Electroactive Nanowells for Concentration, Electrochemical Sensing and Spectrographic Microfluidic Memory

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Abstract
In this work we describe the development of electroactive micro-/nanowells which exploit highly localized electrokinetic effects in order to actively concentrate, confine, store and reject particles in well defined geometries. In this article we present experimental results demonstrating repeatable trapping and repulsion of polystyrene particles in wells ranging in diameter from 100 nm to 20 µm. Immediate applications include active cell trapping and concentration and unlabeled sensing and the development of a spectrographic microfluidic memory.

Summary of Research
The ability to deliver individual or small numbers of particles into confined geometries is of great importance for a number of biological applications (including high throughput pathogen detection, enhanced sensitivity for surface phase binding assays, parallel single cell trapping, interrogation and storage) and non-biological applications (including storage of information, directed or passive self-assembly processes and organic electronics). Within this broader set of devices, microwell arrays have become a popular tool for trapping and storage of particles as they enable discrete immobilization of cells without the need for surface binding chemistry (as the trapping site geometry is designed to prohibit trapped particles from dislodging easily) in a simple platform compatible with fluorescence microscopy.

Devices and Fabrication
Figure 1a shows a schematic of our “electroactive microwells” outlining the basic architecture. The electric field is applied between the upper and lower indium-tin-oxide (ITO) electrodes, and the wells are defined photolithographically in a polyimide (PI) dielectric. As can be seen, particles are driven, sensed and repelled from the well depending on the polarity. Microwells with sizes ranging from 6 to 25 µm were patterned on a 5 µm thick spin-on photoactive polyimide dielectric on top of a 8 Ω/square surface resistivity indium tin oxide (ITO) coated glass slide. An additional ITO electrode was inserted on top of the wells, separated from the polyimide by two 70 µm spacers, serving to enclose the channel structure and to close the electric circuit. Figure 1b is a finite element simulation of the electric field in the well.

Figure 2 shows our initial trapping experiments using a 0.1 mM phosphate buffer solution at pH 7 containing 1.9 µm diameter polystyrene particles. These particles were carboxyl modified, giving them a negative ζ-potential. It is expected that by applying a positive voltage on the bottom electrode, the PS beads will be driven from the bulk flow into the well, and they will be ejected by reversing the polarity. Figure 2 displays time lapse images of particle trapping and rejection in a 20 µm well for the case of a 5V applied DC bias and an imposed pressure driven flow of 30 µm/s (average velocity). During the attraction phase, Figure 2 (a-d), particles were drawn...
Particles which were either initially positioned or convected into a region approximately three times the diameter of the well would be captured (we refer to this region as the “attraction basin”). However, particles which approached the well in a plane near the surface were observed to be repulsed from it in an upwards and radial direction, implying that additional electrokinetic effects aside from the expected electrophoresis have significant impact on the overall attraction process. When the polarity is reversed, Figures 2 (e-f), particles are repelled out of plane as they approach the well’s edge. Particles ejected from the wells form ring-like patterns, suggesting a strong repulsion force that points radially outward from the well’s center. The size of the ring shown in Figure 2f roughly coincides with the attraction basin, suggesting that particles decelerate due to both the drop in field intensity away from the well and the contribution of viscous drag.

**Spectrographic Microfluidic Memory**

Current optical storage devices such as DVDs have their read/write capabilities fundamentally restricted by the diffraction limit of light. We are also developing an optofluidic architecture for storing cocktails of colloidal quantum dots in electroactive nanowell structures. One application of these devices is the development of a fluidic memory approach which could enable the generation, reading and erasing of multiple bit information packages on single light diffraction limited data marks by spectral and intensity multiplexing of quantum dot cocktails (Figure 3). Here we focus on the development of the electroactive nanowell trapping architecture. Briefly, we have shown that by applying an electric potential between a top and bottom indium tin oxide (ITO) electrodes, microparticles suspended in solution can be attracted, stored and rejected from a targeted well structure by electrokinetic actuation. Nanowells 100 nm in diameter and 1 µm deep were fabricated by depositing silicon and a small oxide thin film on top of an ITO cover slip, patterning the wells on electron beam resist followed by a series of dry etching steps that leave the ITO substrate exposed in the well sites (Figure 4). When the quantum dots are electrokinetically transported to their sensing sites, they are then excited by a UV-blue light, and their discrete fluorescent signal is captured by a fiber spectrometer. Data erasure can be selectively performed by reversing the polarity of the field and ejecting the quantum dots from the nanowell data marks.