1.0 Background

This document describes in detail the construction of tactile stimulators for use in an MRI environment. Two different stimulators are described; the first measures 1.25" X 2.75" and provides very strong stimulation, the second measures 0.25" X 1.875" and its smaller size allows more discreet placement such as on a single finger, but at a cost of a significantly weaker maximum stimulus strength. Three main issues are addressed to make these stimulators safe for use on humans in an MRI environment; the stimulators are free of ferromagnetic materials to prevent them from becoming a missile when under the influence of the large magnetic field of the scanner, the stimulators are electrically insulated to protect the subject from the relatively large voltages generally used to drive the stimulators, and the stimulators are thermally insulated to protect the subject from possible heating in conductive areas caused by the scanner's rapidly switching magnetic field.

2.0 Materials

2.1 Materials common to both stimulators:

- Rubber-coated 19 gauge fiberglass insulated tubing.
- Non-ferromagnetic brass locking washers, #4-#6 size. Generally #4 is preferable to the larger sizes. When purchasing new washers, test if the washers are ferromagnetic using a small magnet beforehand. If they are affected by the magnet, don't use them.
- Switchcraft TA3MX male mini-XLR type connector. These are available from www.newark.com, part number 89K7625.
- Loctite quick-set epoxy.
- Solder.

2.2 Materials specific to the large tactile stimulator.

- 1.25" X 2.75" piezoceramic bending actuator, available from www.piezo.com, part number Q220-A4-503YB.
- 1" black heat-shrink tubing.
- ¾" clear heat-shrink tubing.

2.3 Materials specific to the small tactile stimulator.

- 0.25" X 1.875" piezoceramic bending actuator, available from www.piezo.com, part number Q220-A4-203YB.
- $^{3}/_{16}$" black heat-shrink tubing.
- $^{1}/_{8}$" clear heat-shrink tubing.

3.0 Equipment

- A solder station.
- A heat gun.
- Scissors
- An exacto-knife.
- Needle-nose pliers.

4.0 Instructions

If a large tactile stimulator is being constructed, use the steps designated with an "L", if a small stimulator is being constructed, use the steps designated with an "S". If a step does not have a letter designation it is common to both stimulators; for instance the sequence for a large stimulator would be 4.1, 4.2, 4.3L, 4.4, etc., while the sequence for a small stimulator would be 4.1, 4.2, 4.3S, 4.4, etc. Before you start each step, read through and understand it in its entirety, as some steps require you to do a series of actions in a short amount of time.

4.1 Figure 4.1 below shows an exploded view of the mini-XLR connector. The crimp bracket is highlighted in red. This piece is made of highly ferromagnetic stainless steel and must be discarded.

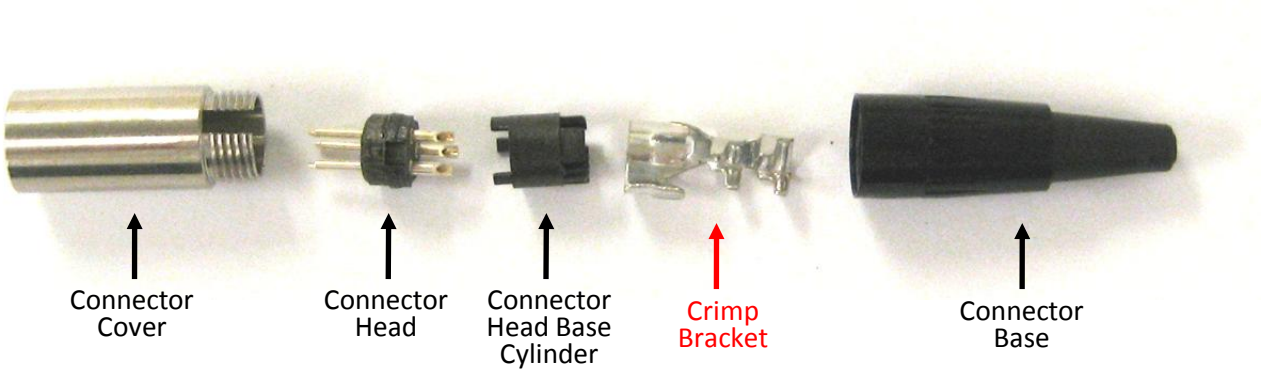

Fig. 4.1 Discard the crimp bracket.

4.2 Cut a 4.5" length of rubber-coated fiberglass tubing. Slide it over both leads of the bending actuator and gently tug on the ends of the lead wires until they both extend the same length from the fiberglass tubing. Trim both leads so that they both have approximately 4mm of exposed wire.

4.3L Cut a ½" length of ¾" clear heat-shrink tubing. Affix this to the base of the bending actuator so that the top of the clear heat-shrink tubing meets the bottom of the piezoceramic rectangle of the bending actuator as shown in figure 4.3L below.

4.3S Cut a $^{7}/_{8}$" length of $^{1}/_{8}$" clear heat-shrink tubing. Affix this to the base of the bending actuator so that the top of the clear heat-shrink tubing meets the bottom of the piezoceramic rectangle of the bending actuator as shown in figure 4.3S below. Sliding the heat-shrink tubing over the base of the bending actuator will be a tight fit. If the heat-shrink tubing gets stuck on the resistor on the base, you can use the tip of an exacto-knife to gently pull the lip of the heat-shrink tubing over it. Be patient and gentle, and always make sure to grip the bending actuator on its base, and not on the fragile piezoceramic piece.

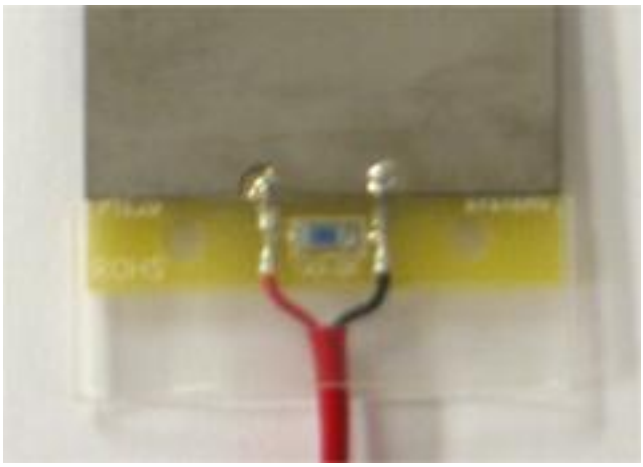

Fig. 4.3L The heat-shrink tubing should come right up to the piezoceramic piece.

Fig. 4.3S Proper placement of the heat-shrink tubing.

4.4 Slide the connector base over the fiberglass tubing. Next slide a brass locking washer over the tubing and use a pair of needle nose pliers to crimp the washer around the fiberglass tubing (Fig. 4.4a). Crimp the washer tightly enough that it stays in place, but not so tightly that it cannot slide up and down the fiberglass tubing. Note: if the ends of the washer overlap or come into contact with each other the washer will be very difficult to crimp. Prior to crimping use a pair of needle nose pliers to twist the ends of the washer away from each other, as shown in figure 4.4b.

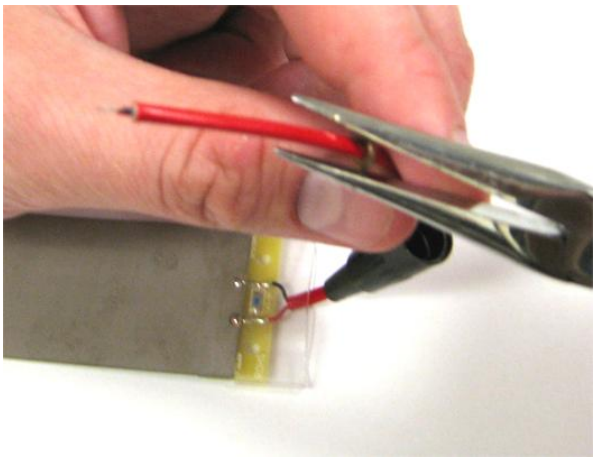

Fig. 4.4a Crimp the brass washer so that it stays put, but can still be moved up and down the fiberglass tubing.

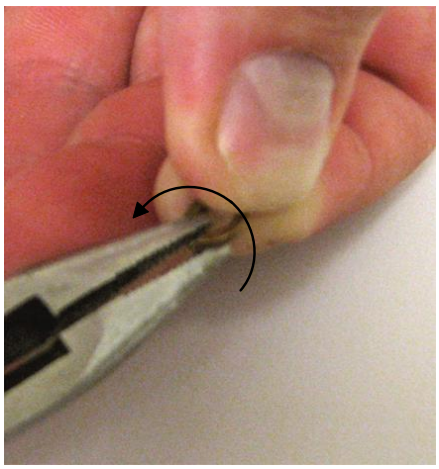

Fig. 4.4b Prior to crimping, use a pair of pliers to twist the ends of the washer so that they don't overlap.

4.5 Slide the connector head base cylinder over the fiberglass tubing, being mindful that the fitting prongs need to be oriented away from the bending actuator in order to connect to the connector head. Solder the bending actuator leads to the connector head. To maintain a consistent phase among all piezos, solder the red lead to the top left pin and the black lead to the top right pin. The top of the connector head is easily identified by the groove knob, highlighted in figure 4.5a, and the orientation of the pin cavities. The bottom pin is left unconnected. The tactile stimulator should now look like the one shown in figure 4.5b.

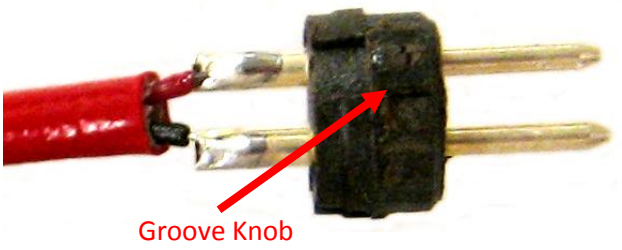

Fig. 4.5a Solder the leads to the top two pins, using the groove knob to identify them.

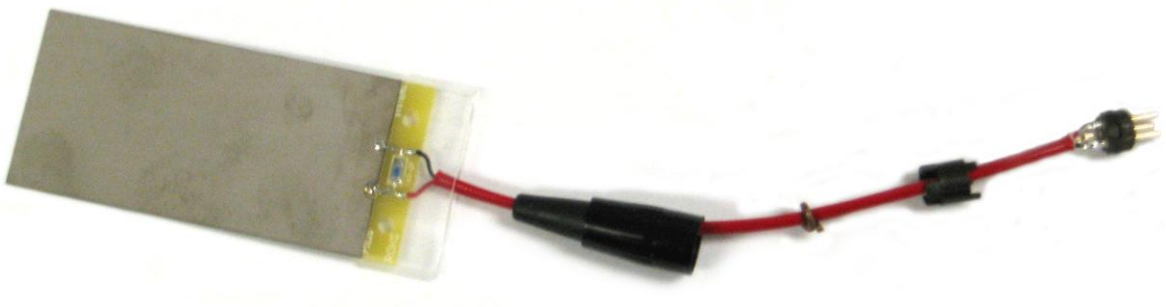

Fig. 4.5b The bending actuator after soldering the connector head.

4.6L Use a heat gun to shrink the ¾" heat shrink tubing that you affixed to the base of the bending actuator in step 4.3L. Immediately after, while the tubing is still hot, place the bending actuator on the table and using a ruler or other flat and stiff instrument, press the heat shrink tubing flat until it has cooled, as shown in figure 4.6a. The heat shrink tubing should look as it does in figure 4.6Lb, with the lip on both sides flat and parallel, and not curling outward. Stir up some epoxy and fill the heat-shrink tubing using a paper clip or thick piece of wire. Fill the heat shrink tubing until the epoxy is flush with the lip of the heat shrink tubing (Fig. 4.6Lc). Make sure that the fiberglass tubing extends into the heat-shrink tubing and epoxy by at least a millimeter, but not too much as the tubing will need enough length to be properly seated in epoxy on the other side as well. When you are done the base of the bending actuator should look like figure 4.6Ld, notice that the heat-shrink tubing is completely filled and there are no large pockets of air.

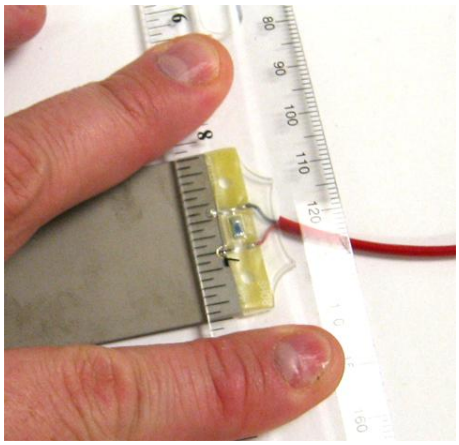

Fig. 4.6La Immediately after using the heat gun, use a ruler to flatten the heat-shrink tubing.

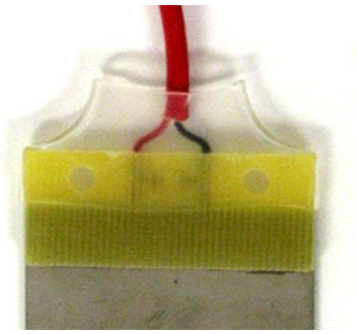

Fig. 4.6Lb The heat shrink tubing lip should not curl outwards.

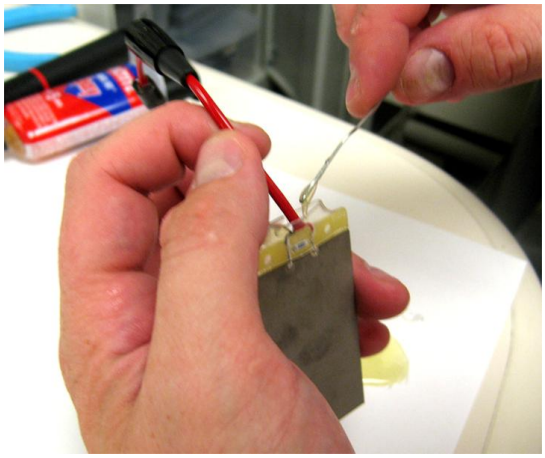

Fig. 4.6Lc Fill the heat-shrink tubing with epoxy. Ensure that the fiberglass tubing extends at least one millimeter in the epoxy and heat-shrink tubing.

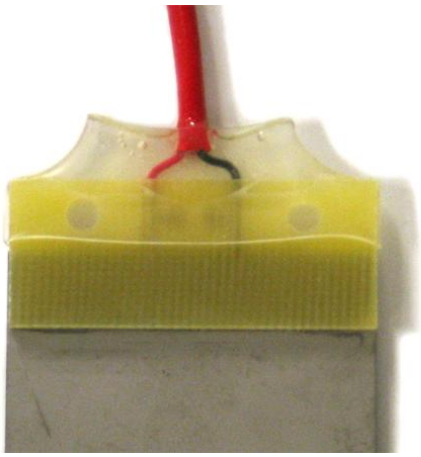

Fig. 4.6Ld The epoxy should completely fill the heat-shrink tubing and be free of any large bubbles.

4.6S Fill the $^{1}/_{8}$" heat shrink tubing that you affixed to the base of the bending actuator in step 4.3L with epoxy using a paper clip or piece of wire (Fig. 4.6Sa). Use a heat gun to shrink the heat-shrink (Fig. 4.6Sb). This will automatically cause the area around the leads to be completely filled and will drive out any air bubbles. It will also cause the surplus epoxy to ooze out; quickly wipe it up using a tissue or paper towel (Fig. 4.6Sc). When finished, the heat-shrink tubing should be tightly gripped around both the bending actuator and the fiberglass tubing, as shown in figure 4.6Sd.

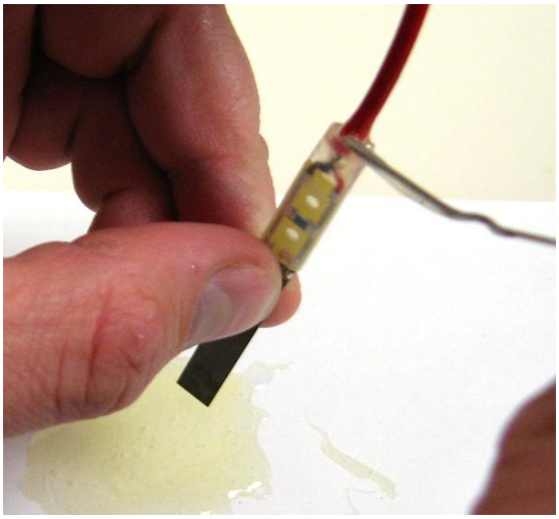

Fig. 4.6Sa Fill the heat-shrink tubing with epoxy.

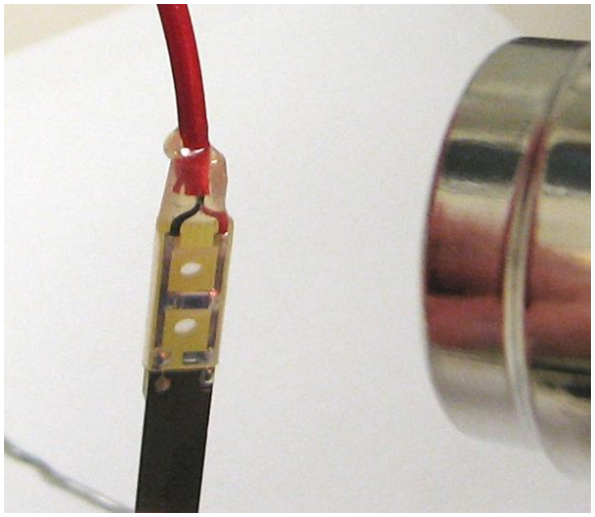

Fig. 4.6Sb Use a heat gun to shrink the heat-shrink tubing.

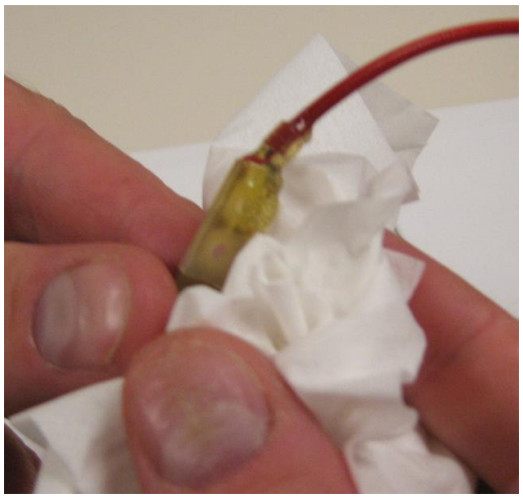

Fig. 4.6Sc Use a tissue to wipe away the excess epoxy.

Fig. 4.6Sd After shrinking, the heat-shrink tubing should firmly grip both the piezo base and the fiberglass tubing.

4.7 Slide the connector head base cylinder down and fit it with connector head. Fill the base cylinder with epoxy until the epoxy is approximately flush with the top. Again make sure that the fiberglass tubing extends into the base cylinder and epoxy by at least a millimeter.

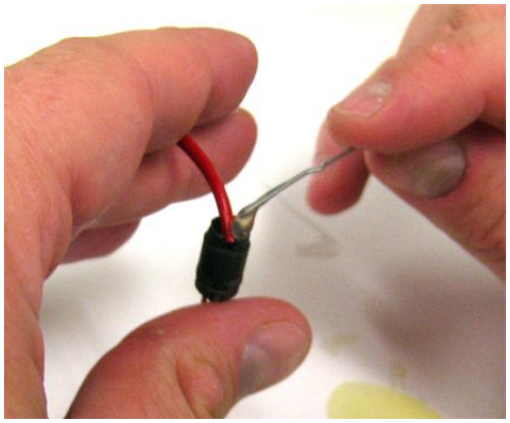

Fig. 4.7 Fill the connector head base cylinder with epoxy. Ensure that the fiberglass tubing extends at least one millimeter into the epoxy.

4.8 Let the epoxy sit overnight to fully set.

4.9L Cut a 3.25" length of 1" black heat-shrink tubing. Place it on the bending actuator so that the end of the tubing lies just about a millimeter over the edge of the base of the bending actuator as shown in figure 4.9L.

4.9S Cut a 2" length of $^{3}/_{16}$" black heat-shrink tubing. Place it on the bending actuator so that the end of the tubing lies just below the surface mount resistor on the base of the bending actuator as shown in figure 4.9S.

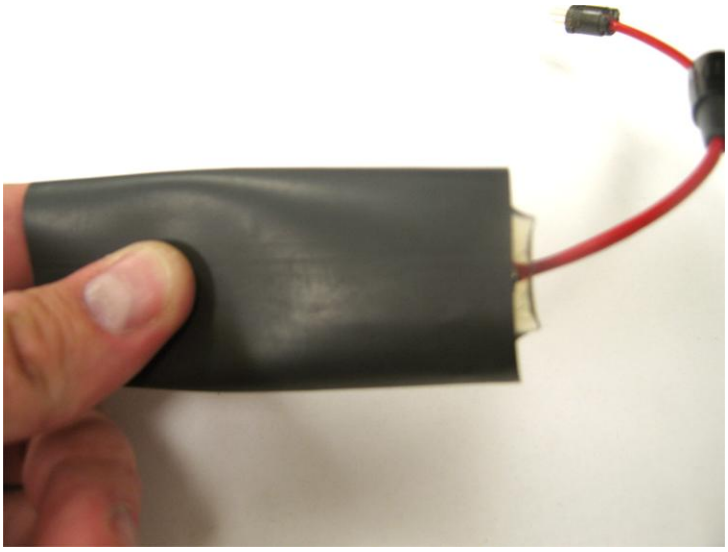

Fig. 4.9L The heat-shrink tubing should extend just over the edge of the base of the bending actuator.

Fig. 4.9S The heat-shrink tubing should extend just over the bending actuator's resistor.

4.10 Use a heat gun to shrink the heat-shrink tubing, starting at the bottom (Fig. 4.10a). To prevent bubbles, continuously move the heat from the front to back and vice versa as you move your way up the tubing. Immediately after removing the heat, cut the end of the heat-shrink tubing off about a millimeter past the edge of the bending actuator (Fig. 4.10b). If done correctly, the hot heat-shrink tubing will bind to itself, creating a water-tight seal at the end, as shown in figure 4.10c. If any openings exist at the end then you either cut the tubing too short, or you allowed the tubing to cool too much before cutting it. If it is cut too short, you will have to carefully strip the heat-shrink tubing away and try again. Otherwise you can try heating it up again with the heat gun and either pinch it shut with a pair of smooth-mouthed tweezer pliers, or use a table top and a ruler to press it closed.

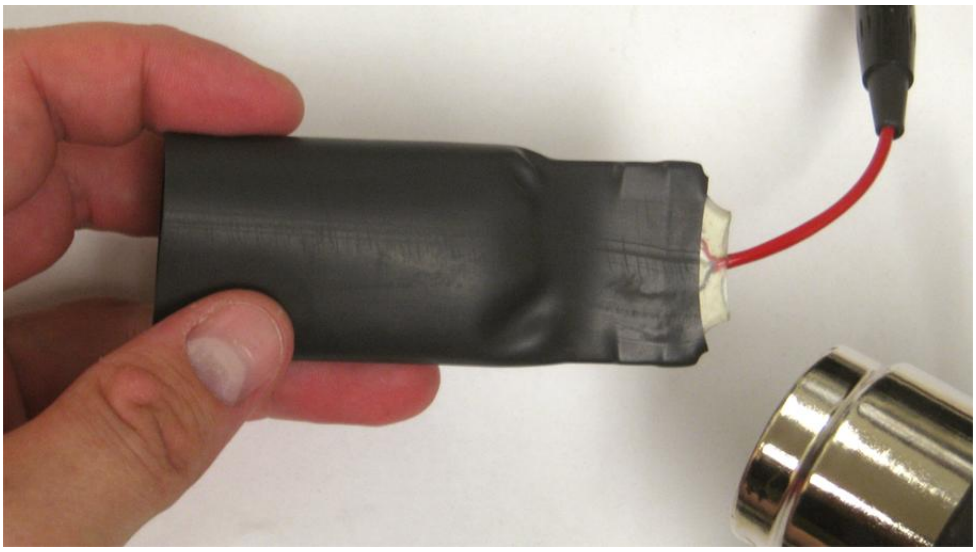

Fig. 4.10a Use a heat-gun to shrink the heat-shrink tubing starting at the bottom.

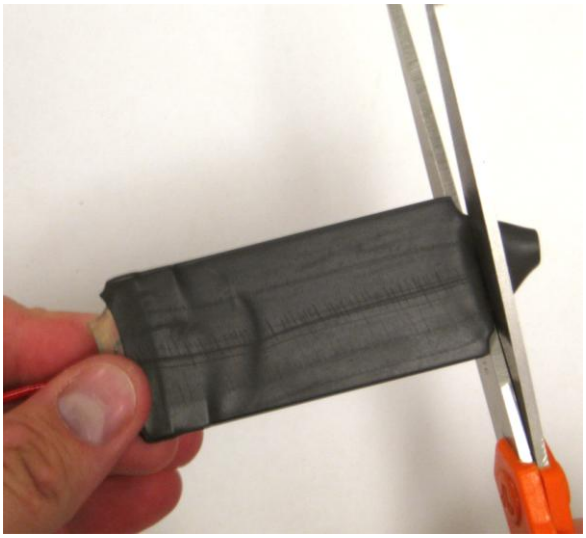

Fig. 4.10b Quickly cut the excess tubing away with a pair of scissor before it has a chance to cool.

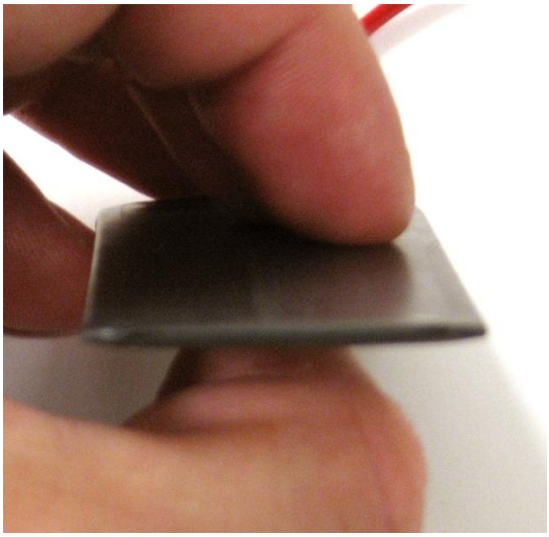

Fig. 4.10c If done properly, the end will be fully sealed.

4.11 Next the brass locking washer needs to be positioned. First slide the connector head cover over the connector head and making sure it is firmly seated; use a pair of needle nose pliers to force it down until it pops into place, if necessary. Slide the washer back so that it is at least an inch away from the connector cover (Fig. 4.11a). Next bring the connector base to the connector cover, dragging the washer along with. Screw it down tightly (Fig. 4.11b). Now unscrew the connector base and pull the washer back about a quarter of an inch (Fig. 4.11c). Crimp the washer down

tightly using a pair of pliers until it is completely immobilized (Fig. 4.11d). Screw together connector base and connector head cover again; however since the washer is now crimped tightly to the fiber glass tubing, and the washer will now be rubbing up against the inside of the connector base, you may have to grip the fiberglass tubing below the connector to prevent it from twisting. Note: to prevent excessive friction between the washer and connector base crimp the washer as illustrated in figure 4.12e-f. Crimp the washer so that the ends cross so that it forms an α shape (Fig. 4.12e). Crimp it tightly so that it is completely immobile. Next crimp down the ends (Fig. 4.12f) so that the washer is coiled around the fiberglass tubing (Fig. 4.12g).

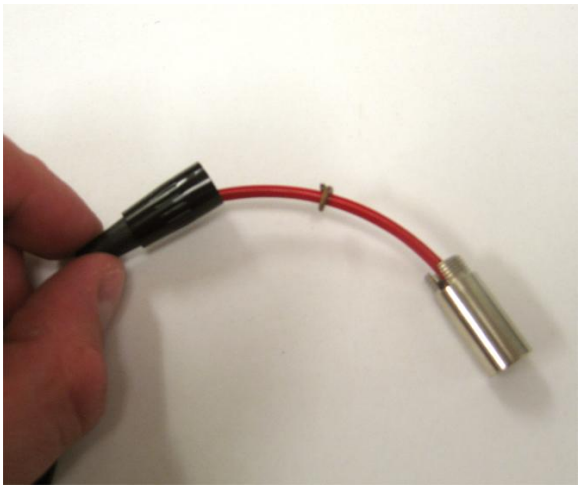

Fig. 4.11a Slide the washer about and inch away from the connector cover.

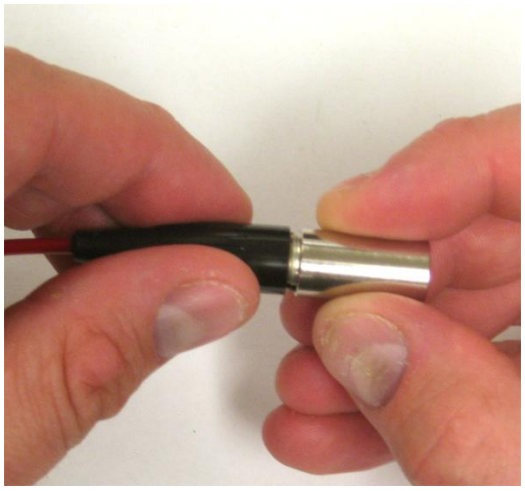

Fig. 4.11b Screw the connector base to the connector head cover.

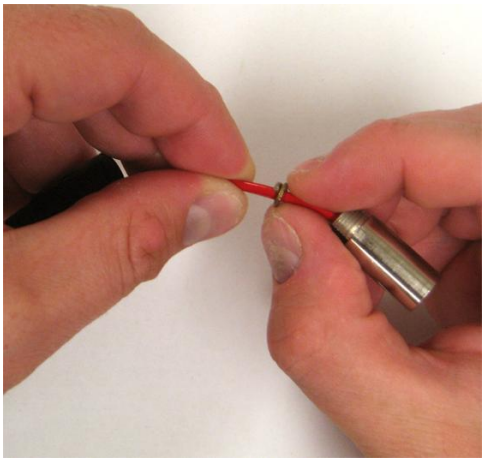

Fig. 4.11c Unscrew the base and slide the washer back a quarter inch.

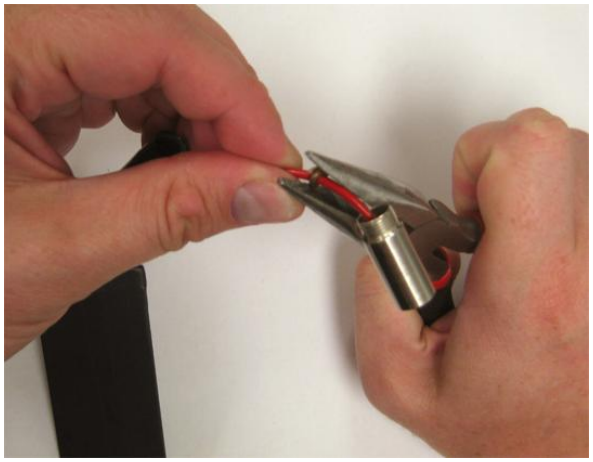

Fig. 4.11d Crimp the washer down tightly until it is immobile.

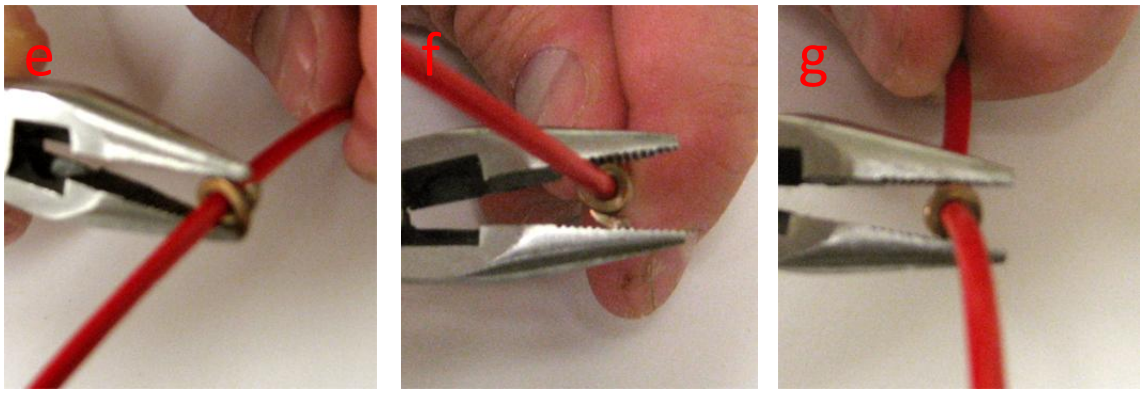

Fig. 4.11e-g e) Crimp the washer tightly into an α shape. f) Crimp the ends down so that they don't stick out. g) The washer should now be tightly coiled around the fiberglass tubing.

4.12 Your stimulator is now finished and should look like one of the two below.

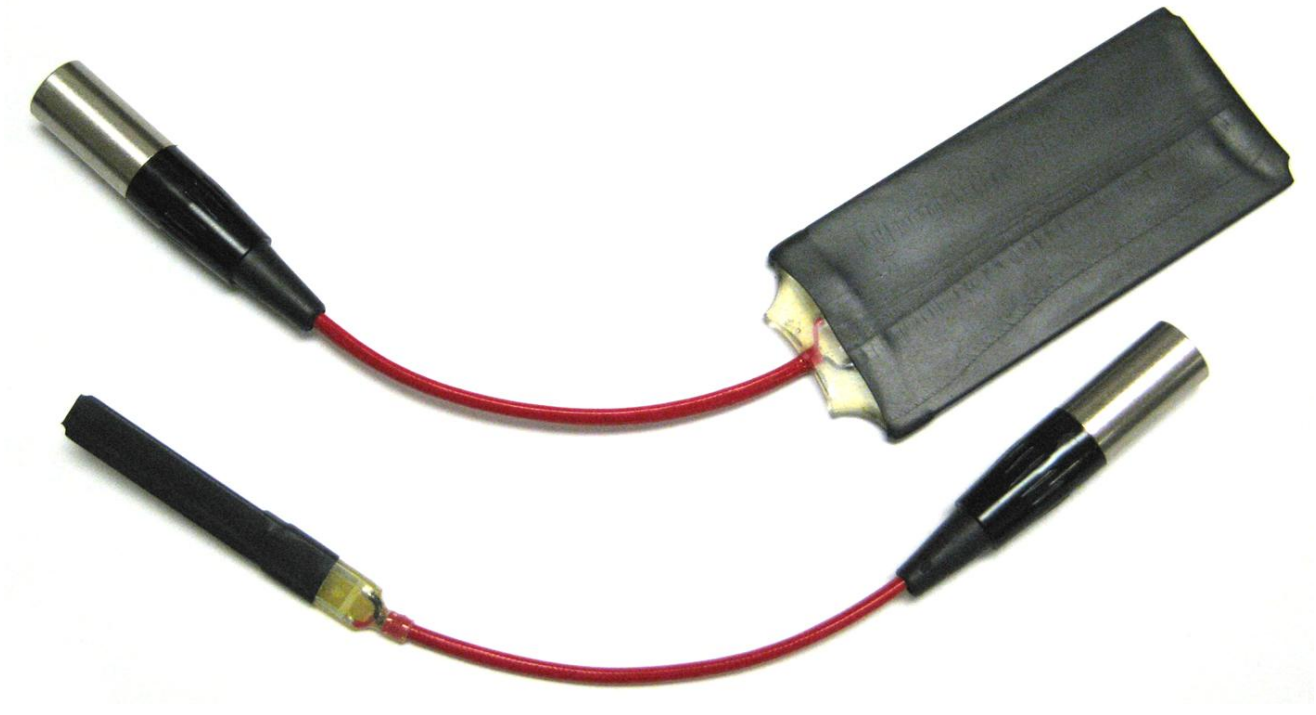

Fig. 4.12 Finished stimulators.