Driving Cell Rotation Using Conventional Dielectrophoresis

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Statement of Purpose: Rotating electrical field is often used to induce cell rotation by generating a rotating dielectrophoretic (DEP) force. However, the electrode setup for generating a rotating electrical field cannot be used for other kinds of cell manipulations. It is thus desirable to manipulate cells as well as drive cell rotation using conventional DEP. With the current prevailing DEP theory it is impossible to know if it is even feasible to drive cell rotation with conventional DEP. In this study we use COMSOL simulation to reexamine the DEP phenomena by accounting for the field distortion caused by the presence of a particle having different permittivity than its surrounding medium. With this new approach, we are able to predict that it is possible to drive cell rotation provided that the cell body can be regarded as having anisotropic structure. To validate our modeling results, we performed experiments using rat adipose stem cells and achieved cell rotation with parallel interdigitated electrodes biased under alternating current (AC) DEP.

Methods: 3D electrostatic COMSOL models are developed. In modeling the cell rotation behavior, we hypothesized that the cell rotation is caused by the non-spherical shape of the cell body and the off-centered location of its nucleus, and that the rotation direction depends on the relative location of nucleus with respect to the electrical field. Thus we consider ellipsoid-shaped cells with off-centered nucleus. The cell nucleus is assigned a higher conductivity value compared than cell plasma due to greater hydrated free ion content, making the relative permittivity of cell nucleus higher than that of the cytoplasm. We considered two cases: 1) the nucleus is off centered to the right above the center line and 2) it is off centered to the right below the center line. For experimental validation, a glass slide with etched parallel gold electrodes is used to deliver the conventional DEP forces. Rat adipose stem cells in a glucose/sucrose mixture solution are used. A glass cover slip is used to ensure a uniform height of the liquid layer. A functional generator and an amplifier are used to provide sine wave AC potential.

Results:

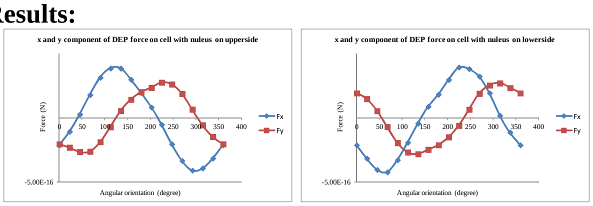

Fig.1. The x- and y-components of DEP force obtained for an ellipsoid-shaped cell with its nucleus off-centered on the upper side (left) and on the lower side (right).

Fig.1 shows the obtained DEP forces as a function of the cell orientation angle for both cases. As the cell orientation angle changes from 0° to 360°, the x- and y-components of DEP force exerted on the cell follow a sinusoidal wave pattern having a 90° phase delay. This indicates that there exists a net rotation force causing the cell to rotate in the x-y plane. To determine the rotation direction we obtained the torque exerted on cell. As shown in Fig.2 the cell with its nucleus off-centered on the upper side (Fig.2 left) is expected to spin clockwise because it is subject to a predominately negative torque most of the time and the cell with its nucleus off-centered on the lower side (Fig.2 right) will spin counterclockwise because it is subject to a positive torque most of the time.

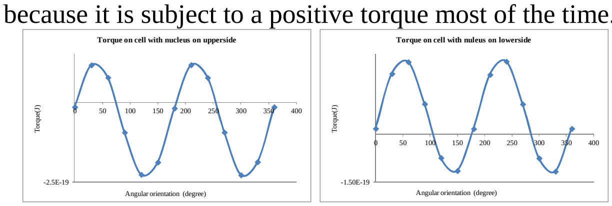

Fig.2. The resulting torque obtained for the cell with its nucleus off-centered on the upper side (left) and on the lower side (right).

In experimental validation, by sweeping the frequency of the AC biasing from low to high, we noted that cells accumulated along the edge of electrodes at first and then moved to the center of gap region between electrodes. For those cells in the gap region, those that are not adhered to the bottom surface will spin either clockwise or counterclockwise as shown in Fig.3. Note that although these are still images, one can still see the different orientations of the two cells circled in red and green. The red-circled cell is rotation counterclockwise and the green-circled cell clockwise.

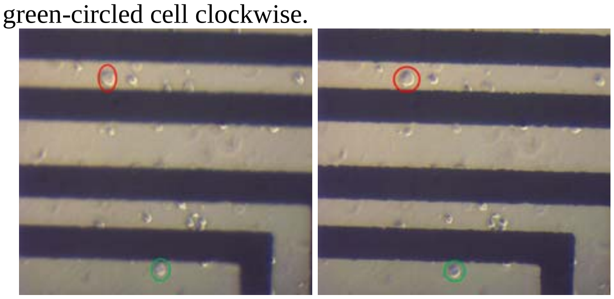

Fig.3 - Optical images showing cell rotation under DEP force at 200Vpp and 300KHz.

Conclusions: Our hypotheses that the cell rotation is caused by the non-circular shape of the cell body and the off-centered location of its nucleus and that the rotation direction depends on the relative location of nucleus with respect to the electrical field are confirmed. In essence the cell rotation can be achieved using conventional DEP by taking advantage of the anisotropy of the cell body structure. The off-centered nucleus causes asymmetry, thus affecting the rotation direction. In experimental validation, we observed cell rotation behavior under normal DEP, and that cells may rotated in the clockwise direction or the counter clockwise direction dependent on the related locations of their nuclei.

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