HYDROPHILIC POLYMERIC COATINGS FOR ENHANCED, SERIAL-SIPHON BASED FLOW CONTROL ON CENTRIFUGAL LAB-ON-A-DISC PLATFORMS

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ABSTRACT

In this paper, we implement rotational flow control on a polymeric microfluidic "lab-on-a-disc" device by combining serial siphoning and capillary valving for sequential release of on-board stored liquid reagents. The functionality of this integrated, multi-step centrifugal assay platform is tightly linked by the capability to establish reproducible, capillary-driven priming of the innately hydrophobic siphon microchannels. We here demonstrate for the first time that spin-coated hydrophilic polymeric films of poly(vinyl alcohol) and (hydroxylpropyl)methyl cellulose provide stable contact angles.

KEYWORDS

Hydrophilization, spin coating, centrifugal microfluidic platform, lab-on-a-disc, capillary force, serial siphon.

INTRODUCTION

One of the most crucial steps in biological analysis systems is the spatio-temporally controllable release of a repertoire of assay reagents. On the here considered centrifugal microfluidic "lab-on-a-disc" platform, we chose serial siphoning to direct the sequential delivery of bioreagents [1, 2]. However, their main drawback of serial siphoning constitutes the requirement of low-contact-angle polymeric microchannels [3, 4]. While there is a well-documented suite of surface functionalization processes such as oxygen plasma treatment, chemical vapor deposition, UV-irradiation [5-7], still most of them are either of transient nature (plasma treatment) or involve rather complex process steps and equipment.

The present paper proposes the deposition of hydrophilic polymeric thin films onto polymer (disc) substrates, such as PMMA, using the commonly used spin coating. The main advantages of the method include quick formation of uniform layer (within 20 min), stability (over a month) and low-complexity / low-cost infrastructure.

EXPERIMENTAL AND RESULTS

The PMMA disc is constituted of five layers (Fig. 1a): 1) top PMMA disk 1.5 mm-thick with sample loading and venting holes, 2) top pressure-sensitive adhesive (PSA), 3) middle, 2mm-thick PMMA disc exhibiting CNC-milled chambers, valves and siphon microchannels (Fig. 1b), 4) bottom PSA layer and 5) a blank, 5 mm-thick PMMA disc for the sealing of the microchannels at the bottom side. The microchannels are 250 μm wide and 250 μm deep, the capillary valves are 350 μm and the loading chambers are 1.7 mm deep, respectively. The basic design paradigm of the disc-based functional structures is motivated by previous publications [4].

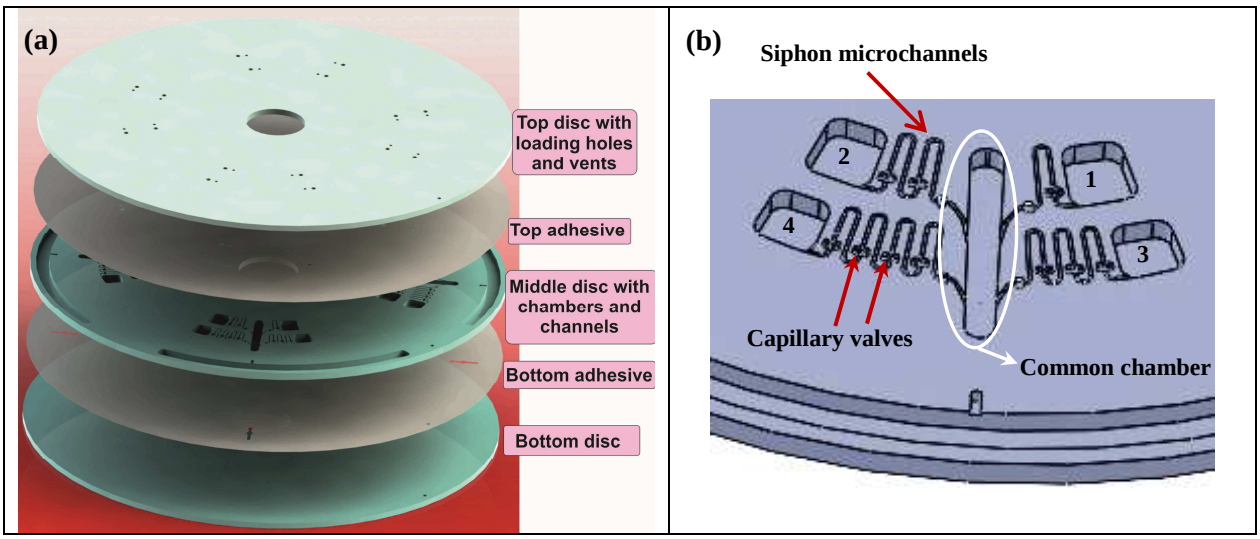

Figure 1: a) Schematic illustration of the 5-layered disc assembly which features four devices, b) Schematic of the main microfluidic layer (middle disc) which consists of four chambers, valves and siphon microchannels for the introducing of different liquids to a common chamber.

The polymeric materials deposited onto middle milled disc are 2-4% aqueous solutions of poly(vinyl alcohol) (PVA) and (hydroxylpropyl)methyl cellulose (HPMC). The PVA molecular weight is 31K-50K, 87-89% hydrolyzed. The film formation conditions are: spin coating at 3000 rpm, for 30 seconds and baking on a hot plate at 60°C for 20 minutes. The selection of those coatings has been made using as a criterion their enhanced hydrophilicity in comparison with PMMA. The static contact angles of both PVA and HPMC have been measured as ~ 20°, whereas the plain PMMA sheet contact angle amounts to ~70° (Fig. 2). The respective surface energy values are 68 mN m^{-1} (hydrophilic coatings) and 31 mN m^{-1} (PMMA) which have been calculated by using deionized water, chloroform, isopropanol and cyclohexane as test liquids. The increase in surface energy significantly influences the flow rate of liquids in the siphon microchannels. The high surface energy of the coated PMMA substrate is further demonstrated by the concave meniscus of the liquid in the microchannel (Fig. 3).

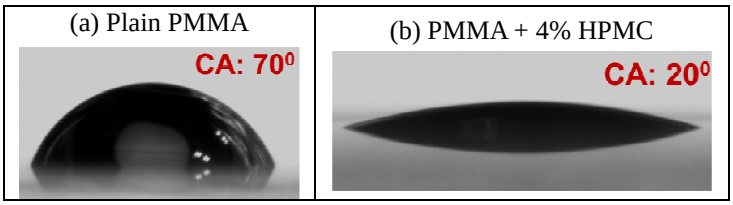

Figure 2. Static contact angle measurements of PMMA sheet surface a) before and b) after the deposition of hydrophilic HPMC coating.

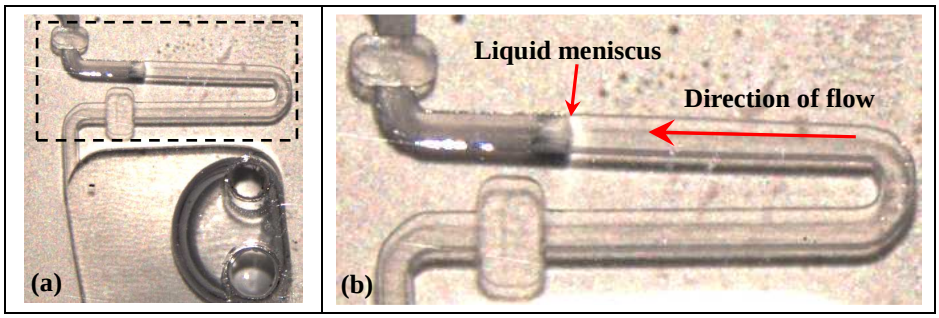

Figure 3. a) Image of the capillary liquid (water) flow through the siphon microchannels of an HPMC-coated PMMA disc, b) Zoom in the meniscus shape.

The effectiveness of the PVA and HPMC coatings on the liquid flow rate in the siphon microchannels has been demonstrated using food dyes in phosphate buffer solution (PBS). As shown in Fig. 4a, all chambers are pre-loaded with food dyes and the disc is spun at 975 rpm (Fig. 4b), where the centrifugal force dominates, to release the liquid into the microchannels. After about 1 min, the rotational frequency is reduced to 75 rpm where capillary forces prevail in order to prime the microchannels (Fig. 4c). While staying below the burst frequency, liquid stopped just before the valve. Figure 4d establishes the successful delivery of food dye from the first siphons when the speed was increased again up to 975 rpm and Fig. 4e displays the second siphon priming. Finally, in the 3 last images (Fig. 4f,g,h), the liquid delivery of the remaining siphons are portrayed, which occurred by repeating the same cyclic change in the spinning frequencies.

CONCLUSION AND OUTLOOK

Compared to our previous publication [8], this is the first time that sequential release of liquids has been demonstrated by the serial siphon paradigm on this centrifugal microfluidic lab-on-a-disc platform. The same sequential release has been recorded by using biological reagents such as 3% bovine serum albumin (BSA) in PBS. The future work focuses on the application of the proposed surface-modified lab-on-a-disc platform to a range of biochemical assays and enzyme-based reactions for use in both clinical and industrial environments. More specifically, we intend to use the microfluidic platform for bioprocess monitoring of therapeutic antibodies such as human immunoglobulin G (IgG).

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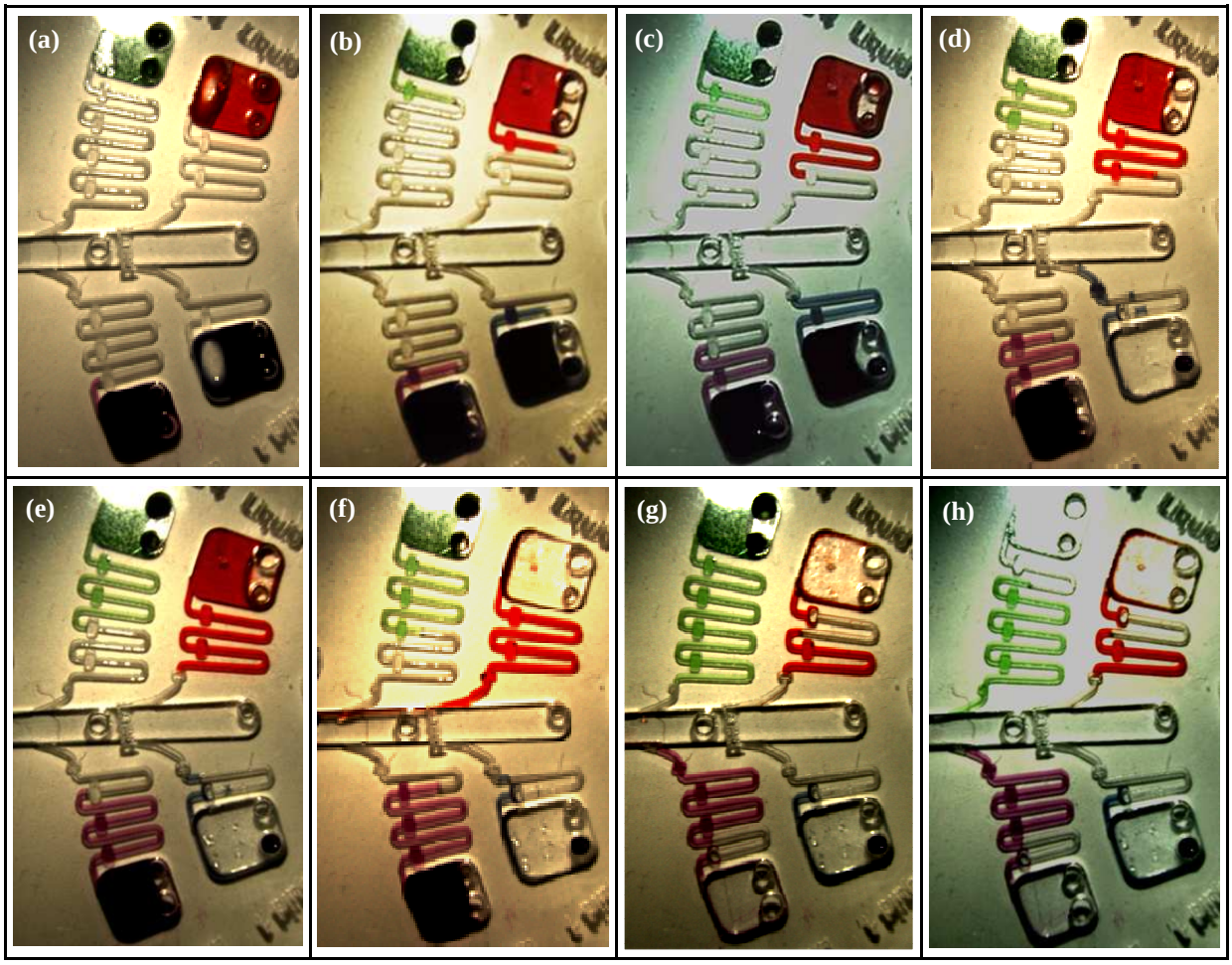

Figure 4. Microscope images of the sequential release of food dyes from four individual chambers (30 µl volume) to the common central chamber through the siphon microchannels: a) liquid loading in the reservoirs, b) high-speed / centrifugal forces, c) low-speed / capillary forces, d) first liquid delivery e) second siphon primes, f,g,h) second, third and fourth liquid delivery, respectively.

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