

DIELECTROPHORETIC TRAPPING OF BEADS IN COMPACT CAPILLARY-DRIVEN SYSTEMS WITH MULTIWALL ELECTRODES

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ABSTRACT

We present a concept and fabrication of a compact capillary-driven microfluidic chip with multiwall electrodes for dielectrophoresis-based microbead trapping. The fabrication process comprises two photolithography steps and a low-temperature (45 °C) cover film lamination. The process enables the realization of hydrophilic channel walls where up to three walls can have metal electrodes with 5 μm minimum feature size inside 20 μm deep channels. Owing to a dielectric recessing step, the patterned electrodes are made level with the surrounding dielectric. Within these microchannels, 10 μm polystyrene beads were efficiently trapped by dielectrophoresis (DEP) while continuous liquid flow was sustained by the capillary pump.

KEYWORDS: Dielectrophoresis, Capillary-driven microfluidics, Microfluidic chip fabrication, Anisotropic silicon etching, Multiwall electrodes

INTRODUCTION

DEP has been extensively studied over the past several years for particle and cell manipulation [1]. Generally in DEP, electrodes are patterned on flat substrates and covered with microfluidic structures, and liquids are actively pumped [2]. Given the broad number of DEP-based applications in the lab-on-a-chip community, we found it interesting to utilize passive capillary pumps [3] for creating more compact, autonomous and efficient systems. However, the compatibility of the chip materials with capillary filling and the embedding of electrodes into the channels makes this goal challenging. Here, we implement a fabrication process to create hydrophilic channels having multiwall electrodes and a cover film sealed using low-temperature lamination (Fig. 1a). This process also involves a "recessing" step, which makes a top metallic pattern co-planar with the chip substrate. This minimizes surface topography, favors efficient sealing, and reduces edge-defects on the electrodes.

EXPERIMENTAL

The chip measures 23 × 9.3 mm² and comprises a loading pad, a microchannel with embedded electrodes, a capillary pump, air vents, a cover film and electrical contacts mating with a card-edge socket (Fig. 1). Silicon substrate is used to leverage the well-established micromachining processes as well as the favorable properties of Si and SiO₂, such as channel etching with tapered sidewall profile [4], hydrophilicity of SiO₂ for capillary filling, thermal and chemical stability, mechanical robustness, compatibility of SiO₂ surface with many biomolecules, and well defined and reliable chemical composition.

In the fabrication process, channels were anisotropically etched in the silicon substrate to about 20 μm depth using TMAH 25% aqueous solution at 100 °C and electrically passivated by 200 nm thick thermally grown SiO₂ film. Typically for electrode patterning, lift-off after double-layer resist photolithography and metal evaporation is widely used in the microfabrication community [5]. However, the conformal coating of thin sacrificial resist (first layer) and photo-sensitive resist (second layer) in the presence of microfluidic channels is very difficult in practice with spin-coating techniques. Moreover, double layer resist processing requires more time since the coating and soft baking steps have to

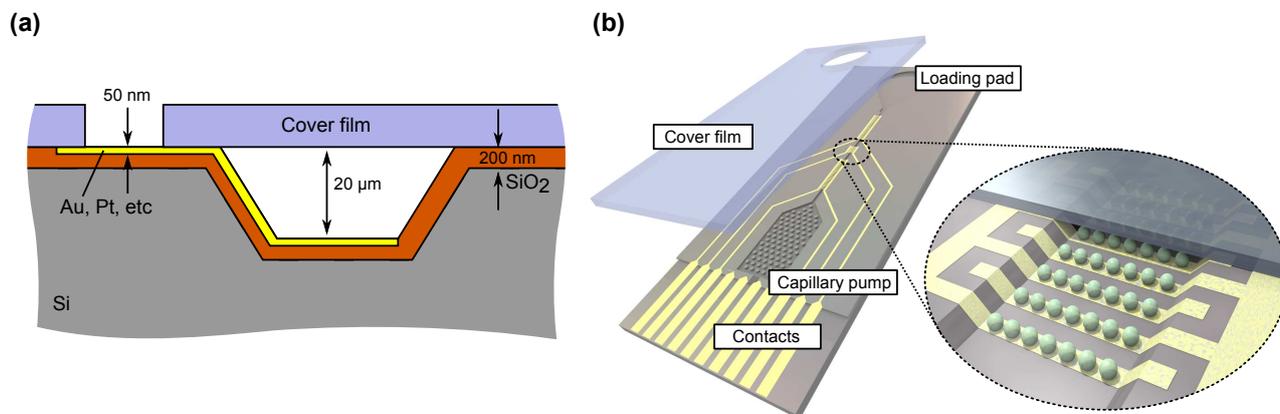


Figure 1: (a) Cross-section view of the microfluidic chip showing an anisotropically-etched and SiO₂-passivated Si channel, a conformal metal electrode recessed into the SiO₂ layer, and a pre-patterned cover film laminated on top. (b) Illustration of the capillary-driven microfluidic chip with embedded electrodes and the illustration of the bead trapping on interdigitated electrodes by dielectrophoresis (DEP).

be done twice. In this work, in contrast, the electrodes were patterned by metal evaporation and lift-off after conformal coating and patterning of a single-layer positive-tone photoresist in a closed chamber coating system. This provides better coverage on the tapered sidewalls and at the channel edges. Prior to metal evaporation, a short isotropic SiO₂ etching in buffered hydrofluoric acid (BHF 7:1) was introduced to assist lift-off and minimize edge-defects by creating an undercut and to recess the electrodes for a co-planar surface, which is not possible to realize by metal etching techniques.

In order to compensate the pattern widening due to resist thickness difference inside the channel and on the surface, as well as the photolithographic imaging errors due to the gap introduced by the etched structures, the resist exposure dose and development time were optimized to achieve at least a 5 μm minimum feature size in 20 μm deep trenches. Following the dicing and the cleaning steps, a 50 μm thick hydrophilic (~70° contact angle) dry-film (EMS, USA) cover was laminated at 45 °C to seal the microfluidic structures (Fig. 2). Compared to other microfluidic channel sealing techniques (such as wafer bonding), the dry-film lamination requires much less time and temperature. Moreover, this film is sufficiently rigid to tent over the channels without collapsing, has excellent optical properties and provides good adhesion to the surface without causing delamination or liquid leaking. SEM inspection confirmed that the cover film tents over the channels and the capillary pump pillars (Fig. 3a and b) and also showed that the electrodes have minimum edge defects and flat surface topography owing to the SiO₂ recessing step (Fig. 3c).

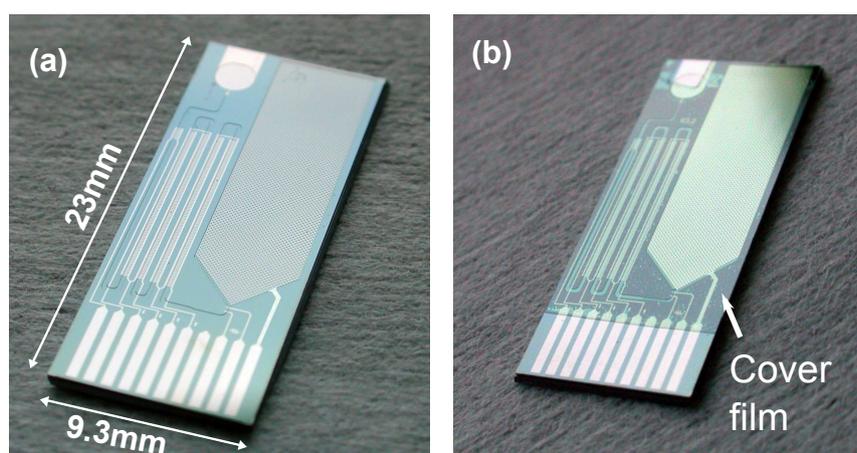


Figure 2: Photographs of diced chips before (a) and after (b) cover film lamination at 45 °C.

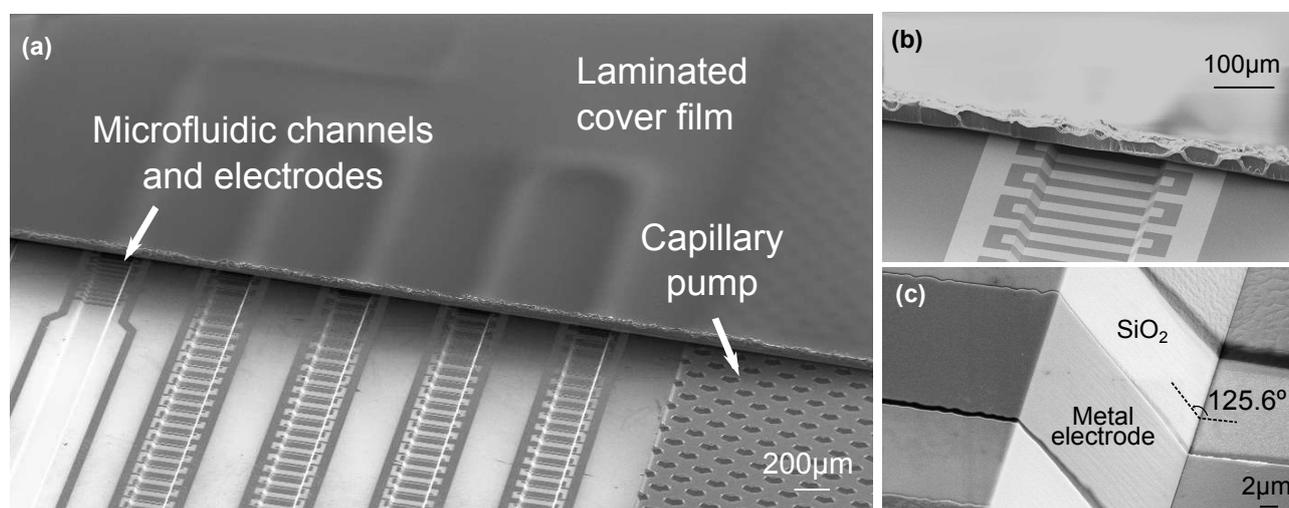


Figure 3: SEM images of the microfluidic channels where the cover film is precut across the channels for inspection. (a) The laminated film tents over the channels. (b) Patterned electrodes covering the three walls of the channel. (c) Close-up view of the tapered sidewalls where the electrodes are recessed into the SiO₂ layer.

RESULTS AND DISCUSSION

Functionality of the chip was demonstrated by trapping beads during continuous filling of liquid in the microfluidic channels and the pump by capillarity. Chips were rinsed with ethanol and dried under a stream of N₂ and then the cover film was laminated on a hot plate. Unlike many other capillary-driven systems, this technique does not require any chemical or plasma surface treatment to obtain hydrophilic channels since all four channel walls are inherently hydrophilic and the wetting properties are stable over time. For the bead trapping, 10 μm diameter polystyrene beads

(Thermo Fisher Scientific) were suspended in a $1\times$ Tris-EDTA buffer and pipetted to the loading pad while $10 V_{pp}$ potential at 1 MHz was applied to the interdigitated electrodes ($20 \mu\text{m}$ width and spacing). The buffer solution filled the channels (Fig. 4a) and pulled the beads towards the DEP trapping region. Beads were trapped on the first electrodes (Fig. 4b) and distributed to the other electrodes by tuning the potential (Fig. 4c).

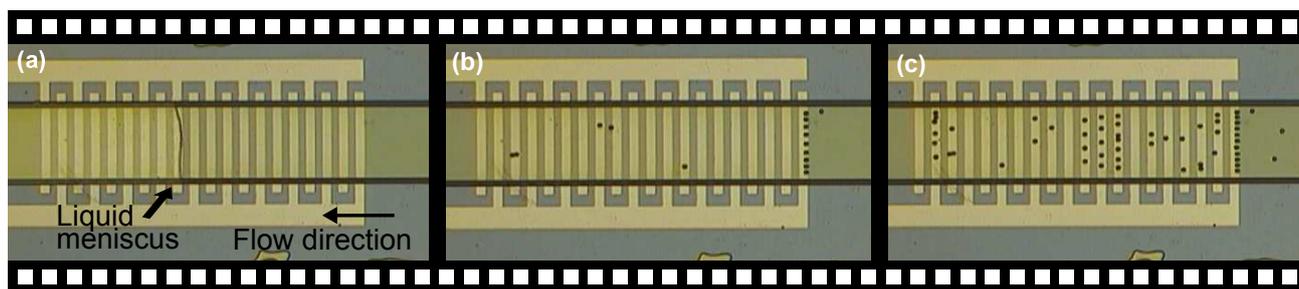


Figure 4: Snapshot images showing (a) capillary filling of a $1\times$ Tris-EDTA buffer in a microchannel having electrodes for DEP and (b and c) the resulting trapping of $10 \mu\text{m}$ beads.

CONCLUSION

We demonstrated a robust silicon microfabrication process to realize hydrophilic channels with integrated multiwall electrodes in level with the surrounding dielectric layer. The microfluidic structures were sealed with a low-temperature lamination of a pre-patterned cover film with outstanding optical and mechanical properties. The experiments showed autonomous flow generation and reproducible bead trapping. The combination of conformal electrode patterning and capillarity-compatible channel fabrication may extend the application areas of advanced and autonomous microfluidic chips for a range of electrokinetic phenomena without adding excessive complexity in design and fabrication.

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