DOI 10.5162/SMSI2020/P2.9

Packaging concepts and development progress of ceramic thermocouples for up to > 1800 °C

Paul Gierth, Lars Rebenklau, Bing Feng, Hans-Peter Martin
Fraunhofer IKTS, Winterbergstrasse 28, 01277 Dresden, Germany
paul.gierth@ikts.fraunhofer.de

Summary:
Measurement of temperatures is critical for many technical applications in the modern industries. Common used temperature sensors are based on metallic and not many alternatives are given until today. Therefore, semiconductive ceramic materials based on boron carbide were developed to generate miniaturized thermocouples for temperatures up to > 1800 °C. An overview of the ongoing development process of the system embedding of this kind of thermocouples is given. Risks and chances of ceramic thermocouples were discussed.

Keywords: high temperature, thermocouple, ceramic, packaging

Motivation

The measurement of temperatures is critical for many technical applications in the modern industries. Different measurement concepts can be used depending on process temperatures. Most common are thermocouples (TC) consisting of two different metallic. Many of the common metallic combination [1] show acceptable long time stability at high temperatures up to 1400 °C. For temperatures measurement above 1800 °C are only thermocouples type A and C (combinations of Wolfram and Rhenium) possible combinations, which have insufficient long time stability. Infrared thermography could also be used but has many disadvantages according sensitivity and system price. Therefore, a clear demand on long time stability thermocouples for temperature ranges above 1800 °C is given. First ceramic thermocouples were already described in the 1980s [2]. Fundamental working principles were demonstrated in this publication, but many technology problems could not be solved until today. Especially, a not very high diffusion stability between the used ceramic components was not acceptable. Therefore, novel ceramic composites were developed [3], which show very promising electrical and thermoelectrically characteristics. But now, this materials needs to be transferred into a system concept to generate workable thermocouples.

Semiconductive ceramic thermocouples

Semiconductive ceramic materials based on boron carbide were developed to generate miniaturized thermocouples for temperatures up to > 1800 °C. Therefore, extrusion and high temperature interconnection technologies needs to be developed. Additionally, signal analysis algorithms were reviewed to improve the system.

Results

Materials based on boron carbide and different metallic borides were developed as paste-like mass and characterized after sintering. The first results are very promising (see Fig. 1).

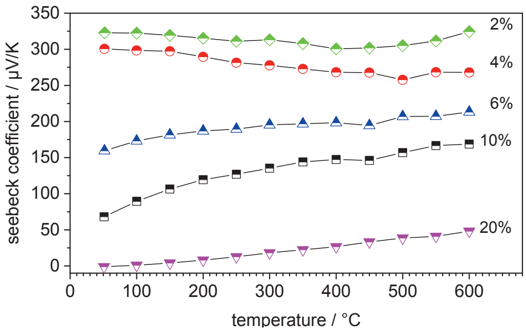

Fig. 1. Seebeck coefficients of sintered boron carbides with different mass-% of metallic borides.

Implementation situation for thermocouples in different oven types with temperatures > 1800 °C were evaluated. Based on these results, first system concepts were developed and realized. The materials can be extruded in different shapes in a nearly endless length, but are limited in the length of available sintering ovens. Therefore, all system designs assuming an interconnection between semiconductive ceramics and metallic compensation cables inside the oven chambers.

DOI 10.5162/SMSI2020/P2.9

Compensation cables with identical characteristics like the developed ceramics are not available. Therefore, the measured temperature T_1 must be referenced to the temperature T_2 at the interconnection joints between ceramic and metallic parts (see fig. 2). Additional electromotive force EMF_b can be negligible if both metallic wires are made of the same material.

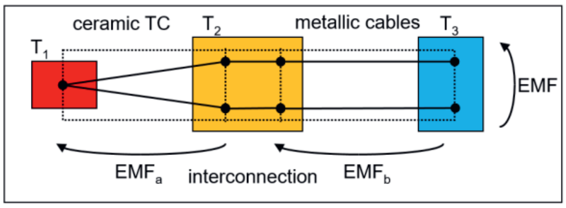

Fig. 2. Forming of the measurement signal of ceramic thermocouples with metallic cables.

Unlike common metallic TC, the reference temperature area can´t be implemented in the voltage measurement tool. Therefore, a concept for controlled and measureable reference temperatures was developed (see Fig. 3)

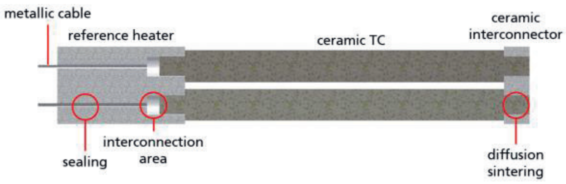

Fig. 3. System concept for ceramic TC with reference heater at interconnection joints.

The interconnection joints between metallic parts and ceramics were integrated in a small insulating ceramic element. This element compensates temperature differences between the interconnection joints, which could influence the measuring signal by generating additional thermo voltages. Interconnection joints itself could be generated by brazing, active soldering or welding. Especially the already in thermocouples industries well established welding technology would be preferable. Boron carbide could be welded i.e. with platinum or nickel wires. This kind of joints can withstand very high temperatures as seen in Fig. 4.

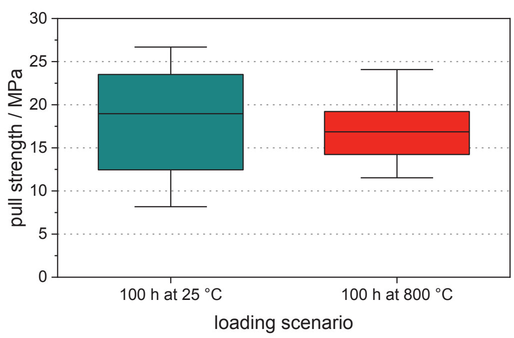

Fig. 4. Pull strength of welded platinum wires on boron carbide after different loading scenarios.

This basic system design is compatible to industrial thermocouple terminal heads and can be mounted in a neck tube. Temperature measurement at this reference area could be realized by implementing an additional metallic thermocouple in a hole inside the insulating ceramic reference area. In that way, measured temperature T_1 is always referenced to a resulting temperature T_2. This requires complex signal analyzing algorithms, so that a constant reference temperature T_2 would always be preferred. Such constant temperature can be realized by functionalizing the insulating ceramic at the interconnection area into a temperature controlled reference area by screen printing platinum heating areas on its surface. Therefore, needed heating energy to generate an adjustable reference temperature between 300 °C to 800 °C was calculated. Corresponding heating resistances are designed (see Fig. 5).

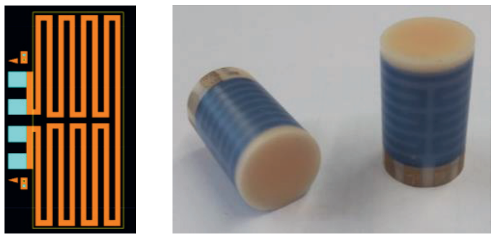

Fig. 5. Realized adjustable high temperature reference areas. Left: screen-printed layout of orange heater area and blue interconnection pads, right: realized functional samples with blue insulating surface coating.

By using these adjustable reference elements, the heat transfer from the hot end of the ceramic TC to the cold end could be reduced. Therefore, a much better temperature signal stability and an improvement of the sensor long time stability is expected. Additionally, an self-monitoring of the TC is possible by the wide adjustability of the reference temperature.

Conclusiones

Ceramic TC are a promising alternative to metallic elements in terms of increasing EMF values and long-time stability. System integration could be more complex compared to common TC, but offers interesting alternative measurement and self-alignment aspects.

References

[1] DIN Standard 60584-1: Thermocouples – EMF specification and tolerances, Beuth Verlag, 2014.

[2] Hunold, K. et al. (1982). German Patent No. DE3235838. Kempten, Germany.

[3] Martin, H-P, Feng, B, Michaelis, A. Pressureless sintering and properties of boron carbide composite materials. Int J Appl Ceram Technol. 2019; 00: 1– 6. https://doi.org/10.1111/ijac.13423.