CHARACTERIZATION OF SILICON MICROELECTRODES FROM THE EU VSAMUEL PROJECT

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INTRODUCTION

The principle goal of the European Commission sponsored VSAMUEL project is to develop the means to enable neuroscientists and engineers to acquire simultaneous recordings of the activity of hundreds of cells in the central nervous system in the animal model. To attain these goals, VSAMUEL consortium is developing a multi-sited microelectrode array based on batch fabricated Silicon-on-Insulator wafers, connected to the outside world via flexible interconnects.

As a measure to control the quality of VSAMUEL probes, several characterizations are under evaluation. They must first be simple enough to be able to be performed at the manufacturing site, and perhaps by the end user, yet, they must be comprehensive enough to detect flaws of the electrode or predict the performance of the electrode during use. We have focused on three methods of probe characterization: visual, electrical and mechanical. The present paper focuses on the latter two characterizations. "Visual" characterizations involve the use of electron- and optical microscopes and are primarily used to identify structural faults from the manufacturing process and will be reported elsewhere. Electrical characterisation was performed using a novel rapid 3-point electrode impedance characterisation system with the probes immersed in normal (0.9%) saline. Mechanical characterisation is made using a recently developed force measurement device to determine insertion mechanics of the probes implantation into nervous tissue. As a first step towards designing these tests, we are running comprehensive characterizations of electrode impedance spectra and destructive mechanical testing to determine the signature characteristics of a normal, functioning probe and its possible failure modes. Once identified, simpler evaluation tests could be designed and implemented for quality control

METHODS AND RESULTS

Electrical Characterisation - Impedance

The active sites of VSAMUEL electrode arrays were placed in a measurement cell filled with 0.9% saline. The active sites of the electrode array were immersed in the saline solution 5cm from a large Ag/AgCl counter electrode. A standard Ag/AgCl reference electrode (Cole Palmer, Vernon Hills, IL USA) was placed in the solution between the test electrode and the counter electrode 0.9% saline solution at between 21-23°C. Each of the 18-20 wired sites on each probe was tested sequentially using 5-second rapid 3-point electrode impedance measurements. No attempt was made to clean the electrode array or convert the sputtered Ir on the active sites of the electrode to IrO_x these tests, as they were meant to characterize the impedance of newly manufactured probes. These measurements were made with respect to the reference electrode using bandwidth limited noise excitation current of ~2µA_{pp} between the test electrode and the counter electrode.

The rapid 3-point electrode impedance measurement technique is a modified version of the rapid 2-point electrode impedance measurement technique described in [3].

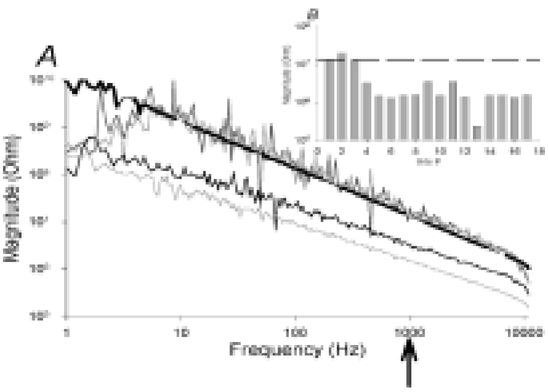

Figure 1: Set of typical impedance data in saline for Ir SOI-microelectrodes [1]. A shows a set of impedance spectra, whereas B illustrates site impedances at 1kHz. The thick dashed line indicates the maximum impedance measurable by the device.

Use of a 3-point measurement scheme eliminates the effect of the counter-electrode impedance on the overall impedance measurement. The technique yields the electrode impedance spectrum between ~1 Hz and 10kHz with short 1-10 second measurements.

Shortly, a bandwidth limited noise current is passed through the test electrode and large Ag/AgCl counter electrode immersed in 0.9% saline. The current through the test electrode and the voltage drop across the test electrode and a separate Ag/AgCl reference electrode is measured. Fast Fourier Transforms are taken of the appropriately sampled and windowed voltage and current waveforms and the empirical transfer function estimated. This estimate directly yields the impedance spectrum of the test electrode. A typical set of impedance spectra is shown above in figure 1.

Mechanical Characterisation – insertion force
The sciatic nerve 1 cm distal to the sciatic notch to 1cm distal to the branch point of the tibial and peroneal branches was excised from a New Zealand White rabbit immediately post-mortem and stored in a vial of normal saline at 4°C until the insertion experiments took place.

During the insertion experiments the peripheral nerve tissue was maintained in the saline solution at room temperature. Sutures were tied to the nerve ends to anchor the nerve and to adjust the tension on the nerve. Insertion force was measured using a custom build force/dimple transducer device described in [2]. The force sensor consisted of a DC-DC lateral displacement transducer (LVDT 0200-000, Trans Tek. Inc., Connecticut, USA), a steel core attached to a spiral spring and a coupling junction attached to the probe (see insert figure 2) . To test the principle of the method, we characterized the insertion force using a 50µm electro-sharpened tungsten needle similar in dimension to the VSAMUEL probe.

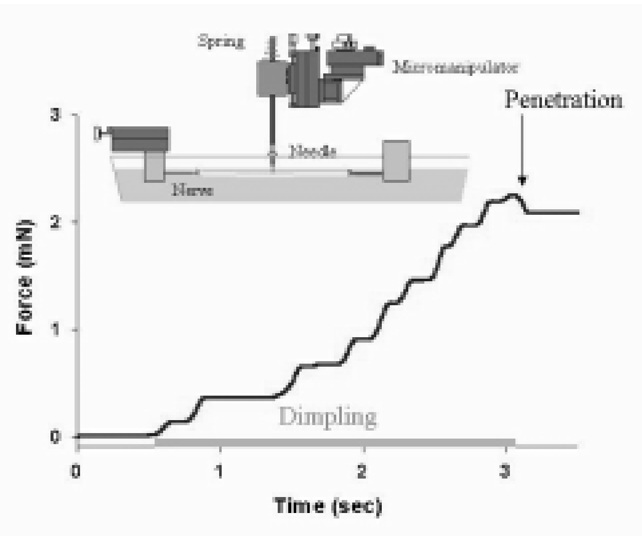

Figure 2: The force applied to a tungsten needle at contact and insertion plotted as a function of time. Insert: The experimental set-up. Peripheral nervous tissue is placed in a 0.9% saline solution. The custom build force measurement device consisted of a linear displacement transducer and a ferrite core.

The test structure is advanced into the nerve normal to the surface of the nerve. The force applied to the structure was measured and a typical result is plotted in Figure 2. Dimpling started to occur at the point of contact between the nerve and the tungsten needle. As shown, the force and the dimpling increased as the tungsten needle was advanced. At the point where the needle penetrated the epineurium the force had exceed 2 mN. Furthermore, at this point the dimpling resolved and the force decreased. Similar experiments were performed with 25-40µm wide and thick silicon probes and found that they can withstand several mNs of axial loading during penetration.

DISCUSSION

Ongoing work on the VSAMUEL microelectrode probes make use of these characterisations to determine and optimise the parameters necessary to ensure the proper functioning and integrety of the electrode and, in future, to design a battery of tests to ensure quality of probes meant for dissemenation. These preliminary results show that the active site impedance of the first run VSAMUEL probes are consistent with those of single site needle electrodes that are capable of making electrophysiological recordings. They, moreover, show that the sites are extremely consistent and the yield of good sites relatively high. Preliminary results from the mechanical characterisation indicate that the electrodes are structurally strong enough to penetrate central nervous tissue, but are not strong enough to penetrate peripheral nerve without pre-scribing of the perineurium. They may also indicate that the tip geometry and overall probe size need to be modified to allow implantation into peripheral nerve.

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LITERATURE

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