Glass-Carbon-Composites for Heating Elements Manufactured by 2C-PIM

Todays power resistors and heating elements are usually made of metal wires wound around a core. Due to the non-adjustable resistivity of typical resistance alloys these components may become quite large in dimensions and therefore the overall size determining components in complex electric devices. Furthermore, prices of metals are rising over the last years. Pursuing an alternative material concept promises wide market opportunities. Glass-carbon composite materials are such systems. Fraunhofer IKTS has adapted powder injection moulding for this material system enabling a mass production technology of complex shaped electrical conducting glass-carbon components.

Conventional glass components are usually shaped from a melt by blowing, drawing, rolling, or casting. This does not only imply high temperatures but also includes limitations for structural details. Since stresses arise during cooling from the melt, edges have to be rounded for preventing stress peaks. Realizing structures like well-defined channels require mechanical machining or chemical etching. Manufacturing glass components by a powder route has advantages. Sintering is conducted above glass transition temperature but well below the molten state what in turn saves energy. Functional glass matrix composites can be realized by adding particulate additives which are not affected by side reactions with the glass melt as the glass viscosity required for sintering is lower than for melting. This extends the opportunities for possible composite combinations and allows for a wide range of secondary phases. Among the various powder technological methods powder injection moulding is the one suited best for high complex parts produced economically in large numbers. Holes, rips, mountings and undercuts can be formed in near net shape and machining efforts after sintering are minimized. The process two-component injection moulding (2C-PIM) takes even a step further. Two different materials are combined in green state and then co-sintered. In this way joining steps of sintered parts are omitted and complex shaped interface structures can be realized. In order to explore new opportunities for multifunctional components we combined conductive and insulating glass based composites by applying 2C-PIM. As matrix material a borosilicate glass from Schott was used. The conductive component is a glass-graphite-composite based on the same glass. The carbon species is incorporated into the glass matrix and forms a network of conductive particles. Above the percolation threshold electrical current can flow through the touching particles and due to ohmic losses heat is produced. This principle is the basis for its application as heating device. The resistivity depends on the graphite content which ranges from 300 Ω/cm at 1 mass-% down to 1 Ω/cm at 7 mass-% graphite (Fig. 1). This wide range allows for realizing customized resistivities for different applications. In microscopic images we see cross-sections of graphite platelets and more spherical graphite particles embedded in the glass matrix which appear locally separated (Fig. 2). But in fact they form a percolating three-dimensional network of conductive pathways.

One of the major challenges in developing a feedstock couple for 2C-PIM is synchron-

Keywords
2C-PIM, glass-carbon-composites, heating devices

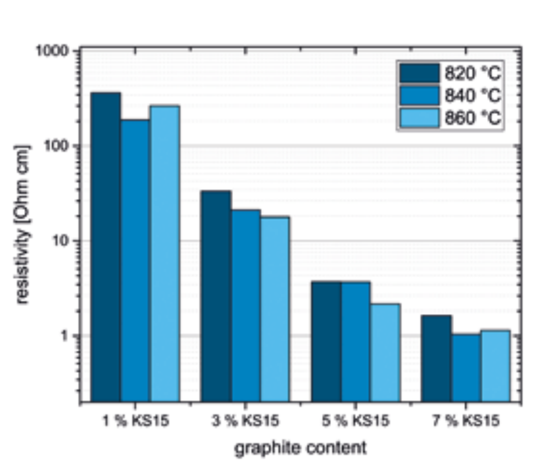

Fig. 1
Resistivity of glass-carbon-composites for different carbon contents and sintering temperatures measured at 100 °C

Anne Mannschatz, Axel Müller-Köhn, Axel Rost, Tassilo Moritz, Jochen Schilm, Alexander Michaelis
Fraunhofer IKTS
01277 Dresden

www.ikts.fraunhofer.de

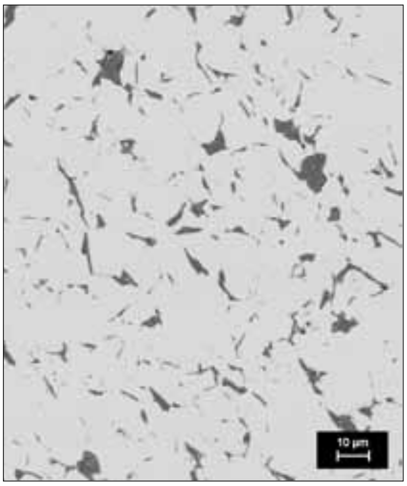

Fig. 2
Microstructure of glass-graphite-composite with 5 mass-% graphite

izing sintering which involves both the sintering curve and the maximum shrinkage. The existence of carbon in glass affects sintering behaviour significantly. The graphite particles constrain sintering and the sintering temperature is shifted towards higher values. Therefore the graphite containing glass cannot be combined with the pure glass by co-firing in order to prevent stresses in the interface. Two alternative composites based on the same matrix glass were developed as counterparts. Since even small amounts of graphite attain a noticeable effect on sintering behaviour one non-conductive partner included 1 mass-% of a high resistivity carbon black, as advised by Imerys.

For the second insulating partner 5 mass-% alumina powder was added to the glass. Alumina has a similar effect on sintering temperature like the graphite. The alumina powder was chosen with respect to the particle size of the glass powder.

The output of the development work was a heating nozzle consisting of an inner insulating cup which is partially covered by an outer conductive shell surface (Fig. 3). The nozzle or, if its orifice is closed, the crucible was designed as a demonstrator capable to show the potential of the material combination. The component was produced using a two-component injection moulding machine of Arburg (Allrounder 320S). During the manufacturing cycle the inner component is moulded first, transferred into the second cavity of the mold and then the second component is injected. Debinding and sintering is performed in nitrogen up to 750 °C.

The two-component parts were subjected to a functionality test. A low ohmic contact was made by sintered thick film metallization layers. The demonstrator heats up as shown by an infrared camera image (Fig. 4). With slowly increasing electrical power the temperature reaches 240 °C by applying a power of 16,7 W (Fig. 5). At fast heating rates maximum temperature is obtained within 2-4 min. With respect to the negative temperature coefficient of graphite the resistivity of the glass-carbon composite decreases with temperature.

This behaviour implicates decreasing ohmic losses and hence limits the heating. This behaviour is advantageous for controlling the temperature since it is a self-limiting process and the danger of overheating can be reduced. The temperature was homogeneously distributed and no hot spots were visible.

The results of the heating tests combined with the good chemical stability of glass and the advantages of two-component injection moulding allows for many interesting applications in the future: directly heated nozzles or crucibles, or a new generation of heated chemical reactors which can be equipped with microstructures, consumer products such as water boilers or coffee machines.

Fig. 3
Sintered 2C-nozzles in two material combinations

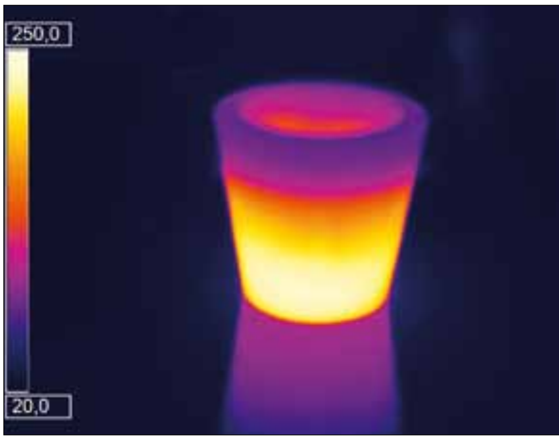

Fig. 4
IR-camera image of heated nozzle

Acknowledgement

The described work is part of the IGF-project 17755 BR funded by the German Ministry of Economics and Energy (BMWi). The authors thank the companies of the advisory board for their support: Arburg, Klaus Hoffman GmbH, Imerys Graphite & Carbon, Inmatec Technologies, Invenios Europe, Kläger Spritzguss, ROBU Glasfilter-Geräte, Schott AG.

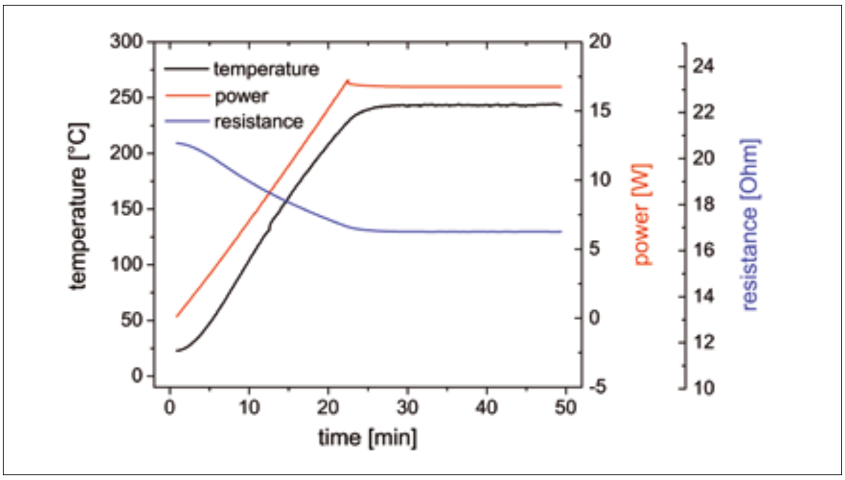

Fig. 5
Controlled heating of a nozzle with slowly increasing power reaching a quasi-stationary state