

# **The Making of Electrodes for Uwe Thomas/Eckhorn Multi-electrode Arrays, and Carbon Fiber Electrodes**

*by Harold Kyriazi*

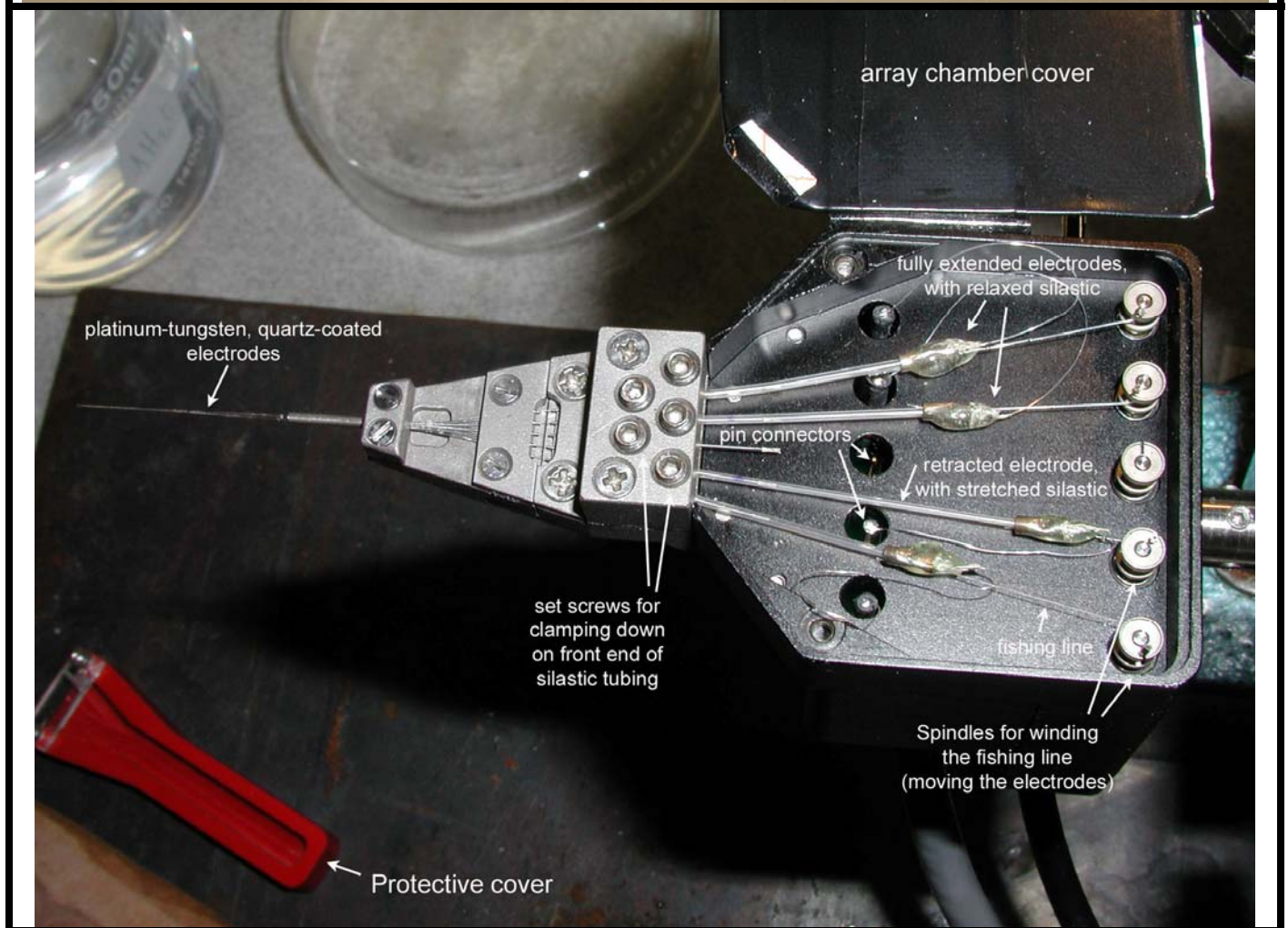
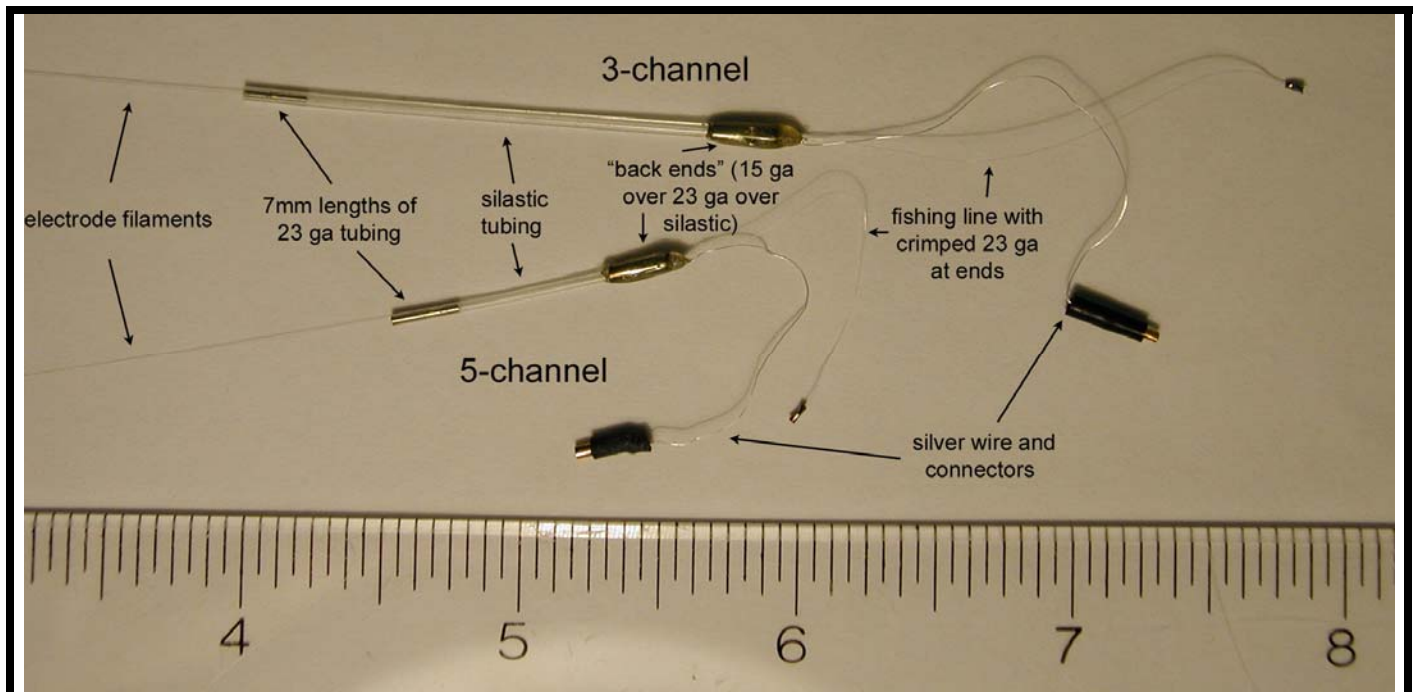
## **Preface**

This is a work in progress, and geared toward those working in the Simons' lab. It is meant to allow those who are already familiar with the Thomas/Eckhorn arrays to construct their own microelectrodes. It is more a collection of notes than a complete document.

# Table of Contents

Preface .....	1
Table of Contents .....	2
Figure 1. The electrode assemblies for Eckhorn arrays, and a 5-channel array. ....	3
List of Parts and Suppliers.....	4
For array electrodes .....	4
For individual electrodes .....	4
Making Parts.....	5
Steel tubing sections .....	5
Fishing line with crimped 23 ga tubing .....	5
Connecting wires .....	6
Wire connectors .....	6
Assembly .....	7
5-Channel.....	7
Figure 2A.....	7
Figure 2B.....	8
Figure 2C.....	9
Figure 2D.....	10
3-Channel.....	11
Individual Electrodes .....	12
Figure 3A.....	12
Figure 3B.....	13
Figure 4. ....	13
Carbon Fiber Electrodes.....	14
Materials:.....	14
Assembly:.....	14

**Figure 1. The electrode assemblies for Eckhorn arrays, and a 5-channel array.** The microelectrodes are made from filaments of platinum-tungsten in quartz glass. The various parts are described in subsequent pages.



## List of Parts and Suppliers

### For array electrodes

7 mm lengths of 23 gauge, stainless steel type 304W thin wall (TW) tubing, ([www.smallparts.com](http://www.smallparts.com), 0.025" O.D., 0.017" I.D., 0.004" wall), deburred using #11 scalpel blade tip, and reamed out using a constant-diameter, used electrode, and cleaned in ethanol (sonicated and then dried), to be used on both ends of the electrode assembly, inside the silastic tubing

1.5 mm lengths of above 23 ga SS TW tubing, for crimping onto "Rio Powerflex" 1.5-lb fishing line (0.003" diam., 2" lengths) (for 3-channel array, use "Stren Clear/Blue Fluorescent" 2-lb test line (0.006" diam., 3" lengths))

silastic tubing (for 5-channel: 1-inch lengths of 0.020" ID x 0.037" OD, Bio-Sil, from Sil-Med Corporation, Taunton, MA, part # 30200, 1-800-722-7106; for 3-channel: 1 $\frac{7}{8}$ -inch lengths of 0.025" ID x 0.047" OD, Dow Corning Corp., Midland MI, Cat. # 508-003, 517-496-6000)

6 mm lengths of 15 gauge SS type 304W TW tubing (0.072" O.D., 0.060" I.D., .006" wall), deburred, reamed, and cleaned in EtOH (for crimping/gluing onto back end, over the 23 ga and silastic)

wire connections: for 5-channel, 1.5" lengths of silver wire, teflon-coated (0.003" bare wire, 0.0045" total; A-M Systems, Inc. Cat # 7855), with ~2mm exposed wire on each end; for 3-channel, use ~2.5" lengths of stainless steel wire (0.003" bare wire, 0.0055" coated, A-M Systems, Cat # 7910)

contact pins (for connecting to Eckhorn); 5mm, cut down from female amphenol pins (FHC Catalog # 30-40-1) (use these for both 5- and 3-channel)

6 mm lengths of 1/16" heat-shrink tubing (these go over the pin connectors)

### For individual electrodes

2-2.5" lengths of 30 ga TW SS tubing, deburred, reamed and cleaned; 1.5-2" lengths of 0.75 mm (O.D.) capillary glass; 1-1.5" lengths of 1.5 mm glass (with capillary bead removed); amphenol pins (Newark Electronics, amphenol pins, part # 1-66507-0(N)-C). The 0.75 mm glass fits neatly inside the 1.5 mm glass.

## **Making Parts**

Most of these operations are performed under a dissecting microscope.

### **Steel tubing sections**

To get them the proper length, and to hold the short finished piece effectively, I grab a piece of the long tubing near the end, using the tip of some small, needle-nose pliers, with my fingers holding the long piece (2 foot sections should probably be cut down to 1 foot, to avoid bending of the tubing). (For this procedure, I usually watch through the large, round, lighted, magnifier, that's arm-mounted on the wooden work bench.) The cut is made using the Dremel's thin, cutting disk (Dremel "Cut-off Wheel No. 409"), first cutting, and then smoothing by holding perpendicular to wheel's flat end. This often leaves the end almost completely sealed. To open up the ends and deburr, insert a #11 scalpel blade (mounted on the end of a wooden stick, not the normal scalpel blade holder) and twirl repeatedly, until the opening is maximized. Then ream out the interiors by running in an electrode with a diameter just smaller than the tubing's interior (for this, hold the piece firmly in the needle-nose pliers). I use a special, constant-diameter shank electrode (with yellow insulation on the end) for this reaming. Finish the exteriors of the ends (all but the 1.5mm sections, which are too small to handle) by sanding with fine grit paper, carefully holding the tubing in one's fingers. You may have to re-ream, if any pieces of metal have bent back inside. Clean by placing the pieces in a glass petri dish bottom, adding a few mls of ethanol, and then sonicating for a few minutes (you can let the petri dish float on the surface), and drying (touch each section down on a paper towel, to draw the liquid, and any remaining metal particles, out by capillary action – don't just let them dry by evaporation).

It is somewhat important that these pieces are clean (aside from aesthetics), especially the 23 ga pieces, because the quartz fibers will run inside them, and we don't want the back end of the fiber getting caught on anything on the way in. For the 15 ga pieces, which anchor the back ends, it's important that they not have sharp edges, or shards of metal inside, since the silastic tubing goes inside, and we don't want to cut or weaken it, since it'll be greatly stretched at times.

### **Fishing line with crimped 23 ga tubing**

This is a very tricky operation, and I'm even thinking of dispensing with it, and just using epoxy to glue them on. For crimping, I first grab the 1.5 mm (1-2mm in practice) piece by putting an old electrode through its center, then positioning it in the tip of the small, needle-nose pliers, and then reaming it out with the "yellow" electrode. I then place the piece in the crimping tool end, centered in the middle, and thread the fishing line (1.5- or 2-lb test line, for the 5- or 3-channel, respectively) through. While watching carefully under the dissecting microscope, I position the end of the fishing line close to the end of the crimp tube, and begin squeezing the crimper, constantly moving the line back and forth slightly, to sense when it begins to be gripped by the crimp. Here's where exquisite judgement is required. You have to crimp it hard enough to hold a light pull, but not so hard that it cuts through the line (easily messed up – I lose probably 1/3 to 1/2 of them to one or the other error, which is why I may ditch the whole procedure). Because when these are placed on the array's motorized winding spools, there's really not much pull on the crimp itself, I'm thinking epoxy can probably hold, and we can dispense with the crimping.

If do use epoxy (with or without crimping), make sure you keep it exclusively on the back end. You don't want it running to the inner side, because you need a sharp edge there to hold onto the array motor's spindle. If it's rounded with epoxy, it'll tend to slide off.

## Connecting wires

After cutting them to the right length (I use tiny scissors), I strip their ends of the clear, teflon coating by using a number 11 scalpel blade, while the wires rests on a metal surface (one of the large, inch-thick metal blocks). For the silver wire especially, one must do this carefully, as the wire itself is very soft. (I try to score one side, and scrape the blade down toward the end, then flip the wire over to the other side, and repeat. Sometimes it comes right off, and other times one can try to cut the sides with the #11 blade tip.)

## Wire connectors

One end of the cut female amphenol pin is for going onto the (male) pins of the array. The surface on the other side is flat metal, which we're going to solder the connecting wire to. (The other side of this connecting wire is "silver printed" to the electrode's platinum-tungsten fiber.) To do this *en masse*, I tape a bunch of them to the side of the metal slab, so they're just peaking up over the top, and then I put a tiny blob of "Stay Clean Soldering Flux/Paste" on top, followed by a reasonable sized blob of solder. I then grab a wire and hold it close, using forceps, and remelt the solder, and put the wire smack into it, and let it solidify in place. Then gently straighten the wire, so it runs parallel with the pin, and insert the pin into one of the 6mm sections of heat-shrink tubing, grab the bottom of the pin (the end that will go onto the male pin) with forceps so just a mm or so of the pin shows under the heat-shrink tubing, and **carefully** place it horizontally in a stream of hot air blowing out of the variable-heat "paint stripping" gun, still holding it with forceps. If the heat hits the silver wire, it'll melt it. You just want it to touch the far end and middle of the heat-shrink tubing (i.e., away from the wire) until it shrinks sufficiently to hold the pin.

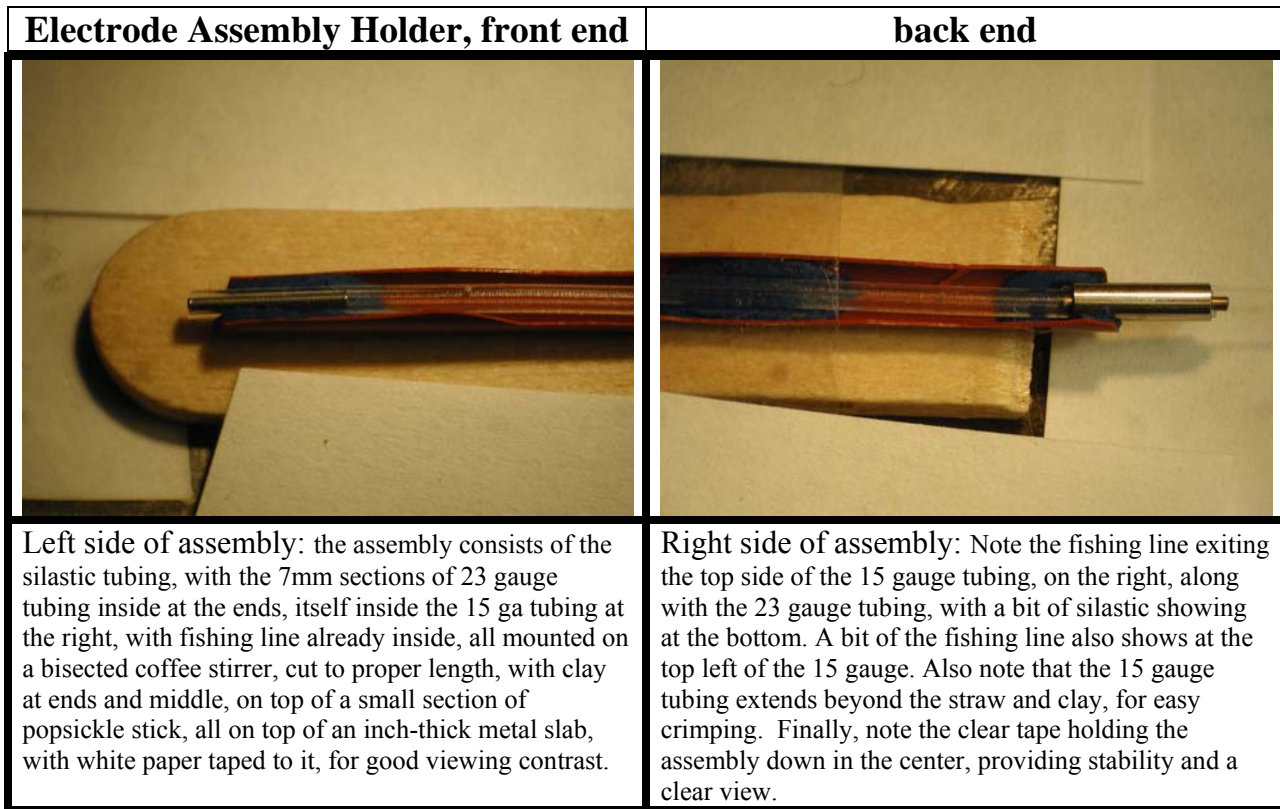
# Assembly

## 5-Channel

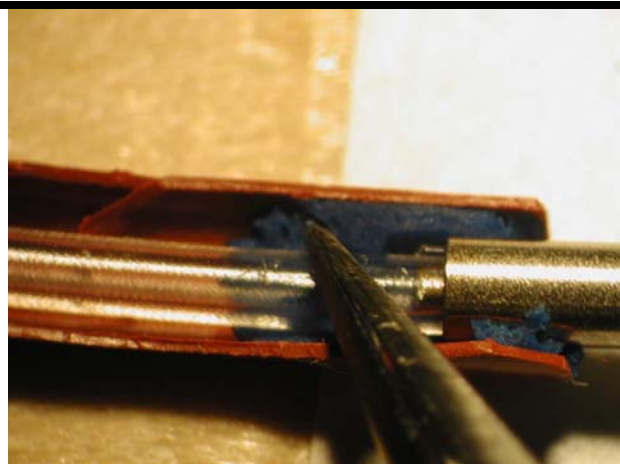
First of all, using a pair of forceps and your fingers, insert a 7mm section of 23 ga tubing at each end, leaving a mm or so of metal sticking out on one end, which will assist in making electrical contact at the back end, between the quartz fiber and the wire connector (via silver print). Be careful not to tear the silastic tubing (I've had some with small tears, though, that didn't subsequently break under tension), as we don't want to weaken it (it may be stretched up to 3 times its relaxed length in the array).

Secondly, it's more efficient to make two of these at the same time (because of the use of epoxy – mixing it up and drying time), so I have two inch-thick metal slabs, one for each.

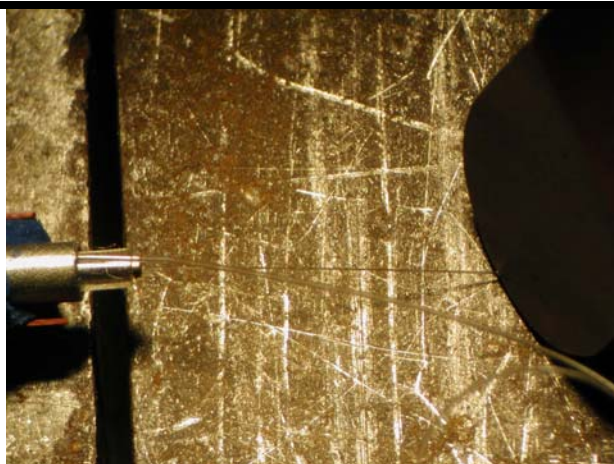
Figure 2A.



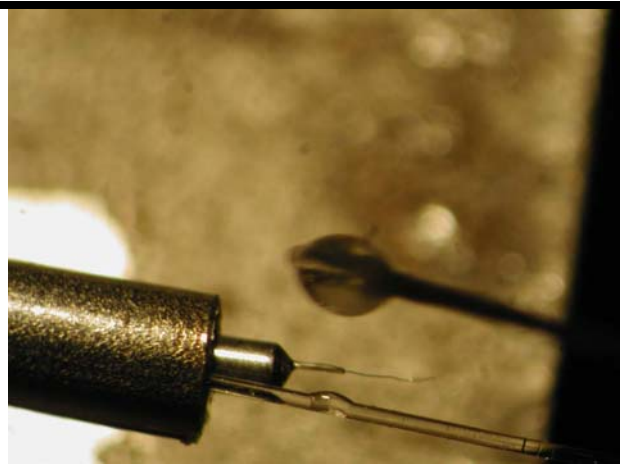
**Figure 2B.**



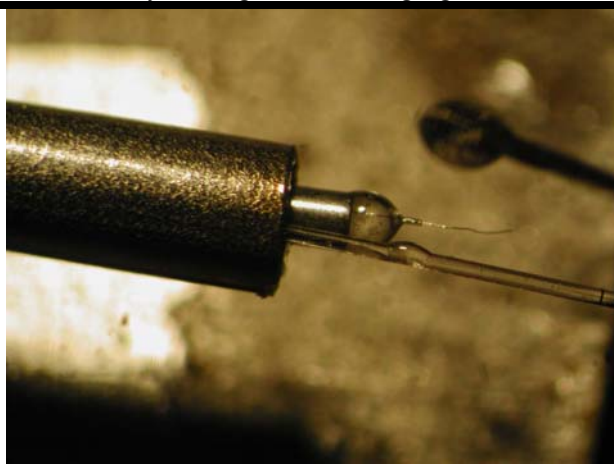
Clip off any metal sticking out of the quartz fiber, as this will likely cause it to get caught on something on the way in. Feed it in from the left side, with the beveled electrode tip at the left. As with everything else, watch it proceed through the silastic tubing under the scope. In the photo above, I'm helping the fiber to go through the section of 23 ga tubing at the right side, by pushing down on the silastic tubing with forceps, to get the fiber away from the wall, and into the center.



Once we get it through, continue pulling it further out the back end (but being careful not to pull so far that the electrode tip enters the assembly – we don't want the tip to get damaged). Position the small inch-thick block of metal under the end, and using the round (back) end of a pair of forceps, crush away 2-3 mm of quartz, exposing the platinum/tungsten wire. If you tilt the forceps slightly (off of 90°), then you'll avoid flattening/weakening the wire. Clean the wire with 100% EtOH using a "Q-tip," and push/pull it forward so that it's barely sticking out of the 23 gauge.



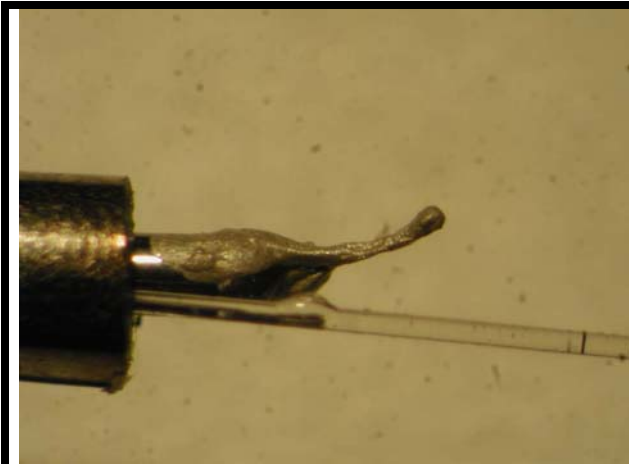
Now you're ready to introduce some epoxy into the 7mm section of 23 ga tubing at the back end, around the quartz fiber, to hold it in place securely throughout its operation in the array. Shown above is the back end, with quartz and wire sticking out, along with the fishing line (clear plastic). Just above these you can see the same, yellow tipped electrode I use for reaming, which I also use for fine application of epoxy. You must apply it just where the glass meets tube, and studiously avoid getting any on the wire (which might insulate it, and possibly break it as well, as it's very easily bent and snapped off). Keep adding until capillary action won't take any more.



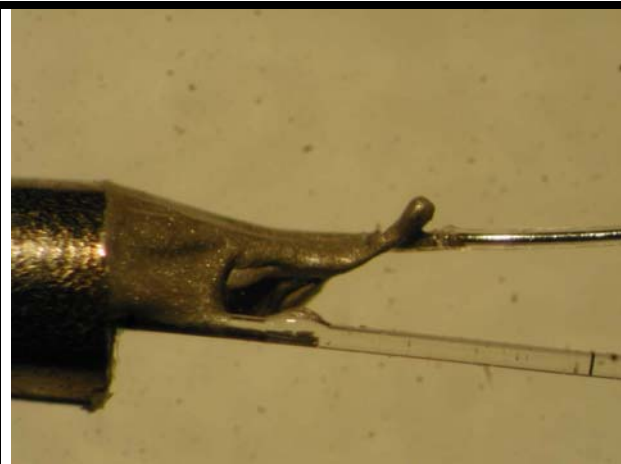
This is what it looks like when the 23 ga tubing will take no more epoxy. (The fishing line is not stuck to the 23 ga tubing, though it appears that it may be. The line can be carefully moved out of the way, for the next step, of adding silver print.)



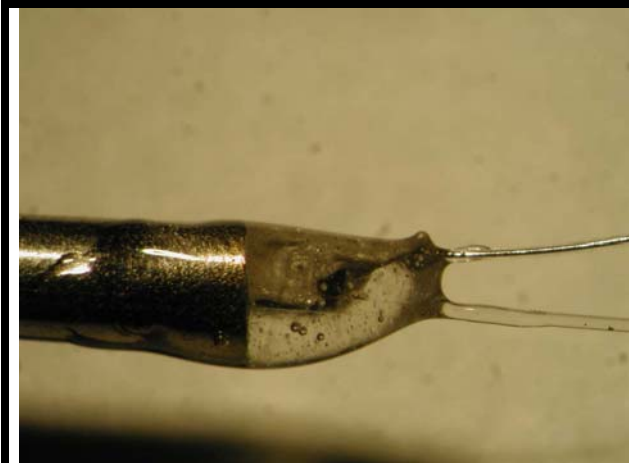
**Figure 2C.**



**Stabilize the filament.** Next, a thin layer of silver print is carefully added to the 23 ga tubing, quartz glass, and especially the tiny platinum/tungsten filament, which adds strength and stiffness to it, aside from forming a much bigger area with which to make electrical contact with the connecting wire. It's a good idea to always pull away from the filament when applying the paint, as it's pretty viscous, and any sideward tug can break off the filament, at which point you're screwed, since it's glued in place. Add a couple more layers, letting each dry for at least 3-5 minutes (we don't want to trap vehicle inside, as the vehicle is not electrically conductive).



**Connect electrode to wire.** Once the filament is dry, you're ready to use the silver print to "glue" the connecting wire in place. I try to bend it so that it rests in position, so I don't have to try to hold it with forceps while it's drying. But, it gets thick pretty quickly, so if there's not too much strain, it'll stay in place. As before, do this "painting" in thin coats, to allow all vehicle to evaporate. (I regularly thin my silver print with butyl acetate, the vehicle [spectral grade, from Eastman Kodak]). NOTE: I only developed this procedure when I began making the 3-channel electrodes. The 5-channel ones had the wire connector coming from the front side, inside the 15 ga tube, and then bent back. We may have to continue making them this way, as there may not be enough room to come out the back side. (The 3-channel array is much longer, affording much more room.)

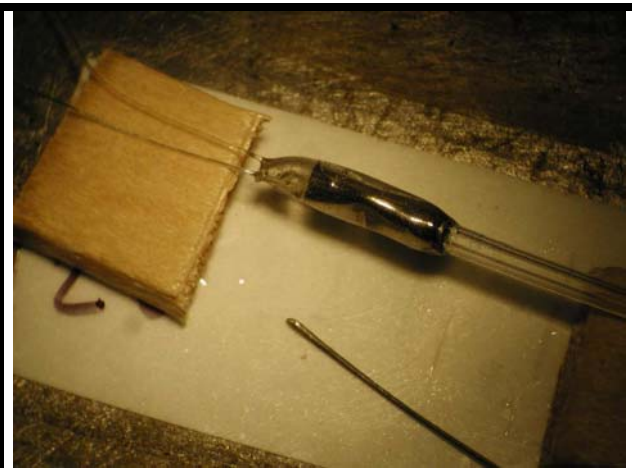


**Stabilize back end** At this point, we're ready to glue up the back end. Make sure the fishing line is positioned properly (have the free end just barely peek out of the other side of the 15 ga tubing). Add generous dollops of epoxy to the back end (though I try not to have it get onto the outside of the 15 ga at this point, unlike the present photo), and let it run inside via capillary action. When it's dry, we'll be ready to crimp.



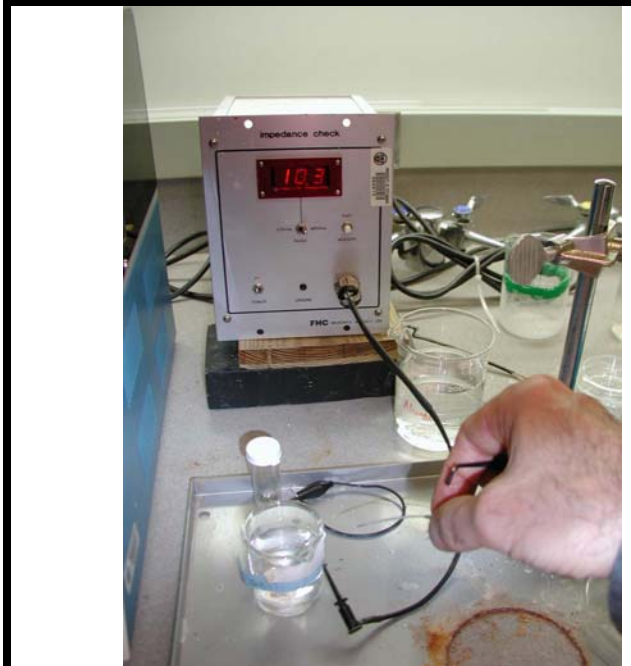
**Crimping** I'm not sure this is necessary, as the epoxy might be good enough. In any case, to crimp (which squeezes the 15 ga tight up against the silastic tubing and fishing line), use the crimping tool (yellow handles), which in the above photo is the hulk at the right. They have a bit of play in the jaws, which makes care required, as poor centering will cause the tubing to twist up to 90 deg., breaking the electrode. This step is one of the reasons for having the assembly sitting on top of the wooden stick. Rest the crimper on the metal slab for stability, of course, and crimp only hard enough to get the 15 ga to collapse, and no harder, to avoid breakage.

Figure 2D.



**Crimp result** Here's what it looks like after the crimp. Often – usually, actually – this causes some dislodging of the epoxy at the back end. No mind. We'll re-glue it in the next step. After this, carefully dislodge the electrode from the clay (loosen the front first, then middle, then the backend shown here). Any severe bending, especially near the back end, will break the filament. You can lift the whole thing from the back end, using your fingers, being careful to pull it straight up, or upward and backward, so as not to damage the tip.

**Epoxy coating of entire back end** At this point, set up some small sections of wooden stick, an ~1 inch piece for the front end, and a much smaller piece (shown) for the back. These are simply to keep the back end off the ground, so we can “paint” it with epoxy. This will add strength, as well as electrical insulation. Shown in the lower end of the photo is the “applicator” electrode we've seen repeatedly in previous steps. This step usually requires two, or even three steps, to get full coverage. (It sometimes pulls back from the metal edges on the first coat, and it's hard to get the bottom with the first coat. I try to twirl it around, though, to get it all at once.)



Once it's thoroughly dry, I measure its impedance by clipping onto the (tightly braced!) electrode lead, and dipping the tip into the saline solution. Rinse the tip thoroughly in an alconox solution beforehand, to remove any oil from the tip, which would act as an insulator. Impedances ranging from 2-10 MOhm are good, with the lower end being better in thalamus, and the higher end being good in layer 4 of cortex.



Record the characteristics of the electrode, and place it in a paper holder as shown above, into a specially prepared slide box, for later loading into the array. Label the paper with the electrode's fiber length, tip shape and dimensions, and impedance. Leave room for notes on use.

### **3-Channel**

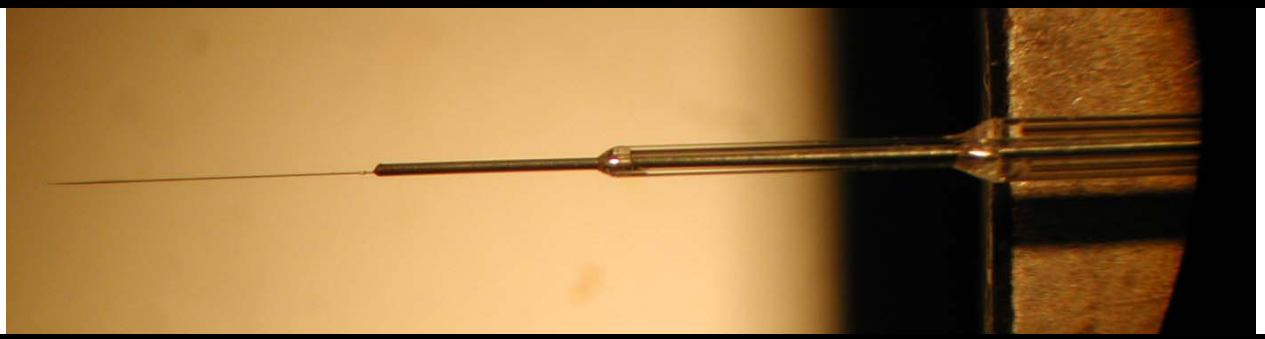
The operations for the 3-channel electrodes are essentially the same as for the 5-channel, but simply using parts that are often bigger and longer (i.e., the electrode filaments, silastic tubing, fishing line, and connection wire).

## Individual Electrodes

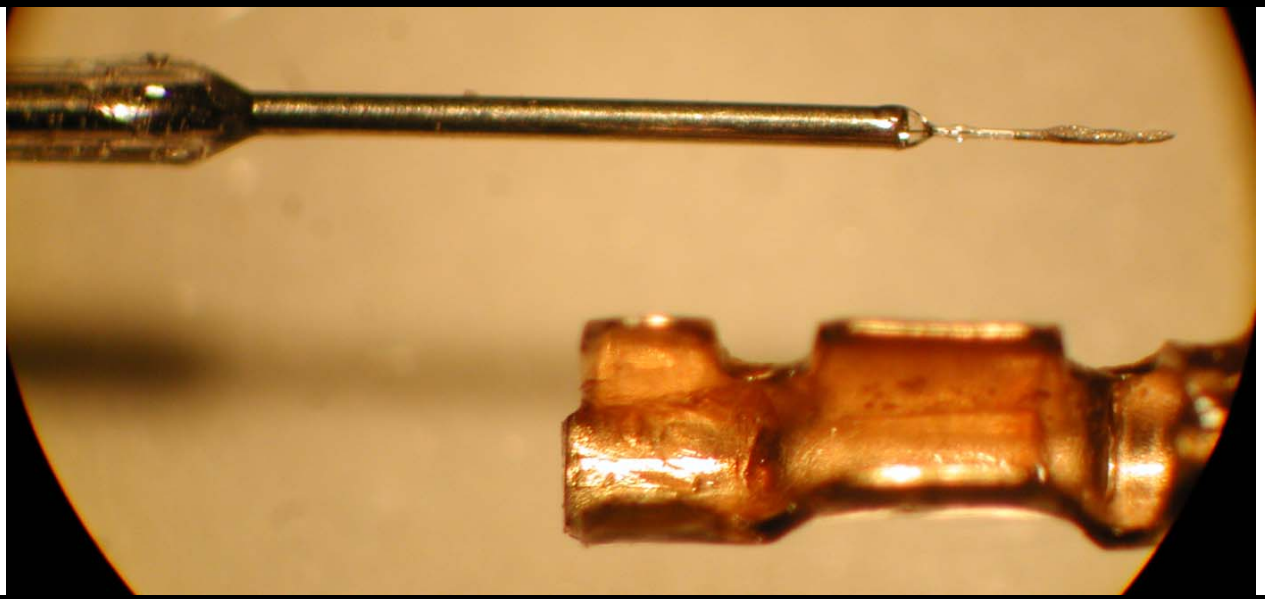
It's essential that these be as straight as possible. There's often play between the quartz fiber and the 30 ga tubing in which it rests. There's not much we can do about this, except to go to smaller tubing (down to 33 ga) – I've yet to try this. Other problems arise if one doesn't properly "nest," or "telescope" the tubes. I've found that the 30 ga nests well inside 0.75mm capillary glass (Cat. # 6250), which itself nests snugly inside 1.5mm glass (Cat. # 6030) from A-M Systems, once the latter's microfilament has been removed (by pushing it out with a section of the 0.75mm glass). Such nesting keeps the fiber colinear with the "holder" (outermost section of capillary glass).

**Figure 3A.**

View of telescoped construction (quartz fiber, 30ga steel, 0.75mm glass, 1.5mm glass), with epoxy visible at joints



Back end, with quartz fiber lined up at the approximate place for soldering into a pin connector

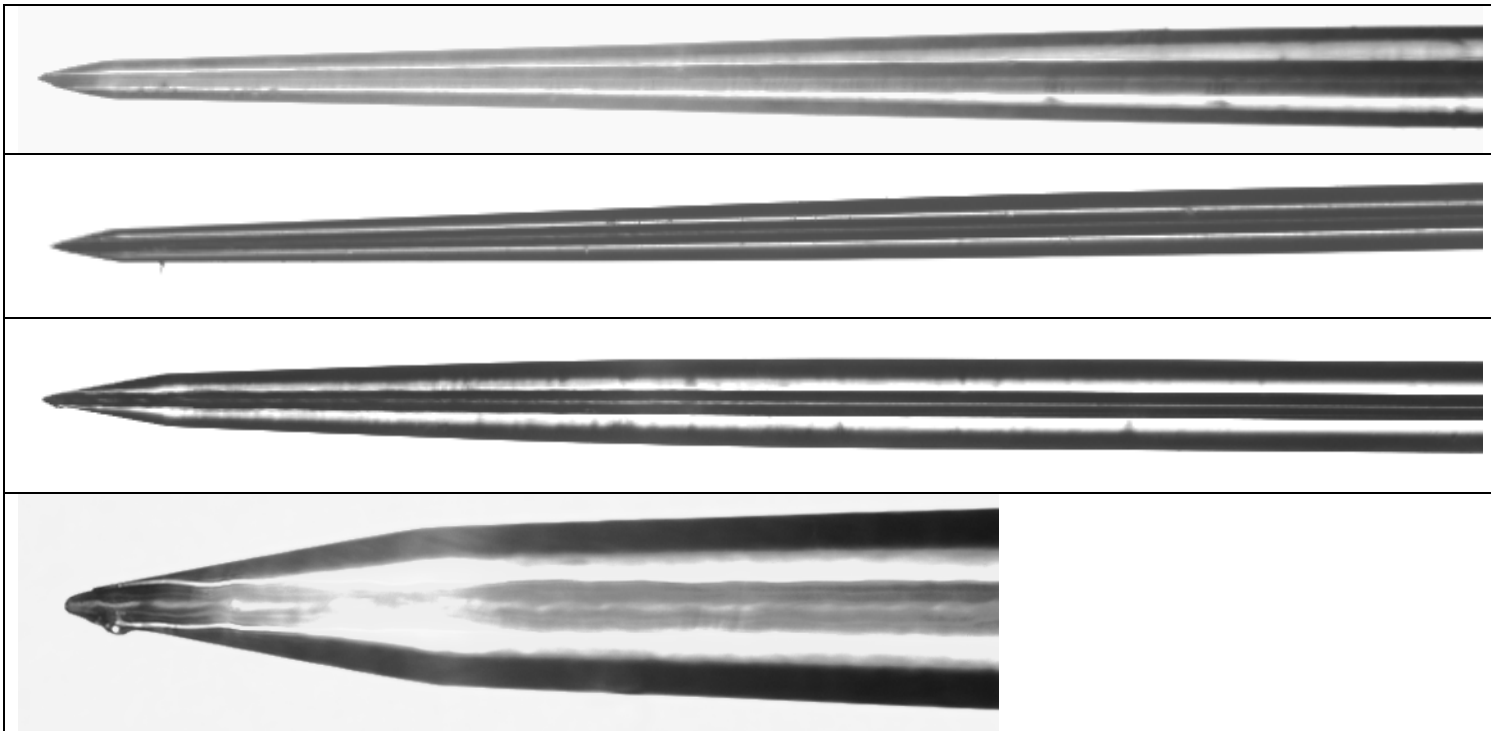


**Figure 3B.**

Back end, after soldering and epoxy stabilization. (More recently, I have only a short section of quartz fiber sticking out, a short metal piece, a short piece of 0.75mm glass, and the 1.5mm glass touching the end of the pin, for greater stability.) Connecting end of pin isn't visible on the right, still being held in a "sandwich" of Popsicle stick and electrical tape, which holds it in place during positioning and soldering.



**Figure 4.** Close-ups of 3 different tips (bottom two show the same tip at different mags; note the metal in glass, sandwich appearance):



## Carbon Fiber Electrodes

We used to etch the tips using a mix of chromic and sulfuric acids, and pull the etched tips back toward the end of the glass, having used DeKotinsky cement to glue the metal contact at the back end, such that it could be melted and pulled back. Aside from the expected difficulties arising from the need to have the tip sticking out only a few micrometers (and accidentally being pulled inside the glass tip) there seemed to be a problem with lack of a good seal between the carbon fiber and the glass. This resulted in liquid leaking into the glass, reducing the impedance and ability to isolate single units.

Lately, we've just used the beveller (K.T. Brown Type Micro-pipette Beveler, Sutter Instrument Co., Model BV-10) to bevel them a minimal amount (using the 104F diamond disk, which has 0.05um grit), and at 45° so that the carbon fiber and glass are pulled tightly along a good length, to insure a good seal. These typically have impedances between 3 and 12 Meg-ohms.

### Materials:

Carbon fibers – 7um diameter carbon fibers (Grafil Inc., 5900 88<sup>th</sup> St., Sacramento, CA 95828, (916) 386-1733; Grafil # 34-700), obtained free of charge from Energy Science Laboratories, Inc.

Stainless steel wire, for making electrical contact: 0.011” diameter (Small Parts Inc., Miami Lakes, FL, 1-800-423-9009; Cat. # SWX-3011, PO # 046516). Larger diameter wire can be used (0.012-0.013”), but these have more difficulty fitting into the smaller diameter capillary tubes (e.g., 0.7mm O.D.).

Glass capillary tubes, variety of sizes and types (1 barrel thru 7 barrel)

### Assembly:

Loading: The trickiest part of the entire procedure is getting an individual carbon fiber of sufficient length (~ $\frac{3}{4}$  inch absolute minimum, and preferably 2.5 inches) safely out of the bundle of fibers. To do this, I try to lay out the fiber bundle (on white paper, for contrast) such that some individual fibers are splayed out, away from the others. I then take a length of the stainless steel wire (minimum of 4 inches, to correspond to the capillary glass length, but starting with pieces of ~10 inches, and gradually shortening with each use), clean it with 100% EtOH, paint the end (~3 mm) with a small amount of silver print (too much, and it won't fit into the capillary glass), and immediately touch it, continguously, lengthwise, with the desired carbon fiber (if you hesitate more than a few seconds, the surface of the paint will dry, and it won't stick). Usually it'll just stick to the outer surface. Being careful to hold the wire steady, I get some more paint on the end of an applicator (usually the applicator brush that is attached to the paint cap), and carefully paint over the carbon fiber (care being exercised not to touch other, nearby fibers, or to touch the fiber in question beyond the tip, which would cause it to stick to the brush, and then break). Let it dry for several minutes. Ideally, the fiber isn't sticking out at an odd angle (where it will likely get broken during loading), and is well-stuck, forming a good electrical contact. Make sure it's dry before putting it in the capillary glass, as it won't dry inside, once you seal up the end with epoxy (the vehicle vapor pressure will simply build up to a point where no more liquid can evaporate, and there won't be good electrical contact).

You should already have the capillary glass sitting out, wedged gently into some clay (near both ends). Take it and place the free end of the metal wire down into one of the glass tubes. (One can use 1-2-, 3- 4-, 5- or 7-barrel glass – best is to use something symmetrical, for evenness of the pull, and the only

symmetrical ones are the 1, 5, and 7 barrel. Nevertheless, even though 2-, 3- or 4-barrel glass pulls off to one side, it's still largely straight. So, use whatever suits your needs.) Run the metal through until the carbon fiber and silver print is just about to touch the glass, and then take a careful look at it, head on, under the dissecting scope (you'll have to do this at the front edge of the work table, and shine the light on it there). What you want to do is have the carbon fiber going in a) so that it doesn't rub against the side of the glass, and b) so that it's opposite the fine, capillary glass fiber within the tube (you don't want the carbon fiber getting caught and broken in that crevice). To do this properly, you must, counterintuitively, have the fiber silver-printed to the outer curve of the metal (the metal is rarely perfectly straight, and always has a slight bend to it). The wire will end up with the middle touching on one side of the glass, and the ends will be touching the inside of the glass on the other side. This leaves the outer tangent of the wire away from the glass on the ends, as desired.

Once you've gotten the wire oriented properly, begin slowly pulling it through, from the other side, while watching the carbon fiber end very carefully. Once it starts going inside, and I can see that the silver print isn't too much, I pull it a bit further, and then place the glass back onto the clay, being careful not to bend the carbon fiber, which is still sticking out of that end. I like to watch it slowly move inside, as I pull it further in, from the other side. If you have only a very short length of fiber, you'll have to leave lots of metal wire inside, so that the carbon fiber is situated such that when it's pulled, it'll be sticking out a bit from the bottom part of the pull. If you have 2.5 inches or more, you'll be able to bring the metal almost all the way down to the end, such that you may end up using only  $\frac{1}{2}$ - $\frac{3}{4}$  inch of wire. Fix it in place by using Epoxy resin.