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Versatile laser microfabrication techniques for lab-on-chip devices in general and uranium analysis in particular

ASMITA MALIK*, S SENDHIL RAJA and P K GUPTA
Raja Ramanna Centre for Advanced Technology, Indore 452 013, India
*Corresponding author. E-mail: asmitamalik@rrcat.gov.in

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Abstract. In a plethora of microfabrication processes available now-a-days, one needs to choose the best possible option suitable for the job on-hand. This paper discusses three versatile approaches to fabricate microchips for lab-on-chip (LOC) applications in general and uranium analysis in water samples as a specific case. Laser-direct patterning succeeded by soft lithography, laser micropatterning followed by HF etching and micromilling have been demonstrated which not only suit the objective of uranium detection but also for most of the LOC applications. The different techniques elaborated enable development of LOCs in polymers as well as glass with a depth ranging from few microns to 100 μm or higher while squeezing the reaction lengths of $\sim$10 cm on a 20 mm $\times$ 32 mm chip. This development equips one to design and develop more complicated LOC devices to take advantage of their hastened reaction cycle with minimal waste in terms of capital and maintenance cost.

Keywords. Microfluidics; lab-on-chip; micropatterning; laser direct writing; soft lithography; uranium analysis.

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1. Introduction

The technology for the development of fully integrated lab-on-chip devices is still at a nascent stage considering the complexity of integration, the various effects of the micro domain that requires one to revisit one's intuitive perceptions of the physical world, and the multidisciplinary nature of the topic. The lab-on-chip devices have the capability to detect samples of interest in miniscule amounts by proactively minimizing the reagent dosage and wastage and, also in hastening the diagnostic cycle. However, they need to be developed considering the usability, cost effectiveness and ease of fabrication of the technique. Point-of-care (POC) biomedical devices need to be fabricated using a cost effective technique for mass production while laboratorial applications take into account the process of hastening and reagent consumption as the basis for fabrication.

This paper discusses three versatile techniques, viz. laser direct writing in conjunction with soft lithography, laser micropatterning, followed by HF etching and micromilling for the fabrication of microfluidic chips to be used in uranium detection in water samples.

2. Chip design for uranium analysis

Microfluidic based on-chip uranium detection reduces the sample volume to miniscule amounts and hastens the detection process. The cuvette-based uranium analysis is limited by the involvement of higher volumes of the samples and reagents apart from adding to the inventory of the radioactive waste. Uranium concentration measurement involves the mixing of uranium containing water sample in sodium pyrophosphate solution (SPS) which acts as a fluorescence enhancer. Thus, the design of the chip incorporates a mixer apart from the respective inlet and outlet reservoirs for the sample and SPS. Depending on the sample type, one has to decide the length of the channel. On-chip uranium detection sensitivity can be greatly enhanced by increasing the fluorescence yield which is a product of larger sample volume without generating higher waste. Folding of sample channel onto a small region keeps the channel length long and reduces the overall waste. Apart from a T-mixer, on-chip passive mixing [1,2] is enhanced through optimized zigzag channel bends with a geometric ratio of 4 with 12 bends at a Reynolds number of $\sim$270. The zigzag channels are designed to cause laminar recirculation that induces a transversal component of velocity consequently enhancing mixing. The mixed solution is rooted to a folded serpentine structure, which serves as the fluorescence detection region of the microdevice. The designed microfluidic chip, handling $\sim$5 μl volume, has been integrated into a small module complete with an LED as excitation source and PMT in photon counting mode as a fluorescence sensor. We have designed and fabricated the uranium analyser chips with three different techniques that have been chosen to demonstrate their versatility for use in LOCs in general.

3. Microfabrication techniques used

3.1 *Laser direct patterning succeeded by soft lithography*

Soft lithography is a very good technique for batch replication of microfluidic and micro-optical components for MOEMS instrumentation. Poly dimethyl siloxane (PDMS) is a widely used polymer in micro/optofluidics due to the ease of fabrication in it using soft lithography. PDMS is a two-part resinous polymer wherein by changing the mixing ratio of the base and the curing agent or the curing temperature one can play with its properties, for instance refractive index. After mixing, the resin is degassed and then poured in the moulds (optically polished) for casting. The uranium analyser microchip has been designed in AUTOCAD which is directly patterned onto an optically polished silicon wafer of 3 mm thickness using a fibre laser marker at 1.06 μm. These Si stamps (figure 1) are then placed in a jig with PMMA juxtaposed to it for 15 min in a pre-heated oven at a temperature of 200°C. After cooling down to room temperature,

Figure 1. Silicon stamp for uranium analysis.

the embossed negative of the design is obtained on polymethyl methacrylate (PMMA). The embossed PMMA is then used as a mould for casting PDMS. A 10:1 mixture of PDMS is then poured onto the hot embossed PMMA and left for curing. After curing, the exact replica of the chip has been formed in PDMS.

3.2 *Laser micropatterning followed by wet HF etching*

Another chip is designed in AUTOCAD with 100 μm width and 250 μm spacing between the meandering channels to increase the interaction region. This design is realized in fused silica by surface micromachining of fused silica succeeded by wet hydrofluoric acid (HF) etching. A Cr/Au mask (50 nm/1 μm) sputter coated on the fused silica substrate (1 mm thick) is used as mask against hydrofluoric acid etching. The Cr/Au mask is patterned by direct laser writing at 1.06 μm using fibre laser marker with a spot size of 30 μm and a repetition rate of 375 kHz. The patterned fused silica substrate is then etched with 48% HF in de-ionized water under ultrasonication. The patterned fused silica microchip has been sealed with PDMS cover chip using surface activation of bonds.

3.3 *Micromilling*

Micromilling machine is used by electronics engineers to develop their copper-coated epoxy-based PCBs. However, we used this machine to write the design onto polymethyl

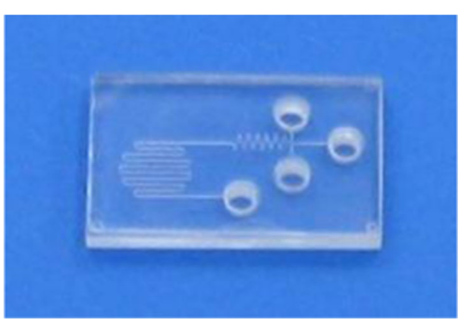

Figure 2. Sealed LOC for uranium analysis.

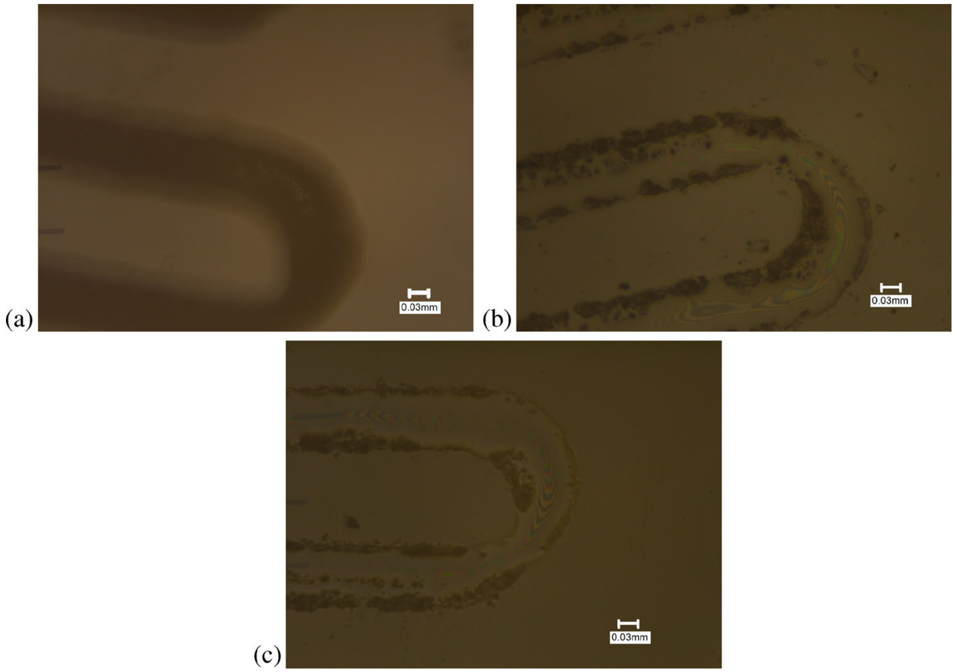

Figure 3. WLI of soft lithographic-based uranium analyser chip. (**a**) Silicon stamp, (**b**) PMMA mould and (**c**) PDMS cast (scale length is 30 μm).

methacrylate (PMMA) which actually is a photoresist ubiquitously used in the development of MOEMS devices. The chip is designed in AUTOCAD which is then transferred to micromilling machine software and is directly written onto PMMA using a 250 μm flat end mill. Figure 2 shows the sealed microchip for uranium analysis which has been fabricated using micromilling. The microchip is bonded to a glass chip using ultraviolet curable adhesive.

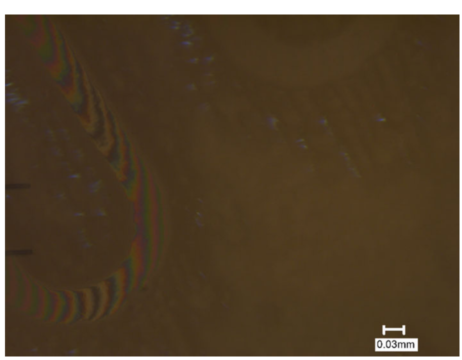

Figure 4. WLI of HF-etched uranium analyser fused silica microchannel (scale length is 30 μm).

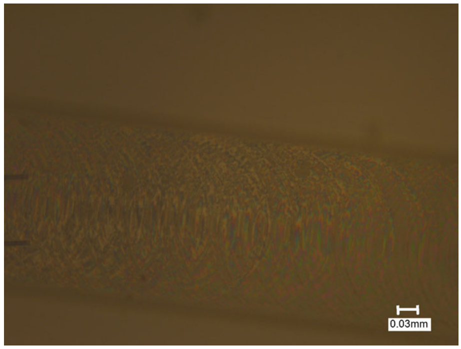

Figure 5. WLI of micromilled PMMA microchannel (scale length is 30 μm).

4. Results and discussions

4.1 *Laser direct writing succeeded by soft lithography*

The depth of the microchannels so formed is 30 μm. The PDMS microchip has been sealed with a 1 mm thick fused silica wafer using surface activation of bonds. Inlet and outlet holes are punched into PDMS at the reservoir using micropunches prior to bonding. Figure 3 shows the white light interferograms (WLI) of the silicon stamp, PMMA mould and the PDMS cast of the uranium analyser microchip channels.

4.2 *Laser patterning followed by wet HF etching*

The depth of the microchannels so formed using this technique has been measured to be 30 μm using white light interferometry (figure 4). The microchip is bonded to PDMS with matching holes for sample/SPS reservoirs using UV-ozone surface activation of bonds under 172 nm DUV lamp.

4.3 *Micromilling*

The microchannel depth and width so fabricated with micromilling machine have been measured to be 150 μm and 250 μm respectively using white light interferometry (figure 5). A fused silica wafer with matching holes for the sample/SDS chambers is bonded on the top of the PMMA substrate to close the channel and form the complete chip using UV curable epoxy.

5. Conclusion

Three different microfabrication techniques have been posited for the development of lab-on-chip devices in general and for microuranium analysis in water samples in particular. The ease of fabrication and the technical/experimental requirement of the chips are the stringent criteria to select a particular fabrication technique over another. For instance, laser direct writing followed by soft lithography is suitable for mass production of chips, laser micromarking followed by HF etching is suitable for those experiments where the LOC is required to be fabricated in no other material than glass while micromilling is suitable where the channel microroughness is insignificant for the experiment to be conducted.

The results of microuranium analysis in drinking water samples using the chips will be reported elsewhere.

References

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