A platform for the assembly of electro-hydrodynamic microfluidics

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ABSTRACT

We present a new method of building electro-micro-devices through the assembly of several commercially available components. Our approach overcomes a number of limitations commonly encountered in studying field-driven phenomena in suspensions at the micro-scale. The proposed method is utilized for the assembly of a microdevice equipped with microelectrode arrays to demonstrate that the application of a high-gradient AC electric field in the MHz-frequency range to an aqueous suspension of polystyrene beads enables one to form and transport distinct particle structures.

Keywords: Microfluidics, dielectrophoresis, microfluidic-platform, electro-hydrodynamics of suspensions, assembly.

1. INTRODUCTION

Current approaches to study field-driven phenomena at the micro-scale involve micro-chambers equipped with an array of microelectrodes fabricated with photolithography methods [1] or/and PDMS-based techniques [2]. The major drawback of currently employed electric micro-devices is the difficulty in properly cleaning the electrodes after the end of an experiment thereby leading to a low reproducibility of the device operation. In contrast, the method and the platform to be presented below allow one to assemble an electric micro-chamber using commercially available components, which can be easily disassembled and properly cleaned for reuse after an experiment. Using this platform, we studied the behavior of aqueous suspensions of $3.1-\mu$m polystyrene beads subject to a high-gradient AC electric field in the MHz frequency range [3]. Specifically, we were able to reproduce the collective field-driven phenomena at the micro-scale, which were previously observed in experiments conducted in millimeter-sized devices on low-conducting oil suspensions of $87-\mu$m polymer particles under the action of an AC electric field in the kHz frequency range [4].

2. MICROFLUIDIC PLATFORM

The schematic of our experimental system with a micromanipulator, having seven degrees of freedoms, is shown in Figure 1. The micromanipulator comprised of three independently adjustable stages with two of them having three degrees of freedom (in the XYZ directions) while the third has an angular rotational degree of freedom (with rotation in the YZ plane). We mounted the microscope (Nikon SMZ-2T, Japan) onto the rotational stage and adjusted it initially to view along the Z-direction. A conducting and transparent indium titanium oxide (ITO) glass slide (ABTECH Scientific, VA, surface resistivity of $10\Omega/\mathrm{cm}^2$) served as the chamber top (ITO coating on the inner side), whereas the ABTECH Scientific, VA, glass chip (shown in Fig. 1) served as the chamber bottom. The latter contains 100 gold electrodes (the electrode width and the interelectrode spacing are both $20\mu\mathrm{m}$) arranged into two independently addressable interdigitated arrays each connected to a conducting bus.

In a typical experiment, we first fixed the bottom microchip onto the lower XYZ manipulator stage and, using the XY-control, brought the chip micro-electrode array under the field of view of the microscope. Then, we rotated the microscope by an angle of 90^0 in the YZ plane to view the side of this microchip by adjusting the Z-elevation of the lower micromanipulator stage. Once the side of the bottom microchip was brought under the field view of the microscope, we fixed the top microchip onto another XYZ manipulator stage, translated it to the position over the bottom microchip, and adjusted the gap between both microchips to the desired value using the manipulator XYZ-controls. Once the gap was adjusted, we brought the microscope back to its initial position so as to observe the field-driven motion of particles along the XY-plane in a suspension filled the gap between the microchips. To generate a high-gradient electric field inside the micro-chamber, an AC voltage was applied to one of the electrode arrays of the bottom chip with a function generator Tektronix AFG 320, while the other array and the ITO

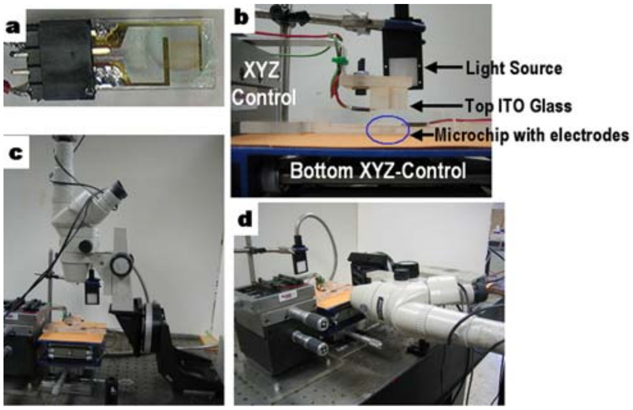

Figure 1: Photographs of the micromanipulator with ABTECH microchip.

coating of the top chip were grounded. A manual switch was used to sequentially energize and ground the electrode arrays of the bottom chip. After an experiment, the microchips were moved apart from each other and the micro-chamber was disassembled. Then the chips were cleaned with acetone and deionized (DI) water for reuse.

Furthermore, our setup enabled us to translate the top and bottom chips relative to one another in the XY plane even while the voltage was applied, thereby providing the capability to study the combined effect of a high-gradient AC field and shear on the particle motion [3]. In principle, an electric-micro-chamber can be utilized for conducting experiments on a flowing suspension by sealing the chamber with a gasket and equipping it with the inlet and outlet tubings.

3. EXPERIMENTAL RESULTS

The suspensions were prepared by diluting, with DI water (pH 5.5-6.0 and conductivity $0.55\,\mu S/cm$), a 10% (by weight) aqueous solution of latex beads (Duke Scientific, CA, particle diameter $3.1\mu m$, particle density $1.05\,g/cm^3$) and were introduced into the micro-chamber using a micro-syringe. The real part of the relative polarizability of the latex beads in the water within the MHz frequency range is ~ -0.45 [5]. After each experiment, the chamber was dissembled and the microchips were cleaned.

As an example, the photos in Fig. 2 illustrate the behavior of the latex beads in the micro-chamber energized with applied voltage 5Vrms/1MHz. As was the case with experiments on suspensions of negatively polarized $87-\mu m$ polyalphaolefin particles in low-conducting corn oil performed in a millimeter-sized device subject to 2-5kVrms, 0.1-3 kHz [4], the application of an AC voltage caused the beads to accumulate in the low field regions located above the grounded electrodes and to form distinct cylindrical columns [4]. These columns can be transported

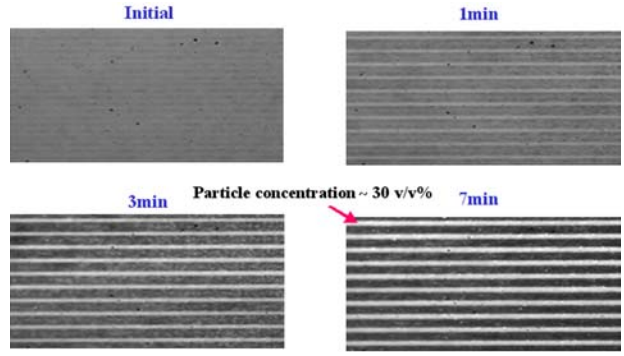

Figure 2: Distinct concentration fronts formed in low-field regions above the grounded electrodes of ABTECH microchip in 1-% suspension of latex beads; 5Vrms/1MHz; the gap between the top and bottom ~ 100 microns.

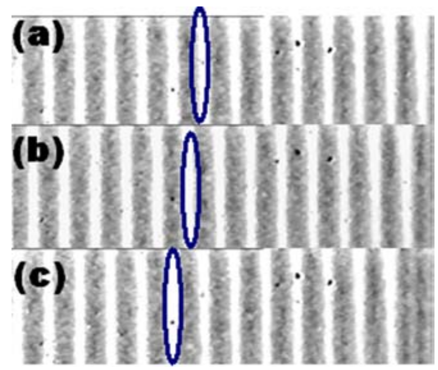

Figure 3. (a) Energizing one of the ABTECH electrode arrays and grounding the other caused the beads to form columns in the low-field regions (seen as *white*) which were then transported to another low-field regions (from a to b and to c) by sequentially energizing and grounding the ABTECH electrode arrays; 1-% suspension of latex beads; 5Vrms/1MHz; the gap between the top and bottom ~ 100 microns. The blue circles indicate the same column.

along the chamber (Fig. 3) by sequentially energizing and grounding the ABTECH electrode arrays [3].

4. CONCLUSIONS

We presented a new method for assembling electro-micro-devices from several commercially available components. In contrast to currently employed techniques for studying field-driven phenomena in suspensions, the use of the proposed platform enables one to easily disassemble a micro-device after an experiment and properly clean the micro-electrodes for reuse. We demonstrated that the application of a high-gradient electric field in the MHz-frequency range caused negatively polarized particles dispersed in water to accumulate in the low field regions, forming distinct fronts. It is also possible to transport these particle structures along the chamber by sequentially energizing and grounding microelectrodes. This fact allows one to use field-driven phenomena, which were previously observed in low-conducting oil-based suspensions in millimeter-sized devices, for the control and manipulation of aqueous suspensions at the micrometer scale.

This work was supported in part by grants from NSF CTS-0307099 and NSF/Sandia NIRT/NER – 0330703 (B.K).

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