Chapter 15.

Materials Index

The following is a list of materials that played a major role in the development of the projects in this thesis. While many materials were experimented with, only a few are listed as examples of materials that did not work. Because accurately measuring the resistance of conductive threads and sewn electrodes relies on creating a stable connection to the thread or electrode, as well as the fact that sewn electrodes vary in resistance across different axis and over time, most of the measurements in this section are an empirical average of repeated measurements taken in different places with different connections.

Stainless Steel Fibers

The bulk of conductive threads in this list are made from extremely fine fibers drawn from cold-worked stainless steel wire. These fibers have enormous advantages. Stainless steel is inert, so surface corrosion is not a problem. These fibers have been

Summary of Materials Index

- Gimped Thread, Wrapped with Metal Foil
- Metallic Silk Organza
- Conductive Hook and Eye Fasteners (Velcro)
- Stainless Steel and Polyester Blend, BK50/2
- 100% Continuous Stainless Steel
- 70-100% Non-Continuous Stainless Steel
- Nylon Wrapped with Continuous Stainless Steel
- Mechanical and Electrical Knot Tying Braid of100% Continuous Stainless Steel Core
- Wrapped with BK50/2
- Snaps, Zippers, Earring Backs, and other Mechanical Fasteners

used in medical electrodes, and are known to have no side effects to humans. They are affordable. Cold-worked stainless steel yarns and fibers are also far more mechanically durable than either deposition coated yarns, or fibers and foils made from more highly conductive, non-alloyed metal fibers or wraps, like copper or gold. But while cold working provides excellent mechanical strength, it also means that stainless steel will never be as conductive a copper, or even hot rolled stainless. As a result, the circuit elements created with these fibers remain low impedance electrodes. Consequently, the applications that have been developed for these materials cleverly exploit low impedance electrodes.

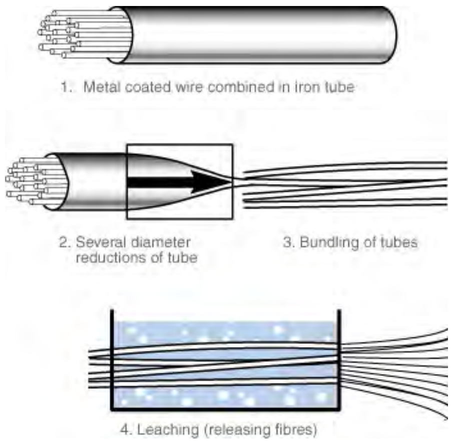

Figure 15.1 Image of the drawing of metal fibers, from Bekeart Website, 1999.

Materials List

Gimped Thread, Wrapped with Metal Foil

Projects: *Firefly Dress and Necklace* and *Ball Gown***.** This thread has central core of cotton or silk, and is wrapped with a soft metal foil, usually color treated copper or silver. It has been used for decorative purposes in many cultures, including France, India and Japan. While this thread is *highly* conductive, it has limited mechanical properties, and cannot be machine sewn without stripping its conductive coating. Metal wrapped yarns like these are generally woven in the weft of a fabric (weft weaving creates little mechanical stress on a yarn), or attached to fabrics for decorative purposes with a process called couching. Couching puts little stress on the thread because it involves mechanically attaching the metallic thread to a

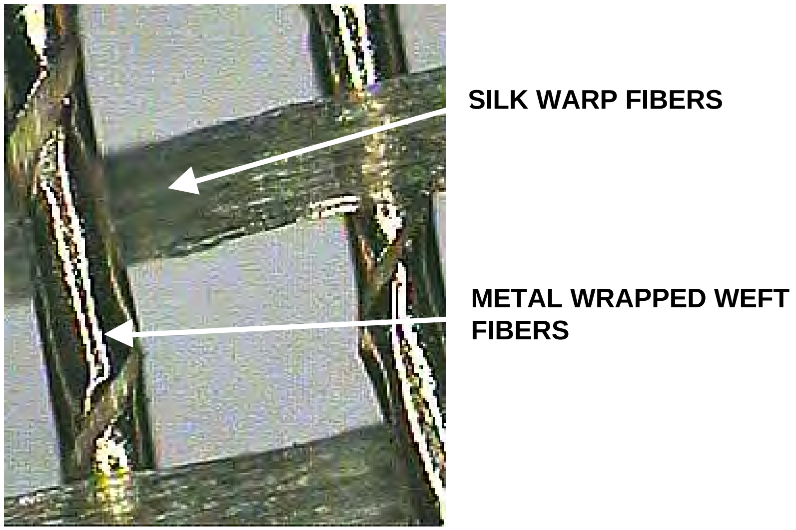

Figure 15.2 Gimped thread wrapped with metal foil, woven into metallic silk organza.

substrate material by “tacking it down”, or sewing another thread around it. This thread was used to create the conductive and flexible tassels of the *Firefly Dress and Necklace,* and the hand embroidered circuit traces in the *New Year’s Eve Ball Gown*. Its wire-like conductivity was essential in the tassels of the *Necklace* because the amount of current they passed to the necklace ultimately determined the color of the LEDs. The flexibility of this thread also let the beaded tassels swing far more freely than they could have with wires inside.

Metallic Silk Organza

Projects: *Piecework Fabric Keypad, Firefly Dress, Serial Suit, Musical Jacket, Ball Gown* and *Electronic Tablecloth.*

Metallic silk organza is a highly conductive fabric from India, where it has been used for decorative purposes for centuries. This organza is woven from gimped silk fibers wrapped with metal foil. These conductive threads run only along the weft of the fabric. The warp is uncoated silk. (Running the thread in the warp would cause the conductor to strip because of mechanical stresses.) Because the conductive fibers are slightly spaced, the fabric is anisotropic conductor, conducting in only one direction, and can be used almost like a ribbon cable. The resistance of the fabric is on the order of 5 ohms per meter. This can be improved if layered. Creating a plane of isotropic conductive material required edging the fabric with a perpendicularly conductive strip, to tie the conductors together. This fabric is not truly flexible, because of the ductility of the metal foil, which means it can be permanently deformed. For that reason, this fabric is usually only used for decorative, or specialty clothing. This fabric was used as both sensors and power distribution in all the electric fashions, a switch matrix in the row and column *Piecework Fabric Keypad*, and a fabric ribbon cable that distributed power, ground, audio, and serial data in the *Musical Jacket*. It was used an *excellent* means to ground the body when doing capacitive sensing in both the *Musical Jacket* and *Ball Gown*. It was also appliquéd onto the *Electronic Tablecloth* to create a capacitive tag reader electrode capable of generating high frequency, and high amplitude voltage swings.

Conductive Hook and Eye Fasteners (Velcro)

Projects: *Firefly Dress* and *Triangles.*
This highly conductive, nylon hook and eye fastener (Velcro) is deposition coated with silver. It is primarily used in EMI shielding applications. It has a male and female component. In cross section (from top to bottom), its resistance is 1.5 ohms. In length, it's resistance is ~2 ohms per foot. The connection between a male and female piece, (if strongly pressed), is ~1.5 ohms. The resistance across two female pieces squished together is 5 ohms. Female conductive Velcro was used as an electrical contact in the *Triangles* and the *Firefly Dress*. Its fuzzy ends help ensure electrical contact between two things without rigid connectors. Magnets also in the *Triangles* insured a stable and accurate mechanical connection.

Stainless Steel and Polyester Blend, BK50/2

Projects: *Musical Jacket, Electronic Tablecloth*, and *Embroidered Musical Instruments.*

This high impedance composite thread is made from short stainless steel fibers bended with polyester and has excellent mechanical properties. The resistance of this thread is not consistent, but in general it averages 3k ohms per meter. In many ways, this thread feels and looks like a normal thread. It is soft, flexible and can be tied in a knot. This was the first thread that we could get through the needle of a commercial sewing machine without mechanical bunching or the damaging of its conductors. That is because the conductance of the thread is the result of lots of tiny steel fibers being in mechanical contact with each other, rather than a single continuous fiber. (As a result resistance across this thread drops dramatically when under tension.) The tiny stainless steel fibers in the thread are hairy and extend beyond the physical edge of the thread. This hairiness has two ramifications: 1)This thread provides lots of metal fibers and surface area to electrically couple to. 2)These fibers can reach out and find each other, creating extremely high impedance short circuits (50mega ohms) between individual traces if they are not sewn correctly. Six inch traces sewn with this thread in the top and bottom measure less than 3k ohms. The *Musical Jacket* and *Electronic Tablecloth* used this thread in both the needle and bobbin of a commercial embroidery machine to sew high impedance electrodes that sense on and off. This

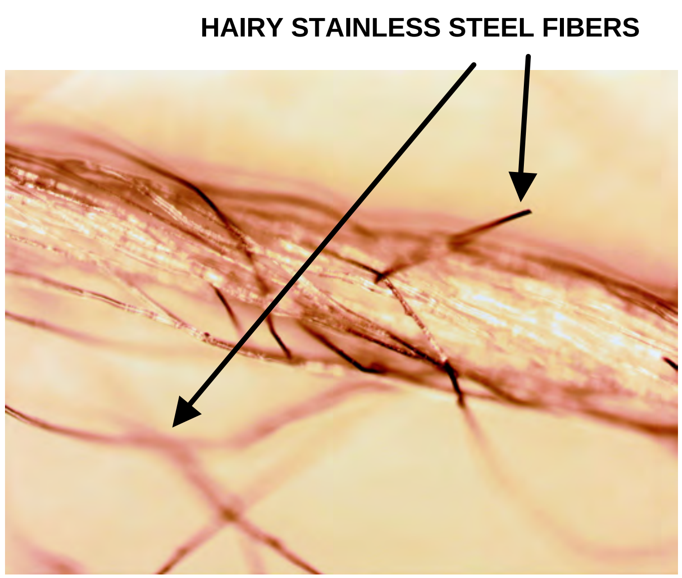

Figure 15.3 Microscopic image of stainless steel and polyester blend BK50/2.

thread is used to sew the top or needle portion of the electrodes in the *Embroidered Musical Instruments*.

100% Continuous Stainless Steel

This thread is made from 100% continuous steel. It is *highly* conductive (on the order of 2 ohms per foot), but has extremely poor mechanical properties. It cannot hold a knot, pass through the eye of a needle, or even be sewn through the bobbin of the sewing machine. Nor can it be well soldered to.

70-100% Non-Continuous Stainless Steel

Projects: *Balls 3 and 4.*
This thread is spun from 100% short stainless steel fibers, or a blend of Kevlar and short stainless fibers. It possesses the high conductivity of the 100% continuous stainless steel, combined with improved mechanical properties based on its structure of spun short fibers. It can hold a mechanical knot relatively well and despite its width (necessary for manufacturing), it can be run through the bobbin of a commercial sewing machine. Unfortunately, the same felting of short fibers that improves its mechanical properties causes other problems. The surface characteristics of both the Kevlar and the stainless fibers are smooth, so there is little friction to hold the fiber in place. This hairiness makes low impedance short circuits between circuit elements that are sewn on the same piece of fabric inevitable. Moreover, those hairs easily get loose from the structure of the thread and cause skin irritation. The hairs make it possible to create a solder joint to it, by literally forcing the solder in between them. (It is not possible to solder to continuous stainless). This thread can hold a

mechanical knot that forms an electrical connection with a sewn electrode. This thread was tied to embroidered electrodes in early balls and then soldered to, and wrapped around wires that connected to the central circuit. (If it was tied to the circuit-board or even got near it, the nearly invisible steel fibers got into the circuit and caused HORRIBLE short circuits.)

Nylon Wrapped with Continuous Stainless Steel

Projects: *Balls 5, 6 and Shaped, Embroidered Instruments*

This very conductive thread consists of a nylon core wrapped with three very fine strands of continuous stainless steel. Its resistance measures around 100 ohms per meter. While passing this thread through the needle of the sewing machine caused the conductors to break and strip, it was successfully used in the bobbin to create highly conductive sewn electrodes. The thinness of the conductors in this thread make it difficult to electrically couple to when it is used alone. (When used in conjunction with BK 50/2, which has lots of conductors near the surface, this problem disappears.) Its use in the bobbin virtually eliminated the high impedance short circuits that occurred between two closely sewn traces made with BK 50/2 in the bobbin and top thread. This thread is used in all the *Shaped Embroidered Musical Instruments*.

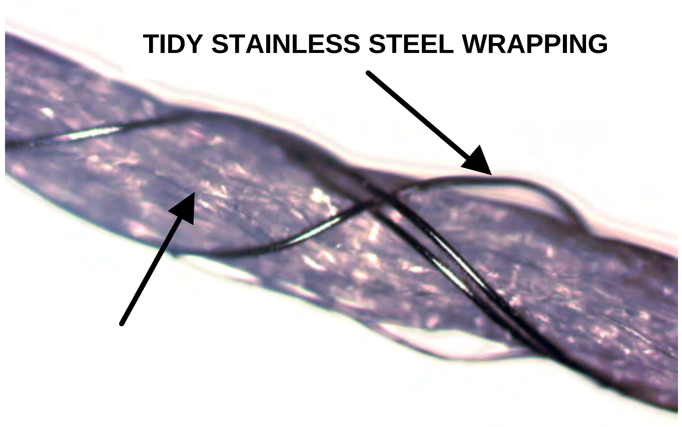

Figure 15.4 Microscopic view of nylon core wrapped with continuous stainless steel filaments.

Mechanical and Electrical Knot Tying Braid of 100% Continuous Stainless Steel Core Wrapped with BK50/2

Projects: *Ball 5, Pyramid, Big Ring* and *Tube.*

I developed this braid with Bekeart Corporation to solve the problem of creating a mechanical and electrical connection between a circuit board and a sewn electrode. This yarn is HIGHLY conductive, ~10 ohms per foot, capable of holding a knot, and does not have a high incidence of stray fibers. This yanr gets its excellent electrical properties and high conductance from its central core of 100 percent, continuous, stainless steel. It gets its mechanical properties (its ability to hold a knot), from the surface characteristics of the BK/50 that is braided around the continuous stainless steel core. The high resistance of the BK 50/2 is not relevant because it is always in close mechanical contact with its highly conductive central core. When a knot is tied around a circuit board, the BK 50/2 only needs to conduct a very short distance, from the highly conductive yarn core, to the contact pads on the surface of the board, and therefore the high resistance of the BK 50/2 does not become a factor in the impedance across a tied connection.

Snaps, Zippers, Earring Backs, and Other Mechanical Fasteners

Projects: *Firefly Dress and Necklace, Piecework Keypad* and *Musical Jacket.*

A number of standard textile fasteners are highly conductive and make for mechanically durable ways to connect circuitry to fabric. Snaps and sippers come to mind. These fasteners can be soldered to the circuit, and attached mechanically to the fabric. Finding a variety of mechanical ways to couple conducting fabric to traditional circuitry has been a great challenge.

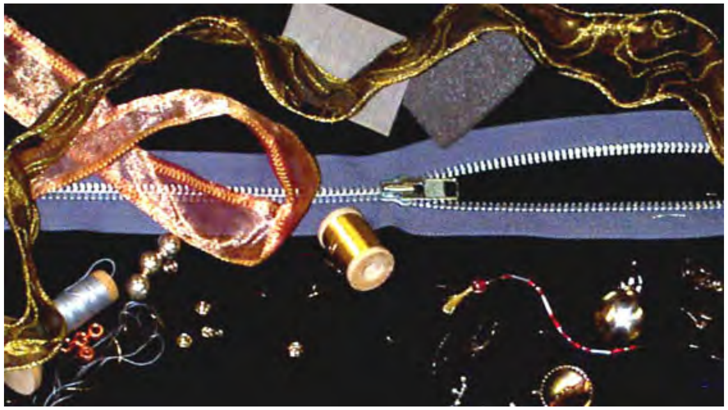

Figure 15.5 Variety of conductive textile fasteners and notions.