SIMULATION STUDY OF ROTATIONAL ELECTRIC FIELD ON SPHERICAL PARTICAL FOR ELECTROROTATION STUDIES

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ABSTRACT

We report three dimensional (3D) rotational (ROT) electric field simulation generated by a biochip to levitate and rotate micron sized bovine cell or a neutrally charged spherical particle. Main goal of this research is to obtain controlled object rotation in yaw, pitch and roll axes for the purpose of automation of enucleation process during bovine cloning. Finite element analysis (FEA) results of rotating electric fields are analyzed for the determination of DEP torque on the cell. This also serves as a necessary tool to determine the dielectric spectrum properties of cells for biologists.

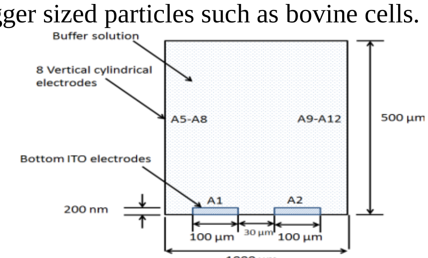
KEYWORDS: Biochip, enucleation, cloning, electro rotation, dielectrophoresis.

INTRODUCTION

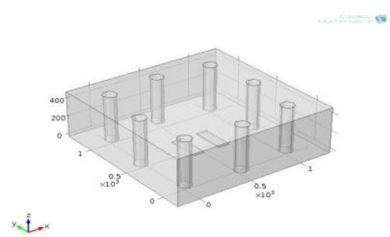
DEP is a phenomenon in which force is exerted on a neutrally charged dielectric particle under the influence of non-uniform electric fields. Different order and shapes of electrodes are designed to obtain fields to induce dipoles in the particle and these dipoles polarize the neutrally charged particles. Any particle under the influence of electric field exhibit DEP. However, the strength of the DEP force on the particle strongly depends upon the electrical properties of the particle and the surrounding medium, on the particle shape and size, and also on the frequency of the applied field. Fields of particular frequency can manipulate and rotate cells and particles with enormous selectivity. This also increases the chances of selectively separating the cells and rotating them at required precision. Electrorotation occurs from the result of superimposition of electric fields on a particular area within the workspace [1]. This workspace composed of optimized space between electrodes and with suitable AC field along with phase shifts. It also depends upon the polarizability of the particle with the surrounding medium [2]. The DEP electric torque generated by polarizing the particle in AC field is given by,

$$T_{DEP} = -4\pi r^3 \varepsilon_m Im(f_{cm}) E^2 \quad (1)$$

Where, f_{cm} is the imaginary part of CM and E is the magnitude of electrical field strength. ε_m is the permittivity of surrounding medium, r is the particle radius. Figure 1 shows the basic design concept of the micro device for applying 3D electro rotation fields and the acting torque analysis of the particle. The rotational torque is applied sequentially on the particle by switching the AC signals. Since DEP force and torque are proportional to cubic r, it implies that bigger the radius of particle larger will be the forces acting on it and also the rotation chamber has to be calibrated to support the rotation of bigger sized particles such as bovine cells.



(a)



(b)

Figure 1 *Basic design concept of the device for particle/cell rotation studies* ***(Not to scale).*** *A1 and A2 as bottom indium tin oxide (ITO) electrodes, and A3, A4, A5, and A6 representing vertical side wall electrodes made of brass. (a). Side view of the device. (b). 3D Model designed in COMSOL v4.3 software. Eight vertical electrodes of 60 µm radius are considered so that cell..*

FEA simulation in COMSOL 4.3v provides suitable means to estimate the rotational electric fields and optimize the electrode shapes and ROT chamber dimensions. Figure 2 shows xy-plane electric field arrow normal arrows along with high resolution matlab software plots for data analysis as shown in Figure 3. A single period electrical potential and phase varying field simulation is considered. Sinusoidal voltage of 45˚ phase shifts is applied at the eight pairs of orthogonally arranged electrodes. At the bottom electrodes 90° phase shift is applied. Rotational fields are controlled by controlling the signals on the electrodes. If vertical cylindrical electrodes are grounded then we get pitch axes rotation if all of the electrodes are activated with AC we obtain yaw axis rotational fields. At the center region constant electric field magnitude is found and the fields have linearly superimposed onto each other. With the change in phase, field rotates and makes 360˚ rotation and is very much evident near the center chamber. It is found that the rotational field remains at constant magnitude near the center region making the torque on the cell solely dependent upon frequency and complex material properties. Through these rotational fields one can control the frequency of fields to control the cell or particle rotation speed. Moreover by having cylindrical micro pillars one can make the channel open, this will provide an advantage of enucleating the rotated cell. It is however, yet unknown as to how to hold the cell after rotating in desired position. This is one of our future goals.

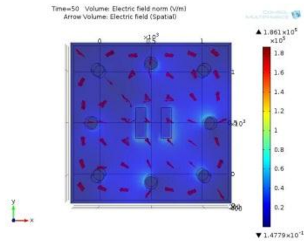
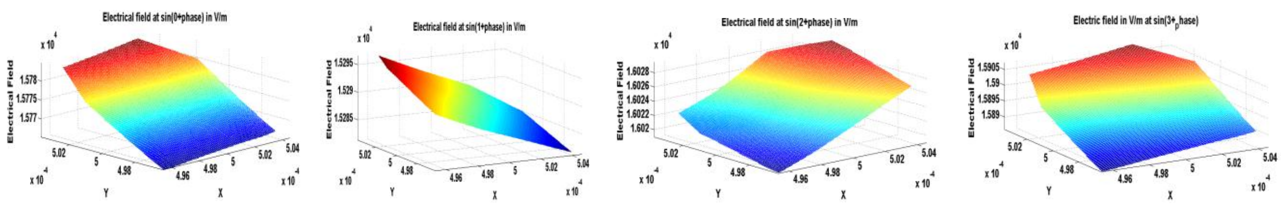


Figure 2. *Electric field simulation field normal arrows along with a legend showing electric field range values. It is found that at the centre 10^5 V/m field present near the centre region of the ROT chamber. These are the results at AC sine voltage of 10 volts peak to peak voltage.*



(a) (b) (c) (b)

Figure 3. *(a). Matlab plot of 10x10 micron high resolution plot of corresponding electrical field from xy plane in Figure (2a). Magnitude of field at the centre is found to be between $1.59x10^4$ V/m to $4x10^5$ V/m. (a) Voltage at sin(0 sec +phase) (b) Voltage at sin(1sec +phase) (c) Voltage at sin(2 sec +phase) (d) Voltage at sin (3 sec+phase)*

Our future vision involves solving a real world cell rotating in AC fields. For this purpose currently a 3D model of cell is prepared and suspended in the buffer solution as shown in Figure 4.

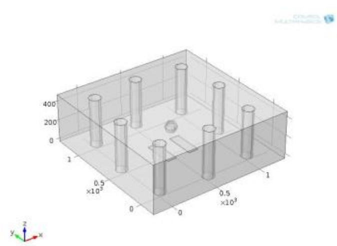


Figure 4. *Model of ROT chamber along with a 3D cell suspended at the centre region*

From simulation studies it is found that rotational fields are possible to be obtained in 3D spaces to rotate and control a neutrally charged particle such as bovine cell in all three axes. Moreover, this rotational field strength is independent of time and hence through this one can determine the dielectric spectrum or torque on the cell by considering electric field as constant magnitude. This provides a suitable means to enucleate the cell in an open channel and also act as a tool to determine dielectric spectrum of spherical cells and particles. However, to apply 8 AC signals one needs 8 channel signal generator. Currently we have fabricated 4 vertical side wall electrodes applied with 4 AC waves from 4 channel signal generator. Simulation results reported in this abstract are unique and will be employed in the upcoming experimental works.

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