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Minco SmartHeat SLT™
Self-Limiting Thin-Film Heater Technology

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Table of Contents

Abstract

Minco's SmartHeat SLT™ (Self-Limiting Technology) heaters can safely achieve constant-use temperatures without the need for a controller or temperature sensor. The heaters respond to changes in thermal load across all points of the heater's surface. The performance is due to the use of a carbon-silicone matrix (CSM) with a positive temperature coefficient (PTC) that comprises the heater core of the laminated heater circuit. The CSM can be formulated to allow for optimization at different steady-state temperatures. SmartHeat SLT heaters are suitable for a variety of applications where reducing the complexity, weight, and space of a traditional control system is beneficial. The performance can be optimized by basic prototyping and consideration of thermal and electrical design.

Background

A typical heater system design using traditional technology will generally require both a temperature sensor and a controller to be able to regulate a heater to keep the object to be heated at the desired temperature. The basic components of a typical thermal assembly consist of an etched-foil heater, a controller with built-in relay, and a temperature sensor (Figure 1). Power is applied to the resistive element of the heater until the sensor reaches the desired set-point, which triggers the controller to regulate the power going to the heater.

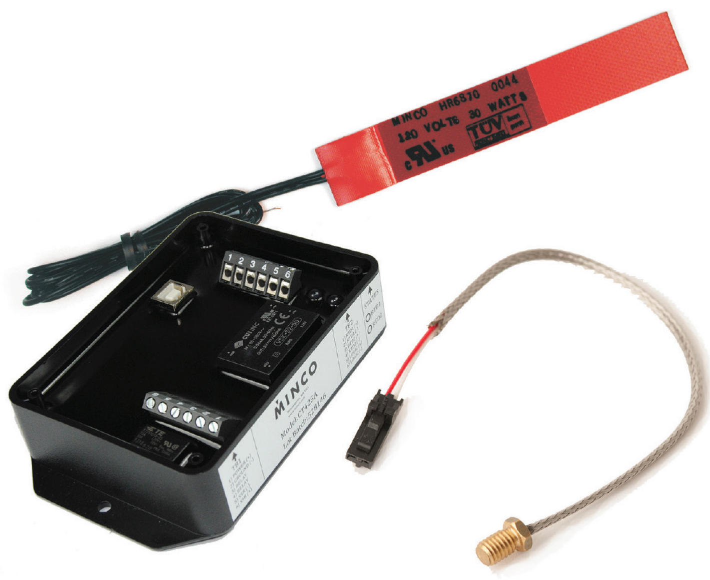


Figure 1: SmartHeat SLT replaces a typical thermal assembly consisting of an etched-foil heater (top), controller/relay (bottom left), and temperature sensor (bottom right).

In some cases, a thermostat or thermal fuse (Figure 2) is also added to the heating system to insure a safety shutoff temperature. This is either done for added redundancy and/or to create a safety shut-off that is based on a physical trigger (e.g. expansion of a bimetallic disk or melting of a fuse) that is not solely based on a digital controller.

Figure 2: Typical safety cut-offs such as a thermostat (left) and thermal fuse (right) aren't needed with SmartHeat SLT.

Using SmartHeat SLT technology, it is possible to eliminate the multiple components used in a typical heating system and replace them with a single self-limiting heater. This single heater can be designed to operate at a specified heater temperature without the need for a temperature sensor or controller while also having a physical safety temperature that can be used to eliminate the need for safety cut-off components.

Description of SmartHeat SLT Technology

SmartHeat SLT is a self-limiting thin-film heater technology. The core heating element for SmartHeat SLT is a carbon-silicone matrix (CSM). The CSM is a thin layer of silicone with conductive carbon particles distributed throughout. The resistivity of the CSM increases exponentially with increased temperature. It is this strong positive temperature coefficient (PTC) of the CSM that allows the heaters to be self-limiting and to function without the need for external controls systems or temperature sensors. Figure 3 shows a rough approximation of the CSM with a "cold" starting condition on the left and a "hot" steady-state condition on the right. In the "cold" condition the carbon particles are more closely aligned within the silicone which allows for low electrical resistivity. During heat-up, the silicone expands and the distance between the carbon particles increases which results in an increase in electrical resistivity.

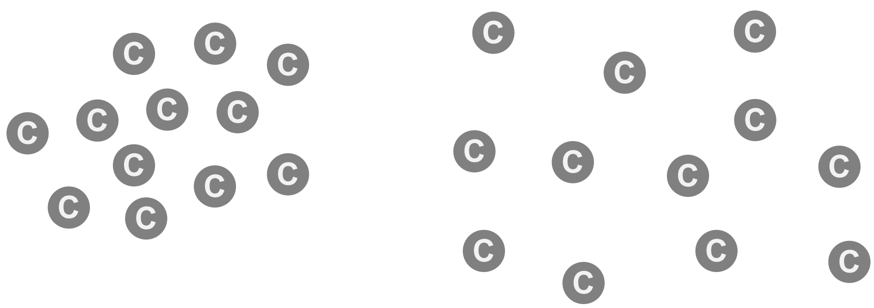


Figure 3: "Cold" (left) and "hot" (right) material conditions show how carbon particles change the material's resistivity.

The exponential PTC effect under a constant supply voltage can be seen in Figure 4. The exponential relationship is indicative of electrical conduction governed by quantum tunneling. An additional indication of quantum tunneling is that the resistance versus temperature curve can be shifted by changing the applied voltage. In common practice, an increase in voltage by 2X will result in an increase in steady-state temperature by 10°C. This may only equate to a 10% to 15% change in power output. For comparison, a typical etched-foil or wire-resistive heater would see a 4X change in power if the voltage was doubled. Relative to other heating technologies, SmartHeat SLT is much more stable to variations in voltage supply.

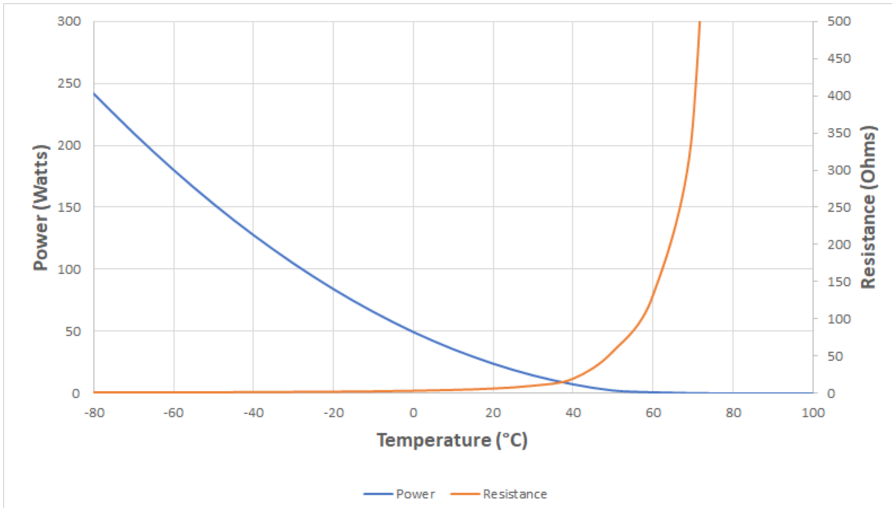


Figure 4: SmartHeat SLT heater's resistance versus temperature curve for a custom design.

The thermal performance of a SmartHeat SLT heater is measured by the power emitted and the heater's self-limiting temperature. For a given heater, this performance is a function of the applied voltage and the thermal load of the system the heater is applied to. The thermal performance seen in the bulk material is the aggregate of the point-to-point performance across the heater. The point-to-point nature of the heater performance allows the SmartHeat SLT heater to self-tune to dynamic environments and variable heat loads across the surface. For example, if a region of the heater cools due to a sudden change in localized heat load, the heater will respond in that area by increasing current flow and produce more heat in that area. In an extreme case a SmartHeat SLT heater can operate with part of the heater bonded to a heatsink while another part of the heater is not in contact with the heatsink.

The examples in Figure 5 below show the thermal performance of a SmartHeat SLT heater relative to an etch-foil heater design with uniform heat-density when bonded to an aluminum heatsink with an acrylic window. The SmartHeat SLT heater with a variable watt-density can self-tune in the acrylic window region by locally supplying less heat to the area. Conversely, the etched-foil heater with a uniform watt-density supplies the same amount of heat independent of the heat load. in this situation the acrylic window region could operate at a temperature beyond its design rating.

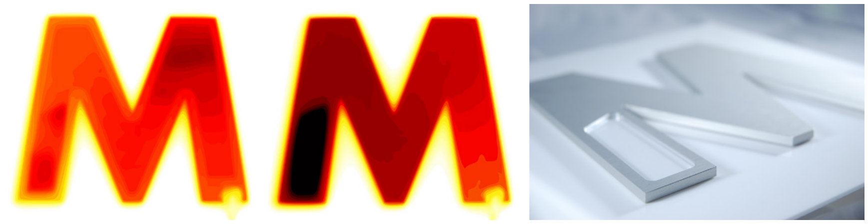
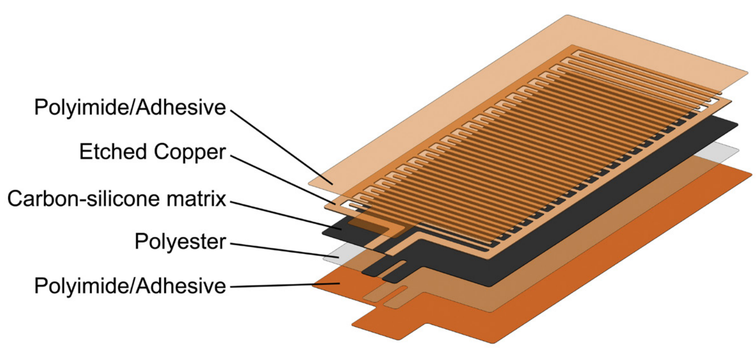


Figure 5: A thermal Image of SmartHeat SLT (far left) shows how the heater self-tunes in response to dynamic environments.

A standard SmartHeat SLT heater (Figure 6) consist of polyimide and acrylic layers used to electrically insulate the copper and CSM core heating element in the same way as Minco's traditional etch-foil heaters. The pattern-etched copper element is used as a path to apply a voltage to the CSM. Generally non-heating, the pattern-etched copper element provides only a small fraction of the heat the SmartHeat's CSM provides. The design of the etched pattern can be used to fine tune the heater's steady-state temperature.



Layer	Material	Type	Thickness (mils)	Thickness (micron)
1a	Polyimide	Dielectric	1.2	30.5
1b	Acrylic	Adhesive	1.2	30.5
2	Etched Copper	Conductor	0.5	12.7
3	CSM	Self-Limiting	5.5	139.7
4	Polyester	Mechanical	1	25
5a	Acrylic	Adhesive	1.2	30.5
5b	Polyimide	Dielectric	1.2	30.5

Figure 6: The heating area for a standard SmartHeat SLT heater consists of several layers of material.

Figure 7 shows a variety of standard and custom shapes for SmartHeat SLT heaters. Custom shapes and sizes are easily designed and fabricated, including holes or cut-outs within the center of the heater body. In a traditional construction, PTFE-insulated leadwires are welded to the copper element layer. This weld junction is then electrically insulated with a potting compound. A standard heater construction would also include a pressure sensitive adhesive (PSA) layer on the side opposite the leadwire welds. The PSA would then be used to mount the heater to the surface to be heated. Other options besides PSA for mounting include mechanical clamping and shrink tape/tubing to secure the heater.

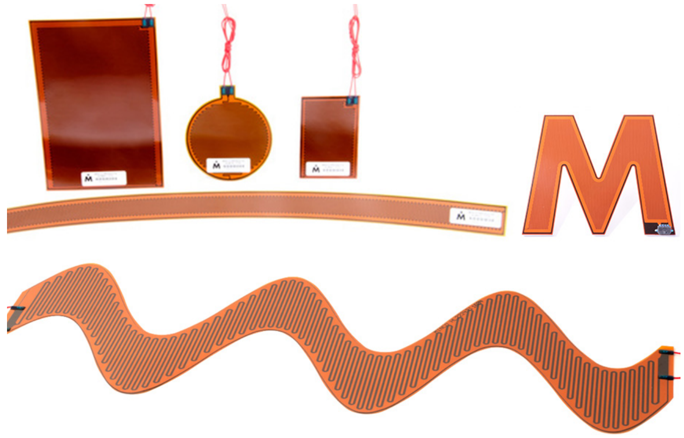


Figure 7: SmartHeat SLT heaters are made in a variety of standard shapes, and customized solutions are available.

As a standard practice, Minco serializes all SmartHeat SLT heaters and inspects 100% for visual quality and consistent thermal operation. In addition to 100% dielectric strength testing, the heaters are also all inspected by infrared camera. Figure 8 shows an end-of-the-line thermal inspection that is performed for each heater. In this inspection, a heater is powered to steady-state at a room temperature environment with a minimal thermal load. The average surface temperature and uniformity is captured, evaluated, and stored for each serialized heater.

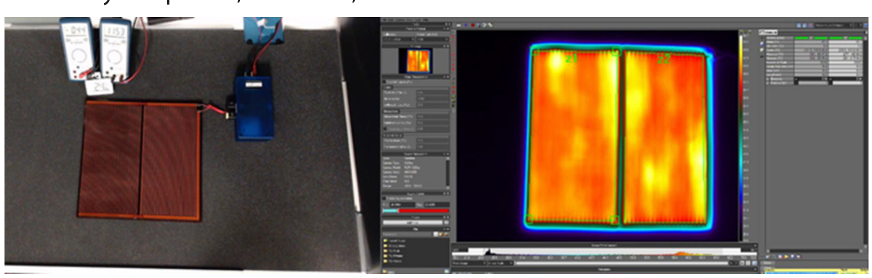


Figure 8: Thermal inspection of SmartHeat SLT heaters is part of the production process.

Applications of SmartHeat SLT

SmartHeat SLT is ideally suited for applications where there is a need to heat above a specified temperature without the added cost, weight, and complexity of external temperature sensors and controllers. Figure 9 lists some typical applications within the Medical, Defense, and Aerospace markets. Additionally, SmartHeat SLT is well suited for applications where point-sensitive temperature control across the heater surface is needed in response to dynamic or uneven thermal loads.

Medical	Defense	Aerospace
IB Fluid Warming	Anti-Fog Optics/Lens	De-Icing Sensors (TAT, AOA)
Reagent Storage Warning	Warming Handleld Electronic Displays	Warming Gray/Potable Water
Humidification (Sleep Apnea)	Lithium Ion Battery Warming	Cockpit Display Warming

Figure 9: Typical applications for SmartHeat SLT in the Medical, Defense, and Aerospace Markets.

The following typical characteristics should be considered when determining the suitability of SmartHeat SLT for an application:

- Temperature Uniformity: 10°C range across the surface. This can be improved with a conductive heatsink.
- Temperature Accuracy: ±5°C heater to heater (in a reasonably constant environment).
- Maximum Designed Self-Limiting Temperature: 70°C heatsink temperature.
- Environmental Temperature Range: -45°C to 100°C. Work is ongoing to expand this range.

The typical characteristics listed above represent the standard values at the time this paper is published. Work is being done on heaters that are suitable for characteristics beyond what is listed. Minco Engineering can be contacted to discuss current options.

Achieve Desired Thermal Performance

SmartHeat SLT heaters are custom engineered for heatsink temperature and self-limiting temperature. This is in contrast to a traditional etched-foil heater where the design is based on constant-power instead of constant-temperature.

Experimental testing is required during prototyping to determine the exact heater construction. There are several design factors that can influence the thermal performance of a SmartHeat SLT heater.

CSM Formulation: The CSM in SmartHeat SLT is formulated in several standard carbon-particle loadings. Designing using an existing formulation is the easiest in terms of time and cost.

Applied Voltage: The voltage(s) available will be a factor in designing a heater. Approximately a 10°C decrease in self-limiting temperature will occur when reducing the voltage by half. In prototyping, if a variable voltage supply is available, it can be used to refine the temperature set point for the system. Communicating this test information back to Minco will allow our design team to refine the heater for a fixed voltage in production.

Heater Geometry: Heater geometry is a factor in both cost and thermal performance. Limiting the size of the heater used will lower costs; however, a large enough heater is required so that it will be able to arrive at the desired steady-state temperature and not be overwhelmed by the heat losses in the system.

Etched Copper Pattern: Through a proprietary design process, the etched copper pattern can be used to fine tune the thermal performance of the system while keeping the heater geometry, voltage, and CSM formulation constant.

Thermal Load Management: During the design and prototyping process, recommendations may be made to limit the thermal load that the SmartHeat SLT heater will need to meet, such as placement/location of the heater, insulation on the heater, and changes to system materials and geometry to limit heat losses. Figure 10 shows the thermal load impact on a SmartHeat SLT heater operating in a free hanging condition at different ambient temperatures. The warm up trend (steady-state temperature and current) is monitored during each cycle. At the greatest thermal load shown of -55°C ambient, the steady-state temperature of the heater is lower than that of the lesser thermal loads.

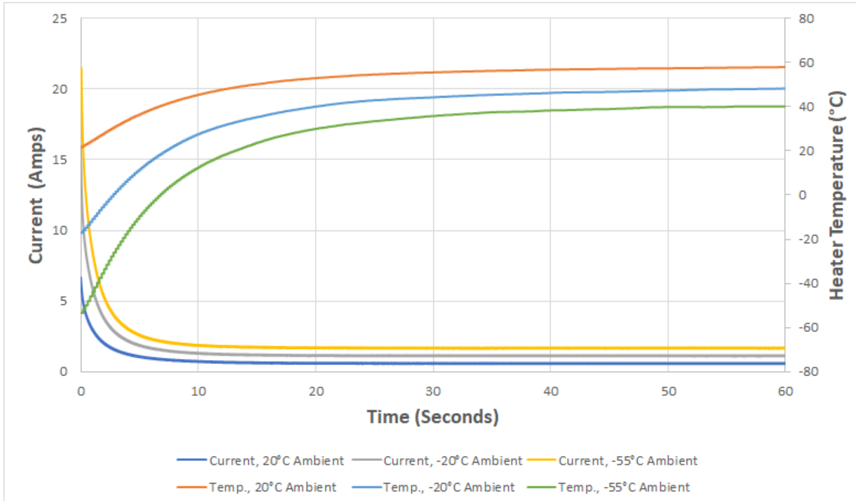


Figure 10: SmartHeat SLT heaters' thermal-electrical performance during a warm-up varies depending on ambient conditions.

Achieve Desired Electrical Performance

Theoretical consideration as well as experimental testing is required during prototyping to ensure that the electrical performance will be suitable for the specific heating application. The strong PTC effect means that at starting conditions, a SmartHeat SLT heater will see a much higher electrical current than when operating at steady-state. For many applications, this “startup-current” is not an issue as it is still within the rating of associated electrical components within the system or the high current level is brief enough to not cause an issue even if exceeding the current rating of components. In the latter case, this is because the amount of energy dissipated is too low to cause issues with common electronic components.

The amount of startup-current can be prolonged to longer time periods if the heater is not properly designed for the application. The factors listed in the previous section on achieving desired thermal performance will also impact the electrical performance and will need to be considered during design and prototyping. Figure 10 gives an indication of the effect of thermal loading on startup-current and steady-state current. The lowest temperature and greatest thermal load shown of -55°C ambient has the largest startup-current and steady-state current respectively. In general, the steady-state current will be approximately 10% of the start-up current.

In cases where design strategies do not fully address startup-current concerns, there are simple electrical components that can be added to the heater design. Both fixed inductors and negative temperature coefficient (NTC) thermistors can offer a cost effective way to lower the startup-current while still not adding to the cost, weight and complexity of an external control system. Figure 11 shows test results of a SmartHeat SLT heater during start-up both with and without a NTC thermistor in series with the heater. The addition of the thermistor significantly reduces the peak start-up current, but does slightly increase the time required to get to a steady-state current.

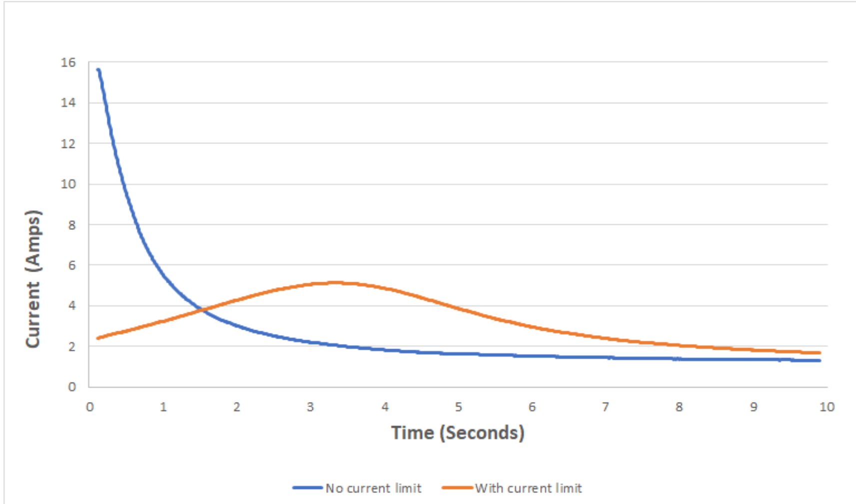


Figure 11: SmartHeat SLT heaters' electrical performance during a warm-up; with and without a Negative Temperature Coefficient (NTC) thermistor in series with a heater.

Summary

SmartHeat SLT (Self-Limiting Technology) heaters provide heating to a constant use temperature without the need for a controller or temperature sensor, while also possessing a safety mechanism that eliminates the need for a physical thermal cut-off component. The heater's carbon-silicone matrix can respond to different thermal loads at all points across the heater. All serialized heaters are 100% inspected for insulation strength and thermal operation.

In addition to basic standard model sizes, custom designs can be tailored to optimize the geometries and thermal-electrical properties needed for most applications.