A SINGLE-MASK SELF-ALIGNED FABRICATION PROCESS FOR ELECTRODE-EMBEDDED MICROCHANNELS
S. H. Song, T. Maleki*, B. Ziaie
Birck Nanotechnology Center, Purdue University, West Lafayette, Indiana, USA

ABSTRACT
In this paper, we report on a novel single-mask self-aligned process for fabricating vertical-sidewall electrodes inside microfluidic channels using soft lithography and injection-molding of a low melting temperature (70 °C) alloy also known as Wood’s metal [eutectic alloy of bismuth (50%), lead (26.7%), tin (13.3%), and cadmium (10%)]. Full sidewall-covering electrodes were achieved by simultaneous fabrication of a central microfluidic channel and two V-shaped channels (intersecting at the middle of the microfluidic channel), which were subsequently filled with Wood’s metal. The central microfluidic channel cross section and the side wall electrode areas were both 20×50 μm². The measured impedances between two electrodes were open circuit, 45 MΩ, and 3.3 MΩ when the microfluidic channel was dry, filled with DI water, and 1X PBS solution. 5% (30 mV) voltage drop across the electrodes was observed when polystyrene beads (nominal-diameter of ~6μm) were flown through the main channel at a flow rate of 0.6 μL/min.

KEYWORDS: Self-aligned, Embedded Electrode, Microfluidic, Soft Lithography, Wood’s Metal.

INTRODUCTION
Metal electrodes patterned inside a microchannel are essential elements in many lab-on-a-chip applications particularly in high sensitivity cell/particle detection [1, 2]. They also play an important role in enabling manipulation of biological objects in micro total analysis systems. In order to increase sensing and control capabilities of such systems, it is necessary to integrate vertical sidewall high-aspect-ratio microelectrodes into the channel network [3]. Although several methods to fabricate such structures have been reported (e.g., multi-step conventional photolithography, electro-less plating, and micromolding in capillary [4-6]), most such techniques require multi-mask complicated fabrication/chemical processes, are costly, and their integration into an integrated system can be cumbersome. In this paper, we describe a novel method for self-aligned integration of the vertical sidewall electrodes into microchannels using a single-mask soft lithography and injection-molding of a low melting temperature alloy.

DESIGN AND FABRICATION
Figure 1 shows a 3-D schematic of the self-aligned microelectrode-embedded fluidic system. It consists of two V-shaped channels containing injection-molded electrodes intersecting a central microfluidic channel. A single-mask process can be used to create the microchannels. Since all three channels are fabricated simultaneously using a single-mold, after injection, the microelectrodes cover the entire side wall of the fluidic-channel at the merging region. Covering the entire sidewall gives superior sensitivity compared to the situation where the electrode is only on top (bottom) of the microchannel.

![Fig. 1: (a) 3-D Schematic of the microfluidic system with self-aligned integrated electrodes, (b) Magnified image of the central region where all three channels are converging.](image-url)

Figure 2 shows a schematic of the fabrication process. Three microchannels were created in the PDMS by molding against an SU-8 master, Figures 2-a to 2-c. These three channels merge at a central region (L=20 μm), defining the length of the electrode in contact with the liquid. Subsequently, access holes were laser-drilled, Figure 2-d, and the channels were covered by a PDMS layer using plasma activated PDMS-PDMS bonding, Figure 2-e. Finally, Wood’s metal was injected into the V-shaped electrode channels, Figure 2-f.
Figure 3 shows a schematic of the method used to inject the alloy into the microchannels. First, melted Wood’s metal was loaded into 1mm diameter silicone tubings connected to the V-shaped electrode channel inlets. The setup was then heated to 120 °C to re-melt the metal followed by its injection into the V-shaped electrode channels. During injection, the central fluidic channel was pressurized with nitrogen (2.5psi) in order to prevent Wood’s metal penetration into the merging area.

Optical images of the microfluidic chip before and after Wood’s metal injection are shown in Figures 4-a and 4-b. For biocompatibility, a thin gold layer was electroplated on the electrode sidewalls, Figure 4-c. Electroplating solution was injected into the microfluidic channel and 1 nA square-wave current was applied to both electrodes. Figure 4-d shows a confocal microscopy image of the metallic electrode at the intersection region.

RESULTS AND DISCUSSION

After fabrication of the sidewall electrode embedded microchannels, electrodes were connected to a signal generator ($V_{pp}=1$ V) through a 5 MΩ series resistance, Figure 5. By monitoring the voltage drop across the resistor, the impedance between two electrodes was measured to be open circuit in dry condition and 45 MΩ when filled with DI water. Figure 6 demonstrates the impedance between two electrodes versus frequency when different media was pushed through the microfluidic channel. As expected, by increasing the phosphate buffered saline (PBS) concentration from 0.1X to 10X the impedance dropped significantly (see red, blue and green curves in the graph). Also, as can be seen from graph, adding...
10% Fetal Bovine Serum (FBS) to Dulbecco's Modified Eagle Medium (DMEM) has minimal effect on its conductivity, yellow curve, while adding 20% Fetal Plex (FP) to DMEM, brown curve, or 5% Bovine Serum Albumin (BSA) to Minimum Essential Medium (MEM), black curve, will increase the conductivity substantially.

To further characterize the system, 1% solid solutions (weight-to-volume) of the polystyrene beads (nominal diameter ~ 6 μm) were pushed through the main channel at a flow-rate of 1 μL/min. Figure 7 represent the voltage drop across the series resistance. A close-up view of the recorded signal in Figure 7 shows the height and width of the pulse are 30 mV, and 1.55 ms, respectively. The signal also shows a high signal-to-noise ratio. This performance is superior to the reported value of 0.5% with other electrode geometries [7]. The theoretical value of the pulse width can be calculated to be 1.56 ms using:

\[
t_{\text{pulse}} = \frac{60 \times (d+L) \times W \times H}{Q}
\]

where \( t_{\text{pulse}} \) is pulse width (ns); \( d \) is particle mean diameter (μm); \( Q \) is flow rate (μL/min); and \( L, H, \) and \( W \) are electrode length across the channel, channel height, and channel width (all in μm).

**CONCLUSIONS**

In conclusion, a novel method for fabricating self-aligned vertical sidewall electrodes inside microchannels was presented in which a low melting temperature alloy acting as the electrode material was injection-molding into PDMS channels. In order to improve biocompatibility, a thin gold layer was electroplated onto the electrodes separates the electrodes. Confocal fluorescent microscopy verified the presence of vertical sidewalls. Passing polystyrene beads with nominal diameter of 6 μm through the system induced 5% drop in the voltage.

**REFERENCES:**


**CONTACT**

*T. Maleki, tel: +1-765-413-8862; tmalekij@purdue.edu