Electrokinetic Microfluidics for On-Chip Bioparticle Sensing

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Bioparticles (e.g. as virus, bacteria, cells) often serve as carrier/indicator of pathogens and/or toxins. As the world becomes increasingly concerned with toxin/pathogenic contamination in food, water and environment from infectious diseases and bioterrorism, and because the threat of pathogen/toxins to societies could be substantially mitigated with early detection, the demand for real-time bioparticle detection is expanding for both civilian and military applications. Consequently, it is of great significance to realize real-time detection of low-concentration bioparticle (e.g. virus, bacteria, cells) in water, food and clinical samples.

Presently, real-time bioparticle detection has a typical sensitivity of $10^6$-$10^7$ CFU/ml [1], while toxic/pathogenic bioparticles are generally present at very dilute concentrations (< 100 CFU/ml) and can still be an infectious dose. Conventional detection involves 24–48 hours of culturing to increase particle counts, which is time-consuming and often unfeasible under field conditions.

There are many prior efforts that elaborate on sensing mechanisms alone to improve the detection sensitivity and selectivity, however, we approach these bottleneck issues (sensitivity and selectivity) with a microsystem approach offered by lab-on-a-chip, i.e. expediting the bioparticle diffusion to the sensors by mechanical convection, enriching particle concentration at detection sites by microfluidic dynamics and realizing detection simultaneously with impedance measurements. Selectivity can also be realized based on the particles’ response to micropumping.

Besides the above lab-on-a-chip approach, the novelty of this research includes our newly-developed “biased AC electroosmosis (EO),” which is adopted for bioparticle transport, capture and manipulation. Such lab-on-a-chip operates at small voltage with low power consumption, and its all electrical processes facilitate portability, parallelism and automation for on-site bioparticle detection. Biased ACEO technique is newly discovered and lies at the forefront of electrokinetic microfluidic research.

ACEO is based on the fundamental principle that a nanometer layer of charges/ions is induced by an AC electric field at the interfaces of electrolytes and solids, whether the solid is a metal or a cell membrane. The interactions between this nano-layer of charges and electrical fields will generate a gamut of fluid/particle motions, which fall into the category of electrokinetics. With appropriate electrical signals and microelectrodes, electrokinetic phenomena can be used to separate, transport and capture particles for biochemical analysis. While there are prior reports using dielectrophoresis (DEP) and electrophoresis (EP) to capture particles, we were the first to demonstrate that biased ACEO can be harnessed to much more effectively and efficiently convect and immobilize particles for a range of electrochemical analysis applications.

Biased AC EO, by adding a DC offset to AC signals, generates a synergy of AC EO and DC EP. Its capability has been demonstrated as follows: (1) to effectively capture bioparticles from sample solutions onto electrodes, thus increasing particle counts at the detectors within a short time. In one experiment, ~60 E. coli were collected into a surface area of 10 µm x 10 µm from a suspension of $10^6$ CFU/ml (in which E. coli were 100 µm apart) within 30 seconds, as shown in Fig. 1; (2) to transport particles/fluids at a surface velocity over 100 µm/sec by applying a mere 3 V peak voltage with low power consumption (mW range), and ~300 µm/sec surface flow rate has been observed; and (3) to maneuver particles across electrode surface, and various responses from particles of different sizes have been observed, which could be used to achieve detection selectivity.

Various microfluidic functionality by biased ACEO is currently being investigated and the results will be presented at the conference.

References


Fig. 1 Assembled E. Coli lines on electrodes.