30th Annual International IEEE EMBS Conference
Vancouver, British Columbia, Canada, August 20-24, 2008

Cortical Recording with Polypyrrole Microwire Electrodes

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Abstract—**The ability to record from the same neuron for extended periods of time is essential to understanding how the brain reorganizes during learning. Conventional chronic recording microelectrodes are made from metal or silicon. However, the large stiffness mismatch between the electrodes and brain tissue causes shear-induced inflammation, limiting long-term recording stability. The flexibility of polypyrrole microwire has the potential to improve the chronic recording stability by minimizing the stiffness mismatch. In this paper, we report the implantation of a conducting polymer microwire electrode in a rodent brain, and the successful recording of cortical activity using such an electrode.**

I. Introduction

Learning motor movements, such as adapting to novel forces, requires considerable practice and occurs over time. In order to understand systems-level learning mechanisms, it is necessary to characterize the activities of individual neurons and the interactions across populations of neurons during the learning period. A chronic cortical recording technique, which can track activities of multiple and identifiable single neurons over time, is essential to investigation of motor learning [1].

Common chronic cortical electrodes are made from metal microwires [2],[3] or are micromachined from a silicon substrate [4]-[7]. In general, once these rigid electrodes are lowered into the cortex, their structural support is either anchored to the skull or tethered to a connector by a thin and flexible cable. However, the brain is allowed to move relative to the skull by the subarachnoid space. The Young's modulus of silicon is approximately five orders of magnitude greater than that of brain tissue. Therefore, when the brain moves, this large mismatch in stiffness causes relative movement between the implant and the brain tissue, resulting in shear-induced inflammation at the implant site. This inflammation leads to the formation of a glial scar, limiting the long-term stability of recording [8],[9].

Conducting polymers are novel materials which have electrical properties similar to metals but mechanical, chemical, and manufacturing properties similar to conventional polymers [10]. With the addition of dopants to the polymer by oxidation or reduction of the conjugated π-molecular orbital backbone, conducting polymers can be highly conductive [11]. These polymers have been used in biomedical applications including biosensors [12],[13] and late cell growth substrates [14] because they display excellent biocompatibility, and can easily be doped with bioactive molecules [11]. In neural probe applications, conducting polymers have been used to improve recording quality and the electrode-cell interface. For example, polypyrrole (PPy) combined with biomolecules having cell adhesion functionality has been deposited onto recording sites of silicon neural probes. The resulting rough surface morphology lowered the impedance of the electrode site by increasing effective surface area, and the biomolecules improved cell attachment on the sites [15].

In this paper, rather than merely coating a metal or silicon electrode, we attempted to record cortical activities with a microwire made entirely of PPy. Since the Young's modulus of PPy is approximately two orders of magnitude less than that of silicon or the metals typically used for neural recordings [16], we expect to see reduced inflammation due to micro-motion between the PPy electrode and the brain tissue. The scope of this paper is to demonstrate that it is possible to record cortical activities from a rodent brain with a conducting polymer microwire electrode.

II. Materials and Methods

A. Fabrication of PPy microwires

Polypyrrole was produced by electrodeposition as in [17]. A propylene carbonate solution containing 0.05 M tetraethylammonium hexafluorophosphate, 0.05 M pyrrole, and 1% (V/V) distilled water was prepared with vigorous stirring and purged with nitrogen. Electropolymerization was carried out galvanostatically in a two-electrode cell at -40° C. The cell uses a glassy carbon anode and a copper foil cathode; polypyrrole is produced on the glassy carbon electrode. The resulting film was opaque black and had a thickness of 20 micrometers. Polypyrrole microwires were prepared by mounting a PPy film perpendicular to the stage of a cryo-microtome, and slicing it in 20 micrometer sections. Fig. 1 (A) shows a single PPy microwire. This microwire was then insulated with a vapor-deposited layer of Parylene 2-3 micrometers thick. In order to maintain an

Manuscript received April 7th, 2008. This work was supported by the McGovern Institute for Brain Research under Grant 1631067.

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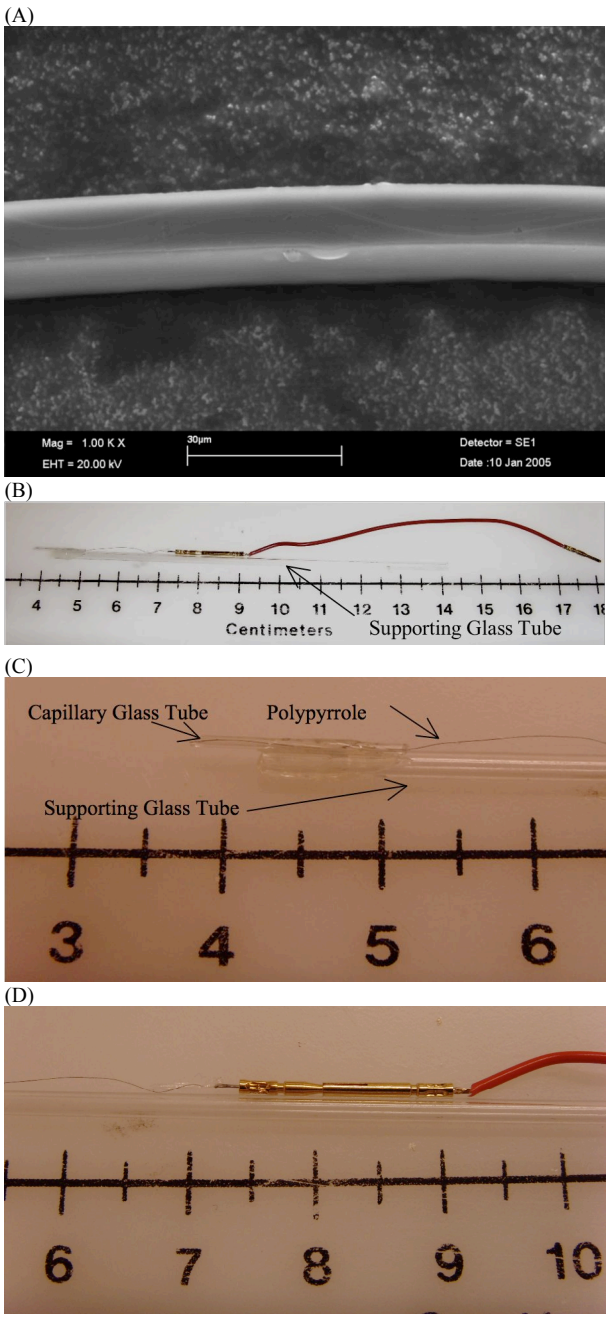

Fig. 1. (A) (Adapted from [17]) A length of 20 µm x 20 µm PPy wire prior to parylene coating. (B) A single PPy microwire electrode. (C) The microwire is inserted into a glass guide tube. (D) The PPy microwire is crimped to a 30 gauge hypodermic tube and crimped again to a male-type pin. A copper wire with female-pin end connects to an amplifier. Scales for (B)-(D) are 1 cm.

exposed length of polymer for an electrical contact later, approximately 10 mm of wire was placed between two glass cover slips and shielded from the Parylene deposition.

B. *Fabrication of PPy Electrodes*

The wire fabrication process provides a wire with 40 mm insulated and 10 mm uninsulated segments. The uninsulated portion was inserted into a 10 mm length, 30 gauge hypodermic tube[1]. Crushing the tube with pliers provided a metal-polymer conductive interface. This hypodermic tube was then clamped into a male type miniature pin[2].

Fig. 1 (B) shows a single microwire electrode connected to a copper wire. Closer views of the recording end and the connector end of the electrode are shown in (C) and (D), respectively. The electrode pin is mounted on a 2 mm diameter, 100 mm length glass tube[3] as shown in (B) and (D). This tube provides a long and rigid support to be held by a stereotaxic vertical manipulator. A 0.8 mm diameter capillary glass tube[4] of 15 mm length was attached to the near end of thick glass guide tube by epoxy as shown in (C). This capillary glass tube provided a rigid support to deliver the flexible polymer microwire into the cortex. The microwire was inserted into this thin glass tube until approximately 1 mm of polymer protruded beyond the tip of the tube. The electrode pin was then attached to a thick glass guide tube with tape (not shown). Cutting the protruded polymer at approximately 0.5 mm from its tip exposed a conductive recording site.

C. *Impedance Measurement*

The impedances of five electrodes were measured with HP 4194A Impedance/Gain-Phase Analyzer. Approximately 20 mm of polymer wire was immersed in physiological saline. The working electrode was the polymer microwire, and the counter electrode was a silver coated copper wire. AC voltage of 20 mV peak-to-peak was applied with a frequency sweep from 100 Hz to 1MHz.

D. *Surgery and Recording*

Surgery procedures were approved by the Massachusetts Institute of Technology Committee on Animal Care. A 430-gram Sprague-Dawley rat was anesthetized with Xylazine-Ketamine. The animal was laid supine and secured in a stereotaxic device. A craniotomy (5 mm in radius) was made 1 mm lateral of bregma in the left hemisphere. An electrode manipulator held the supporting glass guide tube and lowered the electrode into the cortex. The electrode was lowered approximately 2 mm below the surface of cortex. The signals were amplified and bandpass-filtered (300 Hz – 10 kHz) a CyberAmp 380[5]. The sampling rate was 20 kHz, and a faradaic shield enclosed the animal to minimize electrical noise.

[1] Small Parts, Inc.
[2] Card Edge Connector from WPI
[3] Single Barrel Standard from WPI
[4] Drummond Scientific Company
[5] Axon Instrument

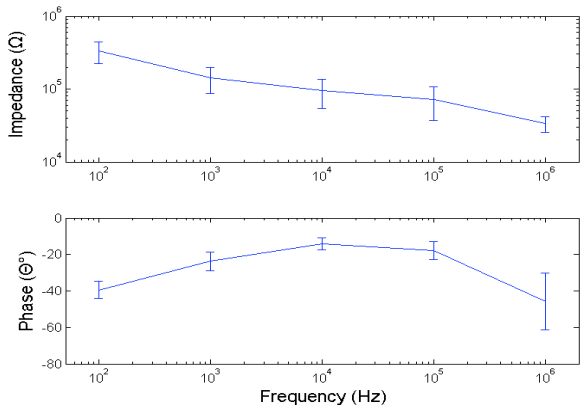

Fig. 2. Impedance data of polypyrrole electrode. (n = 5)

III. Results

A. Impedance

Fig. 2 shows the mean (+/- std) impedance of five polymer electrodes. The magnitude decreases with increasing frequency. The phase is less than 45 degrees upto 100 kHz. At 1 kHz, impedance is 142 ± 55 kΩ with a phase of -24 ± 5.25 degrees. Compared to a metal electrode, for which the phase is closer to -90 degrees, the interface of polypyrrole electrode shows a more resistive nature. Considering the cross sectional area of 400 μm^2, the impedance magnitude is in accordance with previous work with PPy-coated electrodes [18].

B. Cortical Recording

Action potentials were recorded in the left hemisphere (1 mm lateral to bregma, 2 mm deep) for 1 hour and 30 minutes. Fig. 3 (A) shows sample raw recording data for 20 seconds. The RMS noise is approximately 20 µV whereas the average spike is 140 µV peak-to-peak. The spikes of (A) were identified and overlaid within a time window of 1.6 ms in (B). The time windows and repetitive waveforms confirm that the signals were indeed action potentials from a neuron.

IV. Conclusions

A polypyrrole microwire electrode was implanted in a rodent brain to record cortical neural activities. The impedance analysis indicated that the recording site interface had a resistive nature. The polymer electrode recordings had good SNR with clear neuronal activity.

V. Future Research

The success of cortical recording with PPy microwires motivates further development of chronic multielectrode arrays. Future research directions will include functionalization of the recording site with biomolecules, coating the electrode with stiff biodegradable polymers, and designing a substrate for multiple electrodes.

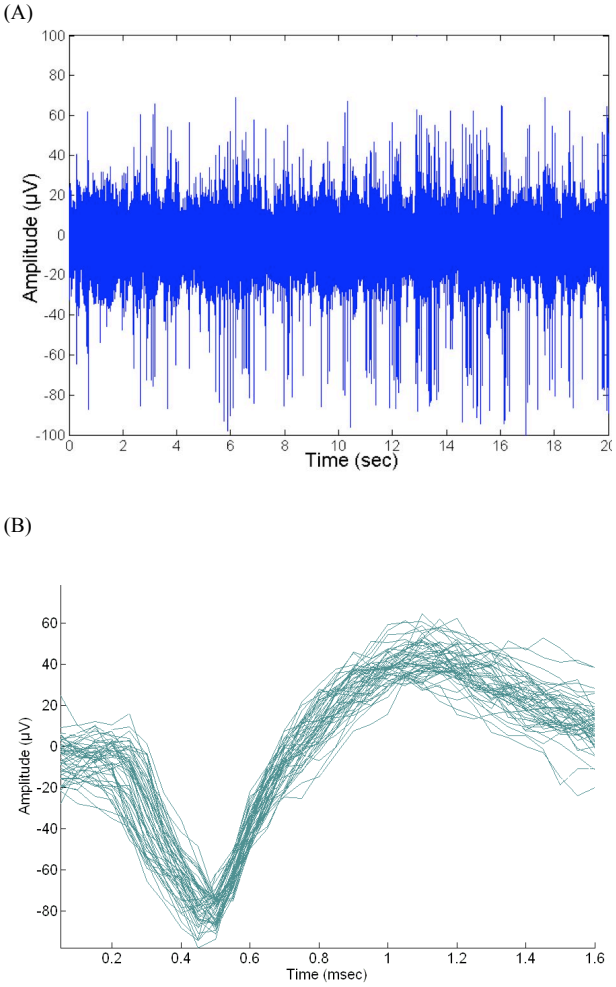

Fig. 3. (A) Raw data of single cell activities for 20 seconds (B) Overlaid Spikes from (A)

Acknowledgments

We would like to thank Margo Cantor for her assistance with surgery and Tommaso Borghi for helpful discussions.

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