I SQUARED R ELEMENT CO., INC.

PRODUCT DATA SHEET

LMA infusion glaze coated Starbar RR SiC Heating Elements

Infusion protected glazed elements for improved resistance to chemical attack

LMA infusion protective glaze coating consists of a complex silicate glass that has been specially formulated to resist oxidation and provide increased protection for Starbar SiC elements in certain corrosive furnace atmospheres.

The high temperature oxidation of silicon carbide occurs in two very different modes:

1. Active oxidation forms a volatile oxide that may lead to continuous extensive attack of the SiC:

$SiC(s) + 0_2(g) = SiO(g) + CO(g)$

SiC type heating elements are generally not recommended for use in conditions where active oxidation reaction will be dominant.

2. Passive oxidation however forms a protective oxide film which limits further attack of the SiC:

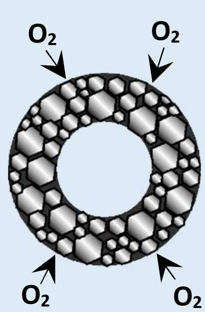
$SiC(s) + 3/2\ 0_2\ (g) = Si0_2(s) + CO(g)$

It is passive oxidation that results in the so called "aging" of SiC type heating elements; whereby the SiC is oxidized to silica, and the electrical resistance of the elements gradually increases over time.

Passive oxidation

$SiC(s) + 3/2\ O_2(g) = SiO_2(s) + CO(g)$

SiC reacts with the O_2 in the air to form a protective silica film. Further oxidation of the SiC can only take place thereafter by oxygen first diffusing through the silica layer to find fresh SiC to react with. This is what limits the oxidation rate.



The rate of reaction is variable according to several factors, including:

- ★ Operating Temperature
- ★ Electrical Loading
- ★ Power supply & Controls Design
- ★ Atmosphere Composition
- ★ Mode of Operation
- ★ Installation Method
- ★ Operating & Maintenance Techniques

The addition of water vapor to the atmosphere mix complicates things further. During wet oxidation, the oxidation growth rate is much faster than that in a dry atmosphere because the leaving water molecule has much higher solubility in SiO_2 than O_2 , therefore, it provides a greater supply of oxidizing species to the SiC surface. The result is a thicker and more rapidly developing oxide layer formed in the case of wet oxidation.

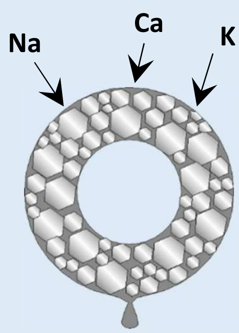
LMA infusion glaze coating provides a high degree of protection against chemical attack in atmospheres containing water vapor, alkali metal species, flux vapors and in applications that utilize oxygen enrichment.

LMA infusion glaze coating is fully penetrative in that the protective solution is fully absorbed into the open pore structure of the element, thereby coating all available crystal faces of the silicon carbide matrix. Elements are then dried and fired at high temperature to form the complex refractory LMA protective glaze coating.

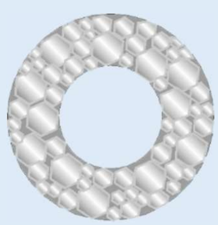
The resulting LMA infusion protective glaze coating is only a few microns thick and not typically visible to the naked eye.

LMA infusion glaze coating actively suppresses the rate of oxidation, inhibits reaction with the SiC matrix from forming non-protective silica types within the structure, and prevents the formation of low melting point silicate glasses which have a tendency to drip off.

Alkali attack
The protective silica film will freely react with alkali metal vapors to form low melting point silicate glasses. Such glasses have a tendency to drip off the elements which exposes fresh SiC for oxidation and further reaction. Over time a gradual erosion of the element can occur.



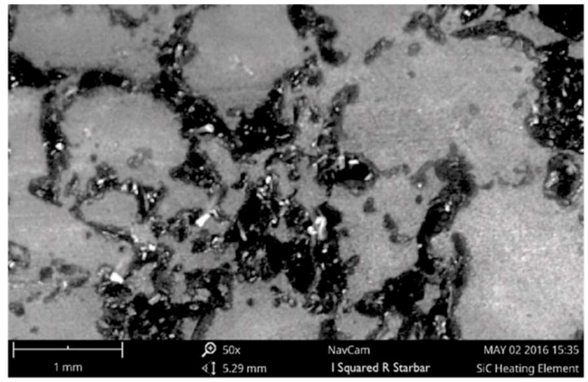
LMA infusion glaze coated elements.
LMA protective glaze coating suppresses the speed of oxidation, by forming a low fluidity high melting point glass. Thereby resisting further corrosive attack.



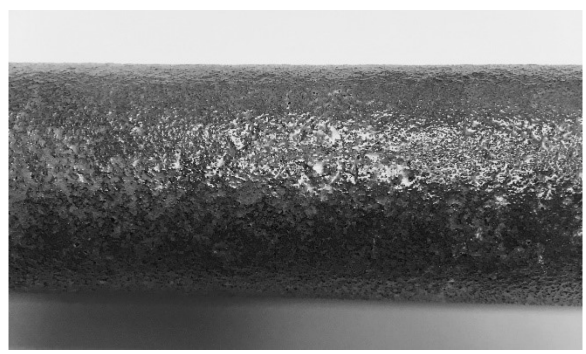
Water vapor, present in new and rebuilt furnaces, and a component of some furnace process atmospheres, has a very aggressive oxidizing effect on silicon carbide.

LMA infusion glaze coating suppresses such aggressive oxidation reaction and prevents the formation of non-protective silica forms that would otherwise be developed within the element pore structure, resulting in short element life through rapid and continuous oxidation.

LMA infusion glaze coating typically results in an element life increase between 30% and 300% compared with uncoated elements, depending on actual conditions in specific cases.



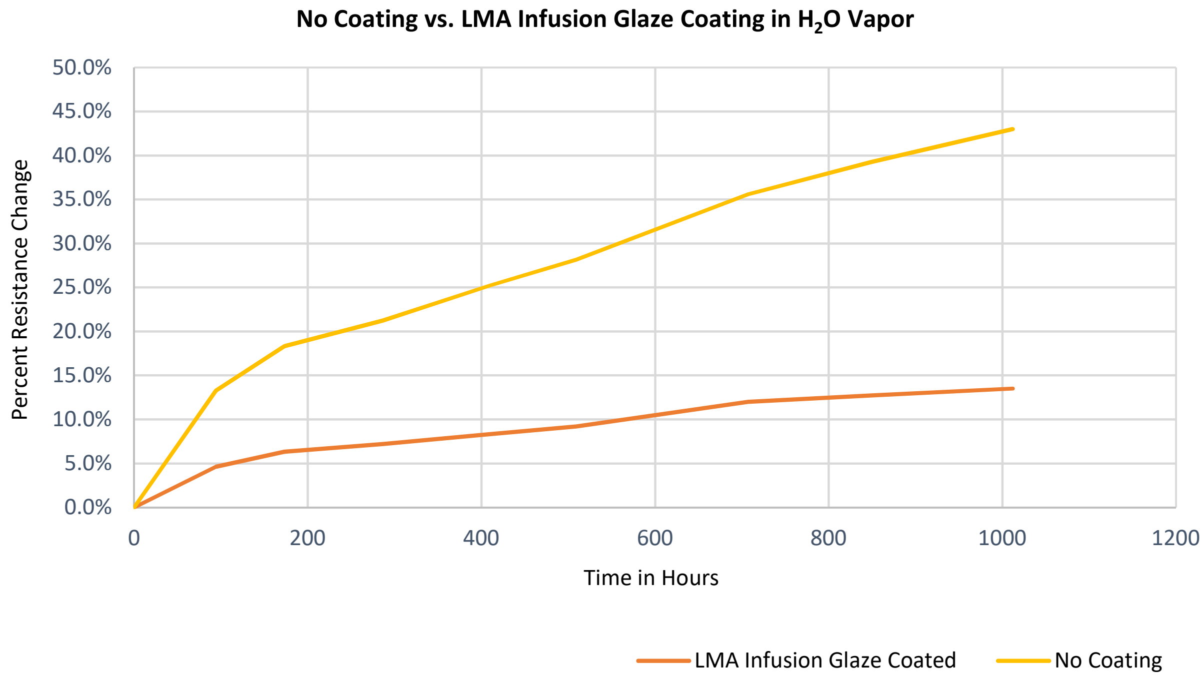
Microstructure of Starbar RR element –
Strong uniform, large grain mass formed during recrystallization produces a robust SiC body displaying slow passive oxidation rate with a high degree of repeatability and reliability.



LMA infusion glaze coated Starbar RR element
after 500 hrs operation at 2730°F / 1500°C

Having been challenged to develop a better performing recrystallized SiC heating element for use in highly demanding corrosive environments, our R&D group also studied the basic science behind protective mechanisms in order to formulate and optimize the composition of a new infused protective glaze coating for our Starbar SiC heating elements.

LMA Infusion Glaze Coating is one of the results of that work.



Comparative performance between uncoated Starbar and LMA Infusion Glaze Coated elements in water vapor at 2600°F/1425°C

LMA Infusion Glaze Coating - up to 4 times the life of uncoated SiC elements.

As can be seen in the performance comparison testing above, uncoated elements show an increase in resistance at a rate almost 4 times faster than elements coated with LMA Infusion Glaze Coating when used in an extremely aggressive atmosphere containing a high concentration of water vapor. These tests are accelerated for the sake of time, by using a much more corrosive atmosphere mixture than would usually be found in most industrial furnace processes. However, the same reaction mechanisms can be found in many furnaces albeit at a much reduced level.

The hot zones for groups of test elements manufactured for comparative testing were taken from the same starting SiC hot zone bars to minimize the possibility of even extremely minute variables from influencing the results. The results however were highly consistent between comparative element groups.

Ordering

LMA Infusion Glaze Coating can be applied to all sizes of Starbar RR one piece and LRE elements, Type-U, Type-W, Type-RU and Type-RA heating elements.

Availability

LMA Infusion Glaze Coating is readily applied, but should be specified at the time of placing an element order. Element descriptions are as follows:

Starbar type RR

Overall length x Hot Zone Length x Element OD, Nominal electrical resistance at 1960°F **LMA**

e.g. Starbar RR116x65x2.12, 1.02Ω ±20% **LMA**

Starbar type U

Overall length x Hot Zone Length x Cold End Length x Element leg OD, Nominal electrical resistance at 1960°F **LMA**

e.g. Starbar U23.5x12x9.5x1, 1.25Ω ±20% **LMA**

Applications

LMA Infusion Glaze Coated Starbar elements may be used either continuously or intermittently.

LMA Infusion Glaze Coated Starbar elements are recommended for all applications where the elements may be subject to high humidity conditions, either for a short period, such as when initially drying out the furnace refractories, or after a furnace has been sitting idle for some time and has absorbed moisture from the environment during the downtime, or, where some degree of water vapor is either intentionally added to the process atmosphere, or is generated as a by-product of the process itself.

LMA Infusion Glaze Coated elements are also recommended for all applications involving fluxes or reactive process residues, where the elements will be unavoidably subjected to alkaline metal vapors, which are ordinarily very aggressive and corrosive towards SiC heating elements.

Applications such as non-ferrous metal melting and holding, glass melting and refining, brazing, sintering of powdered metal components, and pre-sintering of powders for lithium ion battery cells may all benefit significantly from the use of LMA Infusion Glaze Coated Starbar heating elements.

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