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A direct-write microfluidic fabrication process for CMOS-based Lab-on-Chip applications

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ABSTRACT

In this paper, we propose an efficient microfluidic fabrication process for Lab-on-Chip (LoC) applications. This low temperature process is employed to implement different microfluidic components including microchannels, microvalves as well as microfluidic packaging of CMOS chips. Furthermore, we describe the applicability of this direct-write microfluidic fabrication process (DWFP) for LoCs by demonstrating the experimental results of a thermally-actuated microvalve incorporated with a capacitive sensor.

1. Introduction

A Lab-on-Chip (LoC) is a hybrid platform that performs the complete biological and chemical assays [1]. Fully automated LoCs would offer the advantages of rapid analysis, easy handling and low sample consumption suitable for several applications including disease diagnostics and environmental monitoring. A holistic system-based approach to LoC design seamlessly integrates microfluidic structures, microelectronic sensors and/or actuators with biochemical reagents on a single platform. The microchannels and microvalves are key microfluidic components for fluid regulation while the microelectronic devices play essential roles to detect or manipulate bioparticles in a LoC system. Such a hybrid microfluidic/microelectronic system would thereafter be incorporated with certain biochemical solutions depending on application requirements. The later issue is not the case of this paper.

Standard CMOS process by offering the advantages of highly precision interface circuits and embedded sensing or actuating devices is a good alternative over other competitive LoC technologies. To date several papers reported CMOS-based LoC systems for different applications such as on-chip DNA hybridization [2], cell analysis [3] and virus recognition [4]. We have already reported a new capacitive sensor using charge-based capacitance measurement method (CBCM) [5] for organic solvent monitoring [6]. In this paper, we put further on this work by employing the proposed capacitive sensor implemented through 0.18 μm CMOS process along with other microfluidic components for fluidic control and detection purposes as illustrated in Fig. 1.

Until now, several microfluidic fabrication processes have been reported to build microfluidic structures on CMOS chips without any additional corrosive chemical solutions which may damage the underlying circuits. Among these, Rasmussen et al. presented a technique to fabricate microfluidics through standard CMOS processes along with further micromachining processes [7]. As shown in Fig. 2a, based on this technique, the metal conductors are employed as sacrificial layers which were thereafter etched in order to create microchannel. In another effort, Lee et al. reported a spin-coated polyamide which was formed on a SiGe IC [8]. The patterned polyamide was considered as the sidewalls of a microfluidic channel which was sealed with a glass slide. A microfluidic structure can also be constructed through a variety of polymeric techniques and adhesively bonded onto CMOS chips using a specific glue or low temperature plasma bonding (see Fig. 2b). In this way, Sethu et al. implemented several epoxy microfluidic devices for LoCs through casting and molding processes [9]. Herein, in this paper, we address the challenges of on-chip microfluidic packaging by proposing a robotic based microfluidic fabrication process. This

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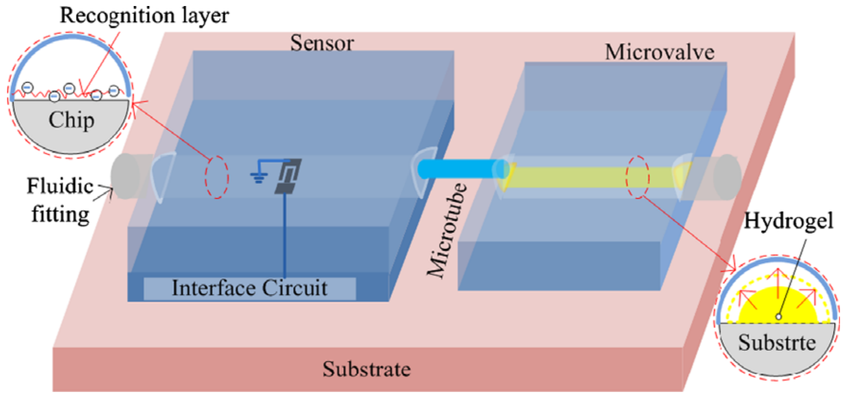

Fig. 1. Illustration of a LoC platform consisting of an integrated sensor and a hydrogel-based microvalve.

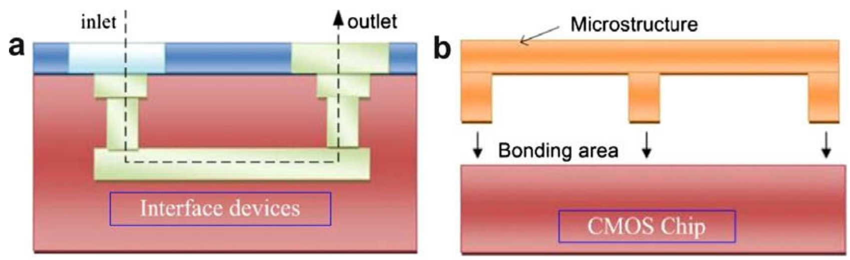

Fig. 2. On-chip CMOS/microfluidic techniques: (a) microchannel realization through CMOS process and (b) adhesive bonding methods.

low temperature and polymeric process is additionally employed to implement the miniaturized fluidic components including microvalves as described later in this paper.

This paper proceeds as follows. The proposed microfluidic fabrication process is introduced in Section 2. In Section 3, the novel microvalve fabrication process is described. Then, a brief description of proposed capacitive sensor is put forward in Section 4. Finally, the experimental results are described and demonstrated in Section 5 while we draw a conclusion in Section 6.

2. Direct-write microfluidic fabrication process

In this process, a mixture of petroleum jelly and microcrystalline ink is dispensed through a micronozzle (Ultra® 2400, EFD Inc.) and deposited on a substrate (or microelectronic chip) as the sacrificial layer using a three axis robot (Model I&J 2200, I&J FISNAR Inc.) [10–12]. This ink filament can be encapsulated with an epoxy resin without any deformation as shown in Fig. 3a and b. Thereafter this fugitive ink is removed in a moderate temperature and light vacuum after the curing of epoxy (see Fig. 3c). As shown in Fig. 3d, DWFP can be employed for on-chip microfluidic packaging. Figs. 4 and 5 show the optical microscopic images of the ink deposition and epoxy encapsulation processes. As shown in Fig. 5a and b, a vacuum degassing procedure should be performed to remove the air bubble created during epoxy preparation from its monomers. An important advantage of DWFP in comparing to other techniques is the polymerization of epoxy on chip that results in a strong and hermetic bonding.

3. Proposed hydrogel-based microvalve

In this section, the design and implementation of a new microvalve through DWFP is described and demonstrated. A brief review of related works is firstly presented for comparison.

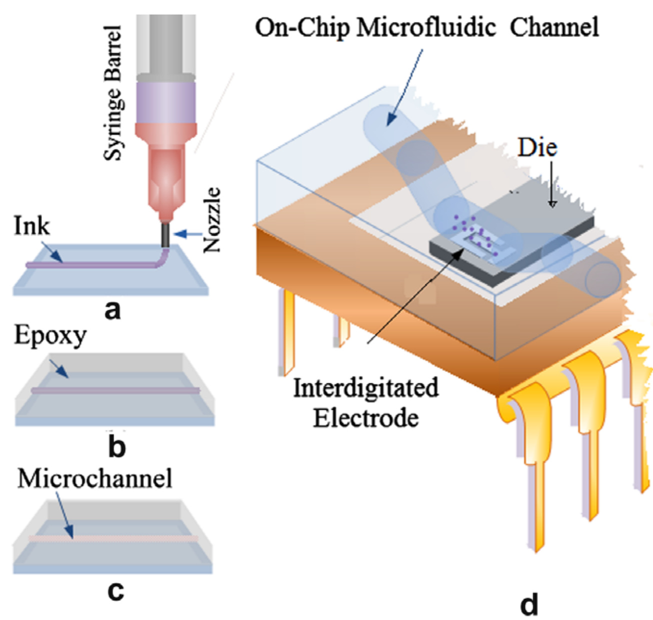

Fig. 3. Illustration of DWFP: (a) ink deposition, (b) epoxy encapsulation, (c) ink removal and (d) on-chip microfluidic packaging.

3.1. Related works

Microvalve is a key device to regulate the fluid in a microfluidic system. The principle of conventional microvalves relies on its mechanical or electromagnetic properties which often are neither biocompatible nor suitable for bioassays. Stimuli-response hydrogels with the excellent biocompatibility and further sensing and actuation functions have become the leading candidate for this purpose. Earlier functional hydrogel-based microvalves were fabri-