ELECTROMECHANICAL PROPERTIES OF BISMUTH GERMANIUM OXIDE ($Bi_{12}GeO_{20}$)

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The elastic and piezoelectric constants and their temperature coefficients of bismuth germanium oxide have been determined. All of the elastic and piezoelectric constants were obtained from dynamic measurements of piezoelectrically driven narrow bars and thin plates at the temperature 22 °C. The temperature coefficients were measured on the same resonators in the temperature range from 16 °C to 70 °C. The thermal expansion measured in the temperature range from 50 °C to 200 °C is also given.

1. INTRODUCTION

Single crystals of bismuth germanium oxide $Bi_{12}GeO_{20}$ belong to the cubic class (23). The elastic, piezoelectric and dielectric properties of the crystals have been partially described in previous papers [1] and [2] where the results obtained from the dynamic measurement of piezoelectrically driven thin plates and from the measurement of surface-wave velocities respectively are given. The growth technique of the crystals is not complicated and as the coefficients of electromechanical coupling of the crystal are large, the crystals are attractive for ultrasonic, acoustic surface waves and electrooptic devices [3].

The results of measurements of elastic, piezoelectric and dielectric constants given in this paper complete the constants published in [1] and [2]. The constants have been determined from the dynamic measurements made on piezoelectrically excited extensional modes in the bars parallel to the planes (100) and on the thickness modes in the plates parallel to the plane (110). The results of the measurement of the thermal expansion coefficient, temperature coefficients of stiffnesses, compliances and piezoelectric constants are also given.

2. THE MEASURED RESONATORS

The elasto-piezo-dielectric matrix of the bismuth germanium oxide single crystal has been given in [1]. The elastic, piezoelectric and dielectric properties of the crystal are described with three independent elastic ($c_{11} = c_{22} = c_{33}$, $c_{12} = c_{13} = c_{23}$, $c_{44} = c_{55} = c_{66}$), one piezoelectric ($e_{14} = e_{25} = e_{36}$) and one dielectric $\varepsilon_{11} = \varepsilon_{22} = \varepsilon_{33}$) constants.

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The series resonance frequency and the parameters of the electrical equivalent circuit of the length extensional mode of vibrations of the bars were measured for determination of the eleastic and piezoelectric constants. The length of the measured bars was $l = 13{\cdot}0$ mm, the width $b = 2{\cdot}5$ mm and the thickness $a = 0{\cdot}80$ mm. The length and the width of the bars were parallel to the plane (100) and the angle between the length direction and the X axis of orthogonal system of axis of the crystal was φ.

The resonance frequency f of the bars is given by the relation

$$f = \frac{1}{2l}\sqrt{\frac{1}{\varrho s'_{11}}} \tag{1}$$

if the width of the bar is neglected in comparison with the length. The effective compliance s'_{11} is

$$s'_{11} = s^E_{11}(\cos^4 \varphi + \sin^4 \varphi) + (2s^E_{12} + s^E_{44}) \cos^2 \varphi \sin^2 \varphi$$

and density $\varrho = 9{\cdot}2 \times 10^3$ kg m^{-3} [1].

The inductance L_1 of the electric equivalent circuit of the bar is given by the following equation [4]

$$L_1 = \frac{\varrho a l}{8b}\left(\frac{s'_{11}}{d'_{31}}\right)^2 \tag{2}$$

where d'_{31} is the effective piezoelectric coefficient

$$d'_{31} = -d_{14} \cos \varphi \sin \varphi \,.$$

The series resonance frequentcy of the thickness shear mode of vibration of the plate parallel to the plane (110) was measured in the following step. The dimensions of the plate were $l = 10{\cdot}9$ mm, $b = 8{\cdot}40$ mm and $a = 0{\cdot}37$ mm. The resonance frequency of the plate is given by the relation

$$f = \frac{1}{2a}\sqrt{\frac{c'}{\varrho}} \tag{3}$$

if the thickness of the plate is substantially smaller than the other dimensions. The effective stiffness c' of the plate completely covered with metal electrodes is equal, in agreement with [5], to

$$c' = c^E_{44} \,.$$

The resonance frequency temperature dependence was measured also on the same group of samples in the temperature range from 16 °C to 70 °C. On the bars with dimensions $l = 13{\cdot}0$ mm, $b = 4{\cdot}0$ mm and $a = 0{\cdot}80$ mm parallel to the plane (111) the thermal expansion was measured in the temperature range from 50 °C to 200 °C.

3. THE EXPERIMENTAL RESULTS

The temperature dependence of the length of the bar measured in connection with the determination of the thermal expansion is given in Fig. 1. From the measurement it is seen that the average thermal expansion coefficient is $13{\cdot}5 \times 10^{-6}\ \mathrm{K}^{-1}$.

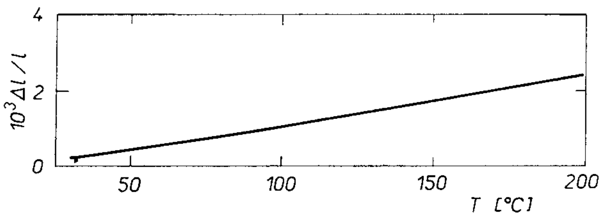

Fig. 1. The result of the measurement of thermal expansion of bar of $Bi_{12}GeO_{20}$.

Table 1

Obtained values of the material constants of $Bi_{12}GeO_{20}$. (The values g_{14} and h_{14} were calculated for $\varepsilon^S_{11} = 3{\cdot}3645 \times 10^{-10}\ \mathrm{m}^{-1}\ \mathrm{F}$ and $\varepsilon^T_{11} = 3{\cdot}800 \times 10^{-10}\ \mathrm{m}^{-1}\ \mathrm{F}$).

Parameter	Value	Dimension
$s^E_{11} = s^D_{11}$	$(0{\cdot}8512 \pm 0{\cdot}0007) \times 10^{-11}$	$\mathrm{m}^2\ \mathrm{N}^{-1}$
$2s^E_{12} + s^E_{44}$	$(3{\cdot}6261 \pm 0{\cdot}0018) \times 10^{-11}$	$\mathrm{m}^2\ \mathrm{N}^{-1}$
$s^E_{12} = s^D_{12}$	$-0{\cdot}091 \times 10^{-11}$	$\mathrm{m}^2\ \mathrm{N}^{-1}$
$c^E_{11} = c^D_{11}$	$1{\cdot}206 \times 10^{11}$	$\mathrm{N\ m}^{-2}$
$c^E_{12} = c^D_{12}$	$0{\cdot}1443 \times 10^{11}$	$\mathrm{N\ m}^{-2}$
$c^E_{44} = 1/s^E_{44}$	$(0{\cdot}2626 \pm 0{\cdot}0005) \times 10^{11}$	$\mathrm{N\ m}^{-2}$
$c^D_{44} = 1/s^D_{44}$	$0{\cdot}2916 \times 10^{11}$	$\mathrm{N\ m}^{-2}$
d_{14}	$(3{\cdot}758 \pm 0{\cdot}004) \times 10^{-11}$	$\mathrm{V}^{-1}\ \mathrm{m}$
e_{14}	$0{\cdot}987$	$\mathrm{m}^{-2}\ \mathrm{C}$
g_{14}	$0{\cdot}0989$	$\mathrm{C}^{-1}\ \mathrm{m}^2$
h_{14}	$0{\cdot}0293 \times 10^{11}$	$\mathrm{m}^{-1}\ \mathrm{V}$

The elastic compliances s_{11}^E and $2s_{12}^E + s_{44}^E$ and their temperature coefficients $(1/s_{11}^E) . (\partial s_{11}^E/\partial T)$ and $[1/(2s_{12}^E + s_{44}^E)] (\partial(2s_{12}^E + s_{44}^E)/\partial T)$ were determined from the measured resonance frequency at the temperature 22 °C and from the measured resonance frequency temperature dependence.

Table 2

Obtained values of temperature coefficients (in 10^{-6} K^{-1}).

Temperature coefficient	Value
$\frac{1}{s_{11}^E} \frac{\partial s_{11}^E}{\partial T}$	282
$\frac{1}{2s_{12}^E + s_{44}^E} \frac{\partial(2s_{12}^E + s_{44}^E)}{\partial T}$	236
$\frac{1}{s_{12}^E} \frac{\partial s_{12}^E}{\partial T}$	−149
$\frac{1}{c_{11}^E} \frac{\partial c_{11}^E}{\partial T}$	−306
$\frac{1}{c_{12}^E} \frac{\partial c_{12}^E}{\partial T}$	−789
$\frac{1}{c_{44}^E} \frac{\partial c_{44}^E}{\partial T} = - \frac{1}{s_{44}^E} \frac{\partial s_{44}^E}{\partial T}$	−218
$\frac{1}{d_{14}} \frac{\partial d_{14}}{\partial T}$	147
α	13·5

The piezoelectric coefficient d_{14} was calculated from the measured inductance of the electric equivalent circuit.

The elastic stiffness c_{44}^E and its temperature coefficient $(1/c_{44}^E) . (\partial c_{44}^E/\partial T)$ were determined from the measurement of the plate.

The calculated values obtained from the measured ones are given in Tab. 1 and Tab. 2.

4. CONCLUSION

The measured and in Tab. 1 given values of material constants are very similar to those published in [2]. In comparison with paper [2] the thermal expansion coefficient is also given in Tab. 1 and the temperature coefficients of the elastic constants are then given more accurately. The temperature coefficient of piezoelectric constant d_{14} was also determined. The author believes that the value of elastic stiffness c_{14}^E is more accurate in Tab. 1 as the conditions for the quantities E or D are in the measuring method used in this paper better specified than in [2].

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