170d Rapid Bacteria Trapping Using Micro-Fluidic Vortex Flow

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Novel microfluidic devices have been developed which utilize dielectrophoresis (DEP), AC electro-osmotic (ACEO) flow, and both in tandem to achieve rapid bioparticle trapping, separations, manipulation, and fluid pumping on the order of a cm/sec. Bacteria trapping time of seconds is achieved for all the bioparticles within a large 70 μL sample volume with a dilute 1000 particles per cc particle concentration in high-conductivity fluids. The trapping time and trapping efficiency are the highest reported. In addition, precise counting, identification and manipulation of the trapped bacteria can be achieved with these new devices. Different from other ACEO flow enhanced DEP traps, the current design concentrates the bacteria within the outer rim of a strong ACEO vortex flow and employs negative DEP to trap bacteria into the gap between two wire segments, instead of onto electrodes. This new trap location allows insertion of electrode sensors within the gap to detect and identify trapped bacteria. Trapping into the gap does not occur until all the bacteria in the sample have been concentrated within the vortex to achieve rapid and efficient trapping. This delayed trigger is introduced by designing an ACEO vortex above a serpentine wire that spans the entire micro-chamber. The wire geometry is such that only the last two segments have a large electric field with a small-field region at the gap in between. The AC frequency is chosen such that the bacteria suffer a negative DEP and are attracted to the gap. However, due to viscous drag by the fast ACEO flow, the bacteria do not enter the gap initially, but accumulate within the vortex rim to form a unique rotating bacteria annulus. As the bacteria concentration increases, the rotation speed decreases due to the increased bacteria suspension viscosity. The time-averaged negative DEP force then increases accordingly until it exceeds a threshold, and all the bacteria migrate into the gap precipitously. Both the trapping threshold and the accumulated number of bacteria within the vortex rim before trapping can be optimized by tuning the wire geometry, the AC voltage and frequency, and the addition of zwitterions to shift the cross-over frequency of DEP. Both DEP and ACEO flow are produced not by conventional electrode geometries, but with an alternating current (AC) carrying planar serpentine or spiral wire structure. Because of the large difference in electrical conductivity between the wire and the electrolyte, the applied current will be largely confined to the wire, thereby eliminating any noticeable electrochemical reactions and pH gradients, even at high voltages (~2500VRMS AC). There is still a large voltage drop between different segments of the serpentine wire. However, the Faradaic reaction this inter-segment voltage would drive is a high-resistance Faradaic resistor in series with the high-capacitance interfacial Stern layer and double layer capacitors. This Faradaic RC circuit is in parallel with the low-resistance wire. Hence, at the high AC frequency (~500 kHz) employed, much higher than the inverse RC time of the Faradaic resistor, almost all the AC current runs through the wire with little AC Faradaic charge transfer, even with high conductivity sample. Because charge transfer into the electrolyte is essentially suppressed, wire structures have many clear advantages over previous electrode devices, such as high voltage ACEO flow (~ 1 cm/sec) and enhanced high field (~ 20,000 V/cm) DEP. More importantly, because large electrode arrays require high surface area to electrolyte volume ratios, they produce large currents in the sample and hence promote Faradaic reactions in the electrolyte, even at low (~ 3V) voltages, and are thus unable to process large (~ 100 μL) sample volumes without fear of sample electrolysis. Wire geometries, on the other hand, do not appear to induce reactions in the electrolyte even when scaled up to dimensions as great as 10 cm2. Therefore, because continuous wire structures allow for order of magnitude increases in both ACEO flow and DEP forces, and can be trivially scaled up in size, large sample volumes can be processed in a very short (~30 seconds) amount of time enabling one to process realistic sample sizes and conductivities. Additionally, it has been found that the use of various ionic molecules (zwitterions) can further enhance both ACEO flow and DEP forces and allow further geometric and frequency alignments of the ACEO and DEP motions. The same device hence allows fast trapping, detection, sorting and characterization on large volume samples with realistic conductivity, volume and bacteria count.