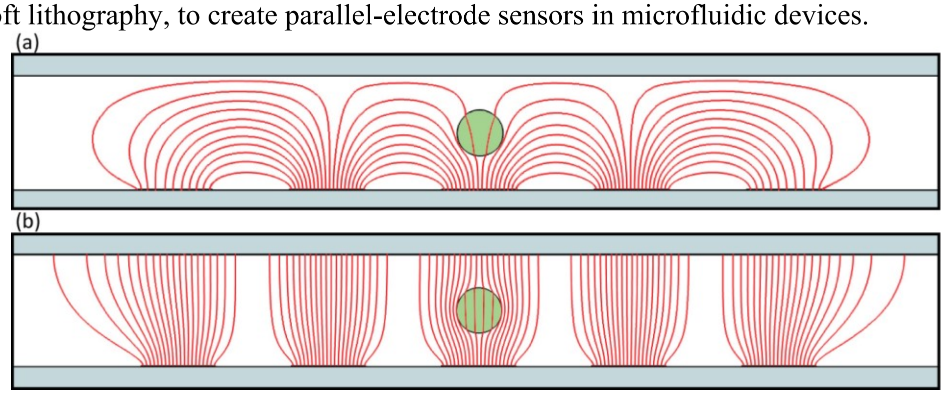

Figure 1: Simulation of the electrical field distribution generated by (a) coplanar-electrode sensor, (b) parallel-electrode sensor fabricated using our approach.

THEORY

We selectively deposit a metal film onto the inner surface of a polydimethylsiloxane (PDMS) microchannel as one of the sensor electrodes. When this metal-coated PDMS is bonded to a glass substrate containing micropatterned surface electrodes, parallel-electrode sensors are formed. The electrode covering the microfluidic channel is conceptually analogous to ground planes in printed circuit boards and significantly simplifies the sensor network layout.

EXPERIMENTAL

Our process (Figure 2) starts with the fabrication of a PDMS microchannel using soft-lithography. We pattern SU-8 photoresist on a silicon wafer using photolithography to create a mold; pour PDMS polymer on the mold, degas and bake. Cured PDMS layer is peeled from the mold and holes are created using a biopsy punch to form fluidic inlet and outlet as well as an electrical port. PDMS microchannel is then coated with gold via sputtering and transferred onto an adhesive tape to selectively remove the gold on the PDMS surface to prevent short circuit. Next, we fabricate electrodes on a glass substrate using a lift-off process. We pattern photoresist on a glass slide with photolithography, evaporate Cr/Au film stack, and etch the resist in acetone. Gold-coated PDMS microchannel and glass substrate with micropatterned electrodes are then activated in oxygen plasma, aligned and bonded. Finally, we inject a conductive epoxy-coated wire from the punched electrical port.

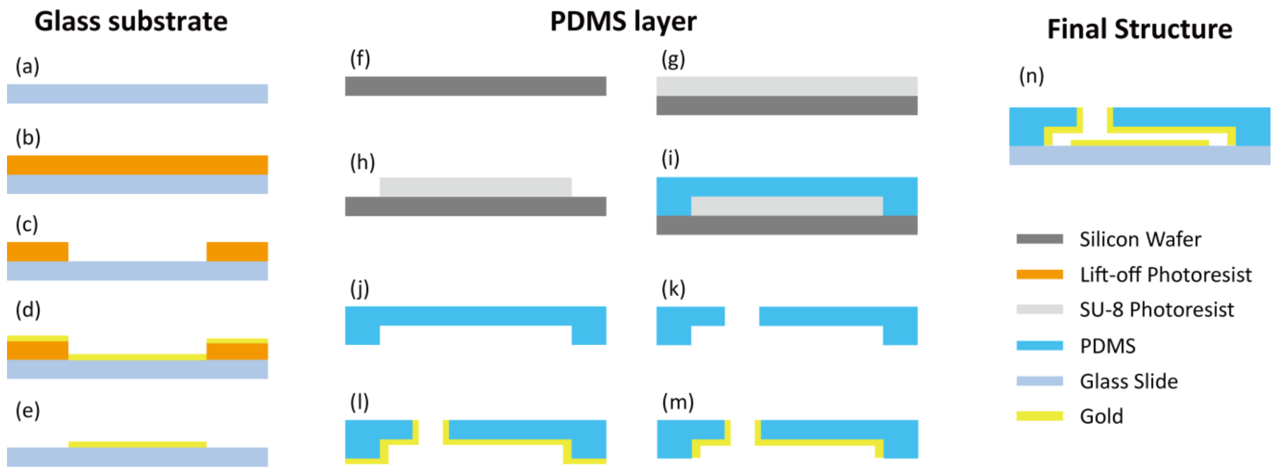

Figure 2: The schematic showing the fabrication process to create parallel electrodes in a microfluidic device. (a)~(e) The fabrication of the glass substrate with micropatterned surface electrodes. (f)-(m) The fabrication of the metal-coated PDMS microchannel. (n) Bonding of the two components to form the final device.

We fabricated microfluidic devices with 100 nm-thick electrodes as a proof of concept demonstration (Figure 3). To test our devices, we drove cultured human cancer cells suspended in buffer into the device using a syringe pump. The electrodes were driven with a 500 kHz sine wave and the root-mean-square (RMS) current amplitude was measured with a lock-in amplifier.

RESULTS AND DISCUSSION

Our results show that individual cells flowing in microfluidic channels could be detected from the differential current signal (Figure 3). Moreover, the comparison of same-cell-generated signals between the coplanar and parallel electrodes sequentially fabricated within the same device demonstrated a higher sensitivity for the parallel electrode arrangement (Figure 4).

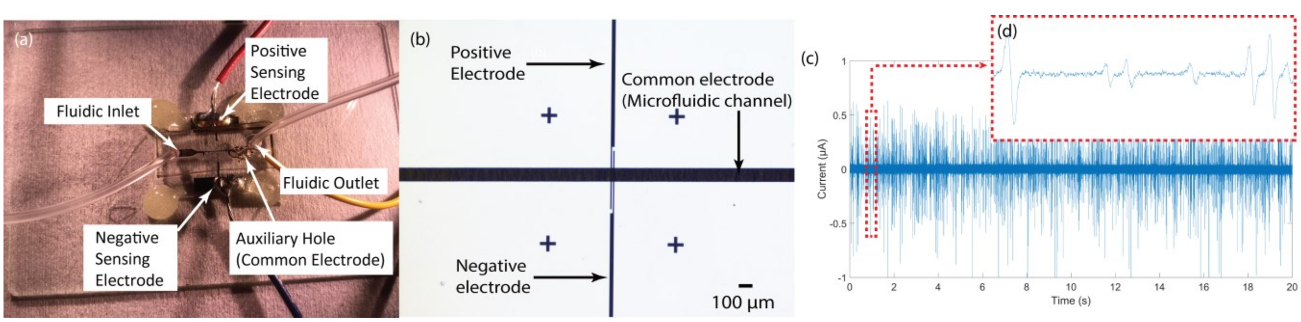

Figure 3: Images of the fabricated microfluidic device and characterization results. (a) A photo of the fabricated device with fluidic and electrical connections and (b) a close-up of the parallel electrode sensor. (c) Approximately 2500 cancer cells were detected by the sensor during 20 s period. (d) A close-up figure showing the signals for 7 detected cells in 0.04 s.

We also fabricated a device with a network of four code-multiplexed sensors encoding 7-bit orthogonal Gold sequences (Figure 5) [3]. The recorded signals from each sensor showed that our approach was able to generate distinct bipolar code signals from an electrode layout that was significantly simplified compared to the coplanar electrode arrangement otherwise required to generate similar signal waveforms.

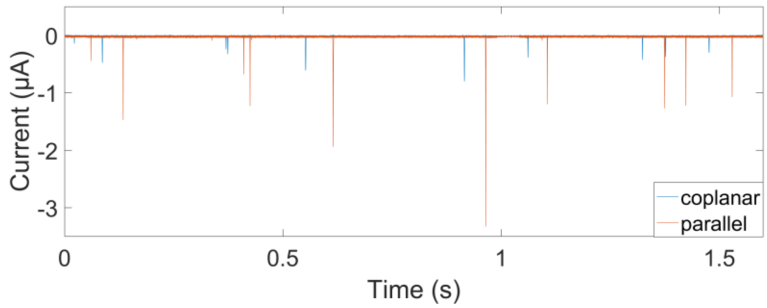

Figure 4: Resistive pulses recorded from a coplanar-electrode and a parallel-electrode sensor sequentially placed on the same microfluidic path with a 15 µm channel height. The peak signal amplitudes generated due to the same cell are on average ~3.7× higher for the parallel-electrode sensor. The result was found to be consistent with the finite element analysis results (not shown).

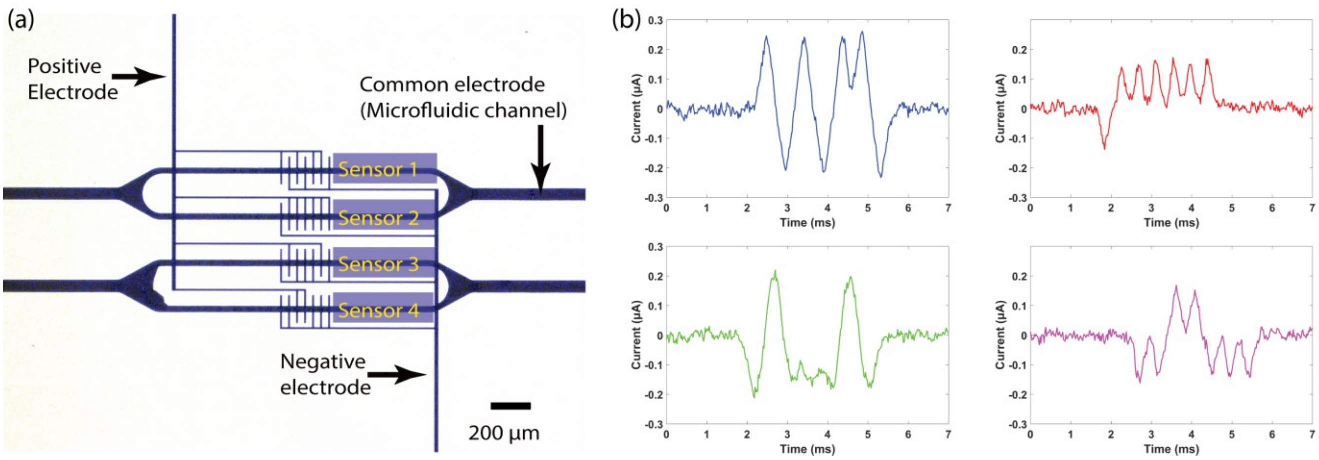

Figure 5: Microfluidic CODES device formed by parallel electrodes and the resulting representative signals from individual sensors. (a) A close-up image of the 4-sensor Microfluidic CODES device fabricated by the reported method. Sensors are encoded with orthogonal digital codes "1010110", "0111111", "0100010", "0011000", respectively. (b) Representative signals corresponding to each sensor in the device shown in (a).

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