PUMPING FLUIDS RADially INWARD ON CENTRIFUGAL MICROFLUIDIC PLATFORMS VIA THERMALLY-ACTUATED MECHANISMS

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ABSTRACT

While manipulating fluids in microfluidic discs by centrifugal forces has several advantages, centrifugal pumping alone only permits fluids to travel uni-directionally. Rather than enlarging microfluidic discs to complete lengthy multi-step assays, a more ideal solution is to transfer fluids radially inward for further processing. To enable such fluidics, we present a novel and straightforward technique, based on thermally-actuated mechanisms, to pump fluids to more central locations on a rotating microfluidic disc.

KEYWORDS: Centrifugal Microfluidics, Pumping, Valving, Fluid Handling, Thermal Energy

CONCEPTS

A defining feature of the microfluidic disc platform is that fluids are manipulated in a non-contact fashion by spinning the disc, offering a simpler world-to-chip interface than stationary microfluidic approaches. However, with centrifugal pumping alone, fluids can only travel from the center to the outer rim. A suitable solution to performing lengthy multi-step assays is to move fluids radially inward for further processing rather than increasing the radius of the disc. To address this critical issue, we report on a technique, based on thermally-actuated mechanisms, to return fluids to more central locations on a rotating disc. Thermally-actuated techniques for liquid handling, such as wax valves, are well suited for the microfluidic disc platform because they can be actuated in a non-contact fashion by peripheral heat management equipment [Figure 1] while the disc is in motion, reducing operation time and preserving the ability to multiplex experiments [1, 2].

Figure 1: Peripheral heat management system for centrifugal microfluidic discs. The IR lamp delivers thermal energy to a focused region on the disc while the IR sensor measures temperatures at the same location [1].

A fluid can be brought back to the center of a rotating disc by the serial integration of two heat-actuated techniques: a wax plug and a thermo-pneumatic pump [Figure 2]. After a fluid is spun to the edge of a disc, a position usually associated with the termination of a fluidic process, a paraffin wax plug is formed in a microchannel to seal ventilation via that pathway followed by transferring the fluid to a more central location by a thermo-pneumatic pump [3]. A paraffin wax plug can be formed on command by briefly heating a wax reservoir while spinning to flow molten wax into a connecting microchannel [Figure 3]. The other thermally-actuated feature, the thermo-pneumatic pump, operates by utilizing the thermal expansion of air in a ventless chamber to pump fluids in any direction on the disc; the behavior of the thermo-pneumatic pump has been previously experimentally and analytically characterized [3].

Figure 2: Schematic design of a microfluidic disc that transfers a liquid sample from the loading chamber to the collection chamber through the integration of two thermally-actuated techniques: a wax plug and a thermo-pneumatic pump.
Figure 3: Wax plug formation mechanism. (a) Solid wax is loaded into a reservoir through a port. (b) After heating the wax reservoir while spinning the disc, molten wax exits and forms a plug in the adjacent microchannel.

EXPERIMENTAL

A microfluidic disc, made of an assembly of polycarbonate and pressure sensitive adhesive layers, was tested in the following fashion. First, a liquid sample (25 μL) was introduced into the loading chamber and transferred to a chamber located near the rim, the intermediate reservoir, by spinning the disc at 2000 RPM [Figure 4 a, b]. Then by heating the wax reservoir while rotating the disc at 300 RPM, molten wax flowed into the adjacent microchannel to form a wax plug [Figure 4c], closing ventilation via that pathway. Once the wax plug hardened, heat was applied to the thermo-pneumatic pump while spinning at 300 RPM to transfer the liquid from the intermediate reservoir to the vented, more centrally-located, collection chamber [Figure 4 d-f].

Figure 4. Stroboscopic sequence of the transfer of a liquid radially inward in a microfluidic disc. (a) Liquid is introduced into the loading chamber. (b) The liquid sample is transferred to the intermediate chamber by spinning at 2000 RPM. (c) At 300 RPM, heat is applied to the wax reservoir and a wax plug is formed in the adjacent microchannel. (d - f) After the formation of the wax plug, heat is applied to the thermo-pneumatic pump while spinning at 300 RPM, transferring the liquid to the collection chamber.
DISCUSSION

Overall, we offer a straightforward technique to move fluids radially inward on a rotating microfluidic disc, enabling the performance of lengthier biochemical assays without increasing the footprint of the device. The presented approach uses a heat management system made entirely of off-the-shelf components and the disc is made of natively hydrophobic polycarbonate, facilitating its fabrication and implementation. Furthermore, as the presented thermally-actuated techniques operate while the disc is in continuous rotation, the approach can be multiplexed such that several fluidic samples are simultaneous transferred radially inward within a single microfluidic disc.

Our strategy differs from previous demonstrations to move fluids to the center of a rotating microfluidic disc by eliminating the need for an external compressed air source [4]. In general, the injection of air into the disc to pump fluids can lead to contamination of the device and compressed air sources are not well suited for portable applications. In comparison, fluids in our approach are pumped by heated air, trapped in the device, via a compact heat management setup. A key benefit of our technique is that it adds to the growing number of heat-based mechanisms for microfluidic devices (e.g., reagent storage, valving, incubation, pumping, and PCR thermocycling), simplifying the design of the microfluidic device and peripheral equipment [1-3].

CONCLUSION

The centrifugal microfluidic disc platform is largely uni-directional with respect to the direction of fluid flow. To address this limitation, we have developed a novel and straightforward technique, based on thermally-actuated mechanisms, to move fluids radially inward. Overall, the fluid handling techniques presented in this report enable the performance of lengthier and more advanced fluidics on microfluidic discs without increasing the footprint of the disc device.

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