DIELECTROPHORESIS ENHANCED ELECTROPORATION CUVETTE WITH INTEGRATED ELECTRODES FOR HIGH GRADIENT ELECTRIC FIELD GENERATION

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Electroporation fenomenon is in high demand on a wide range of biomedical and biotechnological applications. This work covers analysis of cuvette with integrated center electrode for high gradient electric fields generation. Finite element method (FEM) simulations have showed the possibility to induce dielectrophoretic forces across the effective volume of cuvette before and after the high power electroporation pulses. Based on the obtained analysis results, high frequency electric field electrotransfer methods can be further developed.

Electroporation is a microbiology technique in which a pulsed electric field (PEM) is applied in order to increase the permeability of the cell membrane. Applied electric field pulses range from nanosecond to microsecond [1], while the number of pulses and amplitude must be adjusted according to biological object and electroporation medium properties [2]. However, the shorter (membrane permeabilizing) pulses are frequently combined with longer electrophoretic pulses [3] or are delivered with high frequency [4] in order to increase the electrotransfer rate.

Dielectrophoresis (DEP) is a phenomenon that is triggered when a polar or polarizable particle is subjected to a non-uniform electric field, which results in the motion of the particle [5]. Considering that DEP force can be manipulated by the polarizability of the cell, effect volume, square of the applied electric field magnitude and the geometry of electrodes, only the last two parameters can be effectively changed to produce a non-uniform electric field with sufficient DEP force affecting electrotransfer. A value for the factor $\nabla|E|^2$ of around 10^{13} V^2/m^3 is required to produce a significant DEP force.

In this work, we propose a concept of DEP-enhanced electroporation setup and via FEM simulation analyze the resultant electric field distribution inside a cuvette with integrated DEP electrodes. A model of the classical 2 mm gap electroporation cuvette was designed with integrated center electrode for DEP. The resultant electric field distribution in a 2 mm cuvette is non-uniform and considering the form-factor the amplitude of electric field varies significantly. Also, the simulation was performed with a maximum 50 V applied voltage, which resulted in peak PEF amplitudes up to 900 V/cm. Such an electric field is already, sufficient to trigger electroporation, therefore, the target voltage should be lower to prevent undesirable electroporation during DEP step. PEF amplitude scales with the applied voltage and in range of 10–30 V the peak value does not reach 0.6 kV/cm, which is below the typical threshold for electroporation and thus applicable for DEP-based manipulation of cells. Therefore, the 10–30 V amplitudes have been further used in the study for determination of the $\nabla|E|^2$ parameter. The $\nabla|E|^2$ reaches the order of 10^{13}, which was the goal of the work. In all cases the PEF amplitude is below the threshold for electroporation to be triggered, as a result DEP can be induced before the application of pulses.

The advanced model of DEP-enhanced electroporation on the macro scale has been proposed and the parallel plate electrode cuvette with an additional center electrode has been investigated. Using finite element method, it was shown that it is possible to reach $\nabla|E|^2$ in the range of 10^{13} but still be below the threshold PEF for electroporation. Future studies will involve the development of the prototype and testing of the concept in applied experiments.

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