Elucidating the Particle-Particle Interaction under Dielectrophoresis for Developing a Rapid Patterning Technique

Yu Zhao[1], Johnie Hodge[1], Jozef Brcka[3], Jacques Faguet[3], Eric Lee[3], Guigen Zhang[1,2]
[1]Department of Bioengineering, Clemson University, Clemson, SC 29634
[2]Instutite for Biological Interfaces of Engineering, Clemson University, Clemson, SC 29634
[3]Tokyo Electron U.S. Holdings, Inc., U.S. Technology Development Center, Austin, TX 78741

Statement of Purpose: Cells and other biological particles will experience dielectrophoretic (DEP) forces when placed in a non-uniform electric field. DEP forces have been used to separate and sort micro and nano biological particles including biological cells, bacteria and viruses. While the prevailing DEP theory provides good qualitative predictions on the direction of DEP forces, which serves as the basis for particle separation and sorting, it does not account for particle-particle interaction and cannot provide any information on particle alignment. To address this crucial problem, we performed integrated experimentations and modeling with an end goal of developing a DEP-based rapid patterning technique for tissue engineering by elucidating the underlying DEP mechanisms governing the particle-particle interaction and the formation of particle alignments.

Methods: On the experimental side, to generate DEP forces, we etched electrodes on a thin titanium/gold film coated on a glass slide using photolithographic techniques. Several electrode designs with interdigitated geometries were used. During experiments, the electrodes were insulated using a thin (12µm) polyethylene sheet. Drops of DI water mixed with aliquots of polystyrene bead suspension solution were dispensed on top of the insulation sheet while the electrodes were biased using an AC function generator (0-32V peak-peak and 0-20MHz) and the formed bead alignment patterns were recorded. On the modeling side, we developed 3D COMSOL models to evaluate the underlying driving mechanisms. We hypothesize that the volumetric domains of the particles with different dielectric properties than the surrounding media will distort the electric field and affect the resulting DEP forces. Thus the size and location of a particle and the distance between neighboring particles are all accounted for in the modeling.

Results: As shown in Fig.1, polystyrene beads formed alignment patterns quickly under proper DEP biasing conditions. Moreover, the pattern lines consisted of particles aligned parallelly in a pearl-chain manner.

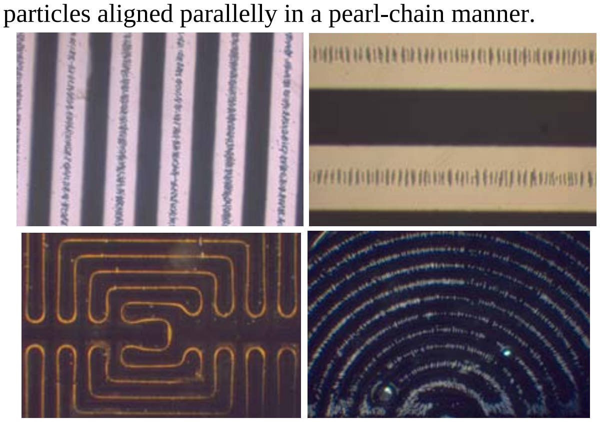

Figure 1 - The resulting alignments of polystyrene beads associated with various electrode design patterns.

Fig.2 shows a COMSOL model in which the effect of the presence of a spherical particle on the resulting electrical field is considered. The insets show the x-components of the resulting electrical fields when the presence of the particle domain is considered (left inset) and ignored (right inset). Clearly, the electrical field surrounding the particle is distorted drastically due to the presence of the particle having a different conductivity and permittivity from the surrounding medium.

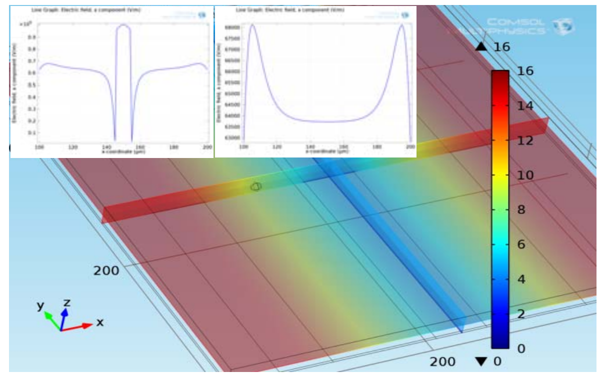

Figure 2 – COMSOL model for quantifying the influence of particle volumetric domain on the distortion of electrical field along with the obtained electrical fields.

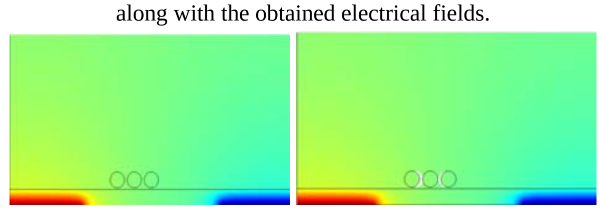

Figure 3 – COMSOL results showing the movement of particles closer together due to particle-particle interaction to forming a pearl-chain (note the white circles mark the new positions).

With this field-distortion effect considered, we then simulated the process of pearl-chain formation. As shown in Fig.3, of the three particles the two on both sides were driven closer to the middle one to form a packed chain, indicating that the DEP forces along with the distortion of electric fields by the neighboring particles generate a driving force to move the particles closer together in a line that is parallel to the overall electric field.

Conclusions: Electrical field distortion is the result of differential permittivity between the particle and surrounding medium. In overcoming the limitation in the current DEP theory, we calculate DEP forces by integrating over the whole volume of the particle such that the effects of particle size, shape and location are inherently considered, and the modeling results prove to be effective in explaining our experimental observations. Knowing the underlying governing principles makes it possible for us to pattern particles in a rapid manner by using DEP along with proper designed electrodes (see Fig.1).