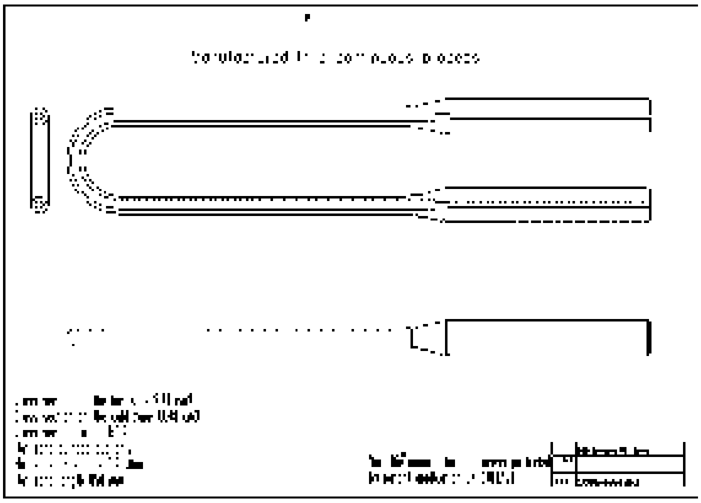
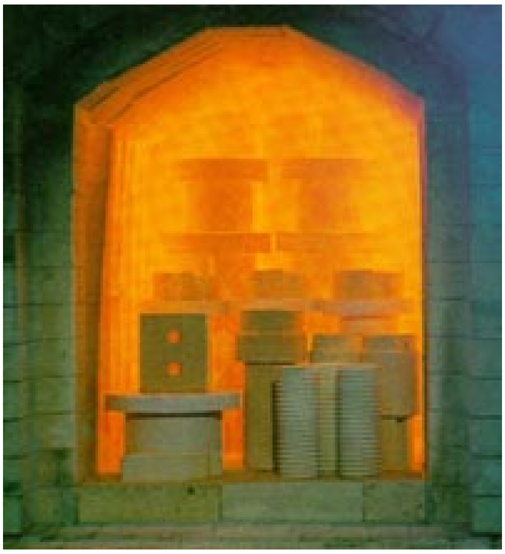
One-piece Heating Element

A very common heating element is the Silicon Carbide resistance element. Ceramic Silicon Carbide heating elements are currently manufactured by a few different companies worldwide. These heating elements can obtain maximum surface temperatures of up to 1650°C, providing a chamber temperature of up to 1550°C. They are reasonably easy to install, they provide good mechanical strength during high-temperature use, and they are extremely practical in furnaces for the ceramic and metallurgical industries. Their lifetime depends on operating conditions, but is generally about 5,000-15,000 hours.

SiC powder material is manufactured by blending carbon and quartz and electrically heating the mix in large stacks to a temperature of about 2500°C. After sintering, the large crystals are crushed to a powder and separated into different size fractions. During the last 50 years SiC heating elements have been manufactured as pipes or rods with a maximum diameter of 108 mm and length of up to 2 meters and having the same cross-section throughout their lengths. The pipes generally being hand-made, some producers have begun to extrude straight pipes with no variation in the diameter, after which the pipes are cut to suitable lengths and assembled manually.



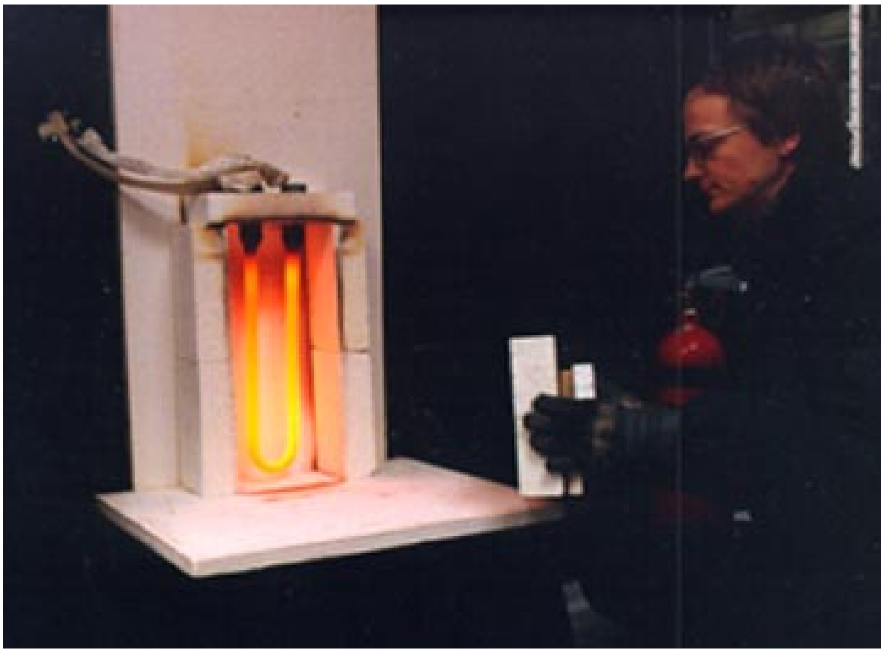
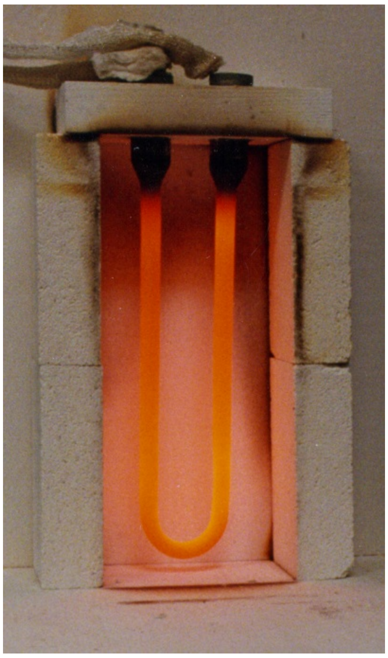


The test result was a one piece U-shaped SiC structure, which is suitable as a heating element with a mechanical strength of 110 MPa when measured in a four point bending test. The strength and the electrical properties of the body are highly correlated to the porosity of the body. This test body was made of relatively large-sized SiC grains (Mesh 240 means grains having a diameter of in the order of 65 µm) but may be manufactured from other grain sizes.

SiC heating elements are based on two crystal structures, Beta-SiC, which has a cubic structure (silicon metal infiltrated) and Alfa-SiC, which has a hexagonal structure. The most important difference between Beta-SiC and Alfa-SiC based heating elements is that Beta-SiC has by nature a considerably lower electrical resistance as well as a flatter and better heat/resistance curve. Unfortunately, Beta-SiC is not commercially available at a reasonable price as a powder, but must be specially processed. Beta-SiC is manufactured into heating elements by sintering carbon, SiO_2 and Si metal and reaction bonded during sintering at 1500-1700°C.

With Alfa-SiC, a high sintering temperature is employed (partial recrystallisation) and a relatively high resistance is obtained. With Beta-SiC, a medium sintering temperature is employed and a relatively low resistance is obtained.

The design of SiC heating elements is governed by the necessary electrical connections, mounting and the acceptable heat loss to the surroundings. Connections are made on cold ends with aluminum/silicon (90/10% by weight) flame sprayed surfaces with an aluminum braid or wire mechanically secured or brazed onto the cold end. The cold end temperatures should not exceed 300°C. Heat loss should be reduced so that the heat load on the insulation on the exterior of the furnace is kept to a minimum. Furnace efficiency and operational costs are reduced if heat loss through cold zone insulation holes is kept to a minimum.

Known SiC heating elements are normally manufactured in one piece which is either cast, pressed or extruded in one stable dimension and sliced or cut after drying or sintering in order to reduce the hot zone cross-section. Known SiC heating elements are manually manufactured from several individual parts. -SiC elements are manufactured with one or several heating zones having a relatively high electrical resistance and two or more cold zones for the electrical connection. The hot zone resistance in -SiC can only be changed by varying the cross-section and the length. Cold zone resistance can be altered by varying the cross-section, length and composition as well as by Si metal infiltration of the extruded body. The length of a heating element is often limited by the furnace design. An -SiC hot zone (high impedance) may be produced by reducing the cross-section, and an -SiC cold zone (low impedance) may be produced by increasing the cross-section.

A prior art SiC one-leg heating element, the most simple version, is manufactured as a straight pipe or rod. It is often symmetrical in the middle, where the hot zone is located, and at each end a cold zone is "glued" on. The hot zone is pre-sintered at a temperature of above 2300°C and assembled with two cold zone Si metal infiltrated electrical connecting parts, after which the entire element is sintered for a second time at 1700°C to form reaction bonded SiC in the connection between the parts. The term reaction bonded sintering refers to the fact that the "glue" (typically C+SiC+SiO2) is blended with extra free Si metal that reacts with the SiC powder. The manufacture of both cold and hot zones as pure Alfa-SiC is also known, the electrical resistance being varied only by altering the cross-section.

An SiC two-leg heating element is traditionally manufactured from two cold zones with a high Si content, two Alfa-SiC hot zones and a bridge. Three of the parts (the cold zones and the bridge) are low-temperature sintered, and two of the parts (the hot zones) are high-temperature sintered, after which the hot zones are electrically characterized for equal resistance at 800°C. All five parts are then assembled manually with cement and sintered once more at 1700°C.

An SiC three-leg heating element is traditionally manufactured from three cold zones with a high Si content, three Alfa-SiC hot zones and one Beta-SiC bridge part, i.e. a total of seven different parts which must be connected. All seven parts must be pre-sintered before the hot zones are electrically examined prior to the manual assembling and re-sintered. The parts are assembled using glue or cement.

It is common knowledge that heating elements built by assembling several individual parts in a bridge have a low mechanical strength, a high weight and a reduced heating surface. Strengthening pins are necessary in the pipe connections in order to increase the joint strength; otherwise mechanical failure is likely to occur.

Both two and three leg elements involve considerable production times and expense due to the many individual parts which must be manufactured separately and then assembled.

It is contemplated that by using the Vari-Die principle, it will be possible to automatically produce, in a single piece, advanced heating element structures as well as other extruded objects not known today, such as W-shaped heating elements or spirals or helixes with several windings and with built-in thick cold ends.

A heating test of the heating element was carried out in a test rig using metal litze connected to the cold ends. The power absorption was measured to 3.4 kW at a hot zone temperature of 1000°C kept stable over 2 hours. The impedance of the above heating element was in the order of 34 Ohm. However, as described above, the impedance of the heating element may be varied by varying the porosity of the extruded body. Thus, it is contemplated that heating elements of the above type having an impedance in the interval 2-35 may be manufactured simply by varying the grain size of the SiC powder used in the starting materials. It may be preferred that the impedance of the heating element is in the order of 5-20, in this case, also the strength of the heating element is more preferred due to the less porosity of the heating element.

Optimum electrical connection to the cold zones of the extruded body was obtained by a metallic coating of Ag deposited by electrochemical deposition.
When extremely high temperatures are needed, resistance heating elements made from graphite are a logical choice as graphite is stable at higher temperatures that SiC.

The manufacture of graphite starts with a so-called green mixture, in which the solid component consists mainly of pitch coke and petroleum coke. The binders are usually pitch but occasionally also synthetic resins. The green mixture is extruded into the desired shape and heated in a baking process to temperatures of up to 1300°C. The primary coke particles in the baked material are bonded together by the coke bridges formed from the binder. To convert the shaped carbon into graphite, it is heated in an electric resistance furnace to a temperature of approximately 2700°C in an argon atmosphere. The graphite production process reduces the strength and coefficient of thermal expansion while substantially increasing electrical and thermal conductivity.

Graphite materials as heating elements are useful for resistance heating in protective atmospheres at temperatures of up to 3000°C. Graphite is the only material that shows an increase in compressive strength with increased temperatures; the compressive strength doubling at 2500°C compared to room temperature. The resistance of graphite is relatively stable at all temperatures, changing only about 50% from room temperature to 2500°C. All electrical connection and mechanical support is performed outside the heating zone with solid water-cooled copper bars. Graphite's electrical resistance cannot be changed by impurities. Only cross-section alterations can alter the resistance and heat dispatch. The hot zone length and cross-section of graphite heating elements may be designed to suit specific needs. Graphite U-shaped (two-leg) heating elements are traditionally manufactured as a U-shaped extruded graphite pipe which is manually bent after extrusion. On each leg, a cold end connection with a larger diameter and full cross-section is attached by threads. Such heating elements are thus assembled manually from a minimum of three parts. Heating elements manufactured in this manner are very expensive.

Per Stobbe - 1989