

The Development and Testing of a Multi-Depth Microwire Electrode Array

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We describe a method by which a single shaft multi-microwire electrode can be easily and efficiently fabricated. The constructed electrode can then be used for multi-depth neuronal unit recording from one or more tracks in deep brain structures of anesthetized or awake animals. The electrode consists of multiple strands of 50 μm Teflon insulated tungsten microwires threaded through a 25 gauge stainless steel cannula. The individual microwires are then cut to specified offsets, depending on which layers the researcher is interested in. In this case the three wires present are cut to 1 mm, 600 μm , and 250 μm from the tip of the distal end of the cannula. These distances correspond to the II, III, and V layer of the rat sensorimotor cortex. At the base of the electrode, the wires are soldered to individual pins of a miniature connector that plugs into preamplifier that is part of a TDT (Tucker-Davis Technologies) modular signal processing system. Although in vivo data has yet to be attained and analyzed for this type of an electrode, EIS (Electrochemical Impedance Spectroscopy) analysis has shown that the electrode design is well suited for brain tissue recordings.

Introduction

The development of multi-depth neural recording electrodes allows researchers to simultaneously record from multiple layers of brain tissue. Regions of the brain responsible for a specific task are organized into columns of pyramidal neuronal cells that perform similar tasks within the same column.¹ Constructing an electrode that is capable of recording from these multiple layers will be advantageous in studying functional interactions among the pyramidal neurons within each layer as well as their interaction between layers.² Cross-correlograms can be constructed to depict the relationship between neighboring neuronal cells.³ The construction of the multi-depth electrodes will provide better means for understanding the relationship between the different layers of the brain. In a similar fashion to cross-correlograms, analysis of data obtained from the multi-layer recordings can be used to map these relationships. With current technology the construction of sophisticated thin film multi-electrodes is possible. They have been used in many research paradigms.⁴⁻⁶ However, the techniques for the development of these integrated circuit electrodes are complicated and the tools that are necessary may not be available to all laboratories. A simpler method for the manufacture of such multi-depth microwire electrodes using simple mechanical tools readily available is explored here. Although other methods for building microwire electrodes are presented in other literature papers, most focus on multi-site microwire arrays and not the multi-depth aspect as in the proposed design.^{7,8}

The procedure described here is one for the construction of a three microwire electrode array. (Figure) The 50 micron microwires are arranged in a triangular pattern supported on all sides by a steel cannula. Each tungsten Teflon coated microwire is cut to a specific length to target the particular brain layer of interest to the researcher. The microwires are soldered to an electrode connector base. The whole assembly is then secured to-

gether with epoxy or other available forms of adhesive glue. Tools and materials for the construction of this type of electrode are readily available for those interested. The simple techniques described can be used to create a multi-depth electrode. Although this electrode design is yet to be tested in vivo, extensive EIS analysis suggests the validity of the capabilities of this particular electrode design as a recording electrode for the electrophysiological activity of neural tissue.

Methods

The electrodes were constructed in several phases. In the first phase the base or connector of the electrode array is prepared to accept the microwires. Then, the microwires are attached to the pins of the electrode connector. During the second phase, the wires are inserted into a cannula and cut to desired lengths. In the last phase the connector, cannula, and microwires are fused together to complete the electrode.

The first step of the microwire electrode construction is preparation of the connector. The desired 6×2 base is cut from a similar larger 25×2 connector base (2.00 mm PitchMilli-GridTM Receptacle from Molex Inc.) Electrode pins are pulled out with needle-nose pliers to allow room for wire cutters. From the now smaller base the extra electrode pins are also removed (Figure 2(a)) to allow more room for the microwires and to decrease the interference they would cause during recordings. The extra pins are then soldered backwards onto the inserted pins in the base. The pins are soldered open end towards the outside of the electrode base to create the pocket into which the microwire can be placed to stabilize them on the pins of the base. (Figure 2(b)) Enough solder is then placed into the electrode pocket pins to ensure electrode wire attachment. The ends of four 100 μm (0.002 " bare, 0.004 " coated) tungsten Teflon coated wires (A-M Systems Inc.) are then flamed with a lighter to burn off

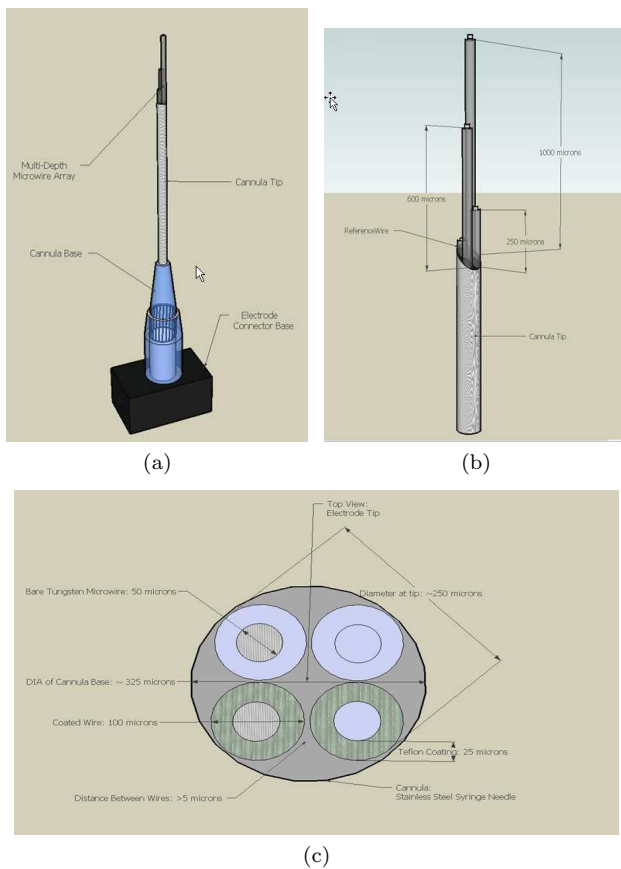


FIG. 1: Depicted is the proposed 3 microwire electrode array depicted in its entirety. Figure includes zoomed in view of the electrode tip to show variations of microwire lengths. Also included is the top view of the electrode tip to show the various diameters of each component of the microwire array. Insertion diameter is determined by the diameter of the longest microwire and ranges from that diameter to summed diameter of all wires to be inserted into the tissue. a) depicts the overall design of the electrode. Total dimensions are $\sim 4 \times 8\text{mm}$, height: 4.5 cm . b) Close up view of the electrode tip. The specified lengths of each microwire depicted surrounded by a cannula (syringe needle). c) Top view of the electrode tip depicting overall diameter of electrode and its various components. All drawings done in GoogleSketchUp.

the insulating Teflon coating, allowing solder to adhere to the wire during attachment (Figure 2(c)). The microwires are then soldered to the pins on the electrode connector (Figure 2(d)).

The second step in electrode construction is manipulation of the microwires themselves. With a pair of tweezers each microwire is fed through the tip of a 25 G 5/8 syringe needle (PrecisionGlide[®], B-D & Co.) (Figure 3) The use of a cannula is necessary to prevent the sprawl of the microwires at the tip of the electrode. The goal is to keep the microwire tips as close as possible to each other. This allows recording of the same column of neuronal cells at relatively same points throughout the dif-

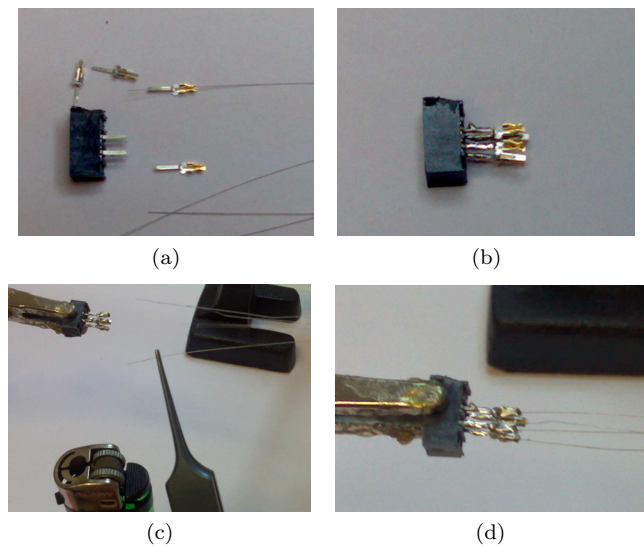


FIG. 2: In this figure the first phase of the electrode making process is depicted. a) The removal of the electrode pins from the already cut electrode connector base. b) Backwards soldered electrode pins on the inserted ones in the base of the electrode. The pins are soldered face out to create a pocket for electrode wire. c) Flaming of the microwire tips to burn off the Teflon insulation. This step is necessary for soldering of the microwire. d) Array of microwires soldered onto the pins of the electrode base.

ferent layers under study. The cannula also makes the wires sturdier during insertion since microwires of this diameter tend to bend very easily. Each microwire is then cut with a pair of scissors to the specified length. The length of each microwire was chosen according to the desired depth of the motor cortex layers under study. In this case cortical layers II/III the 'integrating' layers, and layer V the 'output' layers, were chosen.¹ The depth of the microwires for the appropriate layers are $250\ \mu\text{m}$, $600\ \mu\text{m}$, and $1200\ \mu\text{m}$ for layers II, III, and V respectively.² To measure out the lengths of the microwires a piece of graph paper with a $0.5\ \text{mm}$ grid was used, a microruler will be used in the future to ensure better accuracy.

In the final step of electrode construction the base, needle, and microwires are glued together to complete the electrode design. Cold cure dental acrylic (CO-ORAL-ITE Dental Mfg. Co.) also known as methyl methacrylate was used to secure the three elements of the constructed electrode together. After mixing the two part acrylic in a small tin, it was poured into an ordinary 3 ml syringe (B-D & Co.) for easier manipulation. (Figure 4(a)) The entire electrode setup was secured vertically with alligator grips. (Figure 4(b)) The dental acrylic was injected into the hollow plastic base of the syringe needle. The electrode base was then slowly manipulated into the thickened acrylic to its final position. (Figure 4(c)) The two prototype electrodes are shown in the last figure. (Figure 4(d))

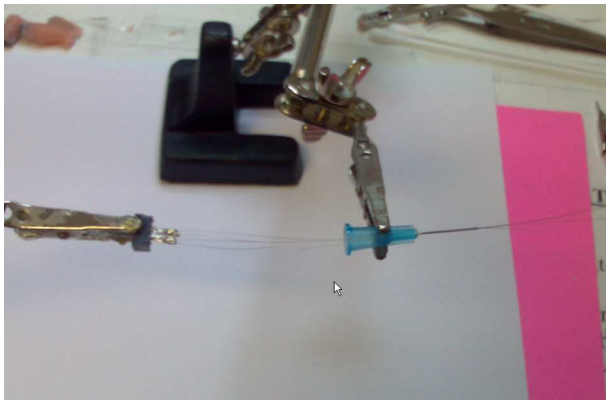


FIG. 3: After soldering the microwires of the array are inserted into a cannula, in this case a 25 gage syringe needle. The cannula prevents the microwire tips from easily bending under pressure from insertion. Also it prevents separation of microwires at the tip.

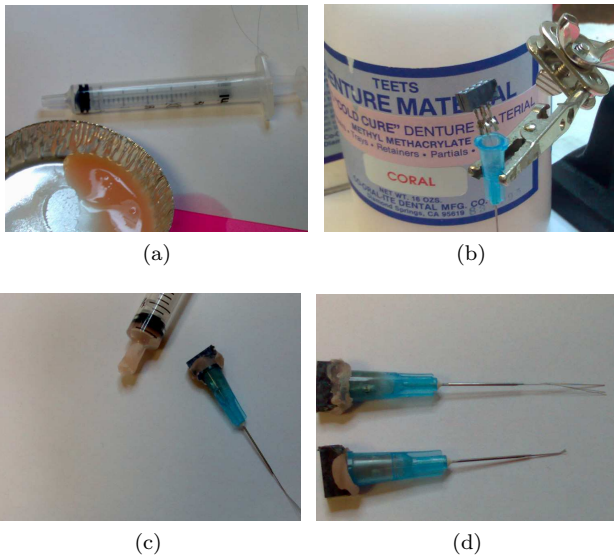
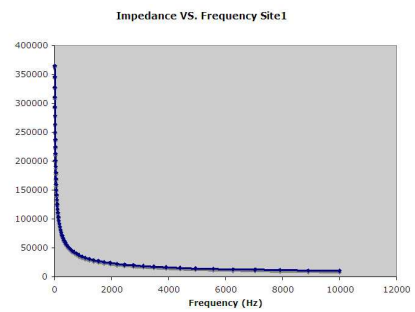


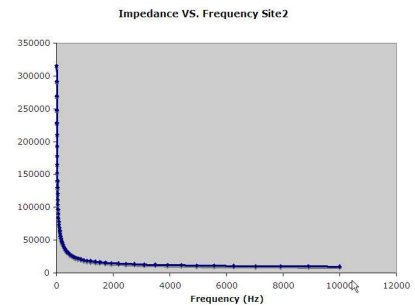
FIG. 4: The final stage of electrode construction is securing all its separate parts together with acrylic. a) After mixing the acrylic it is poured into a syringe to make it easier to inject into base of syringe needle. b) Manipulators with alligator grips are used to make it easier to keep wires straight. c) Using syringe the acrylic is poured into the base of the needle and the electrode connector is lowered into the acrylic for a secure seal. d) First completed electrodes.

Experimental Results

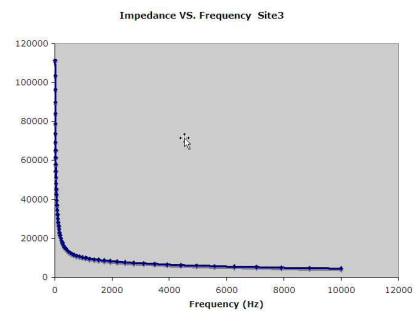
Although no in vivo studies have yet to be performed with this electrode design, extensive EIS (Electrochemical impedance spectroscopy) analysis has been done. In the future electrophysiological signals from the rat sensory motor cortex will be available for further study and analysis. EIS was done on each microwire in the elec-



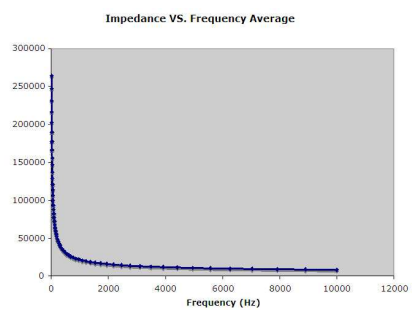
(a)



(b)



(c)



(d)

FIG. 5: Impedance vs. Frequency graphs acquired from EIS analysis of each microwire of the prototype electrode presented in this paper. a) A three trial average curve for the Imp vs. Freq. of wire 1 (Site 1). b) A three trial average curve for the Imp vs. Freq. of wire 2 (Site 2). c) A three trial average curve for the Imp vs. Freq. of wire 3 (Site 3) d) Three averages for Site 1, Site 2, and Site 3, compared to one another in one plot.

trode array. Site 1, Site 2, Site 3, and an average of all three sites referred to in Figures 5(a),5(b),5(c), and 5(d)

respectively, correspond to the three microwires in the array. EIS analysis was also done on the overall electrode Figure 6.

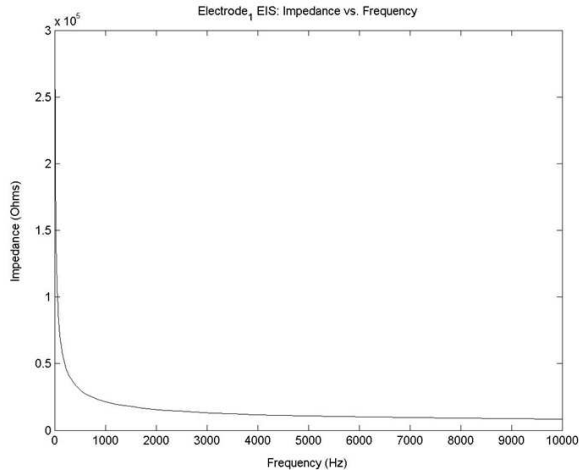


FIG. 6: Impedance vs. Frequency graphs acquired from EIS analysis of the overall prototype electrode design presented in this paper. Shows the same trend as the individual Impedance vs. Frequency graphs of individual components of the electrode and their average.

Discussion

The EIS analysis tests the electrode's electrical resistance, the resistance to current flow through the wires of the electrode. If one has constructed an electrode that is to be used as a recording electrode, one would want the impedance of that electrode to be as low as possible. If however, the electrode is to be used as a stimulating electrode its impedance would need to be high. As one can see in all the figures from EIS analysis, the impedance drops off fairly quickly as frequency of the signal goes up. Because the electrode discussed in this paper will be used as a recording electrode we want the impedance of each of the microwires and of the entire electrode to be

as low as possible at all frequencies. The sudden drop off of the impedance Figure 5 and Figure 6 is a good indication that the proposed electrode will be a good recording electrode. One would be able to attain very nice action potential signals from it upon implantation into the rat brain. At the same time, the electrode must have a high enough impedance to attenuate some of the noises that are present in the body as well as the surroundings. Because most biological noises and signals are of low frequencies this is a difficult task that can only be solved with the use of sophisticated filtering software and is not dependant on electrode design.

Conclusions

This paper presented a method for the construction of a multi-depth microwire electrode array. The electrode's intended use is one for implantation in live behaving animals so that electrophysiological analysis can be done of a specified area of the animal's brain. Not only will multiple layers of the brain can be sampled with this type of electrode, but if several electrodes are made a 3-D map of the electrical activity of neural tissue can be attained. Because the procedure for making this electrode is simple and uses mechanical tools readily available, they can be manufactured quickly and inexpensively. The advantages such construction is that one can collect more data in less time then with other more complicated multi-depth electrodes. More data means a better understanding of what is really happening inside the brain and the different layers within it.

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