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Low frequency linear electro-optic effect in $PbTa_2O_6$

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The transverse linear electro-optic coefficients of $PbTa_2O_6$ crystals, grown from solution in $Pb_2V_2O_7$, have been measured. A half-wave voltage of 600 V applied along the [010] axis, has been determined.

1. Introduction

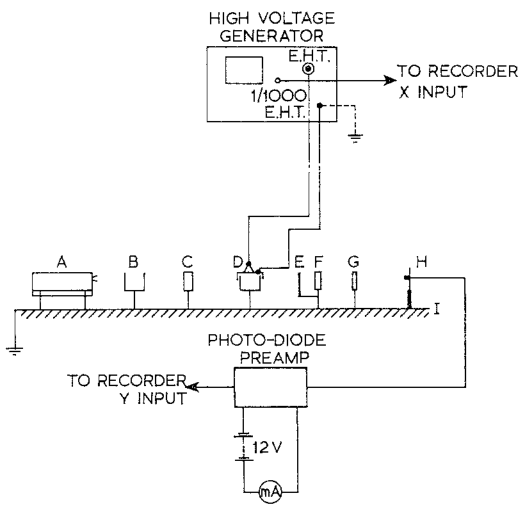
Several materials with the tungsten bronze structure have been investigated as effective crystals for electro-optic applications [1]. Usually the lead-containing compositions of this structure have been neglected, presumably because of the difficulty of preparation by conventional pulling techniques, caused by the volatility of PbO and the consequent lack of homogeneity, in addition to the normal problems of compositional control. This paper reports the growth of single crystals of lead tantalate and the measurement of the transverse linear electro-optic coefficients. $PbTa_2O_6$, is a ferroelectric tungsten bronze [2] with a Curie point 265°C [3]. Its structure is orthorhombic, *m2m*, [3] but it is only slightly distorted from the more usual tetragonal tungsten bronze as: $a = 17.68$, $c = 7.754$ Å and $b/a = 1.002$ [4].

2. Crystal growth

The growth of crystals of $PbTa_2O_6$ from solution in $Pb_2V_2O_7$ has been previously reported [4]. In the present work crystals were prepared by controlled growth on a seed from a solution of 8 mol % $PbTa_2O_6$ in $Pb_2V_2O_7$, cooled at 1.5 deg C h^{-1}. Full details of the growth procedures are described elsewhere [5].

3. Measurement of the transverse electro-optic effect

The apparatus used (Fig. 1) consisted of a 1 milliwatt helium-neon laser as light source, a cell for holding the crystal specimen, and a photodiode as detector. The incident light was polarized at 45° to the principal axes of the crystal and the analyser was crossed. The quartz wedge compensator was adjusted to give maximum or minimum transmission for zero applied field. The detector output, fed through a d.c. amplifier, and the applied voltage were used as the *X* and *Y* inputs to an *XY* chart recorder.



A. He-Ne LASER
B. NEUTRAL DENSITY FILTERS
C. POLARISER
D. CRYSTAL HOLDER AND ELECTRODES
E. QUARTZ WEDGE COMPENSATOR
F. ANALYSER
G. LENS
H. PHOTO DIODE
I. OPTICAL BENCH

Figure 1 The apparatus used to measure d.c. linear electro-optic retardation in the transverse mode.

The crystal specimens were approximately 3 × 1.5 × 1 mm. Each specimen was measured accurately with a micrometer gauge before electrodes were applied. The largest dimension was along the [001] axis, and the polar [010] axis was normal to the 1.5 × 3 mm face. The

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specimens chosen were observed to be single domain by examination under a polarizing microscope. The faces of the specimens were polished with diamond pastes down to 0.25 μm. Silver Dag electrodes were painted on the appropriate faces.

A sinusoidal change in transmitted intensity was observed with increasing electric field. A standard figure of merit for electro-optic materials is the half-wave voltage which is the voltage that has to be applied to a crystal to induce a phase difference of π radians between ordinary and extraordinary rays. That is the voltage required to rotate the plane of polarization of an incident plane polarized wave by 90°. The half-wave voltage is a function of light path length in the crystal and the electrode spacing. The half-wave voltage is usually quoted for a crystal in which these variables are equal and this is known as the half-wave field path length product $(E.l)_{\lambda/2}$. The half-wave voltage measured in this experiment was the voltage which switched transmitted light intensity from a maximum to a minimum. The half-wave field path length product was then calculated using the measured crystal dimensions. The results were found to be consistent from one crystal specimen to another, and from one batch of crystals to another. A variation of $\pm 5\%$ in the half-wave voltage values was observed. The mean values for the different orientations are given in Table I.

TABLE I D.C. half-wave field path length products for $PbTa_2O_6$ at 6328 Å

Light direction	Field direction		
	100	010	001
100	—	1.14 kV	N D
010	—	N D	—
001	1.56 kV	0.60 kV	—

— indicates no effect due to crystal symmetry.
N D indicates effect too small to be measured.

4. Discussion

The half-wave field path length product of 600 V for a field along the polar axis and for light propagating along [001] is relatively small and makes $PbTa_2O_6$ a material of interest for device applications. The crystals grow preferentially along the [001] direction, giving a favourable geometry for measurement.

There are five independent coefficients in the linear electro-optic tensor, r_{IJ}, for orthorhombic, $m2m$, crystal structure [6]. A value of $r_{61} = 3.0 \times 10^{-9}$ cm V^{-1} was obtained by an analysis similar to that of Billings [7], from the value of $[E.l]_{\lambda/2} = 1.56$ kV for light in the [001] and field in the [100] directions. The refractive index of $PbTa_2O_6$ used in the calculation was 1.9 as determined by a true and apparent depth measurement. For electric field in the [010] direction the half-wave voltage is low for light propagated in the [100] and [001] directions. As the half-wave voltage is proportional to $(n_2^3 r_{22} - n_3^3 r_{32})$ in the former and $(n_2^3 r_{22} - n_1^3 r_{12})$ in the latter, then r_{32} and r_{12} may be assumed to be small and $r_{22} = 7.6 \times 10^{-7}$ cm V^{-1}. This assumption is reasonable since no longitudinal effect proportional to $(n_3^3 r_{32} - n_1^3 r_{12})$ could be measured. That there is no measurable effect for field along [001] and light along [100] indicates that r_{43} is very small. Miller's rule [8] predicts that the electro-optic coefficient is proportional to the dielectric constant for a given direction and as the dielectric constants along the a and b axes are much greater than along the c [4], it is anticipated that r_{22} and r_{61} will be greater than r_{43} as the above measurements have shown.

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