Simulation of Electromagnetic Fields in a Microelectrode Array

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Abstract - **An area of significant potential in Micro-Electro-Mechanical Systems (MEMS)-related technology is the construction of microelectrode arrays that can be used to preferentially kill nearby biological cells while leaving cells more distant from the array intact. This paper details some of the basic considerations related to this research area, and goes on to explore electromagnetic field strength and its spatial variation around a simple simulated microelectrode array near a biological medium with σ and ε characteristics similar to that of human blood. Simulations were conducted at maximum field strengths of | 1.1 | volts at a frequency of 100 kHz and 1 MHz.**

Keywords – **electrode, simulation, micro, MEMS.**

I. Introduction

There are many foreseeable clinically-viable treatments in which electromagnetic fields could be used to preferentially kill biological cells that are selected to flow, attach, or be located immediately proximate to the microelectrodes producing the fields. For example, blood could be removed from a body, sent past a series of electrodes designed to kill specific cells in vitro, and then returned to the body.

Work in the area of microelectrodes is, however, at only the earliest stages. [1] Many questions arise, among the most important of which are the following:

1. What is the electric field strength and electric energy density associated with substantive percentages of cell lyses in the biological cells of interest? [2] What are the other salient characteristics of an optimal field (e.g., frequency, temp-oral pulse width, pulse repetition rate, overall temporal duration of a pulsed field)?
2. With a given field, what is the rate of cell lyses in other types of nearby cells? Are human red blood cells, for example, more easily killed than T-cells (CD4+ T-lymphocytes)?
3. What is the optimal geometry for a microelectrode array that would allow for the most precise spatial control of field strengths, so that only cells in the 'kill zone' lyse, while other nearby cells are minimally affected?
4. Do the microelectrodes themselves, during periods of high voltage, release unwanted concentrations of electrode materials into the biological fluid, which may be unwittingly be sent with the rest of the returning biological fluid to the body? [3]
5. Does the introduction of high electric energy densities in a liquid have long-term effects due to hydrated electrons, ions, activated radicals, ultraviolet radiation, and shock waves? [4] (Water, for example, subjected to pulsed electrical discharges, demonstrates a long-term bactericidal property.[5])

The answer to these and other questions lie at the heart of any research in the proposed area. In this brief synopsis, we begin to address the question of optimal microelectrode geometry (question 3 above) through simulations of electric fields using Field Precision's Mesh3W, Pac3_W, and VPac3.[6]

II. Simulations

A very simple microelectrode geometry (Fig. 1) is effective in producing relatively large volumes of high electric field strength in specific spatial locations. In the figure, (also shown in cross-section as Fig. 2), high voltage strips 'constructed' of gold metal (Region 4 and Region 6) at a maximum of 1.1 volts (100 kHz) are alternated with low voltage metallic gold strips (Regions 5 and 7) at –1.1 volts, (likewise at 100 kHz). The 5 micron wide gold conducting strips are 12 microns apart, and are placed atop a surface of silicon-based material ($\sigma = 4.39 \times 10^{-04}$ and $\varepsilon = 12$), separated from one another by Teflon (Region 2). Region 1 represents whole blood ($\sigma = 0.55$ and $\varepsilon = 4000$). (Results for a 1 MHz field are substantially similar, notwithstanding the change of conductivity and permittivity values for blood to $\sigma = 0.71$ and $\varepsilon = 2040$).

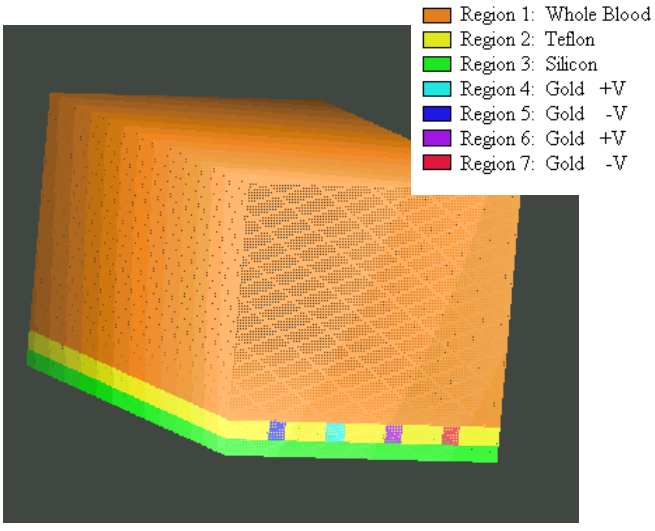

Figure 1: 80 x 80 x 160 micron geometry spaces in which electric fields are simulated. Voxels are each 0.977 cubic microns, with the workspace as a whole containing 10^5 voxels.

The results of Figure 2 show precisely the type of spatial field distribution sought. A field strength of approximately 620 V/cm—the value at which irreversible

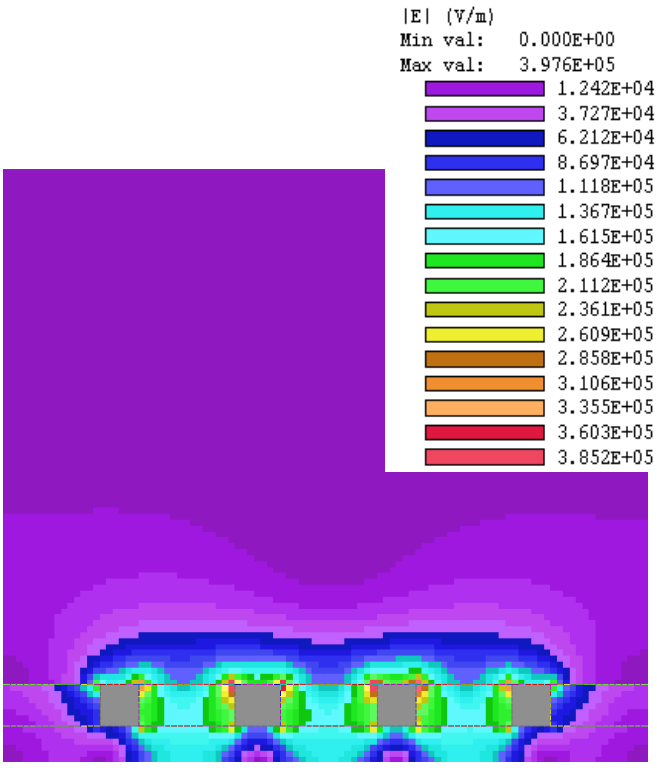

Figure 2: Electromagnetic field strength in a cross-sectional area of Fig. 1. Grey blocks illustrate the high and low gold conductors separated by Teflon. The simulated blood is the large region above the conductors. Below the conductors is a plane of silicon.

electropermeabilization occurs [2], is manifested in a broad swath some 5 to 7 microns tall above the high and low voltage electrode pairs. This is ideal to produce cell death in an immediately proximate 8 to 10 micron diameter cell.

Perhaps as importantly, the field strength quickly reduces outside the 'kill zone' to much lower levels. At some 10 microns above the electrodes, the field strengths in the center of the probe array are reduced to 124 V/cm—well below the 362 ± 21 V/cm field intensity that is the reversible threshold for electropermeabilization [2]. Although this simulation shows only 4 electrodes, expansion of the number of electrodes, brings a larger area of reduced field strength closer to the probes (Fig. 3).

III. Conclusions

A simple microelectrode geometry consisting of alternating strips of high and low voltage strips can produce a surprisingly heterogeneous layer of high electric field strength near to the electrodes that falls off quickly to a low field strength some 10 microns from the electrode array. This provides an efficient spatial field distribution for killing cells that are attached or closely approach the dielectric material between the electrodes.

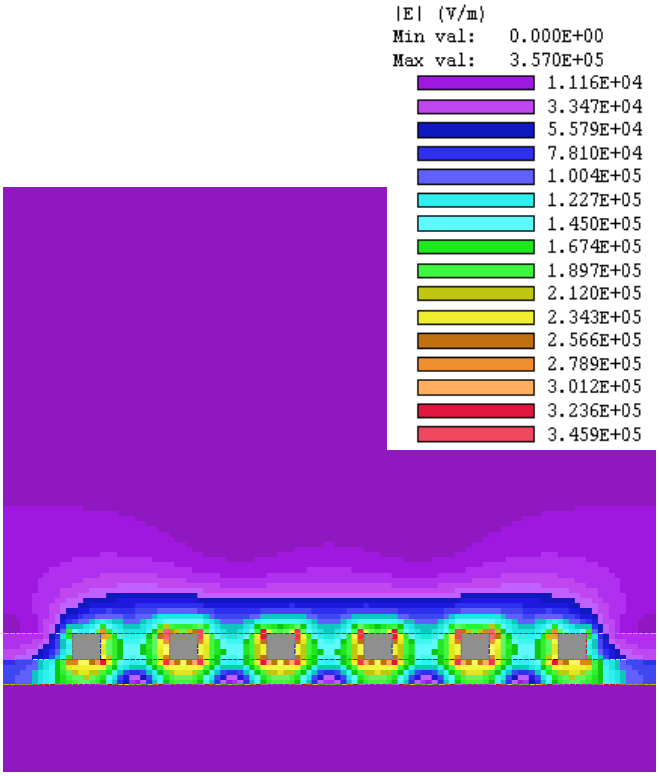

Figure 3: Electromagnetic field strength in cross-sectional area similar to that of Figure 2. Dimensions and physical characteristics of microelectrodes are identical to those of Fig. 1 and 2, except that two additional electrodes have been added on the left and right sides of the array.

Acknowledgements

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