Ultra Dielectrophoresis Using Atomic Layer Deposited Films for Electronic Multiplexed Biomarker Detection

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In this abstract our focus is to develop a robust actuator that can electronically detach protein-bound beads from a solid surface. Our ultimate goal is to develop a low cost electronic platform for multiplexed detection of protein biomarkers in a complex sample. Our platform is based on performing a bead based immunoassay, where along a single channel an array of antibodies is patterned. Below each element of the array is a pair of addressable interdigitated electrodes, which can detach the immunobound beads on each element of the array independently, through the use of enhanced negative dielectrophoresis (nDEP) force, or in other words, ultra dielectrophoresis (uDEP). In this multiplexed assay, the beads are detached region by region using uDEP and then transported downstream where they are quantified electrically or optically (Fig. 1).

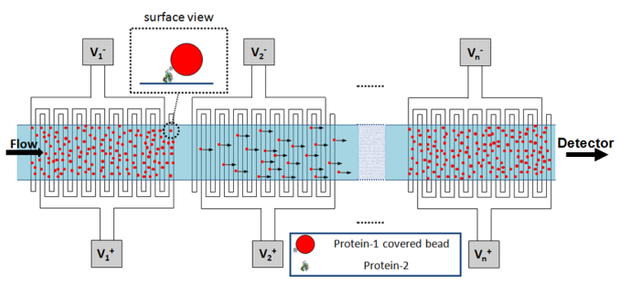

Figure 1. Bead-based multiplexed immunoassay. Applying voltage V_2 turns uDEP on, resulting in elution of beads from the surface of the second set of interdigitated electrodes.

Typically, nDEP provides on the order of a few picoNewtons of force, while the binding force between antibodies and antigens is on the order of hundreds of picoNewtons. When applying high voltages at the electrodes (> 10 V) that are in direct contact with the buffer, DEP force magnitude is limited by electrode corrosion due to electrochemical reactions at the interface of the electrodes and the solution. Using Atomic Layer Deposition (ALD) we deposited a pinhole free nanometer-scale thin film oxide as a protective layer to prevent electrodes from corrosion. By exciting the electrodes at high frequency, we capacitively coupled the electrodes to the buffer in order to avoid electric field degradation, and hence, reduction in nDEP force due to the presence of the insulating oxide layer. Deposition of thin film oxide layer on the electrodes poses a number of challenges. First challenge is degradation of the electric field and hence dielectrophoresis force, as a result of the undesired voltage drop across the oxide. To compensate for the voltage drop across the oxide, one may increase the applied voltage at the electrodes, but that may lead to breakdown of the oxide. Through our analytical and characterization results, we showed that at sufficiently high frequencies (for our device > 1 MHz), the electric field across the oxide layer becomes independent of the thickness, and hence oxide breakdown does not directly impose any limitation on the thickness of the film. Also, by depositing a very thin layer of oxide (10-nm SiO2) as well as exciting the electrodes at sufficiently high frequency (1 MHz) we were able to minimize the undesired voltage drop across the oxide layer to less than 5% degradation.

Our fabricated electrodes are able to withstand voltages up to 100 V_{pp}, beyond which bubble formation inside the channel becomes the limiting factor. This results in two orders of magnitude improvement in DEP force, than what was possible with bare gold electrodes. Using the significantly improved nDEP device, we demonstrated 99.8% detachment of anti-IgG and IgG bound beads within one frame of the captured video (with frame-capture interval of 0.4 s). In comparison to the previous work, the performance of this uDEP device shows 333-fold and 600-fold improvement in on-to-off ratio and switching response time respectively, without need for chemical eluting agents (Fig. 2,3). The operation of this singleplexed device can be extended to perform a multiplexed assay for protein biomarker detection.

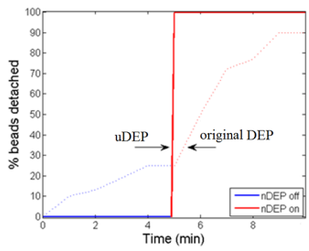

Figure 2. Bead detachment time profile at a flow rate of 0.15 μL min^{-1} using the uDEP vs original DEP device.

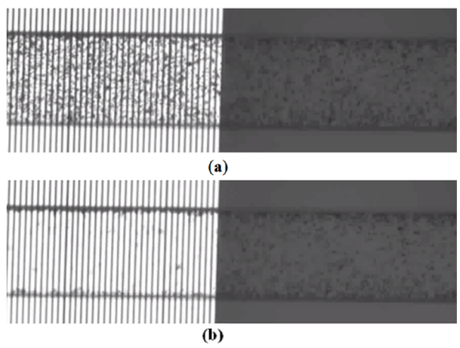

Figure 3. Video snapshots of the beads distribution (b) before (c) after turning uDEP on.

In conclusion, we demonstrated the ability to generate nanoNewton DEP forces using a pinhole free thin ALD oxide film. The pinhole free thin film prevents corrosion, but at the same time because of the film thickness (<20 nm) and also the high frequency applied, the electric field fully couples capacitively to the bulk electrolyte rather than being localized primarily across the film also resulting in film breakdown. The fact that we have the ability to apply DEP forces on this order of magnitude opens up the possibility of a broad range of applications. Here, we developed a robust actuator that can electronically detach protein-bound beads from a solid surface which can be used to perform mutliplexed protein assays. Further applications include actuation of cells at higher flow rates during cell sorting and other various cell handling applications.