Pressure and temperature dependent dielectric dispersion in $\text{Bi}_{12}\text{GeO}_{20}(100)$ single crystals[†]

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Abstract. Bismuth germanium oxide (BGO) has tremendous application potential due to its favourable electro-mechanical and electro-optic properties. The present paper describes some of our preliminary results on the variation of dielectric constant with applied high hydrostatic pressure and temperature. It is noted that BGO is a promising candidate for its application as a pressure sensor.

Keywords. Pressure measurements; sensor; BGO.

1. Introduction

Bismuth germanium oxide ($\text{Bi}_{12}\text{GeO}_{20}$) commonly known as BGO is technologically important material due to its large optical rotary power (Lenzo *et al* 1966), high electro-mechanical coupling (Spencer *et al* 1966), electro-optic effect (Horwitz and Corbett 1978; Astratov and Il'inskii 1982) and photoconduction (Ballman 1967). The present investigation of pressure and temperature dependence of dielectric properties were carried out for two reasons. Firstly, the dielectric properties of this material have not been investigated systematically even at room temperature and atmospheric pressure. Further, different values for static dielectric constant have been reported (Slobodnik Jr. and Sethares 1972; Kuwata *et al* 1981), and there is only one report each on dielectric dispersion (Kuwata *et al* 1981) and pressure variation of dielectric permittivity (Colwell and Tilford 1981). Secondly, the aim has been to explore the possibility of its application as a pressure sensor. This is because the conventional sensors have inherent problem of low pressure cut-off value, zero-shift with time, hysteresis and limited sensitivity (Monlinear *et al* 1986). The preliminary promising results on the dielectric behaviour of BGO under the applied high hydrostatic pressure as a function of the temperature and frequencies are presented here.

2. Experimental

The dielectric properties of both side polished BGO(100) of 25 mm diameter and 1.4 mm thickness obtained from M/s Crystal technology Inc., USA having guarded electrodes were measured under applied high hydrostatic pressure in low frequency region at different temperatures from 290 to 308 K. The guarded electrodes of 15 mm diameter with a gap of less than 12 mm from the guard ring were made by vacuum evaporation of silver at 423 K, using a special gadget. With the given specimen dimensions, the width of the guard ring was suitably adjusted to ensure that there is no fringing field effect (Andeen *et al* 1971).

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Figure 1. Specimen holder.

The specimen was placed in a specially designed specimen holder (figure 1) made of invar. The pressure was applied to the specimen by screwing the sample holder into high pressure vessel made up of maringering steel. The pressure transmitting fluid (ethyl hexyl sebacate) does not interact with specimen and its viscosity does not change appreciably with pressure. The temperature stability better than 0.05 K was attained as described elsewhere (Jain and Kashyap 1996). Pressure was measured by an on line Bourdon gauge (400 MM dial size), having an uncertainty in the pressure better than 0.1%, and the pressure was stable within 0.07 MPa during measurement. Capacitance and the dielectric dispersion were measured with an accuracy of better than 1 ppm at 1 KHz by the automatic digital capacitance bridge (Andeen – The Hagerling Model 2500 A, USA) and at other frequencies with an accuracy of 1% using a capacitance bridge (GR, USA).

3. Results and discussion

Before carrying out the dielectric measurements, the samples were checked for their purity and crystallinity. Secondary ion mass spectroscopic studies made by using MIQ 256 (Cameca, France) gave no trace of even commonly present impurities like Fe, Cr, Al etc in the BGO specimen (Ballman 1967; Betsch and White 1978). X-ray diffraction studies further confirmed the specimen to be pure crystalline BGO. Permittivity ϵ' , the real part of complex dielectric constant $\epsilon = \epsilon' - j\epsilon''$ is calculated from the capacitance value without considering the compressibility of the specimen, as at this stage only a relative change in the permittivity is more meaningful than its absolute value. The dielectric loss, $\tan \delta = \epsilon''/\epsilon'$ is calculated from the dissipation factor.

Figure 2. Temperature and pressure dependence of relative permittivity of BGO at 1 KHz. Curves A, B, C, and D correspond to the applied pressures of 0.1, 69, 138 and 207 MPa, respectively (The inset reveals the linearity in variation of relative permittivity with pressure).

Figure 3. Variance of zero shift with pressure.

Curves A, B, C, and D in figure 2 depict the relative permittivity ($\epsilon_r = \epsilon'/\epsilon_0$) of the BGO at 1 KHz as a function of temperature at the applied hydrostatic pressure of 0.1, 69, 138 and 207 MPa, respectively. It is found that the magnitude of the relative permittivity decreases linearly with the increase of applied pressure whereas its value increases with the increase of temperature. The values of the temperature and pressure coefficients of the relative permittivity as calculated from these curves are nearly 60 ppm/K and 100 ppb/Pa, respectively. The observed higher change in permittivity with pressure (1% per 108 Pa) as compared to a value of 1% change per 2.7×10^8 Pa, and the large temperature coefficient of capacitance in case of CaF_2 indicate the superiority of this material over CaF_2 (Andeen *et al* 1971), due to its higher sensitivity and low temperature coefficient of capacitance. The maximum shift in zero observed during different pressure cycles irrespective of the applied pressure (up to 345 MPa) is always below 50 ppm (figure 3) and the reproducibility in the pressure measured is below 30 ppm.

The dielectric loss, $\tan \delta$ calculated at different frequencies up to 10 KHz agrees fairly well with the earlier reported values (Slobodnik and Sethares 1972). The values of dielectric constant (ϵ_r) of BGO specimen maintained at different frequencies and calculated at different temperatures and pressures are summarized in tables 1 and 2, respectively. Dielectric dispersion curves at different temperatures (figure 4) reveal that the relative permittivity is almost constant in this small range of frequency (up to 10 KHz) and the value is in agreement with the one reported by Kuwata *et al* (1981). In fact there is a small (0.032% at 296 K) lowering of ϵ_r with the increase in frequency.

Table 1. Variation of ϵ_r of BGO with applied frequency and temperature.

Frequency (KHz)	Temperature (K)			
	290	296	298	308
0.2	43.829	43.838	43.856	43.878
0.5	43.829	43.837	43.856	43.877
1.0	43.831	43.838	43.855	43.878
2.0	43.833	43.835	43.855	43.879
5.0	43.824	43.830	43.844	43.873
10.0	43.813	43.824	43.825	43.863

Table 2. Variation of ϵ_r of BGO with applied pressure and temperature (1 KHz).

Pressure (MPa)	Temperature (K)			
	290	296	300	308
0.1	43.813	43.819	43.842	43.878
69	43.518	43.537	43.532	43.583
138	43.233	43.235	43.261	43.285
207	42.931	42.944	42.961	42.997

Figure 4. Dielectric dispersion of BGO at 0.1 MPa.

4. Conclusion

Present investigations reported here clearly show that BGO has an edge over the conventional materials/devices used to measure pressure where the accuracy in the pressure measured is required not better than 2 parts in 10,000.

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