FABRICATION OF 1-D NANOCHANNELS ON PMMA SUBSTRATE BY PHOTORESIST-FREE UV LITHOGRAPHY AND UV-ASSISTED BONDING UNDER LOW TEMPERATURE

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ABSTRACT
A novel method for fabricating PMMA nano- or submicrofluidic chips by means of UV-lithography and UV-assisted low temperature bonding was developed. The nano- or submicrochannels were prepared by exposing the PMMA substrate to the UV-lights through a mask. After the surfaces of the channel-structured substrate and a flat cover sheet were subjected to the UV-irradiation, both the substrate and cover sheet were brought together under the running water. The bonding was performed at a temperature of 45 °C and under a pressure of 1.19±0.12×10^5 Pa. The fabricated hybrid micro- and nanofluidic PMMA chip was demonstrated for the electrokinetic ion enrichment-depletion.

KEYWORDS: PMMA, UV lithography, UV-assisted bonding, ion enrichment-depletion

INTRODUCTION
Nanofluidic chips have become attractive for the applications in the chemical and biochemical analysis due to the unique properties of the nanochannels. One critical issue in nanofluidics is the availability of reliable, reproducible and cost-effective fabrication strategies, including nanochannel fabrication and bonding methods. Molding techniques such as hot-embossing are usually adopted to prepare nanochannels on polymer substrates [1]. With this technique, a mold with nanometer relief is required. Mechanical stretching [2] and electrical breakdown [3] have also been reported to produce nanochannels or nanogaps. With these techniques, however, the inner diameter of the channels can hardly be accurately controlled. The sealing of nanochannels is also challenging. Thermal bonding, which is commonly used for the sealing of microchannels and usually carried out at a temperature close to the soften point of the polymer and under a relatively high pressure, suffers the problem of the collapse of the nanochannels. This paper presents a novel method for preparation of PMMA chips with 1-D nano- or submicrochannels with photoresist-free UV lithography in combination of UV-assisted low temperature bonding.

EXPERIMENTAL
The PMMA nanofluidic chip was consisted of a PMMA substrate sheet (3 mm in thickness) with nanochannels and a flat PMMA cover sheet (also 3 mm in thickness). The PMMA substrate was first exposed to the UV-lights emitted from a low pressure mercury lamp through a quartz mask to produce designed nanochannels (Figure 1 (a)). The photolithographed PMMA substrate together with a flat PMMA cover sheet was then exposed to the UV-lights for 2 h (Figure 1 (b)). The UV-treated sheets were brought together under the running deionized water (Figure 1 (c)). After the two PMMA sheets were sandwiched by two pieces of elastic PDMS slabs and two glass plates (Figure 1 (d)), the assembly was clamped with four clamps that generated a pressure of 1.19±0.12×10^5 Pa. The bonding process was carried out at a temperature of 45 °C for 35 min.

The hybrid micro- and nanofluidic PMMA chip used for the electrokinetic ion enrichment-depletion test consisted of a upper PMMA substrate with two U-shaped microchannels connected by a nanogap and a lower flat PMMA cover sheet. The U-shaped microchannels were first thermo-embossed onto the PMMA substrate, and the nanogap connecting the U-shaped microchannels was then prepared onto the substrate with the UV-lithography technique described above. The bonding process was the same as that described above.

For the test of electrokinetic ion enrichment-depletion, the channels on the hybrid micro- and nanofluidic PMMA chip were filled with a solution of 20 μM fluorescein isothiocyanate (FITC) in 50 μM borate buffer after they were sequentially flushed with deionized water and 50 μM borate buffer. A voltage of 1 kV was applied to the U-shaped micro channels via Pt electrodes. The fluorescent intensity was observed with a fluorescence microscope.
RESULTS AND DISCUSSION

Soper’s group [4] reported that the PMMA surface underwent photolysis when exposed to the UV-lights, resulting in the formation of some hydrophilic moieties on the UV-exposed region. We observed in the present work that recessions with a depth of nanometer level were formed on the UV-exposed region of the PMMA sheets. This could be ascribed to that the polymer chains on the UV-exposed region were degraded to small molecular fragments that could be easy removed via e.g. evaporation. As shown in Figure 2, the depth of such UV-lithographed channels increased with the UV-irradiating time. Figure 3 shows the cross-section profile of a 1-D nanochannel fabricated on PMMA sheet with the described UV-lithography for 1 h. Without the use of photoresist whose solvent may attack PMMA surface, the developed resist-free UV-lithography method enables us to prepare 1-D nanochannel networks with a specific depth of nanometer or sub-micrometer level on PMMA sheets by regulating the UV-irradiating time.

Thermal bonding results from the fusion of the intimately contacted polymer surfaces under the condition of a high temperature close to its soften point and a high pressure, consequently channel deformation or even collapse is inevitable. Bonding at a temperature below the soften point and a low pressure should rely on chemical bonds formed between two contacting polymer surfaces. In the present work, UV-lights were also employed to generate hydrophilic functionalities on the PMMA surface that facilitated the low temperature bonding of the PMMA sheets. Thus, the surfaces of the channel-structured PMMA substrate and the flat cover PMMA sheet were exposed to the UV-lights before bonding. ATR-FI-IR spectra (Figure 4) revealed that polar moieties such as ketone and hydroxyl groups were formed after the UV irradiation. After subjected to the UV-treatment, the two PMMA sheets should be brought together under the running deionized water which created a local clean environment. Otherwise, the dust left on the polymer surface might lead to imperfect bonding or even failure in bonding. The chips bonded with the UV-pretreatment could bear a strength of 6.71±2.50 MPa which was obtained by pull-test experiments, while the chips bonded at the same temperature and pressure but...
without UV-treatment delaminated a few minutes after withdrawn from the clamps. Figure 5 showed a fluorescent image of a nanochannel array that was filled with a solution of 1 mM FITC after the UV-assisted low temperature bonding. The green fluorescent pattern indicated the existence of the nanochannels on the fabricated nanofluidic chip.

A model analyte of FITC was used to examine the effectiveness of the fabricated hybrid micro- and nanofluidic chip for the electrokinetic ion enrichment-depletion. As shown in Figure 6, the fluorescent intensity near the cathode end of the nanochannel increased with the time after a voltage of 1 kV was applied to the U-shaped microchannels while that of the anode end decreased, indicating that the fabricated chip with hybrid micro- and nanochannels worked well for the electrokinetic ion enrichment-depletion.

CONCLUSION

The developed method for fabrication of nanofluidic channels on PMMA chip via photoresist-free UV-lithography in combination with UV-assisted low temperature bonding features simple operation, low cost, good yields and no requirement of expensive equipments and clean rooms. With this method, it is possible to fabricate the nanofluidic chips in common chemistry laboratory. With a few modifications, the developed method could be adopted to prepare nanofluidic chips made of other polymers such as polystyrene.

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REFERENCES


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