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DIELECTRIC PROPERTIES AND ELECTRICAL CONDUCTIVITY STUDIES ON $Gd_3Ga_5O_{12}$ SINGLE CRYSTALS

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ABSTRACT

Dielectric constant (ε) and dielectric loss (tan δ) of gadolinium gallium garnet ($Gd_3Ca_5O_{12}$) single crystal have been measured in the frequency range from 100 Hz to 100 KHz and in the temperature range from room temperature to 400°C. AC conductivity was calculated from the data on ε and tan δ. The room temperature dielectric constant of garnet measured at 10^6 Hz is 12.08. The DC conductivity as a function of temperature is also measured. The results are discussed in the light of existing data.

Key words: Dielectric constant (ε), Dielectric loss (tan δ), AC conductivity, DC conductivity.

INTRODUCTION

Rare earth garnets are extensively used as device materials in magnetic bubble memories[1] and have been used as substrate materials in lasers[2]. Because of their technical importance, several attempts are made to grow these garnets and study their physical properties[3]. Dielectric properties of some gallium garnets $Nd_3Ga_3O_{12}$[4] and $Tb_3Ga_5O_{12}$[5] have been studied by the authors. There is a single report[6] of dielectric constant and loss (tan δ) for $Gd_3Ga_5O_{12}$ at one frequency at room temperature. Electrical conductivity of $Gd_3Ga_5O_{12}$ single crystals of pure and doped with Ca^{2+} and Mg^{2+} are reported[7]. A detailed study of dielectric behaviour and conductivity study on $Gd_3Ga_5O_{12}$ single crystals does not seem to have been made so far. The present study deals with a systematic measurement of dielectric constant (ε) and loss (tan δ) as a function of frequency and temperature. The AC conductivity is obtained from the dielectric data. DC conductivity has also been measured in the range of temperature from room temperature to 400°C. The results are interpreted in the light of existing data.

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EXPERIMENTAL

A single crystal of $Gd_3Ga_5O_{12}$ obtained by Czochralski method was used in the present investigation. It was a crystal of dimension 3.14 cm^2 x 0.05 cm and was well polished. For good electrical contact and to remove air gap, the sample was coated with silver paint. Dielectric constant (ε) and loss (tan δ) were measured using a GR-1620 A capacitance bridge in conjunction with a laboratory built in terminal cell. The temperature was maintained stable within 1K. The measurements were carried out from 100 Hz to 100 KHz in the temperature range from room temperature to 400^oC. For frequencies beyond 10 KHz, an external Oscillator (AGRONIC-72) was used. The room temperature measurement was extended to 10 MHz using a HP 4275A LCR meter. The overall accuracy in the measurement of dielectric constant and loss was 1% and 2%, respectively. The DC conductivity was measured using a Keithley 610 C electrometer in conjunction with a laboratory fabricated cell.

RESULTS AND DISCUSSION

The crystal was annealed at 800 K for about five hours before taking measurements. Initially, the variation of dielectric constant (ε) and loss (tan δ) with frequency was measured at room temperature (Fig. 1 and 2). The dielectric constant was found to be almost independent of frequency and loss was the order of 10^{-5} at 10 MHz. This indicates that the crystal is free of impurities. The dielectric constant 12.08 is comparable with the value reported earlier[6]. Fig. 3 and 4 show the variation of dielectric constant and loss, respectively as a function of temperature. The slow and frequency independent gradual variation in ε upto 200^oC shows that dipolar contribution is negligible. The loss is almost constant upto 100^oC and order of 10^{-3} at 1 KHz. Beyond 300^oC, an increase is observed in ε and also a steep raise in tan δ. In ionic crystals, the slow and frequency independent increase is attributed to electronic and ionic displacement polarization. The steep increase in loss beyond 300^oC could be attributed to conduction mechanism induced by intrinsic charge carriers. The AC conductivity σ is evaluated from the relation $\sigma \approx \varepsilon\, \varepsilon_0\, \omega \tan \delta$, where ε_0 is the vacuum permitivity. The knowledge of variation of σ as a function of frequency and temperature helps in understanding the conduction mechanism in a solid. The Arrhenius plots of conductivity versus reciprocal temperature are shown in Fig. 5. It is to be noted that the conductivity to a value of about 10^{-8} ($\upsilon\ cm^{-1}$) is noted at 350^oC. For comparison, DC conductivity values are also plotted in Fig. 4. AC conductivity is found to be higher than DC component. This is due to small contribution from dipolar effects. In case of yttrium iron garnet (YIG)[8]. The electrical conduction is considered to take place through hopping of electrons. Hopping conduction is induced due to the exchange of electrons between Fe^{2+} and

Fe^{3+} ions located at equivalent crystallographic sites. In the present case, a change of valence in Gd is not expected. Secondly, $Gd_3Ga_5O_{12}$ has a very low conductivity at room temperature, which rules out change of valence of Gd as the crystal is free from aleovalent impurity. The behaviour is similar to $Tb_3Ga_5O_{12}$ single crystals[5,9]. Hence, the variation of conductivity beyond 300°C is due to ionic transport, which are thermally activated in the presence of air.

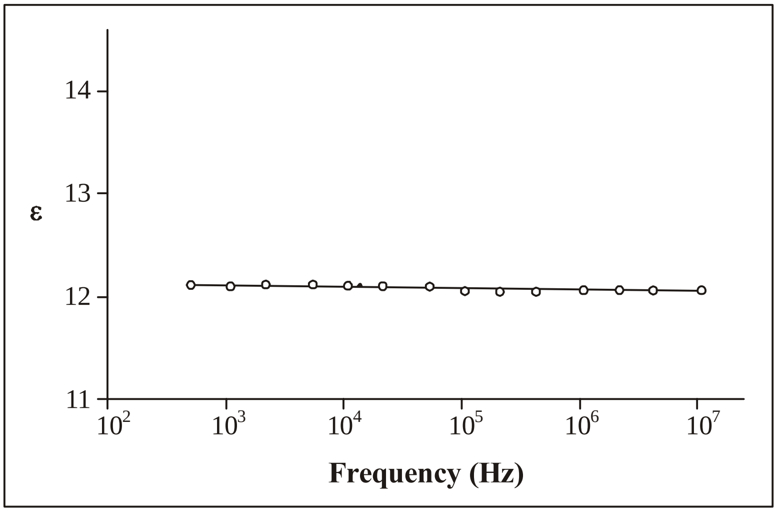

Fig. 1a: Variation of ε with frequency at room temperature

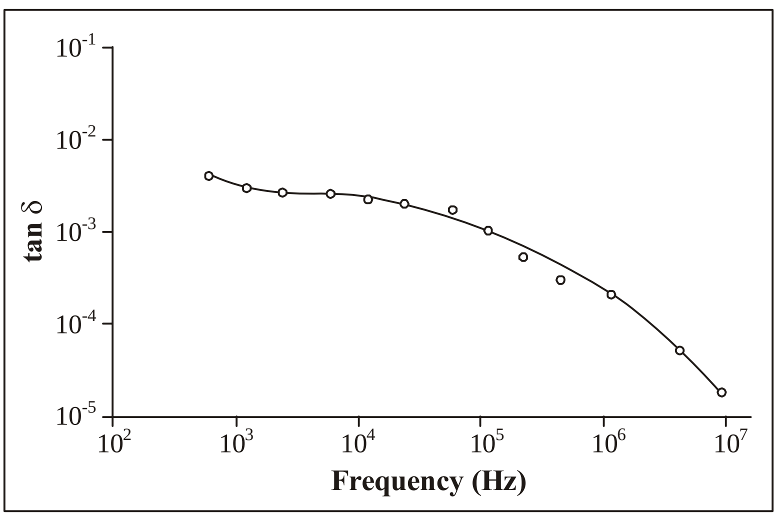

Fig. 2: Variation of tan δ with frequency at room temperature

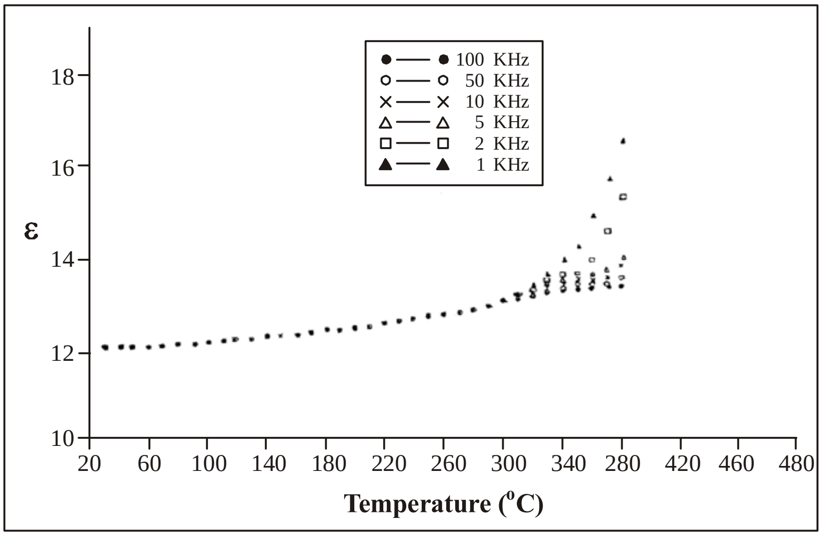

Fig. 3: Variation of ε with temperature at different frequencies

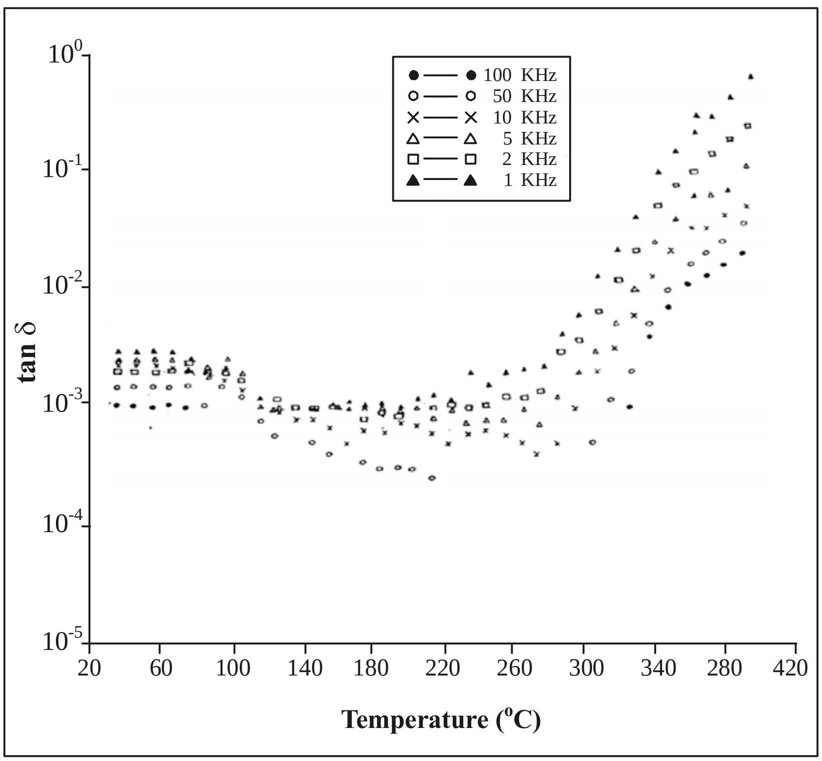

Fig. 4: Variation of tan with temperature at different frequencies

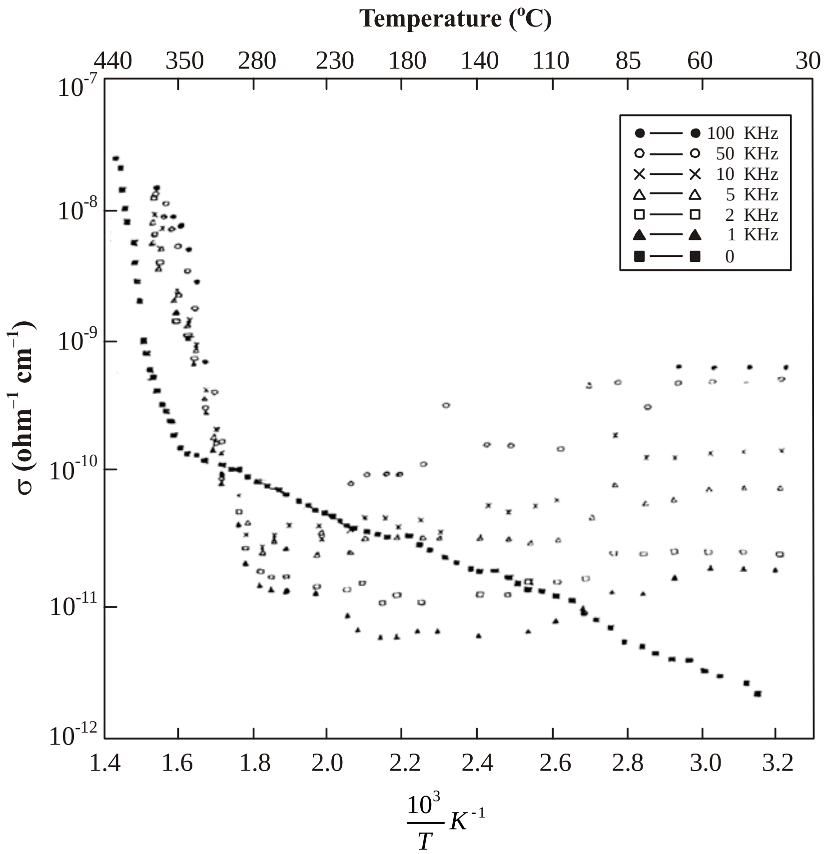

Fig. 5: Variation of log σ with reciprocal temperature at different frequencies

CONCLUSION

The dielectric constant of $Gd_3Ga_5O_{12}$ single crystals is found to be 12.08 at room temperature. The increase in conduction beyond 300°C is attributed to ionic conduction induced due to the presence of intrinsic defects such as oxygen vacancies in the present case.

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