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COPPERLESS Flex Circuits

Building resistive metal foils on a flex circuit to create heat.

by **MARK FINSTAD**

A customer asked if a flex circuit could be made using a metal foil other than copper. They needed to heat a non-flat surface, and wanted the contouring abilities of a flex circuit combined with heating qualities of a resistive foil.

The answer is yes, resistive metal foils can be used on a flex circuit to create heat. Most manufacturers that make resistive flex circuits refer to them as flexible heaters. Many resistive foils can be used for this type of application, as can many different types of adhesive and insulation materials. It is important to understand the differences in the materials used to construct the flexible heater, so that you will know how to properly specify your heater for maximum efficiency and reliability, and also for lowest cost.

While many types of resistive metal foils are available for the construction of flexible heaters, the most common types are cupronickel, constantan (very similar to cupronickel), Inconel and aluminum. The best metal foil type for a given application is driven by the resistance density required. This is derived based on operating voltage and the temperature at which the heater will operate.

Metal foil selection is determined by the amount of resistance needed, and also by the area that that resistance needs to cover. Total heater element resistance is driven by the resistivity of the metal that the foil is made from, the metal foil thickness, and the width of the element conductors. Most flexible heaters are designed to cover roughly 50% of the total heated area with metal. This means that if the heating element traces are 0.020" wide, the spaces between element traces should also be 0.020". This will generally provide the best heat distribution and minimizes the chance for "hot spots" or overheating.

Here is a summary of some common foils and their particular characteristics:

Cupronickel. As the name implies, cupronickel is an alloy of copper and nickel. While there are several types of cupronickel available with different ratios of copper and nickel, the most common alloy for flexible heaters is alloy 715. This alloy is 70% copper and 30% nickel. This material processes during manufacturing in a manner similar to copper, and has the relatively low resistivity of 16.22047 µΩ-inch (for reference, copper is 0.661417 µΩ-inch). This alloy is typically used in applications that don't require a high-resistance density. One advantage of cupronickel is that it is relatively easy to copper plate to this material. This makes it possible to have a flex heater where certain areas (like power leads) will not heat. Plating copper on select areas of the resistive pattern will significantly lower the resistance in that area, resulting in little or no heat generation. Copper plating also makes it possible to make connections between layers using copper-plated through-holes. When using this technique, the resistive foil typically needs to be on an innerlayer with copper pads (and possibly circuitry) on the outer layers. Cupronickel can be soldered to, making it easy to attach lead wires. Cupronickel has a low temperature coefficient of resistance (TCR), so the heater resistance will change very little as the temperature goes up and down. This makes the temperature much easier to control over a wide range.

Constantan. Constantan is a variation of cupronickel with 55% copper and 45% nickel and a resistivity of 19.63495 µΩ-inch. Constantan is typically used in flex circuit applications such as strain gauges and thermocouples. Constantan also has a very low TCR.

Inconel. There are several alloys of Inconel, but all are predominantly nickel, with chromium as a second element. Iron, molybdenum, niobium, cobalt and other metals are used to create the different Inconel alloys. Inconel 600 is probably the most widely used alloy, with a resistivity of 40.6 µΩ-inch. The high resistivity makes this foil ideal for applications that require a high resistance packed into in a small area. This is a very hard foil that is not easily copper-plated. Inconel is also virtually impossible to solder to, which means that lead wires will usually have to be brazed to the heater element. As with the previous foils, Inconel has a low TCR.

Aluminum. Aluminum foil is generally chosen as a heater element material to save money. The resistivity is roughly double that of copper, and like many other pure metals, it has a high TCR. Aluminum also etches very quickly, which makes it difficult for the manufacturer to keep tight resistance control. But, if you are looking to save pennies and unconcerned about tight temperature control, aluminum may be a good choice.

Picking the Correct Adhesive/Insulation System

The choice of insulation and adhesive is primarily driven by the operating environment of the heater (i.e., operating and ambient temperature, chemical contact, etc.), and to a lesser extent cost. Both the insulation and adhesive type must be rated for the temperatures the heater will be operating at, with sufficient margin to account for temperature excursions. Temperature excursions can be caused by variables such as fluctuating supply voltage and elevated ambient temperatures.

While there are many types of flexible insulation types, and an equal or greater number of adhesive types that could be used to make a flexible heater, a few cover 95% or more of all applications. For insulations, these include:

Polyimide. Polyimide film can be used in a wide variety of flexible heater applications. In addition to being an extremely good electrical insulator (0.001" polyimide has a dielectric strength rating of 7700V), it has also been used successfully in applications at temperatures as low as -269°C (-452°F) and as high as 400°C (752°F). For this reason, polyimide heaters are in use in very low-temperature space/satellite applications, and also in high-temperature applications such as semiconductor manufacturing. The high dielectric strength of polyimide film permits use of film thicknesses as low as 0.001". This results in extremely fast response time and quick transfer of heat from the heating element to the object being heated (usually referred to as the heatsink). Polyimide film also has very good chemical resistance. While polyimide film excels in most of the physical and electrical properties required for a flexible heater, its downside is cost.

Silicone rubber. Silicone rubber heaters combine high operating temperature with moderate price. The most common silicone rubber substrates used for flexible heaters are reinforced with glass fibers to enhance dimensional stability. Silicone rubber heaters can operate continuously at temperatures exceeding 450°F. There is no separate adhesive system for rubber heaters. The base and cover material is generally supplied to the manufacturer as a laminate with cured rubber on one side and uncured rubber on the other. The etched resistive foil pattern is sandwiched between the two sheets of rubber and then laminated to seal.

Polyester (PET). Polyester film is a good choice if the application does not have high temperature requirements and is cost-sensitive. The maximum operating temperature of polyester is less than 225°F. This limitation makes polyester a very distant third behind polyimide film and silicone rubber in total flex heater usage. The relatively low temperatures tolerated by polyester also require special attention be paid to manufacturing processes that utilize elevated temperatures. Special nonstandard adhesives may have to be used to bond the foil element to the polyester base and cover.

For adhesives, these include:

Modified acrylic (film). Modified acrylic adhesive is a popular choice for flexible heaters because it is easy to process, has excellent bond strength, and can operate at temperatures of up to 300°F. It is used almost exclusively in conjunction with polyimide film as the dielectric. When processed with good techniques, modified acrylic adhesive will stick well to just about any smooth, clean surface. For this reason, it can be used with all foil types. This adhesive can also be used to permanently bond a finished heater to a heatsink. It is difficult to use acrylic adhesive with polyester because the temperature needed to cure the adhesive would melt or significantly soften the polyester.

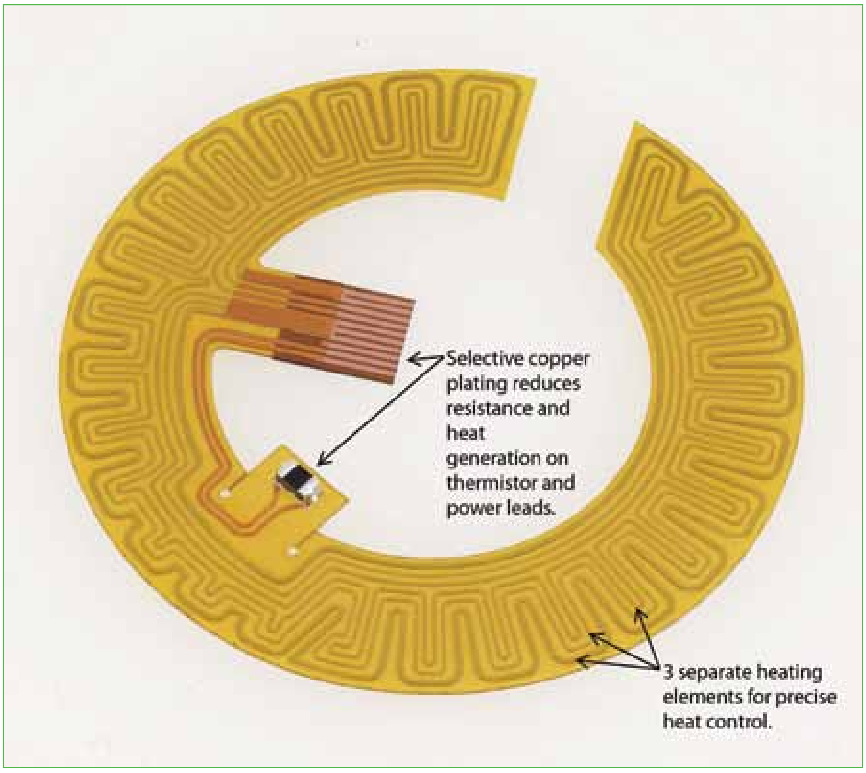

FIGURE 1. Flexible heaters can have multiple heating elements for precise temperature control, and also selective copper plating in areas where heating is not desirable.

Modified epoxy (film). Modified epoxy adhesive is very similar to modified acrylic, and in most cases, the two adhesive systems are interchangeable. Acrylic and epoxy adhesives look the same, process the same, and perform very closely in the finished product. A notable difference is that epoxy has a very slight edge on temperature and chemical resistance over acrylic. US manufacturers tend to lean toward acrylic adhesive, while Asian manufacturers favor epoxy adhesive. Like acrylic adhesive, epoxy adhesive is difficult to use with polyester and is used mainly in conjunction with polyimide film as the insulator.

Teflon (FEP). Teflon adhesive is used in applications that require the material to tolerate either very high or very low temperatures, or both. While this material can operate from less than -300°F to nearly 400°F, its selection significantly reduces the number of vendors that can build the heater due to the high processing temperatures.

Polyimide adhesive. B-stage polyimide is typically supplied to the flex heater manufacturer in the form of a laminate in which adhesive is coated to one side of a sheet of cured polyimide film. This material is the most expensive of the commonly used adhesives, and is also the most difficult to process due to the high lamination temperatures required for curing of the B-stage adhesive. As with FEP, specifying this material will significantly reduce the supplier base. Once cured, polyimide adhesive can withstand much higher temperatures (up to 500°F) than any of the other adhesives.

Heater Design Considerations

Once the materials to construct the heater have been selected, the next step is to lay out the heater element pattern(s). Most heaters will have a single continuous element that serpentines around the heater area, but some heaters will have multiple elements that can be controlled independently from one another for precise temperature control.

The heater element artwork layout requires the heater designer to fill up the area to be heated with uniform conductor pattern(s) that will yield the necessary resistance. Heater element patterns can also be profiled with smaller traces in areas that require more heat and wider traces in areas requiring less heat. As mentioned, selective areas of the heater element can be plated with copper (on cupronickel and constantan) to significantly reduce the heat generated in those select areas.

Once the heater material selection and heater element layout are complete, manufacturing is relatively straightforward. The flexible heaters are processed much like single-sided flexible circuits. The heater element traces are defined using a photo-etch process, and then the cover insulation is laminated in place with heat and pressure. Prior to laminating the cover insulation, many heaters will have lead wires soldered, welded or brazed to the heater element.

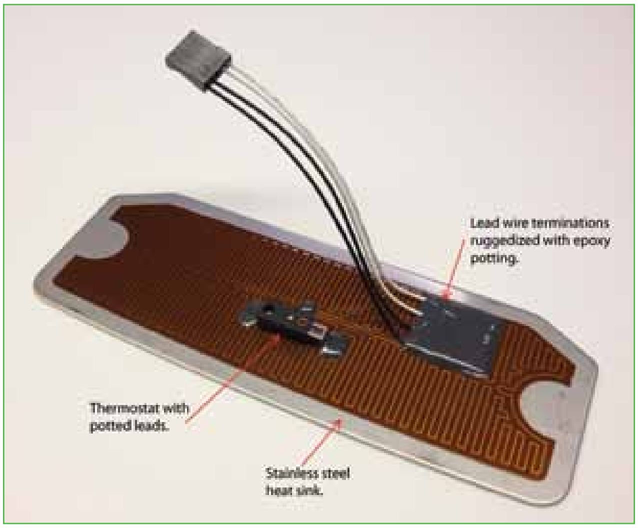

FIGURE 2. Flexible heaters can be mounted to a heatsink to save assembly time and potential yield fallout. Components such as thermostats, thermistors and lead wires can also be mounted and ruggedized.

Terminations. On the vast majority of flexible heaters, power is supplied via lead wires that are welded, brazed or soldered to pads on the heater. Connectors can be used in applications where the foil can be soldered (i.e., cupronickel, constantan, etc.). Also, insulation displacement contacts can be a cost-effective and reliable means to bring power to the heater. Because these contacts do not require soldering, they can be used on all types of resistive foil. When using insulation displacement contacts, heater foil thickness should be at least 0.002" for ease of manufacturing.

Mounting to heatsink. The final step to complete the heater assembly is to attach the heater to the item to heat (heatsink). This can be done by either the end-user or by the flex heater manufacturer. Probably the most common adhesive used to mount a heater to a heatsink is an acrylic or silicone-based pressure-sensitive adhesive. It is very important to ensure that the heater is mounted to the heatsink with no voids or air bubbles between the heater and the heated surface. These voids will keep the heat generated by the element from being transferred to the heatsink efficiently. This in turn can cause isolated hot spots in the heater element. If the hot spot is large enough, the resulting temperatures can cause the heater element to burn out like a fuse. For this reason, most heater users prefer to have the flexible heater mounted by the heater manufacturer.

And I would be remiss if I did not mention that the folks that build these products are the experts. They can assist in material/termination selection, element layout, and heater attachment methods. Engaging them early in the design offers the greatest chance of success on a heating project. PCD&F

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