MECHANICAL ASSEMBLY OF A MICROELECTRODE ARRAY FOR USE IN A WIRELESS INTRACORTICAL RECORDING DEVICE

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Abstract - **Fabrication of a microelectrode array assembly for neural activity recording is described. The assembly forms the mechanical front-end of the Telemetric Electrode Array System (TEAS), a wireless intracortical recording device designed for motor cortex studies in nonhuman primates. The electrodes are manufactured by wire Electrical Discharge Machining (wire EDM) solid titanium. They are then secured in a polyimide substrate. A flexible Printed Circuit Board (flex-PCB) connector cable connects the array structure to the electrical front-end. Parylene and platinum are used as the encapsulation materials. Results from the implantation of a prototype microelectrode array assembly are discussed.**

Keywords - **Microelectrode array, neural implant, intracortical recording, electrical discharge machining (EDM), brain-machine interface**

I. INTRODUCTION

Alongside recent advancements in neurophysiology, and neuroscience in general, the prospects of the brain-machine interface have also advanced. The first humans to benefit from such an interface will likely be the neurologically impaired. The control of a computer cursor, the restoration of vision, or the control over a limb could soon be possible with the development of neural implants. At their core, these implants will have microelectrode array assemblies that are inserted into specific locations of the brain, depending on the application. The assemblies will provide the framework for the spatially separated recordings of action potentials.

Recent advances and experiments have already proven the feasibility of such devices. For example, experiments at Duke University have demonstrated that, using intracortical recording, it is possible to predict a monkey's intended movements a few tenths of a second before the movements actually occur [1]. Similar studies at Brown University have shown that the direct recording of motor cortex neural signals, in conjunction with simple mathematical filtering, can provide effective decoding for brain-machine interfacing without extensive subject training [2]. These experiments consisted of *Macaca mulatto* monkeys tracking continuously moving visual targets that followed pseudo-random trajectories [3].

The Brown experiments were set up in such a way that, with the flip of a switch, the cursor on a screen could be controlled either by hand using a joystick, or more directly by interpreting signals recorded from the motor cortex. It was demonstrated that with the signals from seven to thirty electrodes, targets could be tracked on a screen with only minor differences between the hand- controlled and brain-controlled cases.

These recordings are accomplished using microelectrode array assemblies, such as those developed at the University of Utah [4, 5]. Although several different assembly approaches have been developed [6, 7], the Utah single-component approach is very appealing due to its simplicity and modularity. Though these aspects of the Utah array approach were captured in the device described below, very different materials and manufacturing techniques were employed.

II. THE TELEMETRIC ELECTRODE ARRAY SYSTEM

The assembly described here forms the mechanical front-end of the Telemetric Electrode Array System (TEAS), a wireless, completely implanted intracortical recording device [8]. Designed for motor cortex studies in *Macaca mulatto* monkeys, TEAS amplifies and digitizes action potentials and uses peak detection to extract the information-carrying features of these microvolt signals [9].

The aim of the TEAS project is to eliminate the need to use percutaneous connectors and cables. In addition to reducing the probability of infection by removing the connector site, freedom of movement is gained by the removal of the tethers required during recording. For a human subject, this would represent an incredible quality of life improvement. Additionally, signal integrity is improved by the elimination of noise and of artifacts caused by the movement of the connector cable. Because the digitizing of the signal occurs in the body, there will be less signal attenuation, and the signal-to-noise ratio will be superior to the tethered case.

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The TEAS project takes a brain-machine interface approach, and it places inside the body only the functionality absolutely necessary to record and transfer the desired signal timings and waveforms. By allowing the device to be reprogrammable and modular, software and functionality can be upgraded easily and without additional surgery or further risk to the subject. Much of the required computation is done outside of the body, where power and heating requirements are far less restrictive.

The TEAS project incorporates off-the-shelf components whenever possible in order to decrease development time and complexity. A Bluetooth-based radio link is used to transfer the information in real time, and recharging of lithium polymer batteries through skin allows the system to be completely implanted.

III. DESIGN AND FABRICATION

A. Microelectrode Fabrication

The region of interest for the intended intracortical recordings is at a depth of one millimeter below the surface of the brain. The requirements of the mechanical array are to provide connectivity at an array of positions in the brain, spread over some chosen spacing. A path must be made for the recorded signals to reach the front-end electronics with as little signal degradation possible. Also, the recording sites must be structurally supported and held at the same spacing.

The microelectrode arrays are manufactured by wire Electrical Discharge Machining (wire EDM) solid titanium (99.6+%), stainless steal, or titanium-aluminum-vanadium alloy (Ti90/Al6/V4). Solid titanium was used for the first prototype. The forceless EDM process allows one to obtain aspect ratios, surface features, and surface finishes suitable for assembly and insertion into brain matter. For the first complete assembly, an eight by eight electrode array size was chosen. It must be noted, however, that the design and machining of the electrodes is done entirely by Computer Aided Design (CAD) and Computer Numerically Controlled (CNC) machining that can be quickly and accurately altered to suit the needs of a particular application.

The individual electrodes are one millimeter in length when assembled through the substrate, 80 microns in width, and are spaced about 500 microns apart. The tips are slightly rounded, and the electrode cross-sections are square. The electrodes are initially machined to a length of 1.7 millimeters, with ridges part way along the electrodes that serve as platforms for securing a polyimide substrate. Fig. 1 shows a bulk microelectrode array that was wire EDMed from a single 9.5-millimeter-diameter titanium rod.

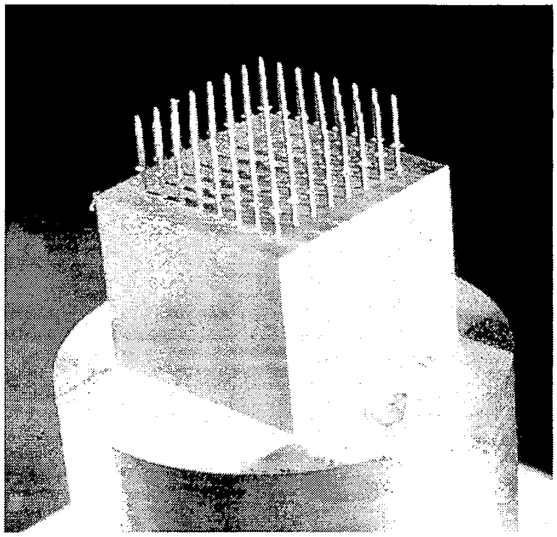

Fig. 1. A microelectrode array still connected to its base. The array shown here was Electrical Discharge Machined (EDM) from a 9.5-mm-diameter, titanium cylinder. The electrodes are 1.7 mm in length. The ridges on the electrodes are about one millimeter from the tips.

After machining, the bulk array is put in a heated hydrochloric acid (HCl, 37% approx.) bath in order to remove the oxide layer, and then immediately electroplated with an acid gold strike that protects the array from further oxidation, aids in the soldering, and provides good adhesion for the encapsulation steps.

B. Substrate Fabrication

A polyimide substrate is used to isolate the microelectrodes from one another and to provide a foundation for the array assembly. Kapton HN 500 is used as the substrate material. The substrate is about 8.5 millimeters by six millimeters and follows the contour of the tip of the connector cable. 100-micron-diameter holes are machined through the polyimide substrate at the bulk microelectrode array spacing using a rapid prototyping system that incorporates a 60,000-RPM spindle. Again, this is a CAD process that can be easily altered to meet the needs of a particular application. Laser machining could alternatively be used for creating the substrate, but milling was found to give adequate results.

During assembly, the polyimide substrate is placed over the bulk metal array, with the microelectrodes passing through the holes. The ridges, machined partway up the electrodes, and as seen in Fig. 1, hold the substrate in position while it is secured.

C. Connector Cable Fabrication

The electronics will for the most part be secured to the skull, beneath the skin. A connector is used to link these front-end electronics to the mechanical array structure. Because the brain will move a distance of up to two millimeters with respect to the monkey's skull, it is important to provide some strain relief in the connector cable.

The connector cable is manufactured from flexible Printed Circuit Board (flex-PCB). The cable is ten millimeters in width and about fifty millimeters in length. An 80-pin Molex connector is used to attach the front-end electronics to the connector cable. Gold-plated pads are used for soldering the connector to the flex-PCB at the electronics end, and through-holes are used for aligning and soldering the electrode array structure at the other end.

Sixty-four parallel 50.8-micron-wide (0.002 inches) copper traces, spaced 152.4 microns (0.006 inches) apart, run the length of the connector cable. 50.8-micron-wide laser cuts, about thirty millimeters in length and centered between adjacent pairs of traces, allow for independent movement of the traces. These cuts greatly increase the overall flexibility of the connector cable and help to provide the strain relief necessary due to brain movement in the skull.

As with the previous two fabrication processes, the design of the flex-PCB was accomplished using a CAD process. The connector cable specifications can be altered with minimal difficulty.

IV. ASSEMBLY AND ENCAPSULATION

The mechanical assembly process involves a number of steps. The process is shown in Fig. 2. The insulating polyimide substrate, with holes at the appropriate spacing, is placed over the electrode tips and epoxied in place. It serves as the foundation of the array assembly. Because the electrodes are machined from a single piece of metal, they are initially connected to a solid metal electrode base. After the polyimide substrate is secured, the base is removed by wire EDM. The substrate is designed with a lip, or wing, that rests on the surface of the brain, keeping the recording sites at the correct depth. Additionally, it provides a surface that can be used in the handling and assembly of the structure.

After the array has been removed from the bulk metal, it is placed in a specially designed jig, electrode tips down. The connector cable, is then placed over the electrode substrate, with the back ends of the electrodes protruding slightly through the through-holes in the flex-PCB. The electrodes are individually connected by soldering the back ends of the electrodes to the pads that surround the through-holes. Future alternatives for this soldering step encorporate wire-bonding or flip-chip technologies, or perhaps electroplating the connection using gold. The solder joints are covered with a thin layer of epoxy for protection purposes.

The entire structure is coated with a 15-micron layer of Parylene C, which provides electrical insulation along the electrodes and biocompatible protection for the entire array assembly. Laser ablation is used to remove parylene from the electrode tips, which are then coated with platinum in order to achieve the desired electrical transfer. The aim is for the recording sites to have impedance values on the order of 100 kO at one kHz. For the initial array assembly, a range of tip exposures from 25 microns to 90 microns was attempted in order to experiment with different electrode impedance values:

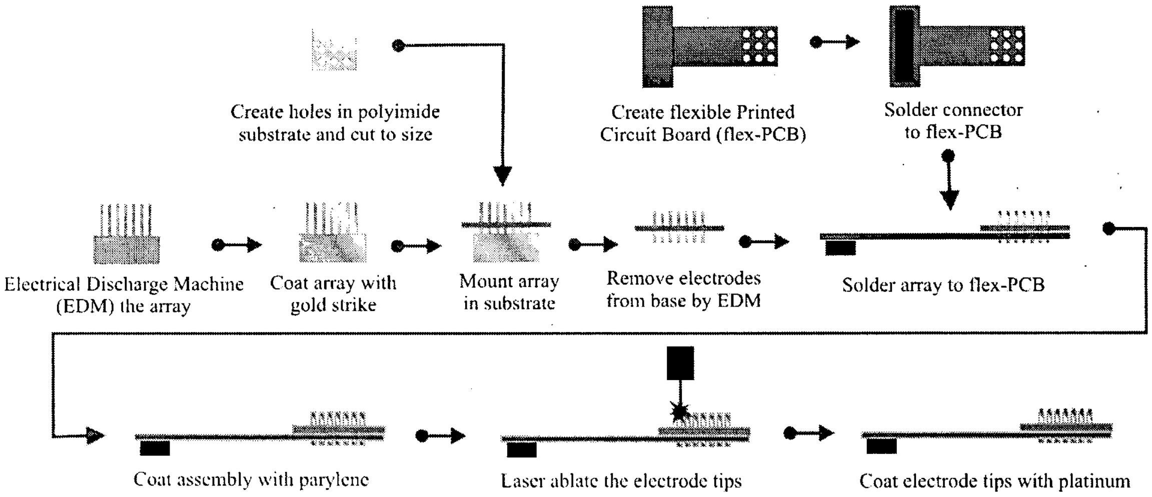

Fig. 2. The mechanical assembly process.

V. RESULTS

The microelectrode array assembly was initially tested in a wired configuration in a *Macaca mulatto* monkey. A completed microelectrode assembly, without the electronic front end, is shown in Fig. 3. For the preliminary tests, a cable was attached to the Molex connector in place of the electronic front-end. The tethered prototype assembly was implanted in a monkey for 31 days. The array assembly was surgically implanted into the brain by placing the array structure at the desired location on the brain surface and inserting it with a pneumatically created impulse.

Upon removal and inspection, the 80-micron-wide, solid titanium electrodes were found to provide adequate mechanical integrity for implantation. All of the electrodes were found to be intact, and the overall structure was unchanged. The parylene coating also exhibited no signs of wear, weakening, or pealing as a result of the implantation.

The 15-micron layer of deposited parylene was determined to be thicker than required. This contributed to two problems: the stiffness of the flex-PCB connector cable was too great, and the laser ablation process gave poor results. The flexibility and plasticity of the connector cable can be increased by removing more polyimide when making the laser cuts and by depositing less parylene onto the cable. The laser ablation process was problematic and will likely be replaced with an alternative method, such as plasma etching, which is not a line-of-sight process.

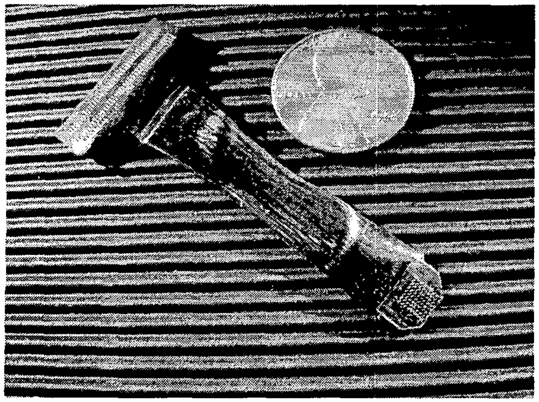

Fig. 3. A completed microelectrode array assembly without the electronics. Laser cuts in the flex-PCB separate the copper traces and allow for greater overall flexibility.

VI. CONCLUSION

An overview of the fabrication process for a microelectrode array assembly for neural activity recording has been provided. The construction materials consisted of titanium, polyimide, gold, platinum, and parylene. Wire EDM, laser ablation, and other more conventional machining techniques were employed in a multiple-step contruction process.

The assembly forms the mechanical front-end of the TEAS, a wireless intracortical recording device designed for motor cortex studies in nonhuman primates. The TEAS project aims to use readily available components and computer-controlled manufacturing techniques as much as possible, in an attempt to reduce development, revision, and fabrication time. While the individual elements are all designed and machined using a CAD approach and CNC machines, the assembly process currently requires some manual steps. These manual steps will be simplified or eliminated as the process matures. The TEAS project represents a significant step in the growing field of brain-machine interface devices.

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