Appendix C: Sensor Packaging and Installation

Installation

Once you have selected a sensor and it has been calibrated by Lake Shore, some potential difficulties in obtaining accurate temperature measurements are still ahead. The proper installation of a cryogenic temperature sensor can be a difficult task. The sensor must be mounted in such a way so as to measure the temperature of the object accurately without interfering with the experiment. If improperly installed, the temperature measured by the sensor may have little relation to the actual temperature of the object being measured.

Figure 1—Typical sensor installation on a mechanical refrigerator

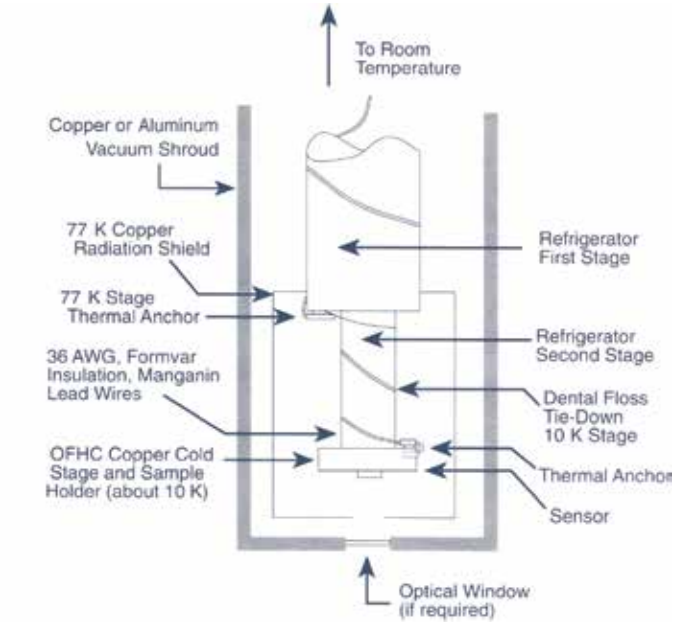


Figure 1 shows a typical sensor installation on a mechanical refrigerator. Note the additional length of lead wire wrapped around the refrigerator stages to minimize thermal conductance along the leads. If the optical radiation load through the window is large, the sample temperature will not necessarily be the same as that of the sensor in the block. A sensor placed in more intimate contact with the sample may be required.

General installation considerations

Even with a properly installed temperature sensor, poor thermal design of the overall apparatus can produce measurement errors.

Temperature gradients

Most temperature measurements are made on the assumption that the area of interest is isothermal. In many setups this may not be the case. The positions of all system elements—the sample, sensor(s), and the temperature sources—must be carefully examined to determine the expected heat flow patterns in the system. Any heat flow between the sample and sensor, for example, will create an unwanted temperature gradient. System elements should be positioned to avoid this problem.

Optical source radiation

An often overlooked source of heat flow is simple thermal or blackbody radiation. Neither the sensor nor the sample should be in the line of sight of any surface that is at a significantly different temperature. This error source is commonly eliminated by installing a radiation shield around the sample and sensor, either by wrapping super-insulation (aluminized Mylar®) around the area, or through the installation of a temperature-controlled aluminum or copper shield (see Figure 1).

2-lead versus 4-lead measurement

4-lead measurements are recommended for all sensors. 2-lead measurements can be performed with diode sensors with a small increase in uncertainty. Refer to Appendix E: Temperature Measurement, for a detailed discussion.

High temperature effects

Below room temperature, the primary effect of using dissimilar materials bonded together in sensing elements or packages is stress-induced by different expansion coefficients. Above room temperature, additional problems can occur. Alloying, diffusion (Kirkendahl voids), chemical reactions, and corrosion (especially in the presence of moisture and chlorine) accelerate as the temperature increases. These factors can cause catastrophic failure with time, or a shift in the sensor calibration. Completely accurate de-rating data for all situations that could be encountered is impossible to compile.

Conduction (lead attachment)

Another source of heat flow that is often neglected is conduction through the electrical leads that run between the sensor and the ambient environment. 32- or 36-gauge, low thermal conductivity wire such as phosphor bronze or manganin is used to alleviate this problem. These leads must also be thermally anchored at several successive temperature points between ambient temperature and the sensor. Performing a 4-lead measurement will overcome the high lead resistance.

The physical mounting of the leads of a sensor is as important as the mounting of the sensor itself. Thermal contact to the active element in a cryogenic sensor occurs both through the sensor body and the electrical leads. In fact, for some sensors (e.g., germanium resistance thermometers) the primary thermal contact is through the leads. For accurate temperature readings, the sensor and its leads must be anchored so they are at the same temperature as the sample being measured. Table 1 shows typical heat sinking lengths.

Table 1—Wire heat-sinking length required to thermally anchor to a heat sink at temperature T to bring the temperature of the wire to within 1 mK of T_{lower}

			Heat-sinking length (mm) for wire sizes			
	T_{upper} (K)	T_{lower} (K)	0.21 mm² (24 AWG)	0.032 mm² (32 AWG)	0.013 mm² (36 AWG)	0.005 mm² (40 AWG)
Copper	300	80	160	57	33	19
	300	4	688	233	138	80
Phosphor bronze	300	80	32	11	6	4
	300	4	38	13	7	4
Manganin	300	80	21	4	4	2
	300	4	20	7	4	2
304 SS	300	80	17	6	3	2
	300	4	14	5	3	2

Note: values are calculated assuming wires are in a vacuum environment, and the thermal conductivity of the adhesive is given by the fit to the thermal conductivity of VGE-7031 varnish

There are a number of ways in which sensor leads can be properly anchored, with the choice usually determined by the needs and constraints of the particular application. Longer leads may be wound directly around a sensor adaptor or another anchor adjacent to the sample and varnished into place. The varnish serves two purposes: it physically holds the leads in place, and it increases the contact surface area between the wire and the sample, or sample holder. VGE-7031 varnish is widely used as a low-temperature adhesive and can be easily removed with methanol. As long as the leads are electrically insulated with an enamel-type coating, such as Formvar® (see caution note) or polyimide, the varnished-down leads provide a suitable thermal anchor (thermal short) to their surroundings. Leads with heavy insulation, such as Teflon®, minimize the potential for making a thermal short to the surroundings, resulting in more thermal conduction down the leads into the sensing element. Resulting temperature measurement errors can be significant.

TIP: maintain electrical isolation

To maintain good electrical isolation over many thermal cycles, a single layer of cigarette paper can be varnished to the thermal anchor first, and the wire then wound over the paper and varnished down. The actual sensor leads are then soldered to this thermally anchored lead wire after the sensor body is mounted. For a more permanent installation, replace the VGE-7031 varnish with a suitable epoxy such as Stycast® 2850-FT.

Caution: varnish can cause crazing of Formvar® insulation.

One can make a separate thermal anchor to which the thermometer leads are attached. A typical technique for producing a physically compact anchor uses small gauge wire (32 AWG) insulated with Formvar®, polyimide, or a similar coating. The wire is wound around the sample in a bifilar manner or onto a separate bobbin and bonded with varnish. For most applications, a bonded length of 5 cm to 10 cm provides a sufficient thermal anchor unless poor practices elsewhere in the system permit excessive heat leaks down the leads. Copper wire may require several meters for heat sinking.

What you may need:

Wire

- ✓ Phosphor bronze
- ✓ Manganin
- ✓ Nichrome
- ✓ Copper
- Constantan
- ✓ Stainless steel coaxial cable

Solders

- 60/40 lead/tin
- ✓ 90/10 lead/tin
- ✓ Silver
- ✓ Ostalloy® 158 (Wood's metal)
- Indium-silver
- ✓ Indium

Fluxes

- RMA
- Keep Clean flux
- Stay Clean flux
- Stay Silv® flux

Insulating materials

- Ceramics
- Masking tape
- ✓ Polyester tape
- Kapton® films
- Teflon® tape
- Heat shrink tubing
- G-10
- Mylar® (polyester film)
- Fiberglass sleeving
- ✓ Epoxies
- ✓ VGE-7031 varnish
- ✓ Stycast® 2850 FT epoxy
- Cigarette paper
- ✓ Greases (Apiezon® N & H)

Conducting materials

- ✓ Silver filled epoxy
- Silver conductive paint
- ✓ Indium foil

Fasteners

- Dental floss
- ✓ Clamps
- Screws/bolts
- ✓ VGE-7031 varnish
- ✓ Stycast® 2850 FT epoxy

Heat sinking

- ✓ Copper bobbins
- ✓ Metallized ceramic chips

Other accessories

- ✓ Vacuum feedthroughs
- ✓ Cartridge heaters

✓ *Lake Shore stocks these accessories as a convenience to our customers*

Cryogenic accessories for installation

Cryogenic wire

Cryogenic wire is different from normal wire due to its low thermal conductivity and high electrical resistivity. The most common types of cryogenic wire are phosphor bronze and manganin. Phosphor bronze is a nonmagnetic copper alloy. Manganin wire has a lower thermal conductivity (a factor of about 1/3) and higher resistivity compared to phosphor bronze wire. Both are readily available in small gauges ranging from 32 to 42 AWG. Either polyimide or polyvinyl formal (Formvar®) is used to insulate the wires. The polyimide is a resin with a 220 °C thermal rating. It has exceptional resistance to chemical solvents and toxic heat. It also is unaffected by exposure to varnish solvent. Formvar® is a vinyl acetate resin rated at 105 °C. It has excellent mechanical properties such as abrasion resistance and flexibility. The film will withstand excessive elongation without rupture when stressed during winding. Formvar® has a tendency to craze upon contact with solvents such as toluol, naptha, and xylol. It should be given an annealing preheat prior to varnish application. The Formvar® insulation can be removed mechanically or chemically during terminal preparation.

Phosphor bronze wire is readily available in multifilar form with 2 or 4 wires. In bifilar form, the wires are twisted to minimize noise pickup. In quadfilar form, the wires are either straight or 2 twisted pairs twisted together. The latter form is most useful for standard 4-lead measurements. The wires are bonded together for ease in heat sinking while the twisting helps minimize noise pickup. Straight Quad-Lead™ wire can be bonded together with the help of VGE-7031 varnish. The bonding agent is soluble in alcohol.

Other types of common cryogenic wires include nichrome wire, which has a very high electrical resistivity making it excellent for heater windings. Ultra miniature flexible coaxial cables with 304 stainless steel or copper conductors are available for providing shielded leads when necessary. For low resistance, heavy duty lead wires and multifilar silver-plated twisted copper wire are available. Constantan wire is another copper alloy having just a little more copper content than manganin. As such, its resistivity is a little lower, while its thermal conductivity is a little higher. Evanohm® wire is a very high resistivity wire (about 5 times the resistivity of nichrome) with very small temperature dependence. This wire is also excellent for heater windings.

TIP: Making your own ribbon cable—ease of handling

Two nails should be hammered into a piece of wood at a distance of just over half the needed lead length. The wire is wrapped continuously from one nail to the other. With a rubber or plastic glove, apply a thin coating of VGE-7031 varnish along the entire length of the wires and allow to dry. Then the cable can be cut for full length. (Remember that the solvents in VGE-7031 varnish will attack Formvar® insulation.)

Solders and fluxes

The most common electrical connections are solder joints. There are a number of solder compounds available such as 60/40 tin/lead, silver, Wood's metal, cadmium/tin, and indium. They have varying melting points, and the melting points sometimes determine the upper temperature limit for a sensor. Care should be taken when using these solders, as the fumes are toxic. Also, many of these solders become superconducting at lower temperatures. The transition temperature should be checked if this could affect your experiment. (Read on to the fasteners section for more comments on solders.)

There are a number of fluxes that are used with these solders. Rosin Mildly Activated (RMA) soldering flux is an electronic grade rosin flux typically used for soldering wires to temperature sensors. Keep Clean flux is a mild acid flux used when RMA flux is not effective. It is strong enough to clean the oxidation off the surface and the solder to promote a good joint. It is very useful in situations where joints are repeatedly made and broken. Stay Clean flux is a corrosive acid flux used when neither of the above are useful. It is commonly used with stainless steel and platinum. Due to its highly corrosive nature, it must be cleaned off with methanol or water or it will continue to corrode the material. Stay Silv® flux is a high temperature flux for use with high temperature solders such as silver solder. It is not useful on aluminum, magnesium, or titanium.

It is often difficult to make electrical connection to many of the materials used for electrical leads in cryogenic applications. These lead materials include Kovar, copper, gold, phosphor bronze, manganin, constantan, platinum, stainless steel, and nichrome. Soldering these materials can be problematic. The small diameter wire complicates the problem by making it difficult to heat the wire uniformly, allowing the solder to flow. Choosing a proper flux and solder for the wire is crucial to making a reliable electrical connection with minimal effort.

Most of the sensors shipped by Lake Shore have undergone testing to ensure proper operation. Their electrical leads have been tinned. For these sensors, a standard electronic grade RMA flux is appropriate. This flux is also appropriate for Kovar, gold, and copper leads that have not been tinned. For other wire types, a more corrosive acid flux is needed. Stay Clean flux is recommended for untinned wire consisting of constantan, manganin, phosphor bronze, platinum, nichrome, or stainless steel.

Note: Care must be taken to thoroughly clean the residual Stay Clean flux off with water or methanol after use to prevent further corrosion.

Typically, standard 60/40 Sn/Pb solder can be used for applications ranging from 0.05 K to 350 K (liquidus point of 461 K and solidus point 456 K). This solder can be used with any of the above material types after tinning. If the application requires a higher temperature, then use 90/10 Pb/Sn solder (liquidus point of 575 K and solidus point 548 K). For very high temperatures up to 800 K, use Stay Silv® flux with cadmium-free silver solder (liquidus point of 922 K; solidus point of 891 K).

Insulating materials

When installing electrical leads at low temperatures, it is important to know what insulation materials can be used. Insulating materials that work well at cryogenic temperatures include ceramics, temporary masking tape, polyester film tape, Kapton® film, Teflon® tape and tubing, G-10, Mylar®, epoxies, varnishes, cigarette paper (used under VGE-7031 varnish), and greases.

The most common varnish for cryogenic work is VGE-7031 varnish. It has good chemical resistance, bonds to a variety of materials and has a fast tack time. It may be air-dried or baked. VGE-7031 varnish is compatible with cotton, Dacron® polyester fiber, nylon, glass tapes, laminates, Mylar® polyester film, mica products, polyester products, vinyl products, wire enamels, paints, rayon, plastics, and metals. The solvents in VGE-7031 varnish will attack Formvar® insulation, causing it to craze, but in most cases this will not be a problem after drying thoroughly.

Stycast® 2850FT and GT are composed of a black epoxy resin, filled with silica powder to give them a lower thermal expansion coefficient. The FT is roughly matched to copper, while the GT is roughly matched to brass. The result is a material that is very strong, adheres well to metals, and tolerates brief exposure up to 200 °C for soldering. The drawbacks are that it is essentially unmachinable, has a non-negligible magnetic susceptibility and a temperature-dependent dielectric constant at low temperatures, and is somewhat permeable to helium at room temperature.

Another useful insulator is Kapton® tape. It is a polyimide tape with a thin coating of Teflon® FEP on either or both sides of the film to provide adhesion. The principal advantages of this severed tape insulation is its uniform, pinhole free covering and thermal stability for continuous use up to 240 °C. It has exceptional cut-through resistance under extreme temperature and pressure conditions. This Kapton® insulation offers excellent moisture protection and, because it is smooth and thin, has a space advantage over glass, Dacron® glass, paper, and fiber-over-film constructions. It is compatible with all standard varnishes, and is highly resistant to solvent attack.

Conducting materials

Sometimes it is desired to make electrical contact between materials. The solders previously mentioned are electrically conducting, as are certain epoxies (silver-filled) and silver conductive paint.

Fasteners

A variety of materials are suitable for fastening sensors at low temperatures. These include dental floss (Dacron® fiber), screws, bolts, pins, springs, tape, pastes, solders, epoxies, and varnishes. You must consider coefficients of linear expansion when deciding upon a mounting scheme. If linear expansion coefficients are too mismatched, mountings will simply come loose, or in the worst case, damage the mounting surface or the sensor. Expansion coefficients should never differ by more than a factor of 3 between two materials being bonded together. Greases such as Apiezon™ N grease, H grease, and Cry-Con® grease can be used to increase the surface area of contact between a sensor and the mounting surface. VGE-7031 varnish accomplishes the same purpose, as does Stycast® 2850. Mounting the sensor with Stycast® is more permanent.

If the Stycast® is being used with diodes, the user should be aware that stress on the diode package can cause piezoresistive shifts in the calibration curve. In extreme cases, (e.g., by using hard solder between the SD package and copper), the package can crack. The best joint in almost all cases is made by pure indium, which remains malleable at all temperatures. The exceptions are for service temperatures over 125 °C or where strength is paramount. Indium can also corrode rapidly in the presence of moisture under thermal cycling conditions.

TIP: Where to buy flux & solder

RMA flux is available from most electronics supply stores as well as Kester Solder, 515 E. Touhy Avenue, Des Plaines, IL 60018

60/40 Sn/Pb solder is also available from most electronics supply stores both with and without RMA flux.

Stay Clean soldering flux, Stay Silv® white brazing flux, and cadmium-free silver solder are available from J. W. Harris Company, Inc., 10930 Deerfield Road, Cincinnati, OH 45242

SD package installation

Three aspects of using a cryogenic temperature sensor are critical to its optimum performance. The first involves the proper mounting of the sensor package; the second relates the proper joining of sensor lead wires and connecting wires; the final concern is the thermal anchoring of the lead wires. Although the sequence in which these areas should be addressed is not fixed, all elements covered under each aspect should be adhered to for maximum operating capabilities of the sensor.

Sensor mounting

1. The mounting area should be prepared and cleaned with a solvent such as acetone followed by an isopropyl alcohol rinse. Allow time for the solvents to evaporate before sensor mounting.

2. The list below provides brief instructions on mounting a sensor using a number of different methods. The constraints of your application should dictate the most appropriate mounting method to follow.

   Mechanical—The preferred method for mechanically mounting an SD sensor is using the Lake Shore spring loaded clamp. This clamp should be ordered at the time the sensor is ordered (-CO suffix on sensor part number). The clamp holds the SD sensor in contact with the surface and also allows the sensor to be changed or replaced easily. A thin layer of Apiezon® N Grease (0.055 mm) or a flat 100% indium preform should be used between the sensor and mounting surface to enhance thermal contact. The spring keeps the sensor from getting crushed.

   Indium solder (100% In)—A low wattage heat source should be used, as the sensor temperature must never exceed 200 °C (147 °C for Cernox®). The mounting surface and sensor should be tinned with a rosin flux (RMA is recommended) prior to mounting the sensor. A thin, uniform layer of indium solder should be the goal. Clean both the sensor and mounting surface of residual flux using rosin residue remover. Once the surface area is dry, reheat the mounting surface to the melting point of the solder (156 °C). Press the sensor into position and allow it to warm to the melting point of the solder. Remove the heat source and allow sufficient time for the solder to solidify (typically 2 to 3 seconds) before removing it.

   Apiezon® N grease—This is best used as a thermal conductor when the sensor is mounted in a hole or recess, and when the sensor is intended to be removed. The sensor should be surrounded with thermal grease and placed into the mounting position. When the temperature is lowered, the thermal grease will harden, giving good support and thermal contact.

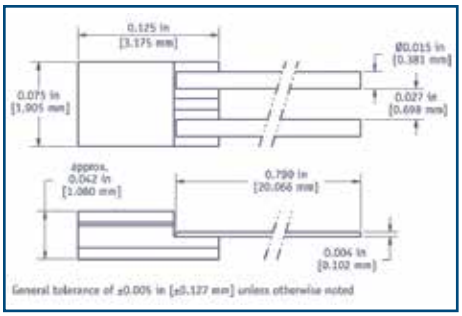


Figure 2 – *SD Package*

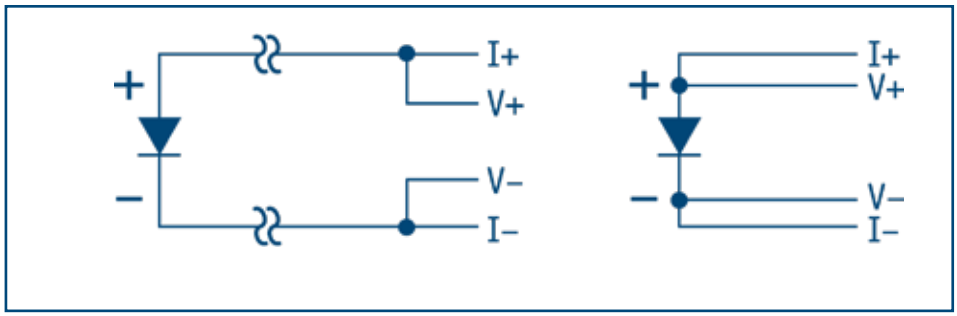


Figure 3 – *2-Lead versus 4-Lead Measurements*

VGE-7031 varnish—Prepare varnish and apply a thin layer on the mounting surface. Press the sensor firmly against the varnish during curing to ensure a thin bond layer and good thermal contact. Varnish will air-dry in 5 to 10 minutes. Sufficient time must be allowed for the solvents in the varnish to evaporate. There is a small probability of ionic shunting across the sensor during the full cure period of the varnish (typically 12 to 24 hours).

Stycast® 2850FT epoxy—Prepare epoxy and apply a thin layer on the mounting surface. Press the sensor firmly into the epoxy during curing to assure a thin bond layer and good thermal contact. Epoxy will cure in 12 hours at 25 °C or in 2 hours at 66 °C.

Note: When using an electrically conductive adhesive or solder, it is important that the excess does not "creep-up" the edges of the sensor or come in contact with the sensor leads. There is a thin braze joint around the sides of the SD package that is electrically connected to the sensing element. Contact to the sides with any electrically conductive material will cause a short.

3. Follow manufacturer's instructions for adhesive curing schedule. Never heat the sensor above 200 °C (147 °C for Cernox®).

Lead attachment

1. Although the SD sensor package (Figure 2) is a 2-lead device, measurements should preferably be made using a 4-wire configuration to avoid uncertainties associated with lead resistance.

   2-lead measurement scheme—The leads used to measure the voltage are also the current carrying leads. The resulting voltage measured at the instrument is the sum of the temperature sensor voltage and the voltage drop across the 2 leads (see Figure 3).

   4-lead measurement scheme—The current is confined to one pair of current leads with the sensor voltage measured across the voltage leads (see Figure 3).

2. Lead polarity: for the silicon diode and for the GaAlAs diode, when viewed with the base down (the base is the largest flat surface) and the leads toward the observer, the positive lead (anode) is on the right and the negative (cathode) is on the left. For Cernox® there is no polarity.

3. Strip the insulation from the connecting wires by scraping delicately with a razor blade, fine sand paper, or steel wool. Phosphor bronze or manganin wire, in sizes 32 or 36 AWG, is commonly used as the connecting lead wire. These wires have low thermal conductivity and high resistivity, which help minimize the heat flow through the leads. Typical wire insulation is polyvinyl formal (Formvar®) or polyimide (ML). Formvar® insulation has better mechanical properties such as abrasion resistance and flexibility. Polyimide insulation has better resistance to chemical solvents, heat, and radiation.

4. Prepare the connecting wire ends with an RMA (rosin mildly active) soldering flux, and tin them with a minimal amount of 60% Sn 40% Pb solder. Use a low wattage soldering iron which does not exceed 200 °C.

5. Clean off residual flux with rosin residue remover. The sensor leads can be prepared in an identical manner.

6. Join one sensor lead with two of the connector wires. Apply the soldering iron to the connector wire above the joint area until the solders melt, then remove the iron. Repeat for the other set of connector wires and the other sensor lead. Heat sinking the SD sensor with a flat jaw alligator clip is good practice to eliminate heat buildup at the sensor element.

7. Avoid putting stress on the device leads, and leave enough slack to allow for the thermal contractions that occur during cooling which could fracture a solder joint or lead. Some epoxies and shrink-tubing can put enough stress on lead wires to break them.

Heat sinking/thermal anchoring

1. Since the area being measured is read through the base of the sensor, heat flow through the connecting leads creates less of an offset between the sensor chip and the true sample temperature than with other types of packages. However, thermal anchoring of the connecting wires is necessary to ensure that the sensor and the leads are at the same temperature as the sample.

2. Connecting wires should be thermally anchored at several temperatures between room temperature and cryogenic temperatures to guarantee that heat is not being conducted through the leads to the sensing element. Two different size copper bobbins are available from Lake Shore for heat sinking leads.

3. If connecting wires have a thin insulation such as Formvar® or polyimide, a simple thermal anchor can be made by winding the wires around a copper post, bobbin, or other thermal mass. A minimum of 5 wraps around the thermal mass should provide sufficient thermal anchoring, however, additional wraps are recommended for good measure if space permits. To maintain good electrical isolation over many thermal cycles, it is good practice to first varnish a single layer of cigarette paper to the anchored area then wrap the wire around the paper and bond in place with a thin layer of VGE-7031 varnish. Formvar® wiring insulation has a tendency to craze with the application of VGE varnish. If used, the wires cannot be disturbed until the varnish is fully cured and all solvents have evaporated (typically ≥24 hours).

4. A final thermal anchor at the sample itself is good practice to ensure thermal equilibrium between the sample and temperature sensor.

CU, DI, CY, and CD package installation

Three aspects of using a cryogenic temperature sensor are critical to its optimum performance. The first involves the proper mounting of the sensor package; the second relates the proper joining of sensor lead wires and connecting wires; the final concern is the thermal anchoring of the lead wires. Although the sequence in which these areas should be addressed is not fixed, all elements covered under each aspect should be adhered to for maximum operating capabilities of the sensor.

Sensor mounting

The CU, DI, and CY packages (Figures 4 and 5) combine a standard SD sensor with a gold-plated copper mounting bobbin. The mounting bobbin of these packages each has a hole designed for mounting with a #4-40 screw. The CD package is shown in Figure 6.

1. A threaded hole in your mounting surface is necessary for mounting the sensor package. The hole in the sensor package will accommodate a #4-40 screw. A brass screw is recommended due to the thermal contractions/expansions of the final assembly.

2. The threaded hole and surrounding surface should be cleaned with a solvent such as acetone followed by an isopropyl alcohol rinse. Allow time for the solvents to evaporate before sensor mounting.

3. Apply a small amount of Apiezon® N grease to the threads of the screw. To ensure good thermal contact between the sensor and mounting surface, use an indium washer/preform or a thin layer of Apiezon® N grease between the mounting surface and the sensor package. Note: An overabundance of grease will increase the thermal barrier. Keep the thickness to 0.05 mm or less.

4. Insert screw through sensor mounting bobbin and tighten screw firmly enough to hold sensor in place. Avoid overtightening (torque of 3 to 5 in-oz [0.2 to 0.35 N-m] should be sufficient).

Lead attachment

The SD sensor has been attached to the mounting bobbin and encapsulated in Stycast® epoxy. The 0.92 m (36 in) Polyimide (ML) insulated sensor leads are 36 AWG phosphor bronze wire which are thermally anchored to the bobbin. Teflon® tubing is used as a strain relief to reinforce the leads at the bobbin assembly. The difference between the CU package and the DI package is the connecting lead configuration. Standard lead configuration for the CU is a 4-lead device [red (I-), green (V-), black/dark blue (V+), clear (I+)] while standard lead configuration for the DI package is a 2-lead device [green = cathode (-), clear = anode (+)].

Figure 4—*CU & DI package*

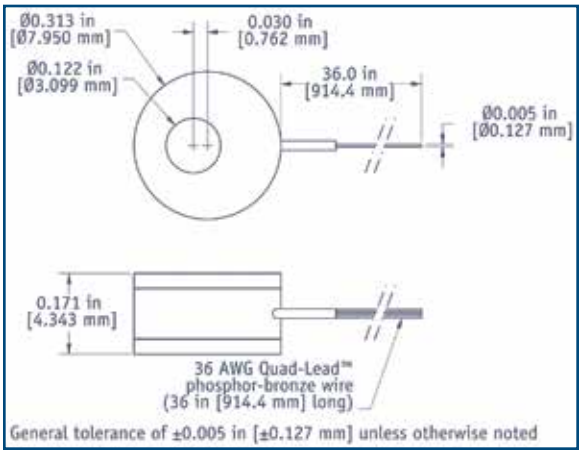


Figure 5—*CY package*

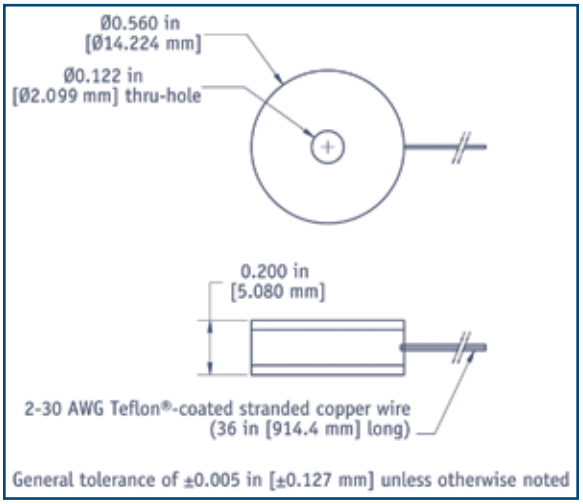
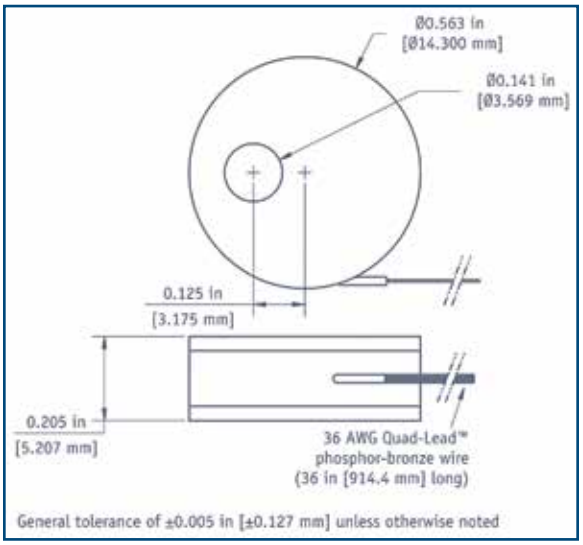


Figure 6—*CD package*



DI package—2-lead measurement scheme

The leads used to measure the voltage are also the current carrying leads. The resulting voltage measured at the instrument is the sum of the temperature sensor voltage and the voltage drop within the two current leads (see Figure 3).

CU package—4-lead measurement scheme

The current is confined to one pair of current leads with the sensor voltage measured across the voltage leads (see Figure 3).

Thirty-six inches of lead wire is attached during the production process. If additional connection wire is required, use the following instructions:

1. Prepare the sensor leads with an RMA (rosin mildly active) soldering flux, and tin them with a minimal amount of 60% Sn 40% Pb solder. Use a low wattage soldering iron that does not exceed 200 °C. Clean off residual flux with rosin residue remover.

2. Strip the insulation from the connecting wires by scraping delicately with a razor blade, fine sand paper, or steel wool. (Phosphor bronze or manganin wire, in sizes 32 or 36 AWG, is commonly used as the connecting lead wire. These wires have low thermal conductivity, which help minimize the heat flow through the leads. Typical wire insulation is Formvar® or Polyimide (ML). Formvar® insulation has better mechanical properties such as abrasion resistance and flexibility. Polyimide insulation has better resistance to chemical solvents and burnout.) Follow the same procedure as Step 1 for preparing connecting wires.

3. DI package—join one sensor lead with two of the connector wires. Apply the soldering iron above the joint area until the solders melt, then remove the iron immediately. Repeat for the other connecting wires and the other sensor lead. Insulate the joints appropriately.

   CU package—identify lead polarities and apply the soldering iron above the joint area until the solders melt, then remove the iron immediately. Leave enough slack to allow for the thermal contractions that occur during cooling, which could fracture a solder joint or lead. Insulating the soldering joint is recommended to prevent shorts. Use heat shrink tubing. Teflon® and Kynar® shrink tubings are more resistant to cracking at low temperatures than polydelefin.

Heat sinking/thermal anchoring

Depending on the application, sufficient heat sinking of the leads may already exist in the bobbin. Use the following procedure if additional heat sinking is recommended:

1. Connecting wires should be thermally anchored at several temperatures between room temperature and cryogenic temperatures to guarantee that heat is not being conducted through the leads to the sensing element.

2. A simple thermal anchor can be made by winding the wires around a copper post, bobbin, or other thermal mass. A minimum of 5 wraps around the thermal mass should provide sufficient thermal anchoring, however, additional wraps are recommended for good measure if space permits. To maintain good electrical isolation over many thermal cycles, it is good practice to first varnish a single layer of cigarette paper to the anchored area then wrap the wire around the paper and bond in place with a thin layer of VGE-7031 varnish. Formvar® wiring insulation has a tendency to craze with the application of VGE varnish. If used, the wires cannot be disturbed until the varnish is cured and all solvents have evaporated (typically ≥ 24 hours).

Copper AA package

Three aspects of using a temperature sensor are critical to its optimum performance. The first involves the proper mounting of the sensor package; the second relates to the proper joining of sensor lead wires and connecting wires; the final concern is the thermal anchoring of the lead wires. Although the sequence in which these areas should be addressed is not fixed, all elements covered under each aspect should be adhered to for maximum operating capabilities of the sensor.

Sensor mounting

Shown in Figure 7, the copper AA package (or "can") is designed for mounting in a 3.2 mm (⅛ in) hole.

1. A hole should be drilled 3.2 mm (⅛ in) diameter by 8.5 mm (0.335 in) deep minimum for the copper can.

2. Surface area should be cleaned with a solvent such as acetone followed by an isopropyl alcohol rinse. Allow time for the solvents to evaporate before sensor positioning.

3. A small amount of Apiezon® N grease should be applied around the mounting surface and the sensor to enhance thermal contact.

4. Position the copper can so that it is fully submerged in the mounting hole.

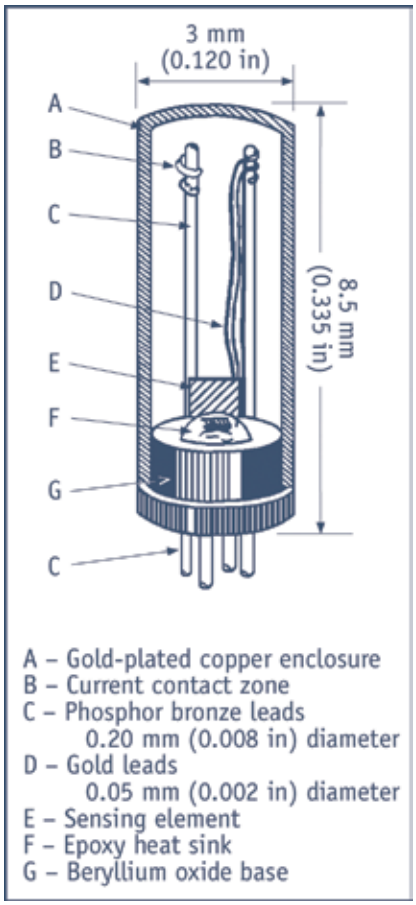


Figure 7—Copper AA package with Cernox® sensor shown. While internal connections are different for the other sensors, the overall package dimensions are the same.

Lead configurations

Four leads are attached with strain relief at the sensor. For Cernox®, germanium, and rhodium-iron sensors, each lead is 32 AWG (0.20 mm diameter) phosphor bronze wire, insulated with heavy build polyimide to an overall diameter of 0.24 mm (0.0095 in), 150 mm (6 in) long. For Rox™ sensors, each lead is 34 AWG (0.15 mm diameter) copper wire, insulated with heavy build polyurethane nylon to an overall diameter of 0.185 mm (0.0073 in), 15 cm (6 in) long. Thermal rating of the insulation is 220 °C. Leads are color-coded at the base of each sensor.

Table 2—Key/color code

	Rox™*	Cernox®	Germanium	Rhodium-iron
I+	—	White	White	White
V+		White	Yellow	White
I–	—	Black	Black	Black
V–		Black	Green	Black

* *The Rox™ ruthenium oxide RTD uses the copper AA package but is a 2-lead only device. The leads have no specific polarity. While the Rox™ is built as a 2-lead device, the sensor should be operated in a 4-lead measurement scheme to eliminate errors due to lead resistance, which can be significant.*

Extra lead attachment

If extra long leads are to be attached, then it is recommended that a 4-lead measurement scheme be used with this sensor. Attaching four connecting wires to the sensor leads is recommended. Refer to Table 2 to determine sensor lead polarity.

1. Prepare the sensor leads and connecting lead wires with a RMA (rosin mildly active) soldering flux, and tin them with a minimal amount of 60% Sn/40% Pb solder. Use a low wattage soldering iron that will not exceed 200 °C. Clean off residual flux with rosin residue remover. The sensing element inside the package should be protected from excessive heat by putting a heat sink clip over the package.

2. Strip connecting wire insulation by delicately scraping with a razor blade, fine sand paper, or steel wool. Phosphor bronze or manganin wire, in sizes 32 or 36 AWG, is commonly used as the connecting lead wire. These wires have low thermal conductivity, which helps minimize the heat flow through the leads. Typical wire insulation is polyvinyl formal (Formvar®) or Polyimide (ML). Formvar® insulation has better mechanical properties such as abrasion resistance and flexibility. Polyimide insulation has better resistance to chemical solvents and burnout.

3. Prepare the connecting wire ends with a RMA (rosin mildly active) soldering flux, tin them with a minimal amount of 60% Sn 40% Pb solder. Use a low wattage soldering iron that will not exceed 200 °C.

4. Clean off residual flux with rosin residue remover. The sensor lead can be prepared in an identical manner.

5. Attach one sensor lead with the connector wire and apply the soldering iron above the joint area until the solders melt, then remove the iron immediately. Repeat for the other set of connector wires and the other sensor lead.

6. Avoid putting stress on the device leads and leave enough slack to allow for the thermal contractions that occur during cooling that could fracture a solder joint or lead. This can be achieved with heat shrink tubing.

Heat sinking/thermal anchoring

1. Since the heat flow through the connecting leads can create an offset between the sensor substrate and the true sample temperature, thermal anchoring of the connecting wires is necessary to assure that the sensor and the leads are at the same temperature as the sample.

2. Connecting wires should be thermally anchored at several temperatures between room temperature and cryogenic temperatures to guarantee that heat is not being conducted through the leads to the sensing element.

3. If the connecting leads have a thin insulation such as Formvar® or polyimide, a simple thermal anchor can be made by winding the wires around a copper post, bobbin, or other thermal mass. A minimum of 5 wraps around the thermal mass should provide enough of an anchor, however, additional wraps are recommended for good measure if space permits. To maintain good electrical isolation over many thermal cycles, it is good practice to first varnish a single layer of cigarette paper to the anchored area, then wrap the wire around the paper and bond in place with a thin layer of VGE-7031 varnish. Formvar® wiring insulation has a tendency to craze with the application of VGE varnish. Once VGE varnish is applied, the wires cannot be disturbed until all solvents have evaporated and the varnish has fully cured (typically 12 to 24 hours).

4. A final thermal anchor at the sample itself is a good practice to ensure thermal equilibrium between the sample and temperature sensor.

Bare chip installation

General comments

All of the possible permutations for mounting the chips have not been thoroughly tested. Also, in order to avoid possible adverse effects on stability and thermal mass, heat capacity thermal response times, etc., chips also are not protected by a coating over the active film. The customer must therefore assume some risk of damaging the chips during installation. The sensor and contact films on the Cernox® chips, however, are refractory materials and difficult to scratch. The material presented below includes the best techniques we know to help assure the successful application of unencapsulated chips.

a. Use good fine-point tweezers. Grasp the chip by the edges at one end (at a contact pad end, if possible). This way, if the tweezers should scrape across the chip, the resistor will not be damaged. Alternately, the wires may be grasped with fingers or tweezers. In the latter case, the operator must develop a very light touch so the wires are not cut or damaged.

b. If it is necessary to apply pressure to the chip, do so with a cotton swab over the contact area, or with harder objects only outside the patterned area. Do not rub the chip.

c. Some dirt particles will not hurt the sensor reading, but conducting particles and moisture may, especially if halogen (e.g., chlorine, etc.) contaminants are present. If it is deemed necessary to clean the chips, place a few into a watch glass and rinse with appropriate solvents. (A watch glass is used because it has a curved surface and the sensor will touch only at its corners. It also has a shallow sloped surface, and the rinse liquids can be easily decanted.) Finish with a rinse of pure isopropyl alcohol. Decant the liquid and dry under a light bulb (≈50 °C). For chips with leads, hold the sensor by the leads and immerse it in isopropyl alcohol for a few seconds. CO_2 snow cleaning can also be very effective, as can ultraviolet/ozone treatments.

Attaching leads

There are several ways to apply electrical leads to the contact pads, which are gold over contact metal (not wetted easily with solder). In all cases, clamp the sensor chip by the edges and, if possible, do not rely on hand control to position and attach the wires. A clamp can be made from a small, smooth-jawed alligator clip (Figure 8) by cutting off the jaw on the side to which the wire is normally soldered and then fastening that side of the clip to a plate. Another method uses tape to hold the sensors (Figure 9). Kapton® tape and its adhesive will withstand epoxy cure temperatures (165 °C) and the adhesive will not come off on the chip. Do not use Scotch® tape.

The best way by far to connect the chip is to use a thermosonic gold ball bonder. The bonding is clean, uses no flux, and can be done at or near room temperature. The ball attachment at the pad also provides a robust way of making a flying lead that can be attached at the other end later (50 µm diameter gold wire).

Another way is to use silver-loaded conducting epoxy. Make sure the wire and the pads are clean. Use a flexible wire, 40 AWG or smaller, so undue stress will not be applied to the pads. Use a needle to apply small amounts of epoxy to the pads and to the ceramic substrate as well. If the epoxy must be heated in order to cure, a temperature of up to 200 °C could be tolerated by the chip (not Cernox®). This should be done before calibrating, however, since the calibration may shift slightly (shift may amount to 1% of reading at temperatures above 50 K and 0.05% at 4.2 K and below).

Mounting sensor chips

There are several means of attaching a chip to a substrate. It is possible for strain-induced shifts in calibration to occur. Therefore, keep in mind that the greater the expansion difference between the sensor substrate, the bonding substance and the mating piece, the more likely a strain-induced shift in the calibration may occur. If the joint is stable, this shift probably will be reproducible, and an in-situ calibration may remove the uncertainty. The only substance we have found capable of relieving stress during use is pure indium. This will only work with metallized substrates and in systems that can be heated if the joint is to be soldered.

If it is deemed advisable to use an indium solder joint for reasons of strain, and the mating piece cannot be soldered, a "buffer" layer of metallized BeO or sapphire can be used. Solder the chip to the buffer with indium, and use Stycast® 2850FT/catalyst 9 or equivalent epoxy to attach the buffer to the mating piece.

Stycast® 2850FT or another low expansion, nonconducting epoxy can be used for direct mounting as well. If epoxy is used to completely encapsulate the chip, stress-induced calibration shifts of up to 0.5 K can occur at lower temperatures.

If a greased mounting is desired (Apiezon® N or equivalent), the sensor could be inserted into a hole lined with cigarette paper or tied to a greased surface with thread or dental floss, with paper over it to avoid abrasion. The leads must be insulated with plastic sleeving, fiberglass sleeving, epoxy, or other technique.

VGE-7031 varnish is also a good mounting adhesive and is more easily removed than epoxy. It can be soaked into cigarette paper for a more reliable insulating layer for the leads. The substrate of the sensor is already insulating.

Figure 8

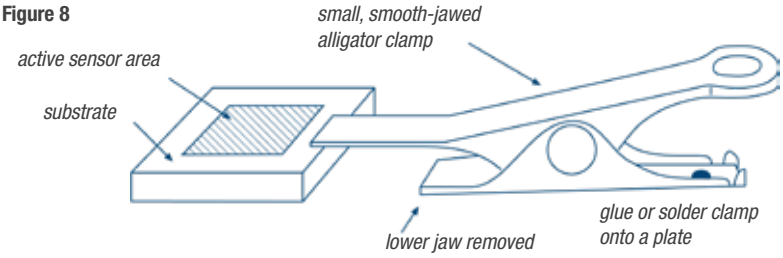
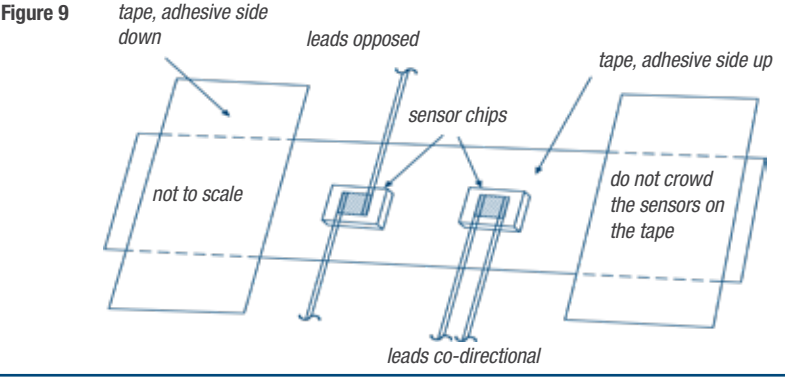


Figure 9



Attaching cable wires to sensor leads

The lead wires on a chip sensor are necessarily small in diameter. 50 µm diameter gold wire has a break strength of about 25 g, and 62 µm (42 AWG) copper wire has a rated tensile strength of about 150 g, but the actual break strength is lower because the weak point is usually at the point of attachment or damage from handling (e.g., tweezer marks). The copper wire will only withstand 2 or 3 sharp 90° bends with a 10 g weight attached. The wire will also peel out of silver-loaded epoxy at a smaller force than the rated break strength. However, with reasonable care, loss from damaged leads is negligible.

Soldering

Both gold and copper wires will dissolve in In and Pb/Sn solders, but gold dissolves much faster. Gold can be successfully soldered by using a temperature controlled iron set just above the solder's melting point. The wire or other attachment point is tinned, and the gold wire stuck into the solder as the iron is removed. If the gold alloy is any length beyond the solder bead, the joint will be greatly weakened, but it is not difficult to repeatedly make successful joints.

Copper wire does not require the precautions above, but repeated soldering will gradually shorten the wire. Keep in mind that heat sinking may be necessary in some situations, but the joints on the chip, if any, will usually be well heat sunk through the chip.

Attachment

The two most important requirements are that the attachment points of the fine sensor wires should be immobile under all operating conditions, and the sensor leads should have some slack to take up contraction upon cooling. If the leads are connected to a cable, the cable should be attached so it cannot twist at the end. 4-wire (kelvin) cabling schemes down to the sensor leads are preferred for resistance sensors. The lower the resistance of the sensor, the more necessary this becomes.

The following sequence is usually the best:

1. Fix the end of the wire or cable in place, with the ends pretinned.

2. Apply an insulating layer on the mounting surface if it is a conductor. The uninsulated sensor leads can be kept separate using small Teflon® sleeving or by making channels out of the cigarette paper, Kapton® film, etc. used for the insulator. (See Figure 10.)

3. Mount the sensor as desired.

4. Adjust the sensor leads into contact with the proper cable wire and solder the joint. It is best to do this by pushing or training the leads into place. (See Figure 11.) Grasping the wire while trying to solder it is inviting wire damage. It is unnecessary to twist the sensor leads around the cable wires. Slack can be built into the leads by using two pairs of tweezers to put an "s-curve" into the wire before soldering.

Figure 10

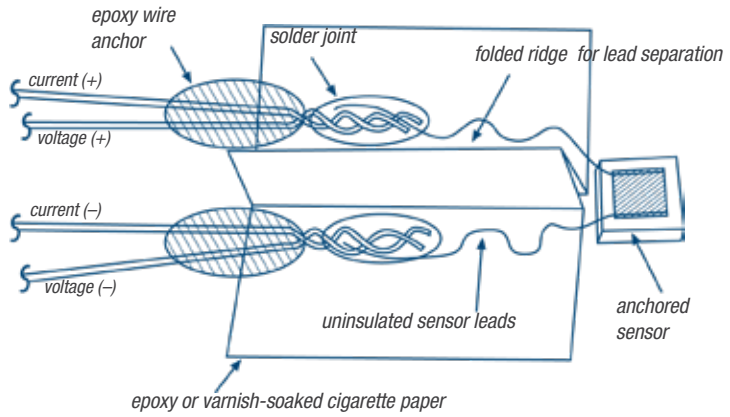
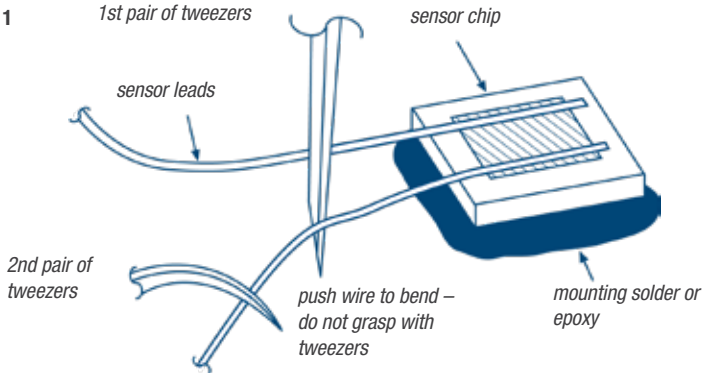


Figure 11



Cryogenic accessories

Recommended for proper installation and use of Lake Shore sensors—see Accessories section for more information

Stycast® epoxy 2850FT
Permanent attachment, excellent low temperature properties, electrical insulator, low cure shrinkage

Apiezon® N grease
Low viscosity, easy to use, solidifies at cryogenic temperatures, excellent lubricant

VGE-7031 varnish
Nonpermanent attachment, excellent thermal conductor, easy to apply and remove

Indium solder
99.99% pure, excellent electroplating material, foil form

90% Pb 10% Sn solder
Greater lead content, for higher temperature applications greater than 200 °C

Soldering flux
Variety of types

Phosphor bronze wire
Available in single, dual, and quad strands, no magnetic attraction, low thermal conduction

Manganin wire
Low thermal conductivity, high resistivity, no magnetic attraction

Heat sink bobbin
Gold-plated oxygen-free high-conductivity (OFHC) copper bobbins