Fullchance kapton heater

Designing with Thermofoil™ Heaters

Estimating power requirements

The total amount of power required for an application is the larger of two values:

1. Warmup power + Heat lost during warmup
2. Process heat + Heat lost in steady state

Warmup power: Watts required to bring an object to temperature in a given time. The basic formula is:

$$P(watts) = \frac{mC_p\left(T_f - T_i\right)}{t}$$

where:

m	=	Mass of object (g)
C_p	=	Specific heat of material (J/g/°C)
T_f	=	Final temperature of object (°C)
T_i	=	Initial temperature of object (°C)
t	=	Warmup time (seconds)

Material	Specific heat (J/g/°C)	Density (g/cm³)
Air	1.00	0.012
Aluminum	1.00	2.70
Copper	0.38	8.96
Glass	0.75	2.64
Oil (typical)	1.90	0.90
Plastic (typical)	1.25	Varies
Silicon	0.68	0.23
Solder	0.17	8.65
Steel	1.88	7.75
Water	4.19	1.00

For other materials see Application Aid #21.

To get:	Multiply:
J/g/°C	BTU/lb/°F × 4.19
g/cm³	lbs/ft³ × 0.016

Process heat: Heat required to process a material when the heater is performing useful work. The formula above also applies here, but must also include latent heat if material changes state (melts or evaporates).

Heat loss: All systems lose heat through convection (air or liquid movement), conduction through support structures, and thermal radiation.

Tools for analytical wattage estimation

Fullchance ApplicationAid#21showshowtoestimatethese losses in the steady state, and provides a formula that includes loss factors in warmup calculations.

ThermalCalcprogram(DOS),freefrom fullchance,assists with calculations.Contact Fullchanc or visit www.silicone-heater.com.

Finite Element Analysis (FEA) creates a mathematical model of a thermal system. The calculations can include temperature gradients and conditions that other theoretical models are not capable of describing. However, FEA can be expensive and time consuming for complex systems.

Conducting experiments

Heat transfer theory is complex. It's usually best to prototype your system with actual heaters to observe behaviorandfine-tunethedesign.Fullchance offersavariety of tools to help you:

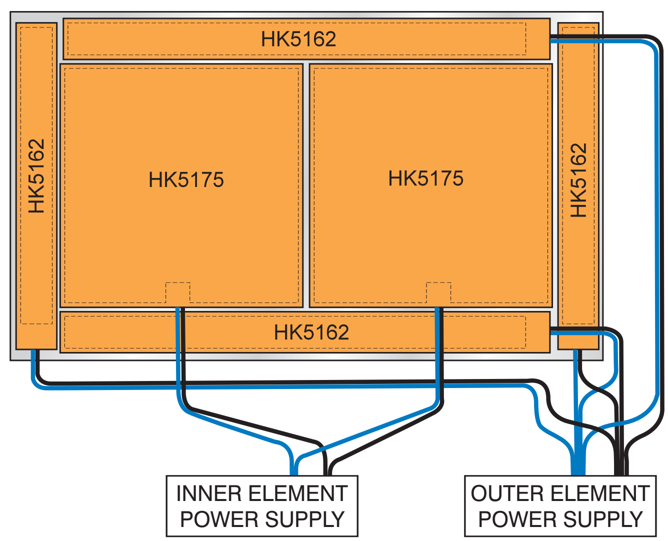
Catalog heaters: You usually can model a custom heater with one or more standard models from this catalog. Stock Kapton heaters (page B-2) are particularly useful. Any combination of models with the same nominal voltage (28 or 115), connected in *parallel*, will give the same watt output per square inch. Also note that HK913 heater kit models (page B-3) will give constant watt density when connected in *series*.

Variable power source: An AC power supply ("Variac"), power resistor, or rheostat lets you test different power levels (across the heater or zone by zone).

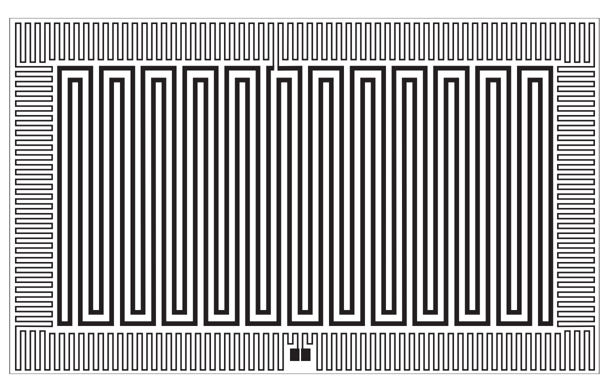
Temperature sensor(s): A small Thermal-Ribbon RTD such as model S17624 is easy to move and reapply to test temperature in various locations.

Indicator: Fullchance modelTI142handheldindicator provides good accuracy at low cost.

Controller: Models CT325, CT15, and CT16A cover the range from simple to sophisticated design for testing control schemes.



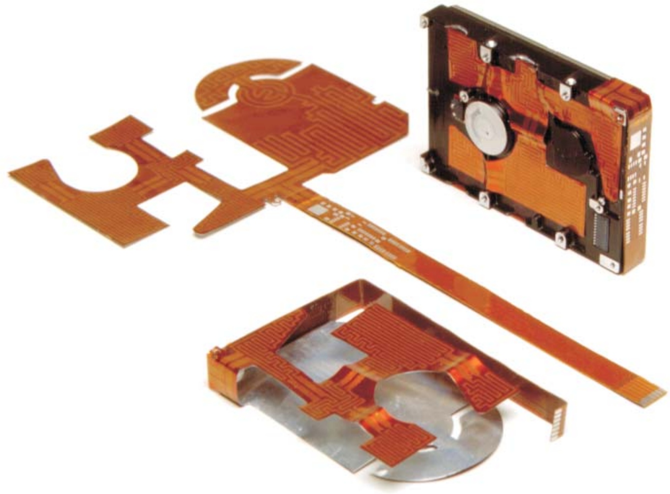
A mosaic of catalog heaters, with dual power supplies, helps to determine edge profiling for uniform temperature.



The resulting custom heater looks like this.

Custom Design Options

Thermofoil heaters give you design options other heater types can't match. Element patterns, outline shapes and heat profiles can be fine-tuned to create the exact thermal and physical component to fit your unique requirements.



Shaped to fit the application

Irregular outlines, holes, and cutouts are defined during initial setup.

Dual elements

Two individually powered heater elements let you:

- ◆ Use both elements during initial warmup, then shut one element off for better steady-state control.
- ◆ Design dual voltage heaters: Connect elements in parallel for 120 V, in series for 240 V.

Profiled and multi-zone heaters

A profiled element levels out temperature gradients by providing extra heat where losses occur, such as along edges or around mounting holes. In a typical case, profiling might reduce a ±25°C temperature variation across a surface to ±5°C or better. Once the best profile isdeterminedfortheapplication,fullchance'sphoto-etching process ensures repeatability from heater to heater.

Methods to derive the profiling pattern include:

- ◆ Experimentation: Lay out a pattern with catalog heaters and vary the power levels until temperature reachesthedesireduniformity.Or,Fullchance canprovide a custom heater with separately powered zones for prototyping.Fullchance willthenreproducethesuccessful profile with a single element.
- ◆ Finite Element Analysis (FEA): Although more expensive, FEA modeling of thermal systems can reduce the number of trials required to design a profiled heater. It may help to map the temperature resulting from uniform heat input (using a catalog heater), then work backward in FEA to derive the profiled pattern.

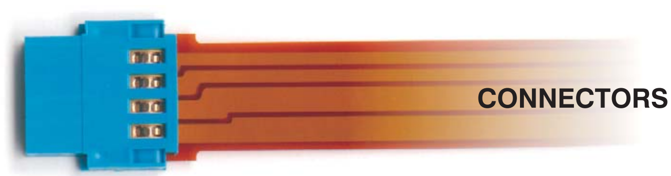
Tight uniformity goals may require more than one profiling iteration, and a given solution is optimized for only one setpoint temperature.

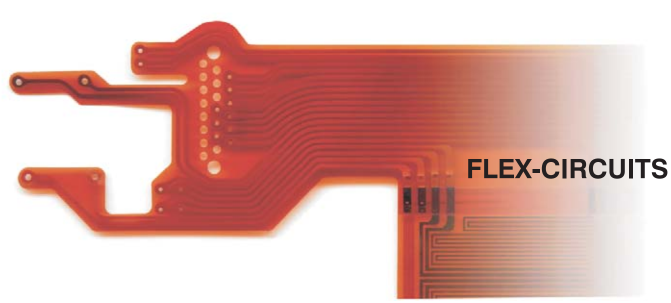
Other element options

- ◆ Dual layer (higher resistance or inductance canceling)
- ◆ Non-magnetic materials

Electrical termination

Leadwires (standard)	Welded leadwires make a strong, reliable connection. Options include different colors, sizes, and insulating materials
Solder pads	Lowest cost, but limits foil/resistance options.
Connectors	Insulation displacement connectors crimped onto etched leads make an economical design. Other connector types are available.
Flex-circuits	Fullchance cansupplyflex-circuitsintegrally connected with heaters.





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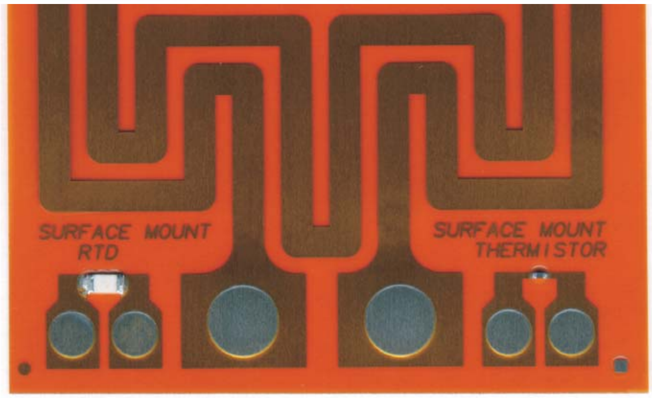
Custom Heater/Sensors

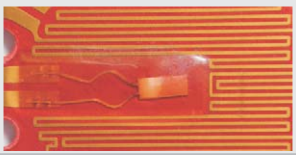
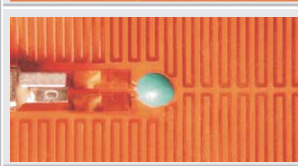
Integrating sensors into heaters simplifies your assembly operations while improving thermal response. The sensor sits in a window of the heating element. It reacts to temperature changes in the component beneath the heater, yet remains close to the heating element itself. This tight coupling of heater, sensor, and load can greatly improve control accuracy.

Sensors can be electrically connected via leadwires or flex-circuitry.

Most heater/sensors are custom designed.Fullchance recommends prototyping with standard heaters and Thermal-Ribbon™ sensors.



Types of sensors used in heater/sensors

	Description	Benefits	Options
	**Thin-film RTD's** Small ceramic elements laminated inside the heater or located on top	♦ Highly stable and accurate ♦ Standardized output ♦ Low cost ♦ Tight tolerance	♦ Platinum, 0.00385 TCR ♦ 100 to 10,000 Ω ♦ Wire leads or SMT ♦ 0.12% or 0.06% tolerance
	**Strip-wound RTD** Sensing wire wound around a flexible insulating strip and encapsulated inside heater	♦ Can average temperatures ♦ Any resistance possible	♦ Platinum, nickel, nickel-iron
	**Flat-wound RTD** Sensing wire laid in a predetermined pattern in a single plane	♦ Fast response (0.1 sec.) ♦ Average temp. over area	♦ Platinum, nickel, nickel-iron ♦ Uniform or profiled
	**Etched RTD** Heater and RTD etched from same temperature sensitive foil	♦ Lowest cost ♦ Fast response ♦ Loose tolerance	♦ Nickel or nickel-iron
	**Thermistor** Bare or coated bead embedded in heater or placed on top and covered with epoxy	♦ High sensitivity ♦ Low to moderate cost	♦ NTC or PTC ♦ Variety of resistances ♦ Bead or SMT
	**Thermocouple** Junction of dissimilar metals laminated inside heater	♦ Low cost ♦ Smallest sensor ♦ Wide temperature range	♦ Wire or foil ♦ E, J, K, or T standard
	**Thermostat** See page K-10 for standard thermostats	♦ No external controller ♦ Low system cost ♦ Slower response ♦ Looser control	♦ Snap action or creep action ♦ Specify setpoint ♦ Wired/mounted to heater

Heater Assemblies

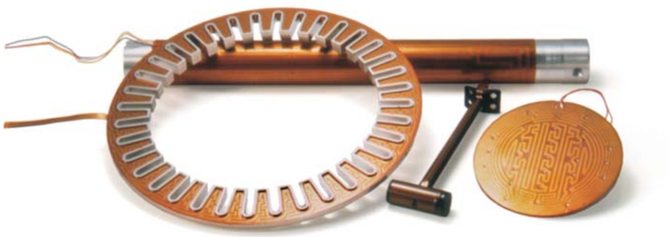
For best heater performance and reduced installed costs,consider Fullchance's capabilities in mounting heaters to make complete thermal subassemblies. You can furnish the heat sinks or we can fabricate them to your specifications. Either way, you get a guaranteed bond, superiorreliability,andthebenefitsof Fullchance's experience with advanced adhesives and lamination equipment. In many cases we can affix the heater to the mating part in the same step used to bond its layers together. That saves money over a two-step process.

Vulcanized silicone rubber assemblies

Fullchacne's proprietary vulcanization processuses no adhesive to bond heaters to mating parts. Eliminating the adhesive facilitates heat transfer, resulting in higher allowable watt densities and longer life.

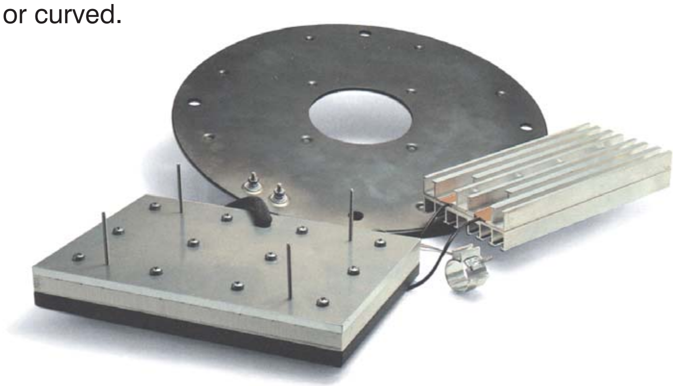
Laminated Kapton heaters

Kapton heaters can be mounted to flat or curved heat sinks using an acrylic adhesive and our specialized lamination equipment. The thin, uniform bond layer provides excellent heat transfer. Watt densities to 50 watts/in^2 are possible.



Clamped mica heaters

Mica heaters must be secured between rigid plates to preventseparationoflayers.Fullchacne canprovidemany styles of mica heater assemblies: bolted or welded, flat or curved.



Factory mounted All-Polyimide (AP) heaters

Factory bonded AP heaters eliminate clamping and provide optimum heat transfer to the heat sink. The excellent chemical resistance and low outgassing of AP heaters,togetherwith Fullchacne's precise machining capabilities, are the perfect solution for chuck heaters in semiconductor processing equipment.

Assembly options

- Fullchacne-suppliedheatsinks:Machined,formed,and extrude dparts from Fullchance's advanced machine shop or qualified vendors
- Coatings: PTFE coating, anodizing, or plating with nickel, copper, or gold
- Temperature sensors: See page K-11 for more information
- Thermostats and thermal cutoffs for control or limit switching
- Wire harnesses, connectors, or flex-circuitry
- Electronic components

Examples of Thermal Systems

Description	Heat a tank containing 2 kg of chemical solution from 20°C to 50°C in 10 minutes. The space available for mounting the heater is 4" × 5".	Heat moving film in a thermal processor. A sheet of polyester film weighing 5 g must be brought from 25°C to 90°C every 2 seconds. The heater will measure 2" × 12" and will be mounted on a metal platen.	An LCD heater must be capable of bringing the 6" × 8" display from -55°C to 0°C in 5 minutes and maintaining it there.
Wattage requirements	From Thermal Calc*, we need 450 watts minimum for warmup plus losses.	From Thermal Calc*, we need 275 watts minimum for warmup plus losses.	From Thermal Calc*, we need 50 watts for warmup and 20 watts for maintenance of temperature.
Electrical parameters	$R = E^2/W = 120^2/450 = 32\ \Omega$	$R = E^2/W = 120^2/275 = 52\ \Omega$	$R = E^2/W = 28^2/50 = 16\ \Omega$
Heater selection	Choosing Kapton for chemical resistance, the best choice is HK5490R27.7L12	Specifying silicone rubber for lower cost, the best choice is HR5433R44.1L12	From Fullchance'sstandard Thermal-Clear™ heaters we choose model H6709R14.8L12
Actual wattage	Wattage is $120^2/27.7 = 520$ W	Wattage is $120^2/44.1 = 327$ W	Wattage is $28^2/14.8 = 53$ W
Watt density	Watt density = W/effective area = 520/17.74 in^2 = 29 W/in^2	Watt density = W/effective area = 327/21.80 in^2 = 15 W/in^2	Watt density = W/effective area = 53/48 in^2 = 1.1 W/in^2
Installation	From watt density charts we specify Acrylic PSA with aluminum backing (E option). This is rated to 31 W/in^2 at 50°C.	Any type of heater mounting will handle the watt density. We will factory vulcanize the heater for lowest installed cost.	We choose Acrylic PSA backing for convenience (B option). The watt density is well within the rated maximum.
Leadwire current	AWG 24 leadwire current rating is 7.5 A. Actual current is I = 120/27.7 = 4.3 A (OK).	AWG 24 leadwire current rating is 7.5 A. Actual current is I = 120/44.1 = 2.7 A (OK).	AWG 30 leadwire current rating is 3 A. Actual current is I = 28/14.8 = 1.9 A (OK).
Control	The CT16A controller with optional AC744 solid state relay will handle the current.	The customer integrates a custom controller into other electronic circuits.	A CT198-1005 Heaterstat™ will control the heater. Its setpoint will be adjustable from 6 to 62°C. We have chosen a model with a higher range in order to ensure that the LCD itself reaches 0°C: we know the setpoint will have to be higher because it controls the heater element which runs hotter than the surface beneath it.
Sensor	An S665 Thermal-Tab™ will be mounted to the side of the tank.	An S247 thin-film RTD will be potted into a hole in the platen. A thermostat with 100°C setpoint will provide overtemperature shutoff.	None: The heater acts as the sensor!
Custom options	An AP heater would provide a higher watt density for faster warmup (at higher cost). A rubber or mica heater would allow more watts for faster warmup, if acceptable in the application.	The sensor and thermostat could be integrated into the heater.	Placing the lead connections on an external tab would remove the lead bulge from the display area. Switching to a sensor and CT325 for control, instead of the Heaterstat, would allow higher wattage and finer control.

*Thermal Calc is a free DOS program, available at www.silicone-heater.com, to assist in estimating heater wattage requirements from known parameters.

Examples of Thermal Systems

Description	Warm a test instrument in an avionics system from as cold as -45°C to 70°C within two minutes with ±2°C accuracy. The instrument is a cylinder 1.25" (32 mm) diameter and 3.5" (89 mm) tall, providing a heating area of 3.9 × 3.5" (100 × 89 mm). The available voltage on the aircraft is 28 VDC.	Maintain 96 sample vials, each containing 10 ml of human blood, at 37°C. The vials are positioned in drilled blind holes in an aluminum block measuring 4.0" × 6.0" × 1.5" with a total mass of 500 g. The sample temperature must never exceed 40°C.	A 300 mm silicon wafer placed on a 325 mm diameter aluminum chuck must be heated from 40°C to 220°C during processing.
Wattage requirements	From Thermal Calc*, we need 60 watts warmup power and 25 watts maintenance power.	From Thermal Calc*, we need 60 watts for warmup and maintenance.	From Thermal Calc*, we need 800 watts to reach the required temperature within the time limit.
Electrical parameters	$R = E^2/W = 28^2/60 = 13.1\ \Omega$	$R = E^2/W = 24^2/60 = 9.6\ \Omega$	$R = E^2/W = 208^2/800 = 54.1\ \Omega$
Heater selection	Commercial and military avionics systems typically specify Kapton insulated heaters. Model HK5482R12.1L12A is selected.	Specifying Kapton because it is resistant to most chemicals and does not outgas, the best choice is HK5491R9.4L12B	The required temperature exceeds the limit for Kapton heaters, and the vacuum process does not allow silicone rubber. An All-Polyimide heater, factory mounted to the chuck, is required.
Actual wattage	Wattage is $28^2/12.1 = 65$ W	Wattage is $24^2/9.4 = 61$ W	Wattage is $208^2/54.1 = 800$ W
Watt density	Watt density = W/effective area = 65/9.8 in² = 6.6 W/in²	Watt density = W/effective area = 61/21.54 in² = 2.8 W/in²	Watt density = W/effective area = 800/109.9 in² = 7.3 W/in²
Installation	For this cylindrical shape heat sink, a BM 3 Shrink Band is selected.	Any type of heater mounting will handle the watt density. We recommend acrylic PSA for fast availability of prototypes.	Factory lamination of AP heaters provides optimum heat transfer and allows operating temperatures higher than other adhesives.
Leadwire current	AWG 26 current rating is 5.0 A. Actual current is I = 28/12.1 = 2.3 A (OK).	AWG 24 leadwire current rating is 7.5 A. Actual current is I = 24/9.4 = 2.6 A (OK).	AWG 20 leadwire current rating is 13.5 A. Actual current is I = 208/54.1 = 3.8 A (OK).
Control	The CT325 controller will be used to control the heater.	A custom control circuit integrated into the system electronics will control the heater. The controller is designed for a 1000 Ω platinum RTD element input.	All electrical and motion control of the wafer processing system is centrally controlled by a computer. Thermal control is integrated into the system.
Sensor	An S665 Thermal Tab provides easy installation in the prototype test system.	A 1000 Ω platinum RTD Thermal-Tab™ sensor is used. The customer tests the sensor in several positions around the aluminum block to determine the optimum location.	An S247 thin film RTD element with high-temperature extension leads will be cemented into a hole in the platen.
Custom options	Experiments confirm the power requirements, but also show that the sensor measures only one point rather than the average temperature of the cylinder. In the final custom design an integrated Thermal-Ribbon strip sensor wraps around the circumference of the cylinder to measure the average temperature.	Testing showed that edge losses required 20% higher watt density around the periphery of the heater to equalize temperature within the block. A custom design with profiled power output, integrated sensor, and 40°C thermal fuse provides a complete thermal system in one package.	The leads exit is located at the center of the heater to fit with the design requirements of the machine.

*Thermal Calc is a free DOS program, available at www.silicone-heater.com, to assist in estimating heater wattage requirements from known parameters.