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Mass-producible opto-fluidic sensors

J. Hiltunen, S. Uusitalo, S. Aikio, M. Hiltunen, O.-H. Huttunen, J. Hiitola-Keinänen, C. Liedert, P. Karioja
VTT-Technical Research Centre of Finland, Kaitoväylä 1, FI-90571 Oulu Finland

jussi.hiltunen@vtt.fi

Abstract

Photonics bio-microsystems developed for sensor usage comprise typically microfluidics circuitry performing sample handling and optical elements for actual sensing. The fabrication includes commonly a number of sequential steps covering micro- and nanostructuring of fluidic and optical features that is followed by biochemical surface functionalization. Additionally, the assembly step is required to integrate functionalities on a single platform. Here we present a methodology to upscale the fabrication of integrated opto-fluidic sensors using high-volume roll-to-roll fabrication.

Key words: optical sensor, microfluidics, roll-to-roll, mass-productions

Introduction

Opto-fluidics is defined as a synergistic integration of photonics and microfluidics [1]. The field is driven by the potential for enhanced sensing performance and simplification of microsystems. However, only few concepts have been transferred successfully into upscaled fabrication of integrated microsystems because of the lack of processing and integration methods. The question is not solely about direct commercialization of designs, but also academic researchers benefit from the high-volume sensor fabrication when the number of samples is not limiting the assessment of the designs and associated test protocols. This paper deals with the production upscale to manufacture optical sensor elements and microfluidic sample handling platforms at high volumes.

Nano-optical sensors by mass-production

Nano-scaled structures have been widely studied with several application areas as they exhibit interesting physical and chemical properties which differ from the properties of the bulk material made of the same composition. The development of different planar plasmonic substrates tries to reduce the repeatability issues of the colloids through periodicity of the nanostructures on top of the substrates [2]. Fig. 1a) shows roll-to-roll (R2R) imprinted periodic nanostructures in roll format and arrays cut from a roll. Scanning-electron-microscope from the surface is shown in Fig. 1b). Microfluidic channels enable flowing sample solution on chip in a controlled way and in some cases the samples can be also accumulated onto the sensor surface by analyte capture. Fig. 1c) presents an opto-fluidic sensor configuration where optical sensor surface is integrated with polymeric microfluidic and lid layers.

Mass-produced microfluidics

Elastomer poly(dimethylsiloxane) (PDMS) has become, and remained, one of the most used material in realization of microfluidic devices in academic environment. The wide usage of PDMS material is originated from number of factors with most importantly the relatively cheap and easy prototyping of small numbers of devices using master moulds for structure replication. PDMS surface properties can be also tuned to become more hydrophilic and to bond PDMS with glass and PDMS itself. These factors have enabled made the realization of prototype devices that test new ideas in a shorter time and with lower cost than that which is reachable using silicon technology. Probably the biggest factor in limiting the usage PDMS outside laboratory relates to the lack of high-volume fabrication methods to produce microfluidics. In our recent work [3], it was demonstrated that also PDMS–based microfluidics can be R2R-produced. Fig. 2a) shows a photograph from the R2R replication process, where PDMS material is casted on Al-coated paper and microfluidic features are replicated by thermal curing. A test device cut

from a roll is shown in Fig. 2b). For the illustrative purposes, the fluidic channels were filled with colored water. In order to validate the replicated molecular diagnostic platforms, on-chip amplification of viral ribonucleic acid (RNA) with loop-mediated isothermal amplification (LAMP) was demonstrated. Amplification of negative control (no RNA) and positive control (RNA) were monitored in real-time by taking fluorescence images with interval of 1 min. Test arrangement with positive and negative samples is shown in Fig. 2c) and corresponding fluorescence signal as a function of time in Fig. 2d). LAMP amplification was triggered by increasing the chip temperature from room temperature (RT) to 70° C within a time period of about 3 mins. The onset of amplification occurred at a time period of about 13 – 16 min.

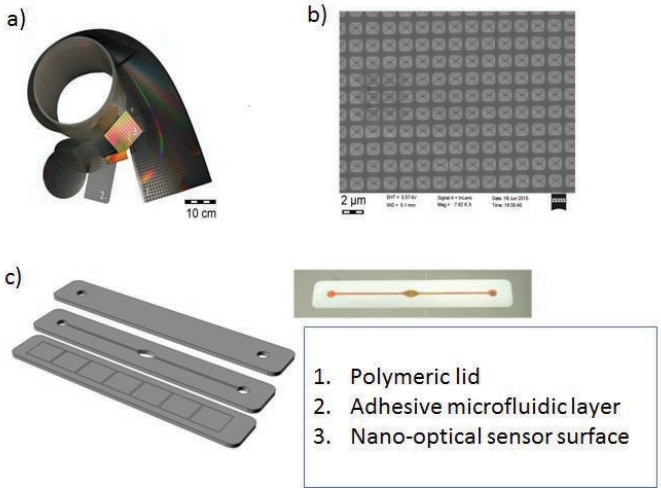

Fig.1. a) Roll-to-roll nanoimprinted optical surface on plastics, b) SEM-image from the surface, c) opto-fluidic sensor configuration with integrated sensors surface and microfluidics.

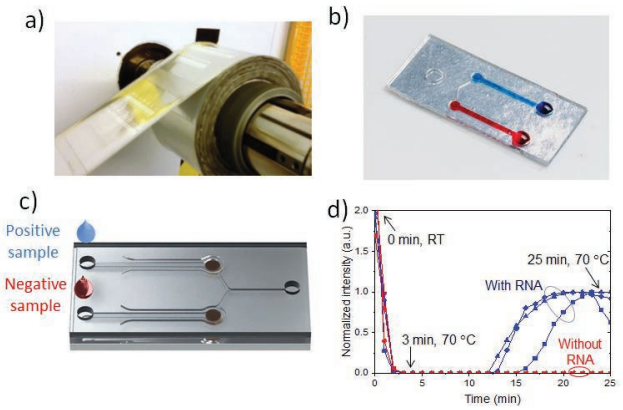

Fig.2. a) Roll-to-roll fabrication of PDMS-microfluidics on paper, b) sensor device where fluidic channels are filled with colored water, c) test configuration for nucleic acid amplification and d) fluorescence signal from reaction chambers with and without RNA template molecules.

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