Progress on the development of fluid central processing unit for large-scale automation of analytical and synthetic tasks

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In almost two decades, microarray biochips and lab-on-a-chip devices have attracted huge interests in bio and chemical applications. However, due to the large variety of analytical and synthetic tasks encountered in bio- and chemical research, it is often imperative to design and fabricate microarrays or lab-on-a-chip devices for each specific application. The complexity in custom design and fabrication of microarrays and lab-on-a-chip devices prevents current microfluidic devices from unleashing their full potentials. There is, therefore, a pressing need in developing a generic microfluidic platform that is suitable for a wide range of bio- and chemical applications.

In this work, we present the development of a novel all-purpose programmable and scalable digital microfluidic platform and its peripherals that have unprecedented power and flexibility for microfluidic applications. The instrument can serve as the fluid central processing unit (F-CPU) for automating a wide range of bio/chem-analytical and synthetic tasks. The main approach is to integrate active-matrix (AM) driving circuitry into droplet-based microfluidic platform (Figure 1). We report recent progresses in addressing key obstacles in implementing a practical large-scale system that has the capability to manipulate each and every droplet in a large array through programming. Those progresses include: a) a novel and effective approach to achieve highly reliable dc and ac actuation of droplets for hours by underlying electrodes without electrical breakdown; b) effective contamination control by novel concurrent driving of cleaning droplets and smart route configuration; and c) world-to-chip interface by a piezoelectric micro-pump array to achieve facile fluid input and output ports. The complete system and its use in concurrent droplet handling are shown in Figure 2. We also show several applications to demonstrate the fully automatic droplet handling with the F-CPU chip and instrument, such as the fully automatic sorting of particles in a droplet for single-cell studies (Figure 3). On-chip synthesis of peptides will be discussed as another important application.

The integration of AM circuitry into microfluidic system brings forth multiple breakthroughs in microfluidic functionality and usability. The functionality of the instrument can be changed based on the content inside the droplets. By selectively addressing a subset of electrodes in the array, the instrument can be dynamically reconfigured to suit a specific task by a computer according to pre-designed application protocols. The freedom in droplet actuation through AM circuitries allows parallel manipulation of multiple droplets with almost unlimited number of serial operations (moving, mixing and splitting). This would provide unprecedented power for addressing large and complex tasks that conventionally deemed prohibitive. Finally, the digital microfluidic instrument is completely reusable, thus lowering its cost-of-ownership and making it broadly accessible. Potential applications include, but are not limited to, genomic and proteomic assays, single cell study, point-of-care clinical diagnostics, toxin and pathogen detection and identification, environmental monitoring, screening for new drugs and fine-chemical synthesis.

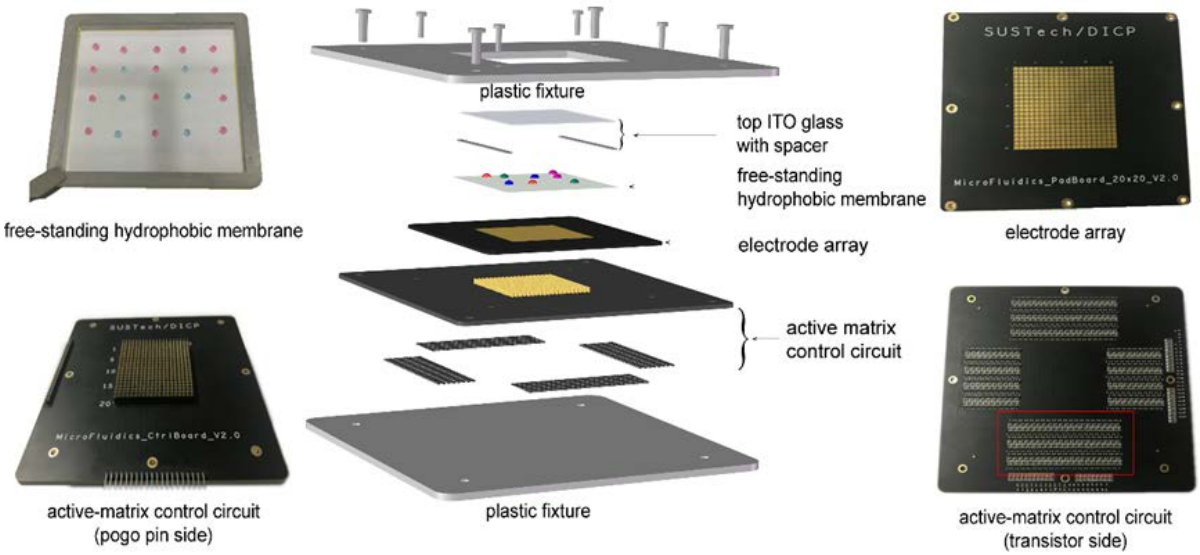

Figure 1. The components and an exploded view of the active-matrix digital microfluidic system as a generic central fluid processing unit.

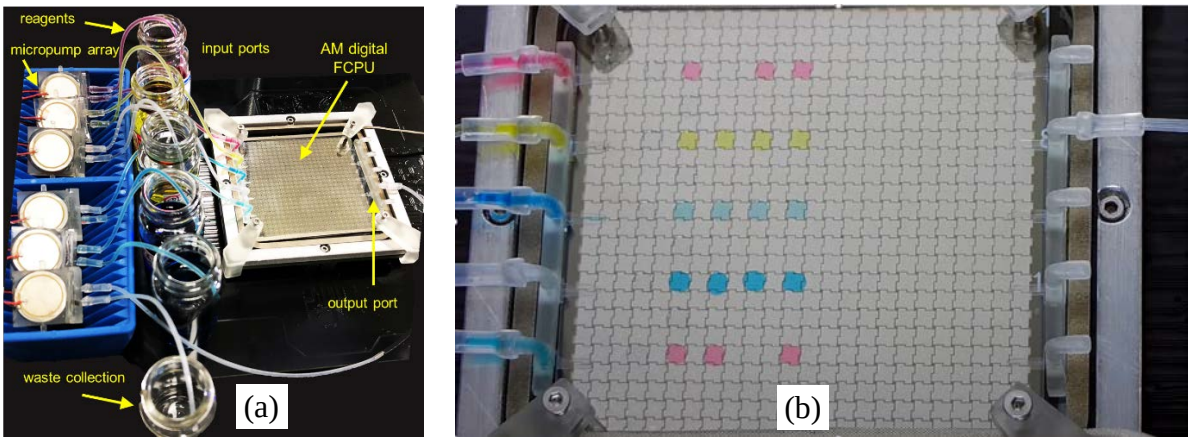

Figure 2. (a) An overview of the fluid central processing unit with micropump-based input and output ports; (b) An image of concurrent actuation of multiple droplets on the active-matrix driven digital microfluidic platform.

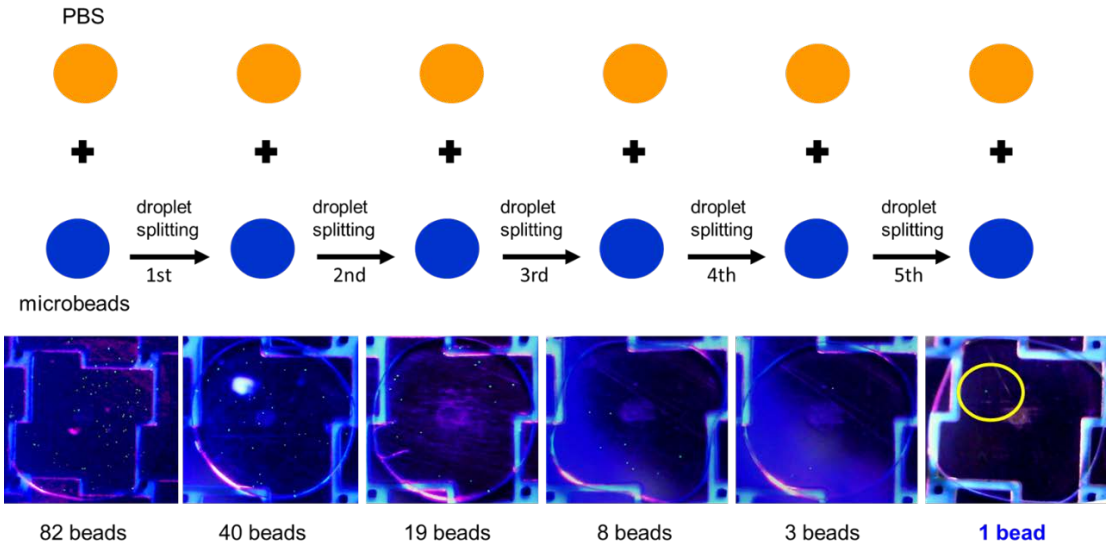

Figure 3. Fully automatic particle sorting using the fluid central processing unit.