Aug 24, 2023

Design and Fabrication of CFET Arrays

DOI
dx.doi.org/10.17504/protocols.io.yxmvm3kpol3p/v1

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DOI: **https://dx.doi.org/10.17504/protocols.io.yxmvm3kpol3p/v1**

Protocol Citation: Helen N Schwerdt 2023. Design and Fabrication of CFET Arrays. **protocols.io** **https://dx.doi.org/10.17504/protocols.io.yxmvm3kpol3p/v1**

Protocol status: Working
We use this protocol and it's working

Created: July 12, 2023

Last Modified: May 31, 2024

Protocol Integer ID: 84912

Keywords: ASAPCRN, fabrication of cfet array, fabrication of carbon fiber, cfet array, carbon fiber, cfet, electrode threat

Funders Acknowledgements:
NIH NINDS R00
Grant ID: R00 NS107639
BBRF NARSAD Young Investigator Grant
Grant ID: 28690
Michael J. Fox Foundation for Parkinson's Research (MJFF) and the Aligning Science Across Parkinson's (ASAP) initiative
Grant ID: ASAP-020-519

Abstract

The fabrication of carbon fiber electrode threat (CFET) arrays is described here.

Troubleshooting

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1 We fabricated CFET arrays of up to 16 patterned CFETs (overall bundle diameter of 40 µm) connected to a flexible printed circuit board (PCB) (flex-PCB) for interfacing with external FSCV recording instrumentation. CFETs and flex-PCBs were constructed separately. Fabrication of the CFETs involved the following steps:

2 Slotted aluminum fixtures were machined to tether bare CFs for subsequent parylene-C encapsulation. Double-sided polyimide tape was placed on both sides of the slot (25 – 35 mm) on the fixture that would be used to anchor the Cu wires and CF tips on either end.

3 10 – 20 Cu (40 µm diameter, annealed) wires (CU005200, Goodfellow Corp.) were cut to lengths of 10 – 15 mm each and were attached on one side of the slot, spaced 5 – 10 mm from each other on the pre-attached double-sided polyimide tape.

4 Single 7-µm diameter CFs (C 005722, 34-700, Goodfellow Corp.), cut to 15 – 30 mm in length, were attached to the free-hanging ends of the Cu wires using silver epoxy (H20S, Epo-Tek), and the CF tips were then attached to the opposite end of the fixture slot on the pre-placed polyimide tape to anchor the CF tips.

5 These long CFs are extremely flexible ($1/k=(4L^3)/((3\pi Er^4))$), where k is stiffness, E is the Young's modulus of the CF ~ 200 GPa, r is the radius, and L is the length) given the ultra-high aspect ratios (length to width ratio of > 2,000) applied here to reach deep subcortical brain targets. A CF will deflect and even attach to nearby surfaces due to air currents caused by its manual repositioning, movements in the room, and room ventilation, as well as electrostatic forces. The purpose of the fixture's slot was to keep the samples anchored, yet elevated and separated to insulate, conformally, the individual Cu-CF assemblies with parylene in subsequent vapor-deposition steps. Standard microscope slides were also used successfully as fixtures where the CF tips were left unanchored and remained elevated vertically above the slide. However, this required greater spacing between Cu-CF assemblies in order to prevent neighboring CFs from contacting and adhering to each other, which would ultimately limit the total number of Cu-CF assemblies that could be placed in the chamber for parylene deposition. Each sample-loaded fixture was placed in an oven to cure the silver epoxy at 80 – 90 °C for 2 – 3 hours.

6 The fixtures had similar dimensions to a standard microscope slide (1/16 inch thick) and were stacked in a standard microscope container tray (82024-606, VWR) that had been trimmed to fit in the parylene deposition chamber (PDS2010, Specialty Coating Systems). All Cu-CF assemblies were treated in an adhesion promoter solution consisting of 3-(Trimethoxysilyl)propyl methacrylate (Silane A174, 440159, Sigma-Aldrich), isopropyl alcohol, and distilled water at a volumetric ratio of 1:1000:1000.

7 Parylene was deposited onto the fixtures containing the Cu-CF assemblies to a thickness of 1.5 – 3 µm. Parylene-coated CFs (Py-CF) were flame etched using a butane torch to expose a discrete length of CF at the tip, following methods established in previous work (Guitchounts et al., 2013; Schwerdt et al., 2020, 2018, 2017a). The level of water relative to the base of the CF controlled the final lengths of the individual electrodes that would be inserted into the brain. The lengths of etched Py-CFs ranged from 5 – 22 mm to reach subcortical brain structures (e.g., striatum) in rats and to target emulated depths of the primate striatum (> 15 mm) in agar brain phantom experiments.

8 Etched Py-CF electrodes were then tested in vitro in saline to record the background current using FSCV and measure targeted functional metrics for sensitivity (i.e., maximum background current) and limits of detection (e.g., noise) to dopamine (Schwerdt et al., 2018). Targeted metrics were 500 – 800 nA for background current, and 90%), as only functional Py-CFs were selected to solder onto the ribbon cable.

9 Dissolvable maltose was coated onto the CFET array to stiffen the bundle to facilitate subsequent brain insertion. A custom-made temperature-controlled dip-coater was used to coat the electrodes reproducibly with maltose. Nichrome (80% Ni, 19.5% Cr, 1.45% Si) wire (20G, Master Wire Supply) was coiled around a hollow ceramic tube. A thermistor was attached to the base of the tube to monitor the temperature of maltose inserted inside the tube, and then the base was sealed to prevent maltose from leaking using thermally-conductive epoxy (832TC, MG Chemicals). A solid-state relay was used to provide DC current (up to 1A) to the heating wire. An Arduino was programmed to switch the current on and off based on comparing the temperature measured from the thermistor to the set-point (110 – 120 °C). Maltose powder (M5885-100G, Sigma-Aldrich) was placed into plastic falcon tube vials and then submitted for gamma-irradiation sterilization (25 kGy, VPT Radiation Lab and Test Services). The CFET array and coiled heater were sterilized using vaporized hydrogen peroxide (Sterrad). The array was lowered into the tube and then maltose powder was poured into the heating tube, and heated until molten. The temperature was lowered by 2 – 5 °C to increase the viscosity and after a few minutes the array was lifted at a rate of 250 µm/s. This procedure produced a relatively uniform thickness of 1 – 2 mm around the bundle, but success was highly dependent on the volume of maltose inside the tube due to the non-uniform temperature distribution across the coil. Alternatively, we also employed a manual coating method for the CFET array. We first melted maltose powder on a hot plate over which CFET array was placed and rapidly lifted to produce a relatively uniform coating of 1 – 3 mm diameter.