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Hot-pressing sintered BN-SiO_2 composite ceramics with excellent thermal conductivity and dielectric properties for high frequency substrate

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ABSTRACT

High thermal conductivity and low dielectric constant are the more and more important properties for high-frequency substrate materials to enhance their heat radiation and reduce signal delay. In this work, a series of BN-SiO_2 composite ceramics for high frequency application were successfully synthesized by hot-pressing sintering method. And their structures, thermal and dielectric properties were systematically studied. According to the results, the excellent thermal conductivity with low dielectric constant and low dielectric loss has been obtained in the BN-SiO_2 ceramic. Compared to the pure SiO_2, the sample with 50 wt% BN addition sintered at 1650 °C exhibited excellent physical properties, including a high thermal conductivity of 6.75 W/m K which is almost five times higher than that of pure SiO_2 and a low dielectric constant of 3.73. The achieved high thermal conductivity and appropriate dielectric property of the BN-SiO_2 composite ceramic make it a promising candidate for high-frequency substrate application.

1. Introduction

With the rapid development of high speed circuits and power electronic devices used in high frequency, how to solve the issues of heat radiation and single delay in the substrate is becoming a bottleneck in practical applications. Therefore, the demand for high-frequency substrate materials with high thermal conductivity and low dielectric constant increases quickly in recent years [1–4]. However, many traditional ceramic substrate materials cannot meet these requirements. For example, Al_2O_3 and AlN are widely used as substrates because of their high thermal conductivity. However, the large signal propagation delay limits their applications at high frequency, resulting from their relatively large dielectric constants [5]. Besides, many ceramics with dielectric constant less than 6 have been reported, such as SiO_2-AlN-BN, LZS-Al_2O_3, Si-N-O_f/BN, CaF-AlF_3-SiO_2 and CaO-B_2O_3-SiO_2 [6–10], but they were lack of an adequate thermal conductivity when used for the heat conduction in the high frequency. So, it is urgent to find or synthesize some materials with both high thermal conductivity and low dielectric constant.

BN is a potential substrate material with high thermal conductivity and low dielectric constant [11]. However, its high cost and tough process technology immensely hinder the wide application of BN substrate [12]. Meanwhile, although the thermal conductivity of SiO_2 is insufficient to meet the requirement of heat radiation, SiO_2 powder is a kind of useful filler in the composite ceramics for its high performance such as low dielectric constant, low dielectric loss, high mechanical strength and low cost [13]. Therefore, if SiO_2 and BN could be combined together, the processing difficulty of BN would be immensely reduced, and the dielectric constant of BN would be further decreased due to the smaller dielectric constant of SiO_2.

Nevertheless, it is difficult to calcine and fabricate dense BN-SiO_2 composite ceramics by conventional pressureless sintering because BN powders are easily agglomerate to form large BN particles or platelets inside the sintered composite and the sintering temperature is very high [14]. According to some reports [15–18], the hot-pressing sintering is a better choice to fabricate dense BN-SiO_2 composite ceramic. Although the BN-SiO_2 composite ceramics with low dielectric constant of 2.5–3.78 and low dielectric loss were prepared in previous studies [19,20], their thermal properties were hardly analyzed.

In this work, a series of BN-SiO_2 composite ceramics sintered by hot-pressing were fabricated. The phases and microstructures of as-prepared products were characterized. Their thermal properties and the dielectric properties were also measured. The optimized sample with addition of 50 wt% BN sintered at 1650 °C exhibits excellent physical properties, including a high thermal conductivity of 6.75 W/m K and a low dielectric constant of 3.73, which make it a promising candidate material as high-frequency substrate.

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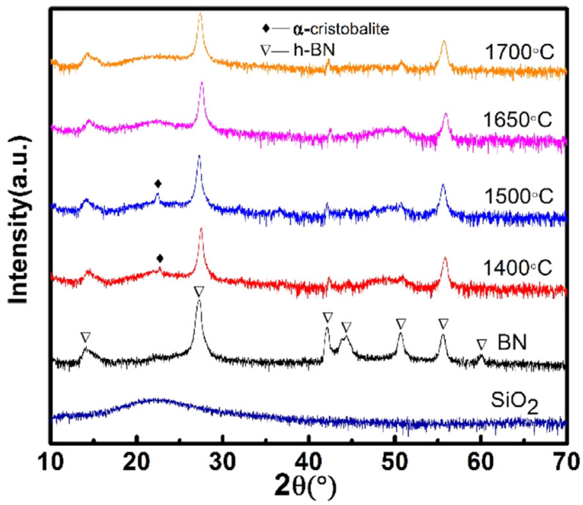

Fig. 1. XRD patterns of the BN-SiO_2 composite ceramic with 50 wt% BN at different temperatures.

2. Experimental procedure

A series of BN-SiO_2 composite ceramics sintered at different temperatures were synthesized by hot-pressing sintering. The boron nitride was purchased from Qingzhou Maiteke new materials Co. Ltd (Weifang, China) with an average particle size about 10 μm and a high purity (≥ 99%). Silicon dioxide (Sinopharm Chemical Reagent, Shanghai, China) was fully amorphous with an average particle size about 10 μm and a high purity (≥ 99%). SiO_2 powders and BN powders were mixed according to the weight ratios of 1:3, 1:2, 1:1, 2:1, 3:1, respectively. The powders were ball-milled with ZrO_2 balls as the media for 4 h with a rate of 400 rpm in ethyl alcohol by planetary ball mill (QM-3SP2, Nanjing Machine Factory, Nanjing, China). Subsequently, the mixtures were dried at 100 ℃ for 12 h. Then the powders were hot-pressed to Φ20mm discs at 1400 ℃~1700 ℃ with a pressure of 30 MPa for 1 h under air atmosphere. After that, the hot-pressed discs were cut into $10 \times 10 \times 2\,mm^3$ standard bar specimens for thermal conductivity testing.

The phases of prepared samples were identified by powder X-ray diffraction (XRD) using Cu-Ka radiation (D/MAX-2400, Rigaku, Tokyo, Japan). The morphologies and the elemental analysis of the ceramics were observed by scanning electron microscopy (FEI QUANTA FEG 250, FEI, Hillsboro, Oregon, USA) and energy dispersive spectrometer module, respectively. Thermal conductivities were measured by laser

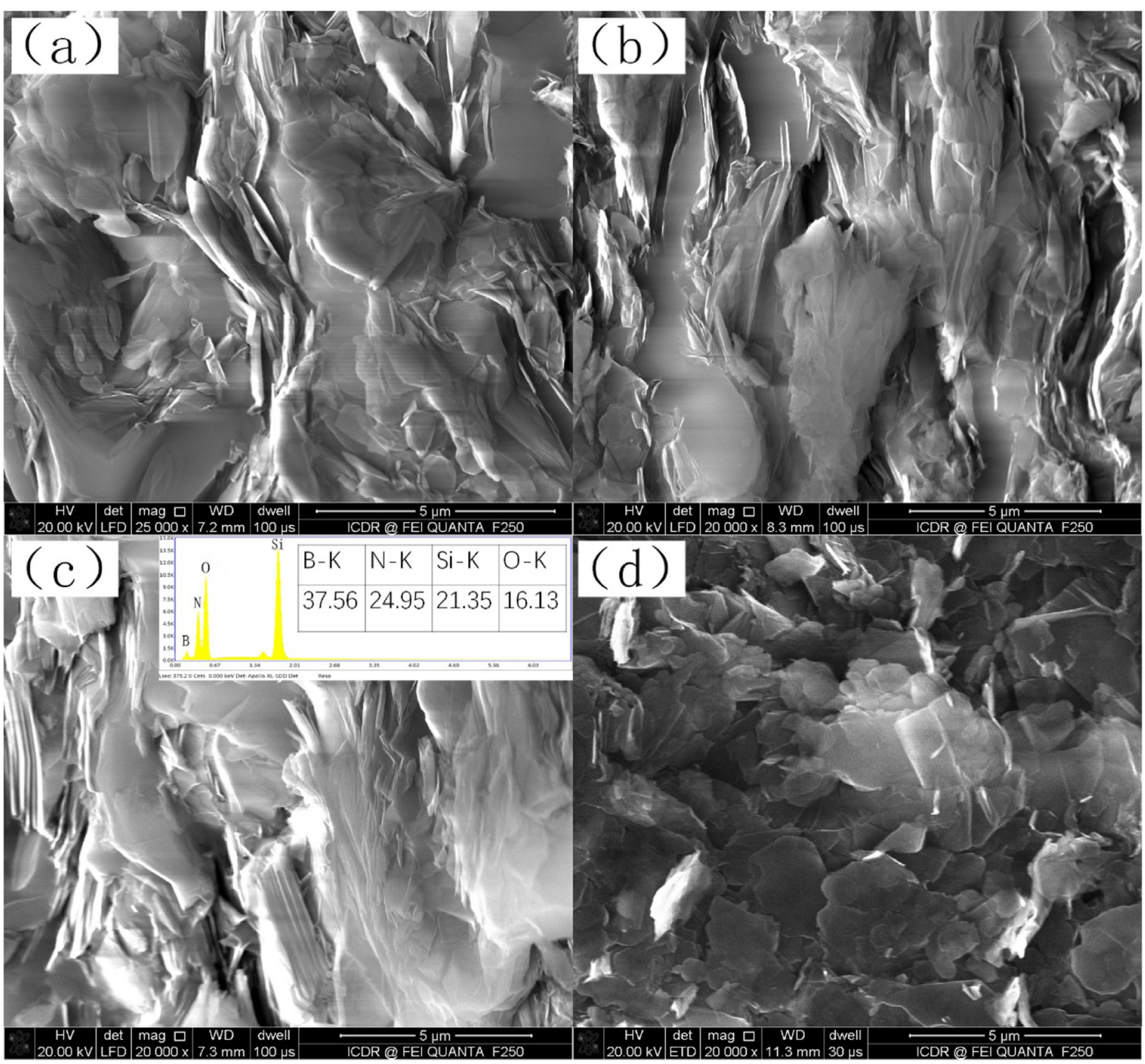

Fig. 2. SEM of the cross-sectional morphology of the BN-SiO_2 composite ceramic with 50 wt% BN sintered at (a) 1400 ℃ (b) 1500 ℃ (c) 1650 ℃ (d) 1700 ℃ and EDS analysis of the cross-sectional morphology of the ceramic sintered at 1650 ℃.