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3D Rapid Prototyping Technology (RPT) as a powerful tool in microfluidic development

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Abstract

A novel method, a 3D printing technique, in particular, acrylic photopolymer material-based Rapid Prototyping (RPT) have been used to 1) fabricate molds for PDMS (PolyDiMethylSiloxane) casting; 2) fabricate RPT-based microfluidics and 3) fabricate RPT-based research instrument platforms. 3D RPT-based molds have been fabricated in order to cast a PDMS flow cell for a Surface Plasmon Resonance (SPR) instrument, and to cast a PDMS chamber for cell lysis in a nanobiological sensor. 3D printing has been utilized to create and test several acrylic photopolymer resin-based prototypes for different microfluidic structures (chaotic mixers, reagent and buffer reservoirs, fluid homogenizers) to be deployed for gynecological cervical sample preparation. Besides, RPT technique has been used also to fabricate platform elements for various microfluidic applications.

Keywords: RPT, microfluidics, SPR, PDMS

Nomenclature

3D RPT	3 Dimensional Rapid Prototyping Technology
PDMS	PolyDiMethylSiloxane
SPR	Surface Plasmon Resonance
ss-DNA	Single Stranded DeoxyriboNucleic Acid

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1. Introduction

Applied research of biosensor based devices and the inherent microfluidic sample handling solutions can be supported in many cases more reliably and quickly with experimental results than with simulations. This approach requires quickly establishable or easily adaptable experimental setups, in order to be productive. 3D printing is a dynamically developing technique used in any industry where prototype parts and physical models are required including aerospace and defense, high technology, manufactory and medical devices. Current 3D printers tend to achieve such a fine resolution (eg. 16 μm layer thickness) that makes them utilizable for microfluidic applications as well. However the full capabilities of 3D printing are not yet fully developed in the field of applied research. Based on literature nowadays only in few cases researchers apply RPT fabricated elements, for example to realize and supplement fluidic connections [1,2,3] or in the field of oral surgery [4]. Therefore with our work we demonstrate the ability of 3D Rapid Prototyping of translucent materials as an effective tool in the field of microfluidic and prototype instrument platform fabrication through the following presented examples:

1) A novel and rapid PDMS based microfluidic fabrication method using RPT molds.
2) A method to apply RPT fabricated elements directly as acrylic resin-based dummy microfluidic prototypes (optionally with surface treatment for compatibility with the liquid content, thus, being capable to serve as functional prototypes).
3) A method to apply RPT fabricated elements in research instrument platforms for various applications.

2. Materials and Methods

2.1. Materials

All the applied reagents were purchased from Sigma Aldrich (Germany). PDMS was purchased from Dow Corning Corp. (USA). FullCure 720 base material and FullCure 705 support material were purchases from Varinex Inc. (Hungary).

2.2. 3D Printing

For 3D RPT printing we applied an Objet Geometries Eden 250 printer with FullCure 720 base material and FullCure 705 support material. All the fabricated structures were immersed in 7 % NaOH solution for 30 min after printing to remove all the remaining support material. Parts to be painted (e.g. instrument platform elements) were first softly hand polished with a 1000-2000 grit silicone-carbide wetsanding kit and then were painted applying Mr. Surfacer 1000 primer and Humbrol acrylic spray. Autodesk Inventor 2010 software was used for designing the objects.

2.3. PDMS casting

Raw PDMS was prepared by adding Sylgard 184 curing agent to Sylgard 184 silicone elastomer in 1:10 m/m ratio. The freshly prepared raw PDMS was casted in the 3D RPT fabricated mold forms in a homemade casting workstation consisting of a vacuum exsiccator, a water stream based vacuum pump and tubing or in a vacuum chamber with an oil based vacuum pump. During the 10 min vacuum exposition all the visible air bubbles left the PDMS body (pressure below 5 kPa). For binding two separately casted PDMS parts together we applied corona treatment surface activation with an Electro-Technic Products Inc. BD-20AC instrument. This laboratory corona treater works with three different shapes of electrodes with an output voltage between 10 – 48 kV and 4 – 5 MHz frequency range.

3. Results and Discussion

3.1. PDMS based microfluidic fabrication

The fine resolution and rapid fabrication of the 3D RPT printed objects make them utilizable as low-cost molding forms for PDMS casting. The total fabrication time of such devices is approx. 3-5 hours including the mold printing and PDMS casting. Fig. 1 shows a PDMS flow cell applied in a Surface Plasmon Resonance instrument casted in an RPT fabricated mold form (channel height: 300 μm, width: 4 mm). The flow cell is closed at the top with a disposable glass substrate (25*25 mm) covered with 50 nm gold and biofunctionalized with the viral ss-DNA. The blood sample to be tested is introduced and drained through the two inlet/outlet openings.

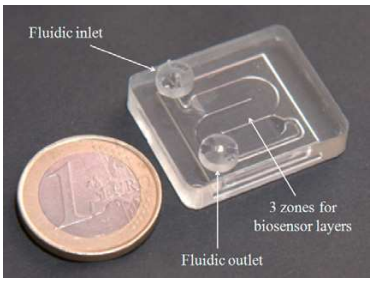

Fig. 1. PDMS flow cell applied in a Surface Plasmon Resonance instrument

Molds for a PDMS based microfluidic cell lysis chamber have also been printed (Fig. 2). The structure was casted in two separate PDMS parts and they were bounded together applying corona treatment surface activation. The chamber has three silicone tubes (4 mm outer and 2 mm inner diameter) introduced as input ports and also has one luer slip connector compatible output port. In the internal part of the chamber the sample is mixed with the buffer solution. To realize the desired volume ratio of sample and buffer (5:1) the input channels have three different cross-sections. The lysis of the cells in the sample takes place in the main meander shaped channel (total volume: 1.2 ml) by heating the chamber to 95 °C. The flow of the liquid is operated by negative pressure gradient between the output and input ports.

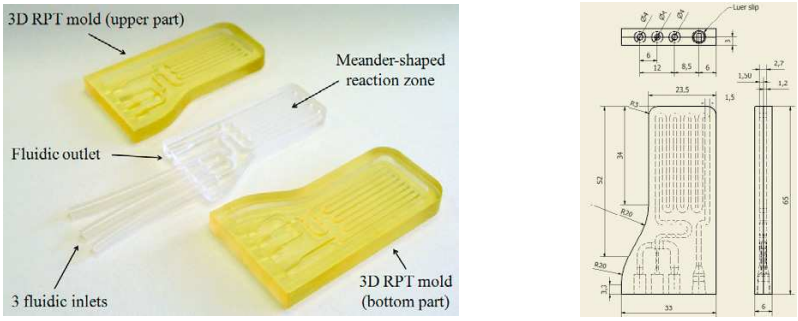

Fig. 2. (a) PDMS microfluidic cell lysis chamber and the RPT molds used for fabrication; (b) design plans of the chamber

3.2. RPT elements as direct microfluidic prototypes

To introduce the utilization of acrylic resin-based RPT fabricated elements directly as microfluidic prototypes we present a cheap and disposable microfluidic system for gynecological cervical sample storage and pre-processing, i.e. DNA and protein separation. A main requirement was that the prototype fluidic system has to be transparent/translucent, one side opened and bonded to a polyester foil. Fig. 3/a shows the fluid mixer and homogenizer part of the platform (channel height: 1 mm, width: 2 mm). The reagent and the sample are stored in two reservoirs which can be expelled by fingertips for mixing. The system is designed to carry the pre-processed

cervical sample safely from the clinic to the laboratory. Our prototypes can be fabricated or modified/redesigned at potentially in one day which is a great advantage compared to other experimental testing solutions.

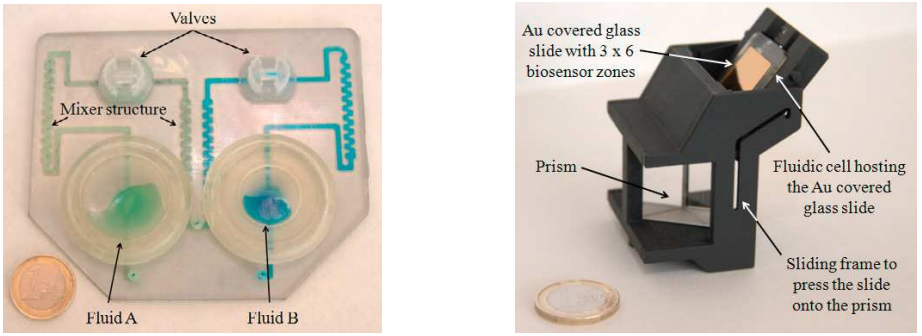

Fig. 3. (a) Fluid mixer and homogenizer prototype platform; (b) prism holder platform for a Surface Plasmon Resonance Imaging instrument

3.3. RPT elements as instrument platform parts

The most simple and widespread application of RPT is the fabrication of mechanical parts for different instrument platforms. Fig. 3/b shows a prism holder platform applied in the same SPR instrument along with the flow cell presented in Fig 1. It is possible to slide the part housing the PDMS fluidic cell in and out under the optical prism to remove and change the biofunctionalized substrate.

4. Conclusion

In our work we demonstrated through realized examples the possibility to apply 3D RPT technology as a powerful and versatile tool for prototyping activities of microfluidic system development and biosensor research. With our novel and rapid PDMS based microfluidic fabrication method using RPT molds it is possible to fabricate fine resolution microfluidic devices in approximately 3-5 hours. We also presented a novel method to apply RPT fabricated elements directly as microfluidic prototypes with a possibility to design, fabricate, test and modify prototype parts rapidly in only one day.

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