Microwave Effect on Nitride Semiconductors at High Temperature

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ABSTRACT

The project of this work is to study the microwave effect on Nitride semiconductors at high temperature. Three samples of nitrides are used for this studying. Boron nitride Bn, Silicon nitride SiN, and aluminum nitride, AlN. A full computerized cavity perturbation technique working in frequency ranges, 615 MHz, 1412 MHz, 2214 MHz, 3018 MHz, and 3820MHz at a temperature ranging from 25 ^{o}C to 2000 ^{o}C, are using to measure the microwave dielectric properties of the three samples. The microwave effect on these samples can be determined due to the variation in the real and the imaginary parts, ε' and ε'', of the dielectric properties in microwave frequency range at high temperature.

KEYWORDS: Composition & Microstructure/Material Type/ceramic, /dielectric properties

INTRODUCTION

Nitride ceramics is an III-nitride compound semiconductor formed due to the bonding of one of the group III elements such as, boron, aluminum, gallium or indium with the group V element, nitrogen. The III-nitrides and their alloys are direct band gap semiconductors.

In recent years, III-nitride semiconductors have gained a significant position in science and technology due to their potential for numerous device applications. Aluminium nitride AlN is a candidate material for high-temperature engineering applications due to its high thermal conductivity, high electrical resistivity and low dielectric properties. It is a covalent compound, limited atomic mobility makes it very difficult for complete densification of pure AlN at reasonable sintering temperature. Silicon nitride have many excellent properties, high strength and relatively high fracture toughness, good wear resistance, good oxidation resistance and good corrosion resistance. Boron nitride is a unique material. It offers outstanding thermal conductivity, excellent dielectric strength, very good thermal shock resistance and is easily Machinable. BN is an advanced synthetic ceramic available in powder, solid, liquid and aerosol spray forms. In an oxidizing atmosphere it can be used up to 900°C [1-5].

Microwave processing of ceramics has advantages in reducing the time and temperature of processing as well as improving the homogeneity of heating. Microwave energy interact with the material at the molecular level, it rises inside the material itself, and depends on the dielectric properties of the material and on the incident microwave frequency. Microwave heating is caused by the ability of the material to absorb high frequency (microwave) and converted it to heat. In microwave materials classified into three types, deflected, transparent, and absorbers based on their interaction with microwave. Absorbers is a high dielectric loss materials which absorb microwave energy to a certain degree based on the value of the dielectric loss factor and convert it to heat. Dielectric properties are one of the important properties to assess the viability of heating effect due the microwave. The ability of a dielectric material to absorb microwave and store energy is given by

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

Where dielectric constant (ε') signifies the ability of the material to store energy and dielectric loss (ε'') represents the ability of the material to convert absorbed energy into heat [6-8].

Microwave measurements the dielectric properties of materials at different frequencies and different temperature can be helpful in understanding the microwave mechanism heating which is based on the dielectric properties measurements. Cavity perturbation technique is the best method for dielectric properties measurements. It is distinguished by its higher measuring precision and simple calculations and does not have a special requirement for one geometry, size and kind of the sample such as solid, powder, and liquid [9-11]. The objective of this work is based on the studying the microwave effect, on the given nitride semiconductor material, AlN, SiN, and BN. The measurements will be done in microwave frequency range and at high temperature using cavity perturbation technique.

Experimental

Cavity perturbation technique was used to measure the complex permittivity of AlN, SiN, and BN in microwave frequencies, 615 MHz, 1412 MHz, 2214 MHz, 3017 MHz, and 3820 MHz and at temperature from 25 ***°C*** to 2000 ***°C*** making measurements every 50 ***°C***. The details of this technique have been reported in [12] and will not be discussed further. Measurements are performed by measuring the resonant frequencies of the cavity with and without the sample, ***f*** and ***f_o,*** respectively, and the quality factors of the cavity with and without the sample, ***Q*** and ***Q_o***, respectively. The simple perturbation formula derived by Nakamura and Furuichi [13] is based on the shift of frequency, □*f*, and on the shift of the reciprocal quality factor, □***1/Q).*** The real, □,*'* and the imaginary, □***',*** parts of the complex permittivity can be calculated by using Eq. (1,2).

$$\varepsilon' = 2 j^2(\chi_{on}) \frac{a^2}{b^2} \frac{\Delta f}{f} + 1 \tag{1}$$

$$\varepsilon'' = j^2(\chi_{on}) \frac{a^2}{b^2} \Delta\left(\frac{1}{Q}\right) \tag{2}$$

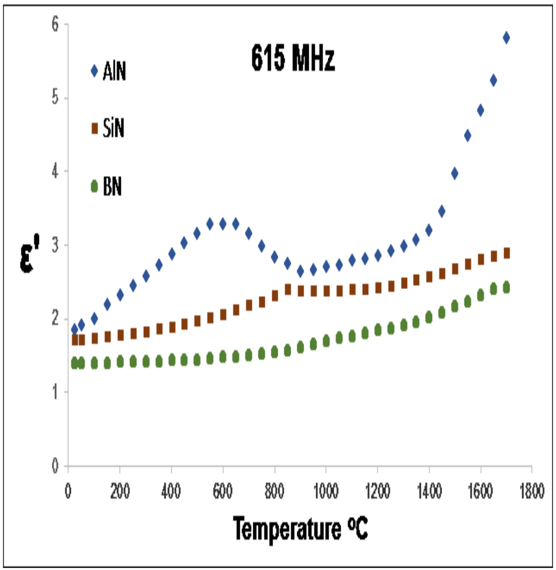
Where χ_{on} is the root of the zero order Bessel function, ***j***, of the first kind. ***a*** and ***b*** are the sample and the cavity volumes respectively.

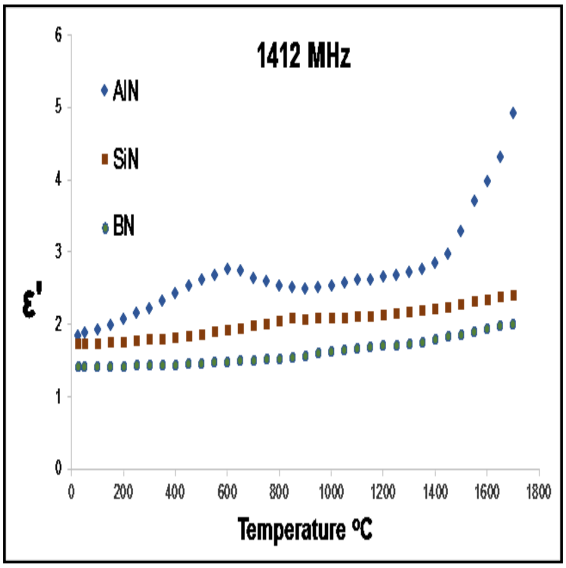
Results and discussion

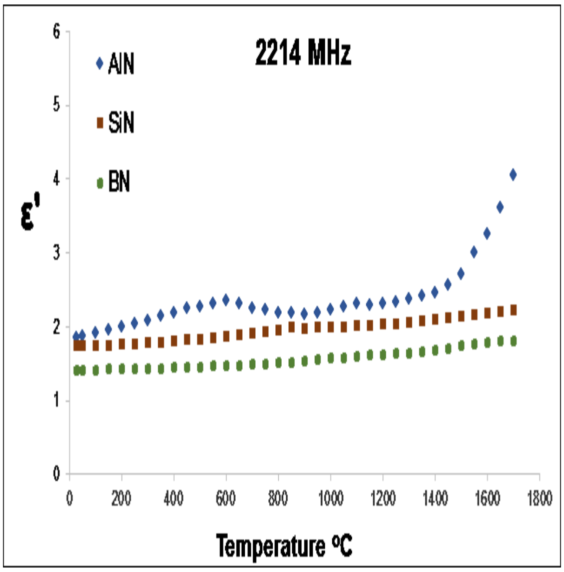
Powder sample of AlN, SiN, and BN are selected to study their electrical characteristics in microwave frequency range and at high temperature. Holder sample is a special silica tube, stand to temperature up to 2000 ***°C***. The tube of 5 mm in diameter was filled by those samples to hold them during the measurements between the cavity and the furnace. Figure 1 shows the dielectric constant,ε', of AlN, SiN, and BN variation with temperature ranging from 25 to 1800 °C in the certain five microwave frequency values, 615 MHz, 1412 MHz, 2214 MHz, 3017 MHz, and 3820 MHz The value of the dielectric constant,ε', of SiN and BN have the same variation is 1.5 up to 2 during the measurements at the five values of frequencies while for AlN the variation is 1.8 up to 6 and decreasing with the increasing of frequency. The peak appears at 600 °C up to 3.5 for all five values of frequencies of AlN. Figure 2 shows the dielectric loss factor (ε'') of AlN, SiN, and BN variation with temperature ranging from 25 to 1800 °C in microwave frequency ranging, 615 MHz, 1412 MHz, 2214 MHz, 3017 MHz, and 3820 MHz From this figure the ability of the material to convert absorbed energy into heat is very low in SiN and BN nitride at all the five frequency values while for AlN it very high comparing with SiN and BN, and increasing with frequency increasing. At higher frequency 3820 MHz the dielectric loss factor (ε'') of AlN decrease and has the same values of SiN and BN nitride.

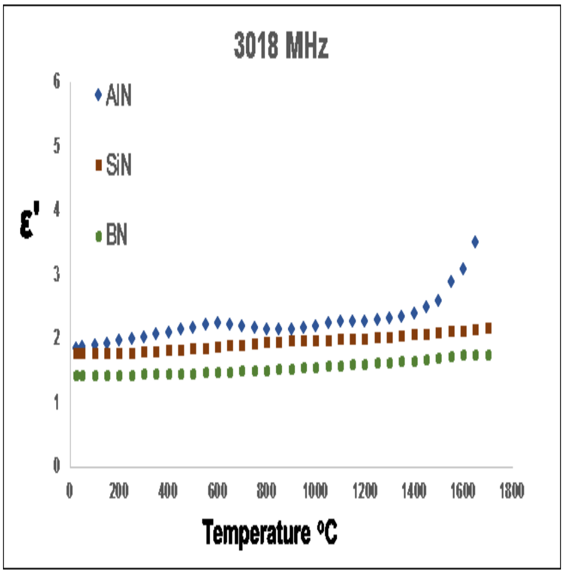
Conclusion

Microwave effect on AlN nitride is larger than those on SiN and BN. This effect on AlN increase with increasing temperature but decrease with frequency increasing. For SiN and BN the microwave effect is constant during the measurements with a little pit of variation.









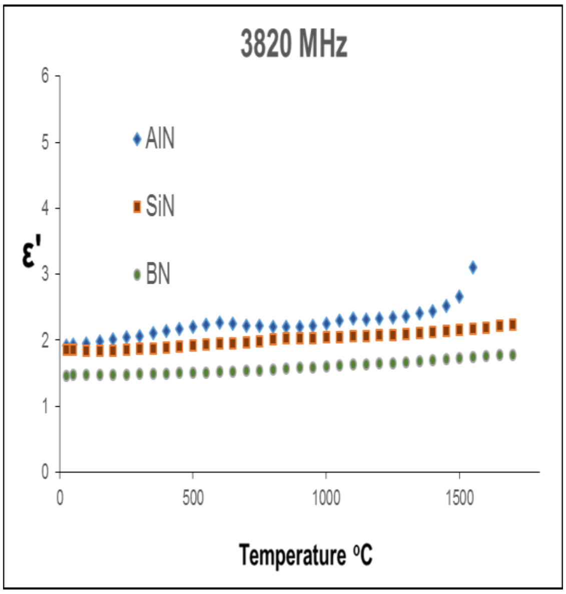
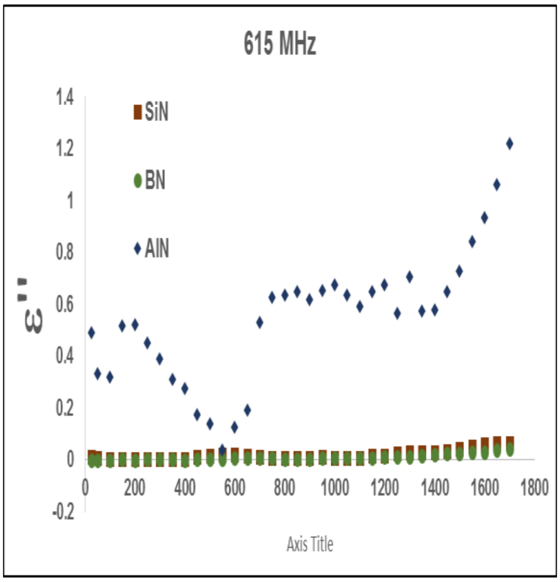
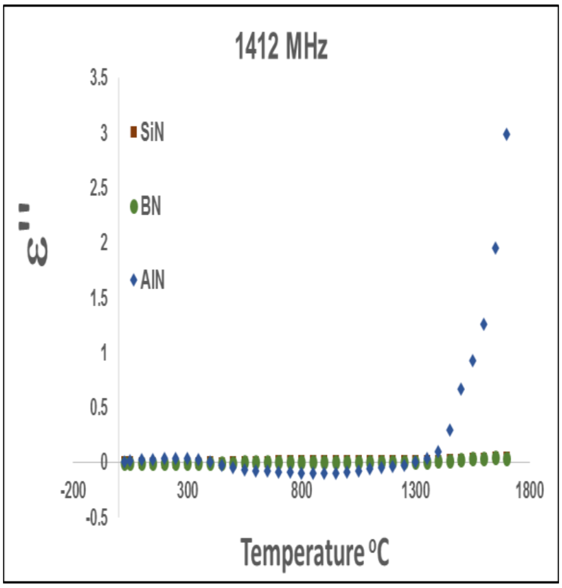
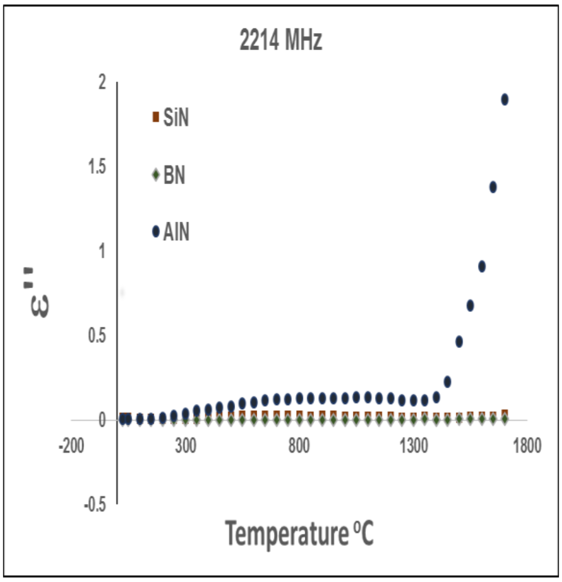
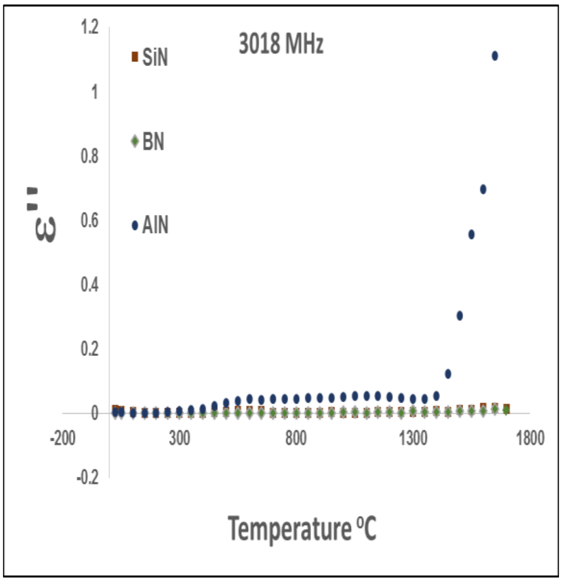


Fig. 1. The dielectric constant, ε', of AlN, SiN, and BN variation with temperature ranging from 25 to 1800 °C in microwave frequency ranging, 615 MHz, 1412 MHz, 2214 MHz, 3017 MHz, and 3820 MHz.









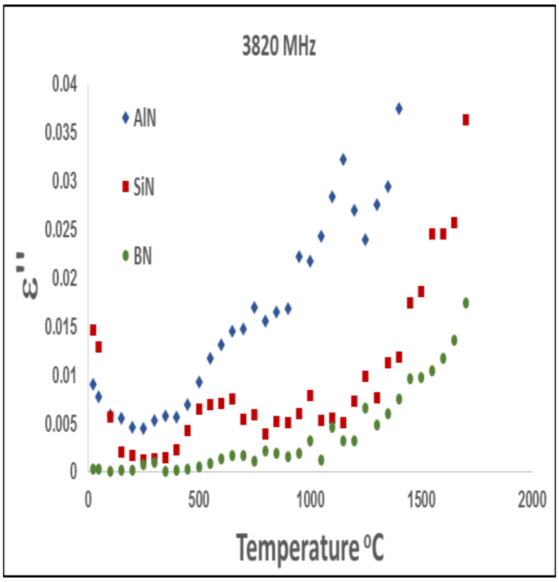


Fig. 2. The dielectric loss factor (ε'') of AlN, SiN, and BN variation with temperature ranging from 25 to 1800 °C in microwave frequency ranging, 615 MHz, 1412 MHz, 2214 MHz, 3017 MHz, and 3820 MHz.

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