**Carbon Fiber Neural Recording Array**

**BME 401 Preliminary Report**

October 4, 2019

Group 12

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**Background**

Neural recording has for over half a century been one of the most powerful tools in a neuroscientist’s toolbox. By allowing researchers to record and stimulate nervous tissue, neural recording has fostered understanding of neuronal function, connectivity, and disease. However, as neuroscience knowledge grows, so do the technological requirements of these recording systems. Researchers require the development of neural recording devices capable of simultaneously recording a large number of neurons, as well as recording chronically1. Such devices would provide large, high-dimensional datasets that lend themselves to a growing number of analysis techniques that elucidate the neural mechanisms that modulate cognition, movement, and behavior.

One of the most important components in neural recording systems are the electrodes that interface with the nervous tissue, record its surrounding extracellular potential, and transfer it to a headstage for initial processing. Traditionally, these electrodes have consisted of fine probes/wires made of stainless-steel, tungsten, silicon, nichrome, or platinum/iridium, which have diameters at or above 30µm2. Major scientific advancements have been made through the use of these type of electrodes, and they continue to be widely used. However, the electrode’s performance and lifespan are limited by the interaction of their materials with the surrounding tissue. During initial insertion, the electrodes causes cell damage and microvascular ruptures at the insertion site. Due to this initial injury, a glial scarring response develops overtime, and encapsulates the electrode3; functionally increasing its impedance and decreasing signal quality.

Carbon fiber is an attractive alternative to previous microwire. The tip of carbon fiber has a diameter of approximately 5µm – a much smaller diameter than the 33µm nichrome wire previously used2. The smaller diameter allows it to sit *in vivo* without causing massive interference with the surrounding tissue, thus preventing an adverse response. Without detrimental responses such as glial scarring, carbon fiber electrodes offer substantially longer lifetimes. One particular researcher seeking applications of carbon fiber microelectrode arrays for multi-neuron chronic recording is Dr. Keith Hengen.

**Need Statement and Project Scope**

The Hengen Lab's single-neuron chronic recording capabilities are currently limited by the low biostability of their nichrome microelectrodes, and they seek the development of a more biostable carbon fiber neural recording array that will enable long term (over 1 year) *in vivo* neural recordings.

The Hengen Lab studies the active self-organization of neural networks and a neural network's stability despite changing surroundings. The Hengen lab currently utilizes nichrome microelectrode arrays to achieve long-term recording of individual neurons. These nichrome electrodes cause microtraumas in the surrounding tissue that lead to an encapsulation response that limits the recording time span to a few months. To achieve his desired long-term recording capabilities, Dr. Hengen requires a new neural recording array that utilizes biostable carbon fiber electrodes. Dr. Hengen requires that this new carbon fiber neural recording array be compatible with the modular, stackable HS-640 e-cube head stage system he currently uses, so that up to 512 channels can be inserted into the same animal. Additionally, Dr. Hengen requires that the end-product be able to be manufactured by a single individual in a lab setting in 1 day (< 8 hours). Completion of this project will include both a fully functioning carbon fiber neural recording array with up to 512 fully functioning carbon fiber recording electrodes as well as any custom tools/jigs that may be necessary in the manufacturing or construction of the arrays.

**Design Requirements**

Dr. Hengen requires a fully functioning carbon fiber neural recording array with at least 512 carbon fiber recording channels that can be manufactured in less than 1 day and can record neural activity for over 1 year without loss of function.

The cost of developing the recording array and all necessary fabrication jigs and other equipment must be under $10,000. Dr. Hengen can fund a larger investigation if necessary, to produce the neural recording array for his use, but he recommends that a scalable and repeatable solution would cost under $10,000 so it can be utilized by other researchers in the field.

The current PCB (designed by a BME 401 group last year) used for the neural recording array has 64 available channels and can be stacked 8 times under a single head stage for a total of 512 implanted electrodes. The final carbon fiber neural recording array cannot have less than 512 channels and each individual PCB cannot have less than 64 channels, but the number of channels per PCB can be adjusted. For example, 4 stackable PCBs with 128 channels could be designed so the total number of channels remains at 512. Any new PCB than may need to be designed must remain compatible with their current stackable HS-640 e-cube head stage system.

The fully functioning carbon fiber neural recording array must be able to be constructed in 1 day (approximately 8 hours). For the current design with 8 stackable PCBs, this means that each PCB with 64 carbon fiber recording electrodes must be constructed in approximately 1 hour. Production of the carbon fiber electrodes may require certain treatments that may take some time but will be hands off, reducing the number of man-hours dedicated to fabrication. These waiting times will not be included in the 1-day construction time, but a complete construction with all treatments should take less than a week.

Size and mass specifications for the end product are the same as the metrics for the current PCBs Dr. Hengen’s lab uses. Each PCB has a mass of approximately 5 g, a length of 13 mm, a width of 5 mm, and a height of 9.4 mm. These metrics must remain the same or smaller so that the total mass (all 8 PCBs) on top of a mouse’s head is no more than 40 grams. Furthermore, the mouse must be able to roam freely and uninhibited by the recording array.

Lastly, the entire carbon fiber recording array must be able function properly for 1 year or longer. To accomplish this, the product must be robust, durable, and biologically stable. Actions of the mouse such as rapid head shaking and hitting the enclosure must not disturb electrode connections. Furthermore, biological responses to the carbon fiber electrodes such as glial scarring or another biological immune response must be limited. The carbon fiber electrodes are inherently biocompatible, so this specification addresses any coatings potentially placed on the carbon electrodes. All of the design specifications laid out above are summarized in Table 1.

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| --- | --- |
| **Specification** | **Metric** |
| Cost of Development | < $10,000 |
| Number of Available Recording Channels | 64 channels per PCB, 512 for 8 stacked PCBs |
| Channel Functionality | 64/64 channels function properly per PCB |
| # of PCBs that can be stacked | 8 PCBs with one headstage (512 channels total) |
| Headstage compatibility | Any redesigned PCB must remain compatible with the current stackable HS-640 e-cube headstage system |
| Time to manufacture 1 functional PCB (64 channels) | < 1 hr |
| Mass per 1 PCB | < 5g |
| Length per 1 PCB | < 13mm |
| Width per 1 PCB | < 5mm |
| Height per 1 PCB | < 9.4mm |
| Electrode Biological Response | No glial scarring around carbon electrodes |
| Electrode Functional Time Course | Electrodes must be able to record properly for longer than 1 year |

**Table 1:** Product specifications with exact metrics. Specifications have been designed to fit Dr. Hengen’s requests. Metrics are estimated based on metrics for the PCB currently in use.

**Existing Solutions**

Because carbon fibers promise to advance the field of neural recording, multiple laboratories have attempted to implement a high density of carbon fibers. The most recognized problem is addressing the difficulty in handling the carbon fibers. One solution is to design a grid-like system that will funnel the fibers into alignment, as proposed by the Maharbiz lab at UC Berkeley4. The paper suggests that a deep reactive ion etching process can properly design a grid that has through holes. The final product successfully lines up the carbon fibers in the desired pattern to make their connection to the array much easier. This concept of a grid system that can control the fibers is highly attractive because of its ability to optimize connection of a high number of fibers as opposed to a one-by-one process. Unfortunately, this process is expensive and time consuming.

Another potential solution is coating the carbon fibers in a biologically inert material. The Chestek lab at the University of Michigan uses a poly(ethylene glycol) (PEG) coating to provide some rigidity to the carbon fiber5. PEG is a water-soluble polymer that is easy to use, very common in lab settings, and is biocompatible. Additionally, a PEG coating increases the diameter of individual carbon fibers so that they may be more easily handled. This would expedite the process of connecting the carbon fibers to the PCB, potentially decreasing fabrication time. The most attractive feature of the PEG is that it can be removed once electrical connection has been made simply by soaking the carbon fiber electrodes (and PCB) in water for an extended period of time. The array can then be placed in an oven to ensure dryness. The reversibility of the PEG coating is what makes it such an attractive solution to handling the carbon fibers.

Another solution is changing the design of the PCB to address array fabrication difficulties. The Chestek lab uses a larger PCB, thereby increasing the spacing between the electrode vias and allowing the carbon fibers to be placed in and soldered much more easily. Additionally, this prevents swaying and consequently tangling of the fibers once connected. While this may seem simple, it prevents connection of a high number of fibers and ultimately reduces the fiber count to 166.

Much of the literature regarding carbon fiber implantation uses a single carbon fiber electrode7. This circumvents the challenges posed in scaling up the number of implantable electrodes. Thus, very few solutions have been posed to properly connect and implant a high-density of carbon fibers.

**Preliminary Design Schedule**

The design schedule has been adapted from a provided Gantt chart. Each task has been assigned so that each team member has a comparable workload. Additionally, all time periods have been estimated as of October 4, 2019, but are subject to change as the project progresses. The Gantt chart is shown in figure 1.

A screenshot of a cell phone

Description automatically generated**Luis Ruiz David Jones Brennan Kandalaft**

**Figure 1:** Gantt chart illustrating the estimated work distribution for Group 12 in BME 401 Senior Design. Brennan Kandalaft is labelled in blue; Luis Ruiz is labelled in yellow; David Jones is labelled in green. Estimated work times are subject to change as the project develops.

**Team Organization and Responsibilities**

The team is dividing up tasks according to historical precedence. Each team member has been responsible with their assigned task in previous projects. This encouraged the organization shown in Table 2.

**Table 2**: Team Responsibilities for Group 12 in BME 401 Senior Design Course. Responsibilities have been assigned according to experience and preference.

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| --- | --- | --- |
| **Category** | **Task** | **Team Member** |
| Administrative,  Note-keeping, Presentations | Scheduling | Brennan |
| Communicating with Dr. Hengen | David |
| Notebook Updating | Luis |
| Weekly Reports | Brennan |
| Prelim Report and Presentation | Brennan |
| Progress Report and Presentation | David |
| V & V Report and Presentation | Luis |
| R&D | General Research | Luis |
| Materials Research and Testing | Brennan |
| PCB Modifications | David |
| 3D Modeling | Luis |
| Manufacturing | Reaching out to Suppliers | David |

**Citations**

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3. Salatino, Joseph W., et al. “Glial Responses to Implanted Electrodes in the Brain.” *Nature News*, Nature Publishing Group, 10 Nov. 2017, [www.nature.com/articles/s41551-017-0154-1](http://www.nature.com/articles/s41551-017-0154-1).
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