Proceedings of the 26th Annual International Conference of the IEEE EMBS
San Francisco, CA, USA • September 1-5, 2004

Multielectrode Impedance Tuning: Reducing Noise and Improving Stimulation Efficacy

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Abstract—**Multielectrode Arrays (MEAs) have emerged as a leading technology for extracellular, electrophysiological investigations of neuronal networks. The study of biological neural networks is a difficult task that is further confounded by mismatches in electrode impedance. Electrode impedance plays an important role in shaping incoming signals, determining thermal noise, and influencing the efficacy of stimulation. Our approach to optimally reducing thermal noise and improving the reliability of stimulation is twofold—minimize the impedance and match it across all electrodes. To this aim, we have fabricated a device that allows for the automated, impedance-controlled electroplating of micro-electrodes. This device is capable of rapidly (minutes) producing uniformly low impedances across all electrodes in an MEA. The need for uniformly low impedances is important for controlled studies of neuronal networks; this need will increase in the future as MEA technology scales from tens of electrodes to thousands.**

Keywords—**MEA, electrode, impedance, electroplating**

I. INTRODUCTION

The electrophysiological investigation of neuronal networks is a complicated task that is further confounded by variability of impedances in the electrodes. Normalized impedances across all electrodes in an MEA create a uniform network by which one can simplify some of the complicated dynamics associated with these studies. In addition, uniformly low impedances offer distinct advantages in terms of reducing noise, calibrating stimulation, and minimizing artifacts.

Electroplating platinum black increases the surface area of the electrode and reduces electrode impedance [1]. Impedance matching is accomplished by introducing some measure of control into the electroplating process. The impedance-controlled electroplating of platinum black device allows us to achieve both low and matched impedances throughout the MEA. The measurement capabilities of this system also have the potential to employ impedance imaging for the investigation of cellular motility, proliferation, and scar tissue formation [2].

In addition to creating the electroplating circuitry, it was necessary to develop a device for mechanically and electrically interfacing the MEA. This device allows us to individually address each electrode and is customized to accommodate electroplating conditions.

II. EFFECTS OF IMPEDANCE ON STIMULATION

Electrical stimulation is a common technique used to evoke cellular responses in neuronal cultures. Recent work has shown that voltage stimulation is not only an easy-to-control mechanism that avoids potentially harmful electrochemical side effects but also may be more advantageous than current stimulation [3]. The efficacy of a stimulus, which is largely determined by local depolarizations in the dish [3], can be related to the impedance of the electrodes. Normalized impedances assure uniform local de-polarizations throughout the dish. Furthermore, a reduction in impedance reduces the required magnitude of the voltage stimulus, which in turn has the advantage of reducing the stimulus artifact. Fig. 1 shows an electrode model that was used to relate the effect of a stimulus to the impedance of the electrode. As a first order approximation, the maximum voltage produced in the media from a biphasic pulse can be shown to be

$$-V\max \approx \frac{-R_m}{R_s + R_m}\Delta V\left(1 - \frac{\Delta t}{2C_I\left(R_m + R_s\right)}\right) \qquad (1)$$

where R_M is the resistance of the medium, R_S is the spreading resistance, and C_I is the interfacial capacitance. The spreading resistance is fixed by the base area of the electrode. Decreasing the impedance has the effect of increasing capacitance, thereby allowing for a reduction in ΔV without compromising the magnitude of Vmax.

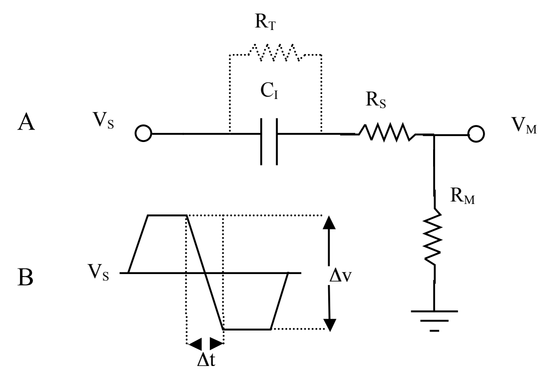

Fig.1. A) Circuit model for the microelectrode. The transfer resistance, R_T, is assumed to be infinite. R_S represents the spreading resistance, C_I is the interfacial capacitance, and R_M is the resistance of the media. B) Biphasic waveform applied at V_S.

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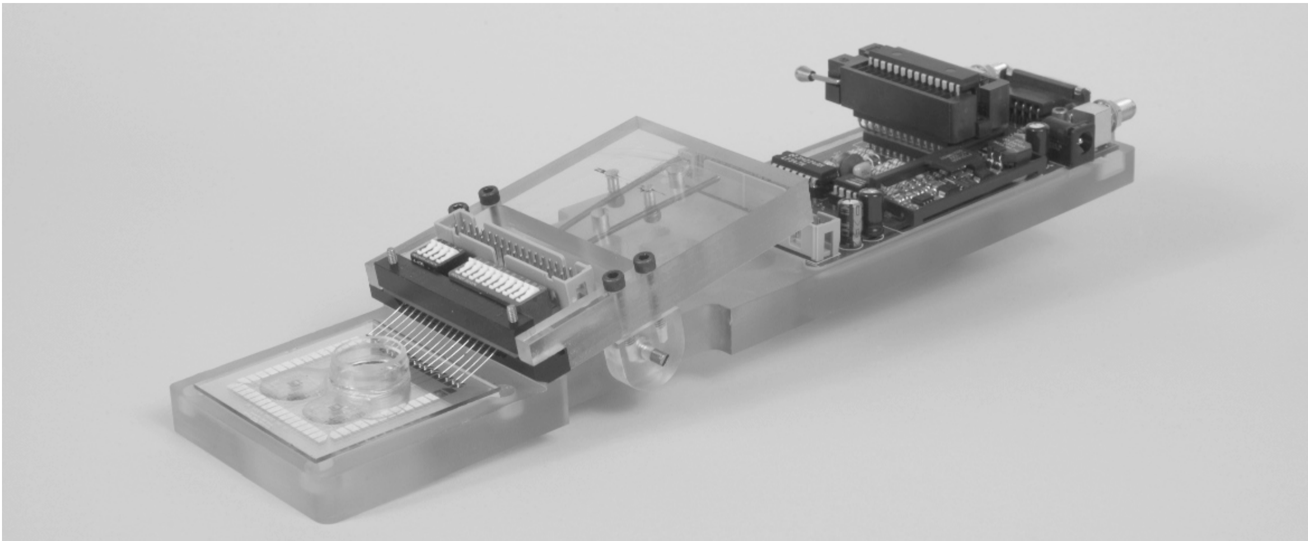

Fig. 2. Photograph of the mechanical interface and accompanying electrode impedance tuning circuitry

III. System Design

The interface consists of all the components needed for effective MEA stimulation, recording, and electroplating placed on a single integrated device. The components are a MEA mount, spring pin electrical interface, and processing and amplification circuitry. The complete assembly is intended to rest on a users desktop but is small enough to fit on a microscope stage for visual inspection.

The mechanical package itself is composed of two main polycarbonate sections, a base and lever, which interact via a hinge mechanism. This hinge is preloaded with two torsional springs such that the device behaves in a clip-board fashion. The base contains recesses for holding the MEA on one end and the main printed circuit board (PCB) on the other. An array of spring pin contacts is mounted on an interface board on the lever and provides the key electrical interface to the MEA pads. The interface board is then connected to the main PCB with a ribbon cable. The lateral positioning of the spring pins relative to the MEA surface is adjusted by rotating the hinge pin, which uses a screw to move the lever back and forth. Figure 2 shows a photograph of the device.

The current design offers several distinct advantages over similar devices. The clip board interface allows for quick and easy insertion of the MEA, reducing startup time and minimally disturbing the neuron cultures present on the MEA. Also, the mounting of spring pins on a hinge ensures an even pressure distribution of the pins across the MEA pads. Finally, the use of an interface board offers two important benefits. To ensure good electrical contact between the spring pins and the MEA pads, large forces are needed. These forces are large enough to warp a typical PCB. By using the interface board, the high stresses placed on the contact pins are mechanically isolated from the main PCB. Also, since the main PCB is electrically connected to the device by a ribbon cable, it can easily be replaced, allowing for PCB upgrades that leave the rest of the device intact

IV. Impedance Controlled Electroplating

The impedances of microelectrodes are reduced and matched by electroplating platinum black. The electrodes are plated under ultrasonic conditions to remove loosely adherent platinum deposits and insure long lasting adhesion [4]. A high level schematic representation of the circuit is shown in Fig. 3. An AC voltage is applied across the electrode and a known reference resistor. Voltage signals V_1 and V_2 are acquired, interpolated, and processed to determine the magnitude of the electrode impedance. The magnitude of the impedance is given by the following simple expression:

$$z_{electrode} = \left|\frac{V_2}{V_1}\right| R_{ref} \tag{2}$$

The measurement error is given by

$$z_{err} = \varepsilon_{V_2} \frac{R_{ref} + z}{V_{in}} + \varepsilon_{V_1} \frac{\left(R_{ref} + z\right) z}{R_{ref} V_{in}} \tag{3}$$

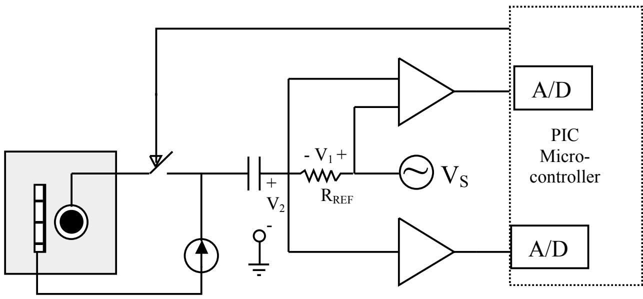

Fig. 3. Schematic diagram for the impedance-controlled electroplating device. A small (mV) AC voltage signal is applied across the microelectrode and reference resistor while an electroplating current is simultaneously applied to the plating solution. The voltages across the reference resistor and electrode are read in through the analog-to-digital converter on a PIC microcontroller which serially communicates with a PC. The PC interpolates signals to calculate microelectrode impedance and controls the switching between electrodes via the microcontroller.

Quantization noise of the A/D is a major contributor to error. The error of the impedance measurement is minimized when the electrode is at or near the reference electrode, which suggests that the resistor should be chosen to match the target electrode impedance. The control mechanism for electroplating is relatively simple: the device plates the electrode at a constant plating density until the desired impedance is reached at a fixed predetermined frequency (usually 1Khz). Fig. 4 demonstrates the performance of the device. The impedances of eight electrodes were reduced to a value that was relatively close to the target. In the future, more advanced control algorithms will be developed that allow the plating density to adjust as the electrode approaches the target value. Additionally, future versions will employ additional hardware and software modifications that will substitute all external instruments with the PIC microcontroller.

V. Conclusions & Future Studies

A device which allows for impedance-controlled electroplating has been demonstrated. Preliminary investigations of this device have begun, but more work is still needed to fully characterize its performance. Additionally, more sophisticated microcontroller algorithms will be developed to implement a quadrature demodulator, which will allow us to acquire both the phase and magnitude of impedance. Uniform impedances are important for controlled studies of neural cultures. This need will increase as MEA technology scales from tens of electrodes to thousands.

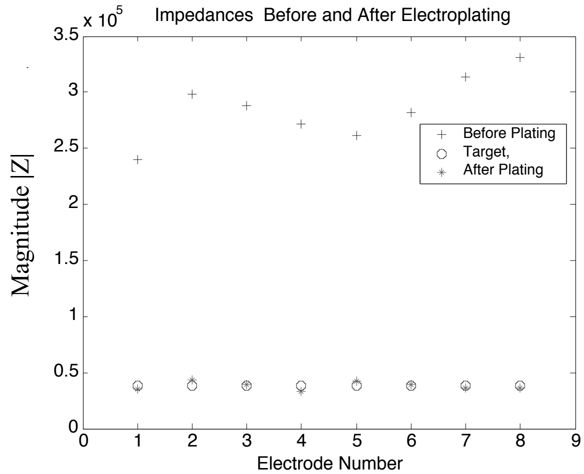

Fig. 4. Graph depicting the magnitude of impedance before and after plating for each electrode. The electrodes very nearly match their targeted impedance.

Acknowledgment

This research is supported by the National Institutes of Health Bioengineering Research Partnership grant (1 R01EB00786-01). Additionally, J. Ross is supported by a National Science Foundation graduate fellowship.

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