Fabrication of Nanochannels with Microfluidic Interface Using PDMS Casting on Ti/Si Nanomold

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ABSTRACT

In this work, the fabrication of nanochannels with microfluidic interface using poly(dimethylsiloxane) (PDMS) casting on Ti/Si nanomold is presented. This new method combines e-beam lithography, Ti metal deposition, photolithography, and casting in PDMS. The combination of nanofabrication with PDMS casting allows the patterning of high-resolution nanostructures while also maintaining high throughput. Additionally, the microfluidic interface simplifies integration with current testing and characterization procedures. This allows the rapid fabrication of nanochannels for basic nanofluidic transport studies, integration with current microfluidic devices, and applications in drug delivery.

Keywords: nanochannels, nanofluidics

1 INTRODUCTION

Biochemical analysis systems have seen remarkable changes in recent years due to the development of microfluidic technology. Microfluidics has opened several new research areas including micro total analysis systems (uTAS) or lab-on-a-chips [1]. These lab-on-a-chip devices have enabled the entire analysis of chemical and biological samples to be performed on a single lab chip, thus significantly reducing analysis times, reagent use, and analysis error [2]. The recent emergence of nanotechnology has enhanced uTAS fabrication possibilities to include nanofluidic devices and systems [3]. These nanofluidic devices offer a wide range of new opportunities for uTAS since many biological processes involve structures in the sub-micron to nanometer scale [4]. The ability to handle and probe samples at their fundamental length scales can thus enable the study of single molecules and cells [5].

While interest in nanofluidic devices has been growing, there has also developed a need for nanofluidic devices to enable studies of nanotransport phenomena [5]. There is large demand that these devices be fabricated quickly, at low cost, and easily integrated with current microfluidic technology, so as to simplify testing and characterization procedures. Poly(dimethylsiloxane) (PDMS) has been considered as a fabrication material for these prototype devices because of its attractive properties, such as low cost, high throughput fabrication, optical transparency, and flexible surface chemistry [6]. Examples of nanochannels fabricated in PDMS have emerged with channel widths below 100 nm [7]. However, it remains a challenge to interface these channels with micro- and macrofluidics and interconnects to create an integrated device.

In this work, a new method for fabricating nanochannels with microfluidic interface is presented. The new method combines e-beam nanolithography and photolithography to fabricate a Ti/Si nanomold for casting in PDMS. This combination allows the patterning of high-resolution nanostructures while also integrating nano- and microfluidics in a high throughput approach. The new Ti/Si nanostructure shows excellent robustness as a nanomold for mass nanoreplica. Additionally, the use of microphotolithography allows the fabrication of many different nanochannel designs while keeping the microfluidic interface constant. This allows the rapid fabrication of nanochannels for basic nanofluidic transport studies, integration with current microfluidic devices and uTAS, and applications in drug delivery.

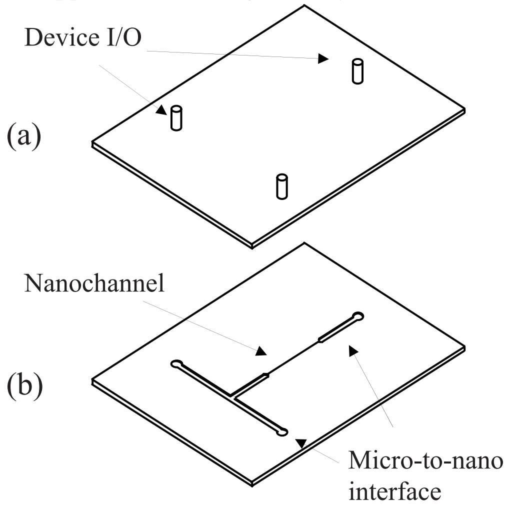


Figure 1: Conceptual schematic of nanofluidic device with microfluidic interface: (a) PDMS cover slip with PEEK tubing used as interconnects for device I/O and (b) PDMS fluidic device with nanochannel and micro-to-nano interface. Layers (a) and (b) are bonded together for a two-layer sealed device.

2 METHOD AND FABRICATION

The fabrication method is a three-stage process involving nanofabrication, microfabrication, and PDMS casting (see Figures 1 and 2). The process begins with the fabrication of a Ti/Si mold that contains both nanofeatures and microfeatures. First, nanofabrication is performed using e-beam lithography, Ti metal deposition, and liftoff to create nanopatterned Ti on Si substrate. These features will eventually be replicated in PDMS to form nanochannels. Microfabrication techniques including photolithography, Ti metal deposition, and liftoff are then used to create micropatterned Ti on the Si substrate. These microfeatures are aligned with the nanofeatues and will ultimately be replicated in PDMS, forming the micro-to-nano interface that couples sample inputs and outputs with the nanochannels. Once the mold fabrication is complete, the entire fluidic system is replicated in PDMS by a casting technique. The fluidic system is then sealed with a PDMS cover piece.

2.1 Nanofabrication

The fabrication process begins with the fabrication of nanofeatured Ti on Si mold (see Figure 2). A 2-inch Si wafer is selected and cleaned using DI H_2O:H_2O:NH_4OH = 5:1:1 by volume at 75 °C for 15 minutes. Positive electron sensitive resist poly(methyl methacrylate) (PMMA) is spin-coated at 4,000 rpm and then baked at 180 °C for 2 minutes. Electron beam lithography is performed using the Raith-150 EBL system, exposing the PMMA resist to an electron beam with a spot size of 10 nm. After exposure, the pattern is developed in a solution of methyl isobutyl ketone (MIBK):isopropyl alcohol (IPA) = 1:3 by volume for 30 seconds, followed by IPA solution for 15 seconds and blow drying with N_2. A Ti metal layer (1,000 Å) is deposited on the patterned wafer using an e-beam evaporator. The sample is then placed in acetone for lift-off.

2.2 Microfabrication

After the nanopatterns have been created, microfabrication techniques are used to produce the micro-to-nano interface (see Figure 2). The nanopatterned sample is cleaned with acetone and methanol. Then positive photoresist (Shipley 1818) is spin-coated on the surface at 3,000 rpm, followed by soft bake at 60 °C in an oven for 30 minutes. Next, the sample is immersed in chlorobenzene for 45 seconds and then dried in an oven at 120 °C for 1 minute. The sample is then exposed to UV light (300-460 nm wavelength) for 10 seconds and developed in DI H_2O:Microposit 351 = 3:1 by volume solution for 1 minute. After drying with N_2, a Ti metal layer (1,000 Å) is deposited using an e-beam evaporator. The sample is then baked at 120 °C for 2 hours, followed by dipping in acetone for liftoff.

2.3 PDMS Casting

After nano and micro patterning of the mold is completed, it is replicated in PDMS using a casting technique [6]. First, a PDMS mixture is made with Sylgard 184:curing agent = 10:1 by weight. The mold is taped to the bottom of a plastic Petri dish and coated with the PDMS mixture. The sample is left for 12 hours to let the air bubbles rise out and then cured at 65 °C for at least 1 hour. The PDMS is then peeled off from the mold and sealed with another slab of PDMS.

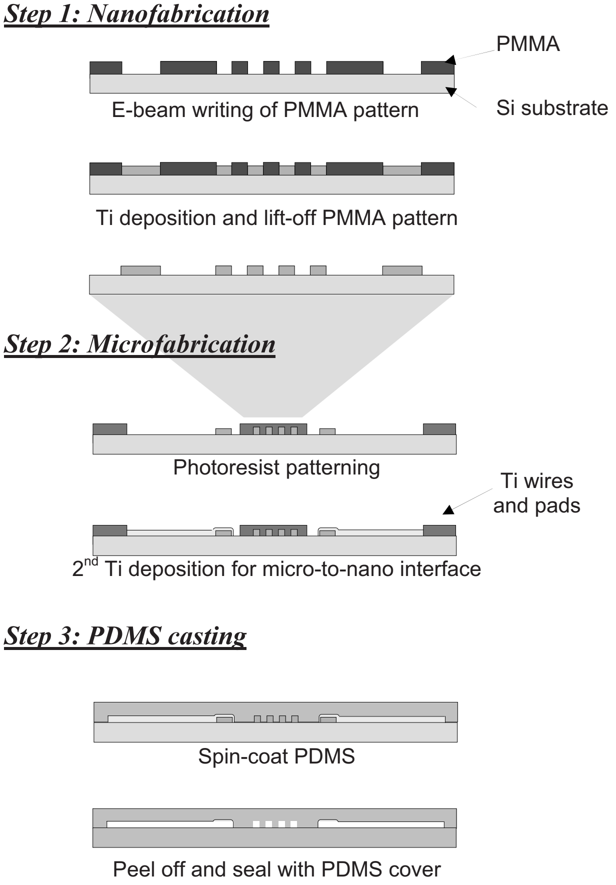


Figure 2: Fabrication process for PDMS nanochannels with microfluidic interface.

3 EXPERIMENTAL RESULTS

Several methods were used to characterize the Ti/Si nanomold and PDMS nanochannel dimensions. First, scanning electron microscopy (SEM) was employed to investigate the nanofeature dimensions of the Ti/Si mold. Arrays of Ti nanopatterns were fabricated with varying structure width from 100 – 500 nm. The resulting SEM measurements can be found in Table 1. The mold nanopatterns were plotted against the original design pattern for the e-beam lithography software as shown in Figure 3.

Comparing the original nanopattern design for e-beam lithography and resulting dimensions of the mold nanostructures after nanofabrication (see Table 1) shows the expected linear correlation, but the mold dimensions are larger than the originally designed pattern. This pattern expansion is most likely due to the proximity effect in e-beam lithography of very thin resists, in which backscattered electrons cause additional resist exposure [8]. To account for this pattern expansion, the chart shown in Figure 3 enables the design of patterns for e-beam lithography that will result in the desired nanofeatures for the mold.

Design size	Mold Size
100	153
200	244
300	347
400	459
500	568

Table 1: Results showing pattern transfer from original design to Ti/Si mold. The dimension for comparison is feature width (nm).

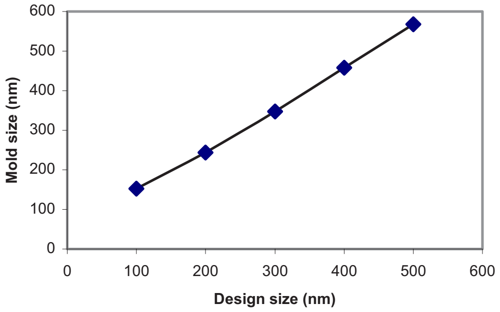


Figure 3: Comparison of original pattern design and resulting mold structures after nanofabrication.

Nanostructures with 459 nm feature size (see Figure 4) were selected for mold replication in PDMS, and atomic force microscopy (AFM) was used to measure the PDMS nanochannel dimensions before the device was sealed. A Digital Instruments Dimension 3100 AFM was used to perform the imaging in tapping mode to obtain surface and cross-sectional images of the PDMS nanochannels (see Figures 5 and 6). Table 2 shows the results of pattern transfer from the Ti/Si mold to PDMS nanochannels. The 459 nm wide mold structure resulted in a 445 nm wide channel width at the bottom of the PDMS nanochannel. The channel depth was measured at 94 nm, which correlates well with the Ti mold structure height of 100 nm. The channel widened to 908 nm at the top of the channel (see Figure 6), resulting in a trapezoidal channel profile. This is likely due to a trapezoidal mold structure profile that results after liftoff.

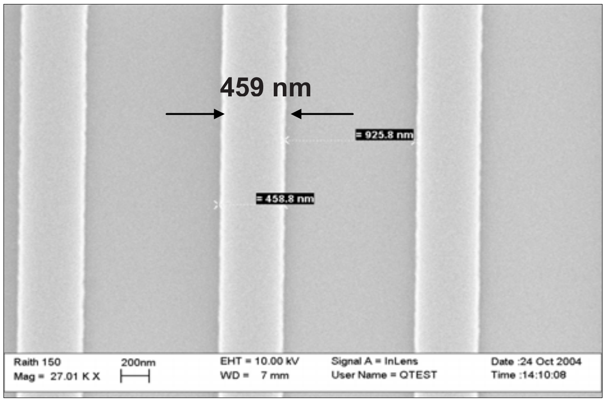


Figure 4: SEM image of Ti/Si mold showing nanostructures array of 459 nm width fabricated by e-beam lithography, metal deposition, and liftoff.

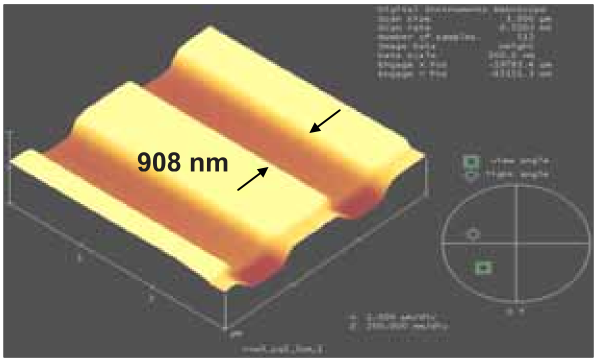


Figure 5: AFM tapping mode surface image of nanochannels in PDMS. Measurement indicated is width at the top of the channel.

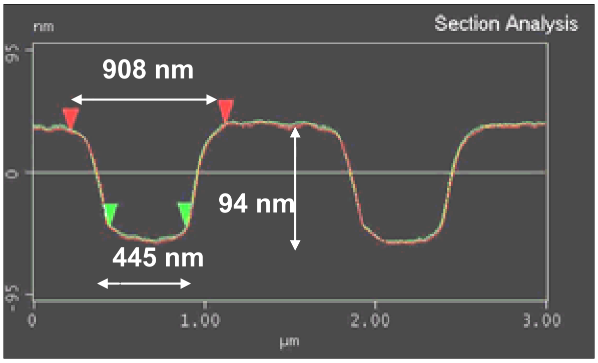


Figure 6: AFM tapping mode cross-section of PDMS nanochannels. Measurements indicated are width at the top and bottom of the channel and channel height.

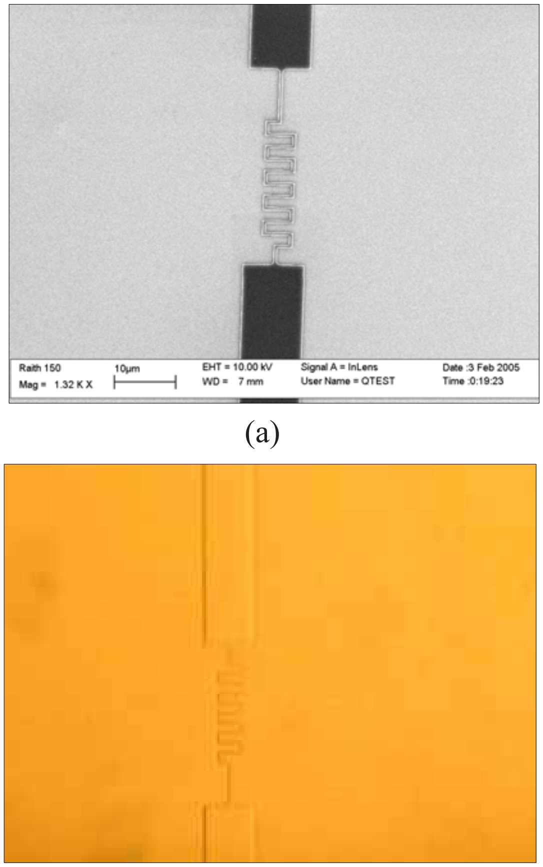
Ti/Si Mold		PDMS Nanochannels	
Width	Height	Width	Height
459	100	445	94

Table 2: Results showing pattern transfer from Ti/Si mold to PDMS nanochannels. Dimensions are in nm.

4 DISCUSSION

The mold for PDMS casting consists of a nano-structured region and micro-to-nano interface. A vital part of the fabrication process is the alignment of the micro patterns with the underlying nanofeatures. If misalignment occurs during the photolithography process, the resulting fluidic circuit in PDMS will be incomplete, causing device failure. To ensure a successful alignment, multipoint alignment markers were incorporated in the nanopattern and micromask for photolithography. During the fabrication of test devices, almost 100% fabrication yield was maintained as a result of these methods.

One of the most important aspects of this work is the flexibility in design. Since the microfabrication and nanofabrication process steps are performed independently, one can design any nanostructure desired in the nanofabrication process and still use the same micro-to-nano interface scheme. This enables the designer to fabricate and test many different nanofluidic devices in parallel, thus reducing cycle times in prototype design. The structure shown in Figure 7 is being developed to investigate mixing properties of nanochannels as a function of channel dimensions such as length, width, and flow path.



(a)

(b)

Figure 7: Device images: (a) SEM image of Ti/Si nanomold and (b) optical micrograph of PDMS channel showing serpentine design with 500 nm width and 100 nm height.

5 CONCLUSIONS

In conclusion, a new method for fabricating nanochannels with microfluidic interface has been presented and successfully demonstrated for the fabrication of a nano/microfluidic chip. The new method combines e-beam lithography and microphotolithography to fabricate a Ti/Si nanomold for casting in PDMS. This combination allows the patterning of high-resolution nanostructures while also integrating nano- and microfluidics in a high throughput manner. Additionally, this method allows the fabrication of many different nanochannel designs while keeping the interconnect scheme constant. This allows the rapid fabrication of nanochannels for basic nanofluidic transport studies, integration with current microfluidic devices and uTAS, and applications in drug delivery.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Mr. Xiaoshan Zhu, and Mr. Ron Flenniken for their technical assistance. M.R. thanks the National Science Foundation for support.

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