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Temperature sensor made of polymer-derived ceramics for high-temperature applications

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ABSTRACT

This paper describes the use of polymer-derived SiAlCN (silicoaluminum carbonitride) ceramics (PDC) to fabricate a temperature sensor for high-temperature applications. A unique sensor head was designed and fabricated with Pt wires seamlessly embedded in as electrodes. Material characterization test demonstrates that the resistance of the senor head decreases monotonically with surrounding temperature, suggesting its readiness to be used for temperature measurement. In actual experiment (temperature up to 830 °C), the measurement of the PDC sensor demonstrates good repeatability to both unidirectional and bidirectional temperature variations for the total span of 10 h, and its measurement follows closely with the thermal couple measurement. These results demonstrated that the temperature sensors made of polymer-derived ceramics (PDC) have excellent accuracy and repeatability, and can be used in high temperature environment.

1. Introduction

Sensors that can be operated in harsh environmentals are highly desired for applications in a variety of high-temperature systems, such as turbine engines, coal gasfication systems, and material processing systems. It is expected that these sensors can measure real-time operating conditions of the systems to provide information for feedback control and system optimization to increase efficiency and reduce pollution, as well as to monitor the health of structural components to improve safety. However, developing such kinds of sensors is not trivial. The critical challenge is that they must survive harsh environments of the systems, including high temperature, high pressure and severe oxidation/corrosion.

Up to now, several materials have been explored for microsensor applications. Among them, semiconducting silicon is the most studied mateial for microsensors due to its controllable electric properties and well-developed microfabriction techniques. However, Si-based sensors can not be used at temperatures higher than 350 °C since severe material degradation at elevated temperatures [1,2]. Silicon carbide is another widely used material for sensors and has been shown to provide better performance than silicon-based sensors in terms of high-temperature capability. Commercially available SiC-based sensors can be used up to 500 °C [3–5].

Recently, polymer-derived ceramics (PDCs) have been considered as promising materials for high-temperature sensor applications [6]. PDCs are a new class of high-temperature ceramics synthesized by thermal decomposition of polymeric precursors. Previous studies have revealed that PDCs possess a set of excellent structural and functional properties, including excellent high-temperature stability [7], high creep resistance [8,9], outstanding oxidation/corrosion resistance [10–14], high-temperature semiconducting behavior [15,16], and anomalously high piezoresistivity [17]. The direct chemical-to-ceramic processing of PDCs is compatible with many manufacturing techniques for making micrometer/nano-sized ceramic parts from the materials [18–21]. In addition, compared to other existing micro-fabrication technologies, the authors have demonstrated that such kind of material has good micro-mechanical machinability with feature size as small as 20 μm, and has been applied for both temperature and pressure

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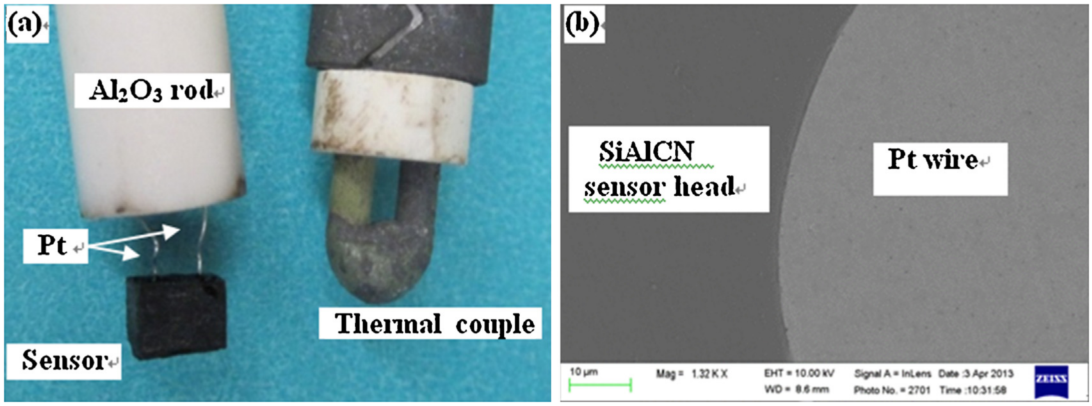

Fig. 1. (a) Optical image showing SiAlCN sensor and Pt leads; (b) SEM image showing the interface between SiAlCN and Pt wire.

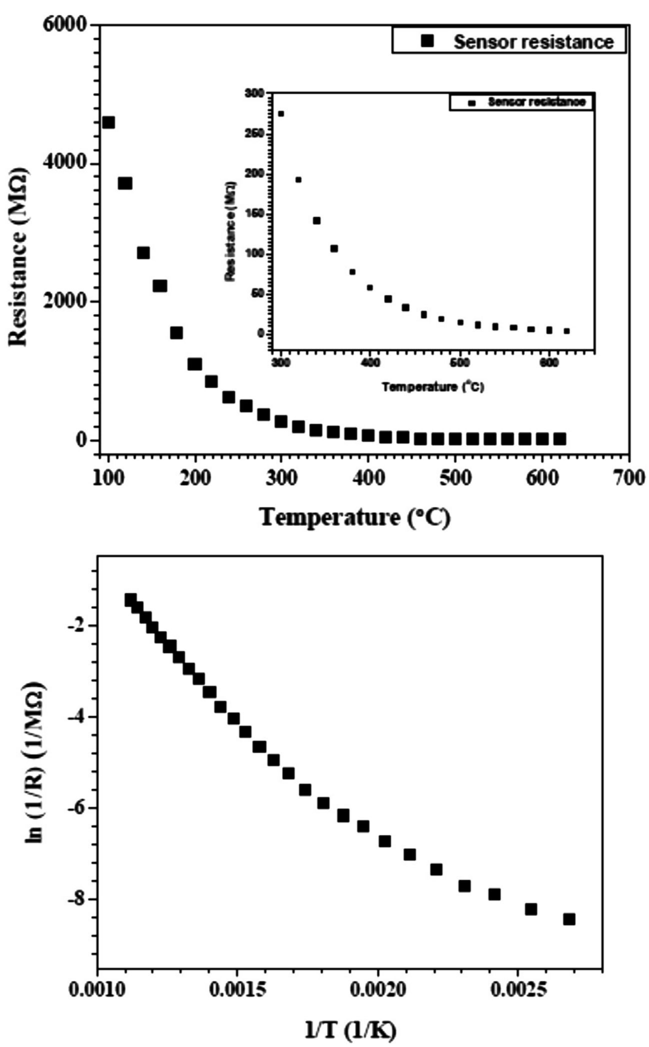

Fig. 2. The sensor resistance with respect to temperature max of 620 °C (inset: relationship in higher part of the temperature range); (b) natural logarithm relationship.

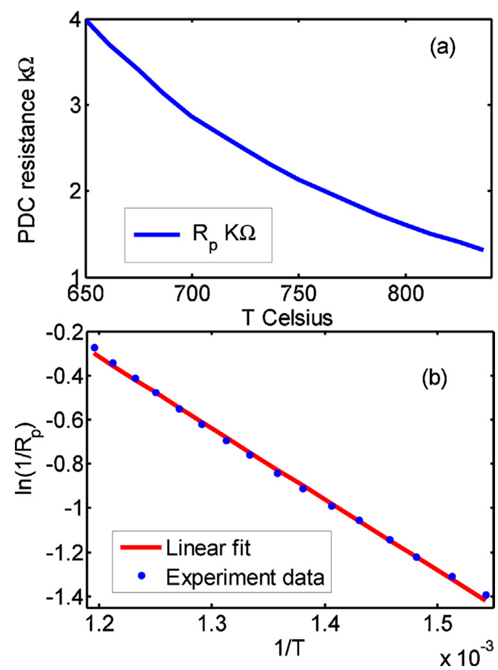

Fig. 3. (a) The resistance of the SiAlCN sensor head as a function of temperature; (b) A plot of resistance of the sensor head vs. temperature in a format of ln(*RP*) vs. 1/*T*; the blue points is experimental result and the red solid line are computed from Eq. (1). (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.)

measurement [26,27]. Previous work has demonstrated the temperature dependence of the electric resistances for such material, suggesting its capability to be used for temperature measurement and heat flux measurement in high temperature and harsh environment [30,31]; however, actual sensors made of the materials have not been reported yet.

In this paper, we report a temperature sensor made of polymer-derived SiAlCN (silicoaluminum carbonitride) ceramic. The ceramic sensor probe was treated as a temperature-dependent potentiometer to simplify the design of the overall sensing system. The temperature can be obtained from the voltage over a shunt resistor connected in series to the probe. In the following sections, we will first present the fabrication and characterization of the ceramic sensor probe followed by the design of the entire sensing system. Finally, we will illustrate the testing results of the sensor performance.