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Measuring the Electric Field of Bioelectrodes in Saline During Stimulation

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***Abstract*— In order to provide effective vision in a retinal prosthesis, it is necessary to provide sufficient phosphene quantities ideally by parallel stimulation of multiple electrodes. A common, limiting factor in parallel stimulation is the occurrence of cross talk, which can cause undesired tissue stimulation leading to inconsistent percepts. In this paper we present a system developed for measuring the electric field in an in vitro environment by stimulation of bioelectrodes immersed in an electrolyte. The results from this study provides a better understanding of the electric field generated by stimulating electrodes. Calculation of activation area can provide useful information in regards to electrode separation to eliminate cross talk during parallel stimulation.**

I. Introduction

NEURAL stimulation has been used to treat a number of medical conditions including deafness, chronic pain, Parkinsonian tremor, and sleep apnea [1]. Restoring vision to blind people is another area of intense interest for many researchers working to develop a retinal prosthesis. Readily available devices like cardiac pacemakers and cochlear implants are comparatively less complex as they require fewer electrodes to efficaciously stimulate the neural pathways. However, to provide useful perceptions, a large number of microelectrodes are likely required to yield high resolution vision. For this reason, in many devices a large numbers of parallel electrical stimuli are used in order to elicit the desired visual response [2]. Efficient prosthetic vision devices must deliver sufficient phosphenes to provide useful vision without damaging the target tissues. Humayun et al. reported thresholds to activate retinal neurons between 0.16 and 70 mC/cm^2 for the human retina [3].

Excess injection of charge and failure to maintain local charge balance under individual electrodes can physically damage the electrode causing electrode dissolution as well as damage to the target tissue. Safe charge injection limits are defined for different materials (e.g. 300 $\mu C/cm^2$ for platinum (Pt) [4]).

Scanning Electrochemical Microscopy (SECM) is a technique used to probe surface reactions of materials at microscopic scales. Reactions, such as corrosion redox reactions, at the interface between two regions are often studied using this technique [5], [6]. SECM gives spatial response of the scanned field at micrometer scale to analyze the reactions in a detailed manner. In neuroscience, SECM is used for three primary reasons (a) in vivo voltammetry, (b) microdialysis of cells in tissues where devices are implanted, and (c) in vitro analysis of isolated living target cells that are available in tissue [7]. The study presented in this paper applies a similar method of analyzing electric field around the electrodes during stimulation.

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II. Method

The system developed for scanning bioelectrodes was based on three microcontroller modules (Atmel, ATMEGA168, San Jose, United States). All three modules were connected to a PC (Personal Computer) through USB (Universal Serial Bus) interface and were controlled by a Visual Basic (VB) Graphic User Interface (GUI).

Fig. 1 shows the block diagram of the system. The stimulating electrodes were placed in a tank filled with 0.9% saline solution. The electrodes were stimulated by a constant current biphasic stimulator while the recording module measured the voltage potential using a tungsten electrode in a plane above the stimulating electrodes. The associated plane and the stimulation parameters were defined in the VB application. At each point of the plane the stimulus was applied and the voltage was measured at the mid of each cathodic phase. An average of ten measurements was recorded. Two-dimensional (2D) and three-dimensional (3D) plots of the measured field were generated using MATLAB.

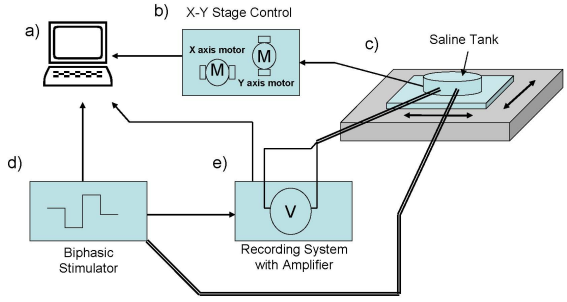

Fig. 1. Block diagram of the system with individual modules labeled. (a) Computer (b) Micro-manipulator controller (c) 2D platform with saline tank (d) Biphasic stimulator (e) Recording system.

1) Stimulator: The stimulating module was an AVR microntroller based, constant current biphasic stimulator that

can provide a stimulating current in the range of 10 μA to 2.5 mA. The phase time can be set between 1 ms to 50 μs.

2) XYstage: The XYstage was a two degree of freedom platform with a minimum step of 2 μm in both axes. The module included motor drive circuits and the movement of the platform was synchronized with the stimulator and the recording module.

3) Recording module: The recording module was connected to a tungsten needle electrode and an $Ag/AgCl$ reference electrode to measure the voltage potential during stimulation. A preamplifier stage, consisting of instrumentation amplifier with high common-mode rejection (120 dB at G $\geq$ 100), was connected between electrode and Analog to Digital Convertor (ADC) to amplify and eliminate the common mode noise present in the measured voltage signal. Recording module was interlinked with the stimulator to acquire the voltage at exact instances of cathodic and anodic phases of the stimulus cycle.

This study comprised two parts:

A. Electrode performance

Different pairs of electrodes were stimulated by biphasic stimuli and the plane above the electrodes was scanned for discontinuities in the stimulating region. 6.9 $\mu C/cm^2$ of charge per phase was injected to get a better resolution of the plane. During this study two types of electrodes were used, a pair of cochlear electrodes and a pair of disk electrodes of 500 μm diameter as shown in Fig. 2.

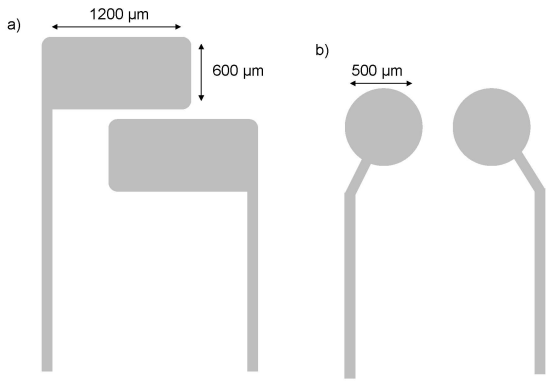

Fig. 2. Electrode pairs used in the experiment. (a) Cochlear electrodes, (b) Planar disk electrodes.

B. Calculation of activation area

The second case was to calculate the activation area in the scanned plane. A pair of disk electrodes of 500 μm diameter was used. A biphasic stimulus of 1.5 mA with a pulse of 250 μs equal to charge density of 190 $\mu C/cm^2$ was injected per phase. Planes were scanned at different heights above the electrode.

III. Results

Electrodes were stimulated by biphasic stimuli and the plane above the electrodes was scanned for any irregularities on electrode surface to check the performance of the electrodes. To begin, a pair of cochlear electrodes was stimulated with a biphasic stimulus of 500 μA and a time period of 100 μs equal to a charge density of 6.9 $\mu C/cm^2$. Fig. 3 shows a 2D plot of the horizontal plane's voltage potential, 200 μm above the cochlear electrode pair. A plane of 1.8 x 1.8 mm was scanned over the electrodes. The color-bar in Fig. 3 represents the voltage potential in mV. A total of 2100 points were scanned. The area with higher (10 mV and higher) and lower voltage (-10 mV and lower) potentials represents the electrodes also marked by black boundary in Fig. 3.

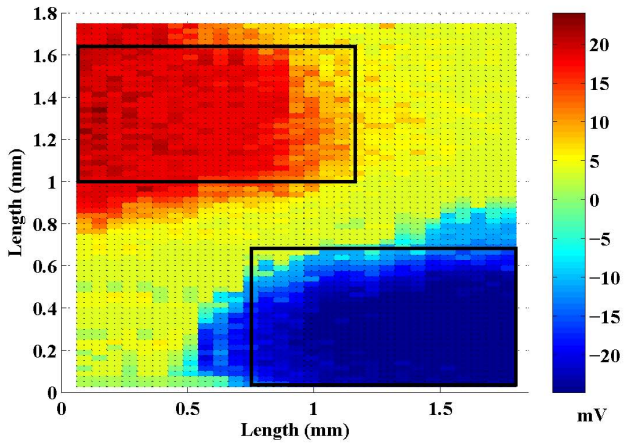

Fig. 3. Electric field plot scanned 200 μm above a pair of cochlear electrodes. The back lines enclosed area represents the electrodes. The colorbar indicates voltage in mV.

Fig. 4 represents a 2D voltage distribution plot of the horizontal plane above a pair of disk shaped electrodes, 500 μm in diameter. The plane scanned was 2 x 4 mm with a total number of 20,000 points. Each point on the plane was separated by 20 μm.

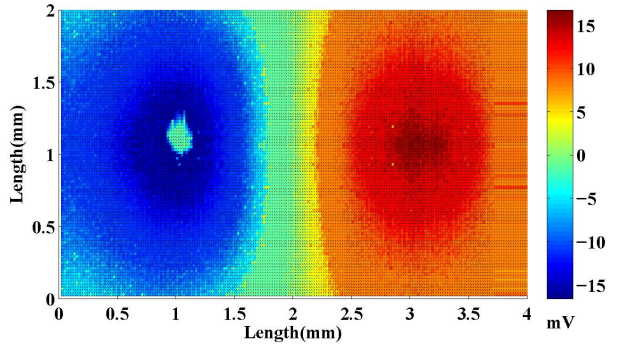

Fig. 4. Measured electric field of circular disk electrodes 500 μm in diameter. The plane is 2 x 4 mm and approximately 200 μm above the stimulating electrodes.

The activation area where the electric field exceeds the threshold voltage for cell activation was calculated. Stim-

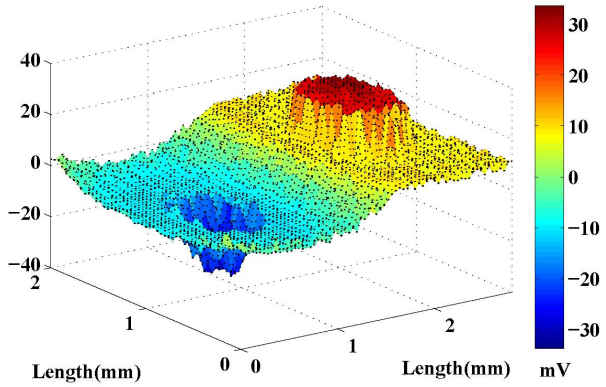

Fig. 6. Three dimensional electric field plot of the disk electrodes stimulating at injected charge of 190 $\mu C/cm^2$. The vertical axis and the colorbar indicate the voltage in mV.

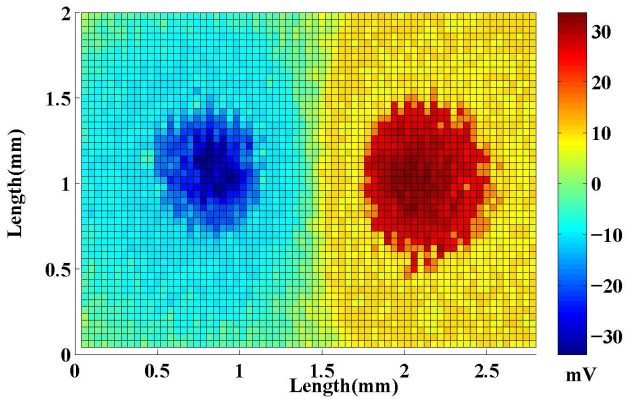

Fig. 5. Two dimensional voltage distribution plot measured 100 μm above the surface of disk electrodes stimulating at injected charge of 190 $\mu C/cm^2$. The colorbar represents voltage in mV.

ulation parameters provided by Humayun et al. were used to stimulate the electrodes [3]. A total of 190 $\mu C/cm^2$ charge was injected per phase which is within the safe charge injection limit of platinum. A voltage distribution plot is shown in Fig. 5. The electrodes shown in this figure are 500 μm in diameter. A total of 3621 points was scanned on the plane of 2 x 2.8 mm.

Fig. 6 shows the same scanned electric field as Fig. 5 in a three dimensional plot. The vertical axis represents the voltage.

IV. Discussion

Examining the electric field of the electrodes is an effective way to check the performance of the electrodes. Initially electric field of cochlear electrodes was scanned while the electrodes were stimulating. The size of each electrode was 600 μm by 1200 μm which is approximately equal to the high and low voltage potential regions of Fig. 3. There was no irregularity seen on the conducting surface of the electrodes.

During this study, disk electrodes were also scanned for their electric field. In Fig. 4 the electric field of a disk electrode is shown. There is a small region on the plane, just above the electrode surface, where an abrupt change in voltage can be observed. Following visual inspection this was a non conductive area on the electrode surface. The non conductive region was found coated with silicone during the manufacturing of the electrodes. Serendipitously, this provides a means of scanning the conducting surface of the electrodes so that they may be thoroughly visualized for defects. Stimulating the electrodes with high charge densities is not recommended during this study as the generated electric field becomes quite strong which makes it impossible to locate the discontinuities.

The typical resting potential of retinal neurons was 50-70 mV [8], [9]. Depolarization of the cell membrane by 5-25 mV is sufficient to transmit a signal to other neurons, including bipolar cells [10], [11]. Cross membrane depolarization can be achieved by application of an electric field to the surrounding medium. Palanker et al. calculated the magnitude of electric field $|E|$ to achieve a cross membrane depolarization. Electric field $|E|$ threshold for activation was 30 V/cm [12].

In Fig. 5 a voltage distribution plot is shown. A total of 3621 points were scanned out of which 255 points exceeded the electric field limit of 30 V/cm to activate a cell. The area of each scanned point was calculated to find the activation area in the plane. Points were 40 μm apart from each other on both axes. Considering the point to be a circle of 40 μm diameter, the area of each point will be 0.0013 mm^2. In Fig. 6 the points over threshold were 255 which is equal to an activation area of 0.1993 mm^2. This is approximately equal to 0.1963 mm^2, the geometric area of the stimulating electrode.

The same parameters were used to scan the plane for voltage at different distances from the electrode surface. Fig. 7 shows the relation between the activation area and the distances of the scanned plane from the electrode. The steps are an approximation of the distances from the electrodes. The area of activation increases with the increasing distance from the electrode surface. This increase in area will overlap

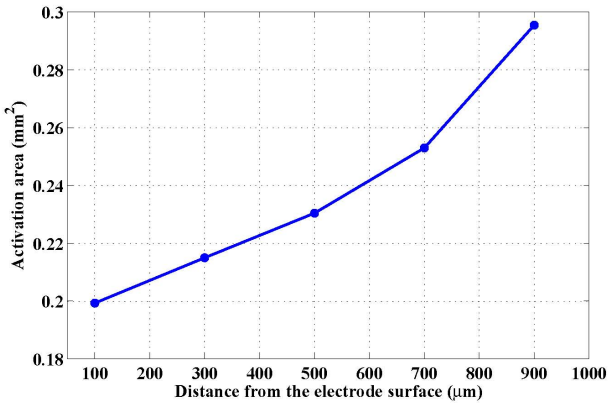

Fig. 7. Activation area at different distances from the electrode surface.

with the activation area of other electrodes when stimulating simultaneously in the form of an array. If the target cells are a few 100 μm away from the electrode surface the overlapping region will compromise selective cell activation. Increasing the separation between individual electrodes in an array can avoid overlapping of activation area. This leads to the calculation of separation of electrodes in an array for effective parallel stimulation. A 500 μm diameter electrode, stimulating at a charge density of 190 $\mu C/cm^2$ per phase, should be 550 μm apart from the neighboring electrode to avoid overlapping of activation area measured at 500 μm above the electrodes.

V. Conclusions

The technique presented in this paper is useful in understanding the behavior of electrodes during stimulation. Monitoring the electric field of the electrodes can detect small surface defects which are induced during manufacturing. This process can be used as a method for testing electrodes after manufacturing to check the performance of the electrode before being used clinically.

The technique is also beneficial in finding out the activation area. One major issue with parallel stimulation is cross talk, which may cause undesired tissue stimulation as well as charge imbalances. With this technique, the cross talk can be eliminated or at least reduced by calculating the desired separation between the electrode to avoid overlapping of activation regions.

VI. Acknowledgments

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