A METHOD OF MEASUREMENT OF A SMALL BIREFRINGENCE

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The method of measuring of small birefringence is described. As an illustration of this method the stress induced birefringence in ZnTe and natural birefringence of CdS, CdSe and mixed crystal of CdS—CdSe near the inversion point was measured.

Introduction

The most usefull and exact method of determining the birefringence as a function of wavelength is based on the measurements of the interference fringes in polarized light. This method was applied for example by Wardzyński (1961) for Cadmium Selenide and by Parsons, Wardzyński and Yoffe (1961) for mixed crystals of CdSe—CdS and CdSe—CdTe. The serious limitation of this method comes from the requirement that the product of the difference of refractive indices and the thickness of the crystal has to be large enough to produce the interference fringes. In many practical cases samples are very thin crystals and do not produce measurable sharp fringes. On the other hand even with a thick crystal when the birefringence is very small, fringes do not appear. This is first of all in the case when the birefringence is induced by some external interactions like stress, magnetic fields *etc.*

In the case of measurements of stress induced birefringence in alkali halides a certain differential method was developed (*e.g.* Srinivasan (1959)). In this method the phase shift gained by the light beam during traveling through the measured crystal was cancelled by the known stress induced birefringence in fused quartz. Although this method enables for small birefringence to be measured, it presents many experimental difficulties.

Measurement of small birefringence

To measure small birefringence the following idea was used. If a plane parallel plate of uniaxial crystal (CdS, CdSe, quartz, $CaCO_3$ *etc.*) with optic axis in the plane of the plate is placed between the crossed or parallel polarizers so that angle between the optic axis and

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the direction of the electric vector is 45°, the interference fringes appears. Let us place between the polarizers at the same time also a plane parallel plate of the crystal whose birefringence has to be measured. The optic axis of this crystals is parallel or perpendicular to the optic axis of the first (basic) crystal. Let us assume that the birefringence of the

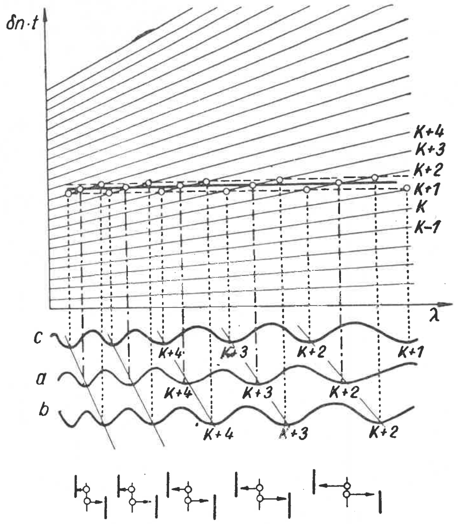

Fig. 1. a – fringes given by the basic crystal, b and c – fringes shifted by the measured (additional) crystal

second (additional) crystal is very small and that this crystal therefore does not produce the interference fringes alone. This second crystal will only shift the fringes produced by first crystal as it is demonstrated schematicaly in Figure 1. The additional crytal will shift the fringes as it is shown in Fig. 1b if the basic and additional crystal has the same sign and both optic axis parallel. The additional crystal will shift the fringes as it is shown in Fig. 1c if the signs of both crystals are opposite and the optic axis parallel. The rotation of one of the crystal (basic or additional) by 90° about the axis parallel to the light beam shifts the fringes from position b to c or from c to b. If therefore the sign of the basic crystal and the direction of the optic axis of both crystals is known, the sign of the measured (additional) crystal is easy to determine.

If t_b — is the thickness of the basic crystal, $\delta n_b = n_{\parallel} - n_{\perp}$ — the difference of refractive indices of the basic crystal and t_m and δn_m — the thickness and difference of refractive indices of measured crystal respectively then the wavelength λ_m corresponding to the minimum of light intensity must satisfy the equation

$$\lambda n_b t_b \pm \delta n_m t_m = k\lambda_m \qquad k = 1, 2, 3, \ldots$$

Crystals in this case are placed between the crossed polarizers. Plus or minus should be selected according to the sign of both crystals and the directions of its optic axis.

Birefringence of the measured crystal will be given by

$$\delta n_m = \frac{k\Delta\lambda}{t_m}$$

where $\Delta\lambda = \lambda_m - \lambda_0$, λ_0 is the wavelength of the fringe when only the basic crystal is placed in the light beam. This formula is true only if δn_b is constant (does not depend on the wavelength) k — the order of the fringe may be found by the method described by Wardzyński (1961).

To demonstrate the possibility of measuring the birefringence by this method, the birefringence induced by uniaxial stress in ZnTe and natural birefringences of very thin CdSe and mixed CdSe—CdS crystals were measured.

Experimental arrangement

For measuring the birefringence of a thin plate of CdSe single crystals and mixed crystals of CdSe—CdS in the vicinity of the inversion poin and stress induced birefringence of ZnTe single crystals, the arrangement shown schematicaly in Fig. 2 was used. A Zeiss SPM 2 mono-

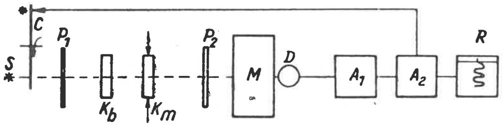

Fig. 2. Experimental arrangement S – light source, C – the chopper, P_1, P_2 – polarizers, M – monochromator, D – the detector, A_1 – selective amplifier, A_2 – phase sensitive amplifier, R – recorder, K_b – basic crystal, K_m – measured crystal e.g. stressed

chromator with glass prism (600 Å/mm for $\lambda > 1\mu$) or difraction grating (40 Å/mm, $\lambda < 1\mu$), a chopped light source and photomultiplier or PbS cell as a detector were used. Sygnal was fed to the selective amplifier and phase sensitive detector. As a basic crystal CdSe 5 mm thick or quartz 20 mm thick were used.

CdSe as a basic crystal

Birefringence of CdSe between 1.2 and 2.6 μ, according to Wardzyński (1961), is constant. In the short wavelength region birefringence changes appreciably. Birefringence of this part of the spectrum is shown in Fig. 3. In the region where birefringence is not constant the

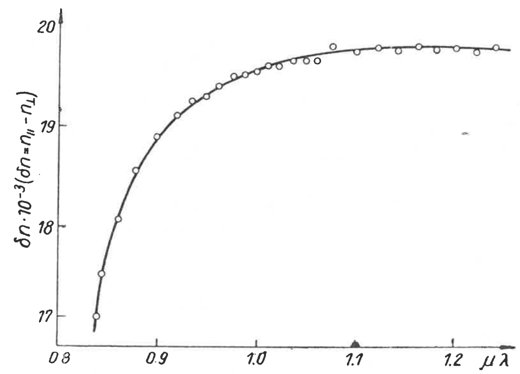

Fig. 3. Birefringence of CdSe

formula for δn_m given above should be modified. It is easy to derive that in the case when δn_b depend on the wavelength

$$\delta n_m = \frac{k\Delta\lambda}{t_m} - \frac{d}{d\lambda}(\delta n_b)\Delta\lambda\,\frac{t_b}{t_m}.$$

Therefore in the region where δn_b depend on the wavelength the correction term $\frac{d}{d\lambda}(\delta n_b)\,\Delta\lambda\,\frac{t_b}{t_m}$ should be introduced. Dependence of $\frac{d}{d\lambda}(\delta n_a)$ on wavelength for CdSe is given in Fig. 4.

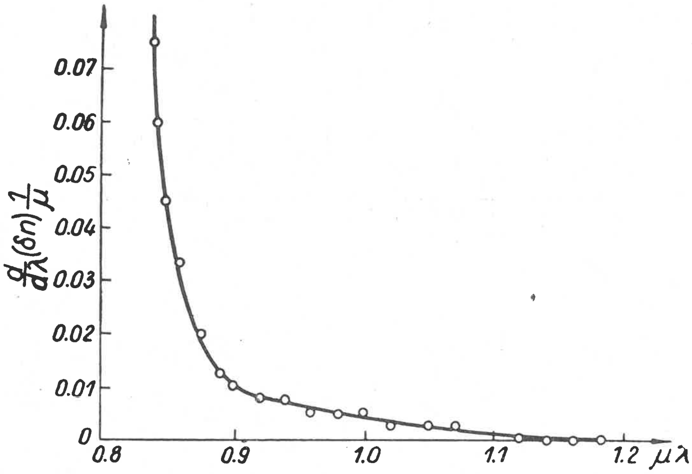

Fig. 4. $\frac{d}{d\lambda}(\delta n)$ for CdSe as a function of wavelength

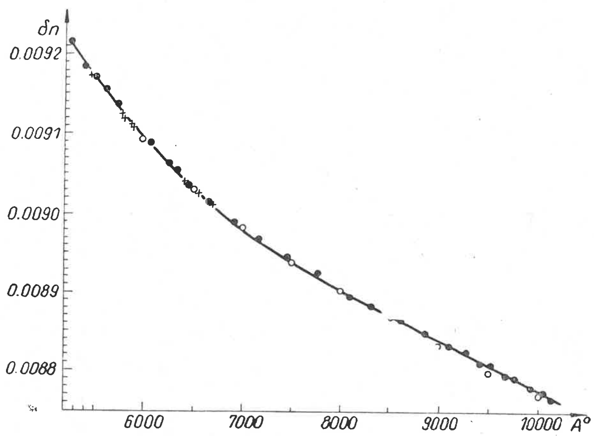

Fig. 5. Birefringence of quartz. + – after Smartt *et al.* (1959), ○ – after Shields *et al.* (1956), ● present measurements

Quartz as a basic crystal

Birefringence of quartz is very well known and is shown in Fig. 5 according to Shields and Ellis (1956), Smart and Steel (1959). However, there were some reports (Beckers (1967)) that the values of birefringence may differ for a different samples. Therefore the birefringence of quartz used in the present experiments was measured independently and the results

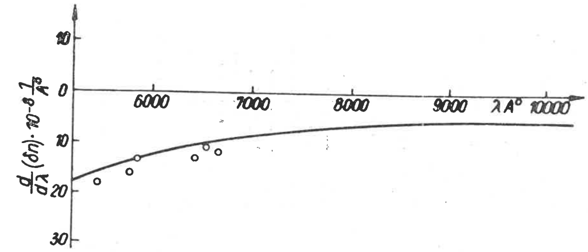

Fig. 6. $\frac{d}{d\lambda}(\delta n)$ for quartz as a function of wavelength. ○ – after Smartt *et al.* (1959)

are given in Fig. 5 as well. One can see from this figures that there is some spectral dependence of birefringence. Fig. 6 shows the spectral dependence of $\frac{d}{d\lambda}(\delta n)$ of this crystal.

Birefringence induced by uniaxial stress in ZnTe single crystal

As an example of the utility of the method, birefringence induced by uniaxial stress in ZnTe between 8300 Å and 8500 Å was measured. Single crystal was grown by the sublimation method in a sealed quartz tube in vacuum. The stress was applied in [100] direction.

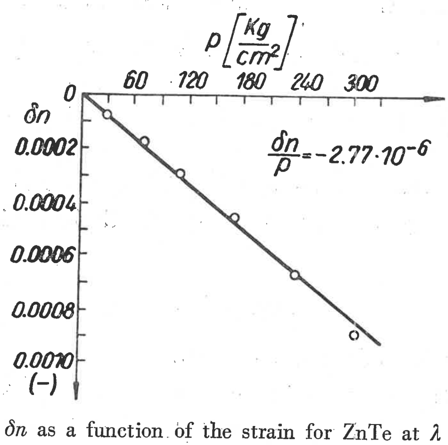

Fig. 7. δn as a function of the strain for ZnTe at λ 8400 Å

The direction of the light was [110]. Birefringence induced by uniaxial stress is proportional to the strain as it is shown in Fig. 7 $\delta n/p$ as a function of wavelength for ZnTe is given in Fig. 8.

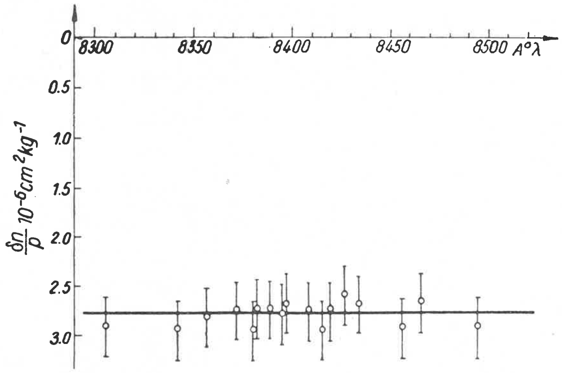

Fig. 8. $\frac{\delta n}{p}$ as a function of wavelength for ZnTe

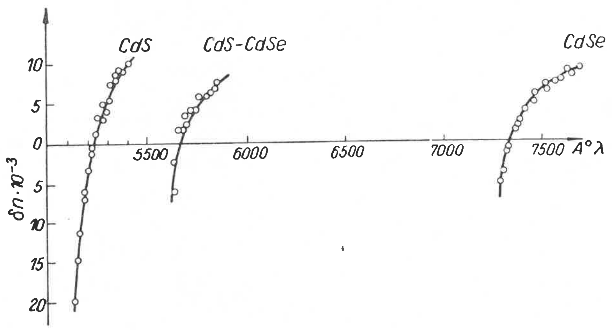

Fig. 9. The birefringence of CdS, CdSe, and CdS—CdSe mixed crystal near the inversion point

Inversion point of CdS CdSe and CdS—CdSe mixed crystals

Using a very thin crystal plate grown from the vapour phase by the Frerichs method, it is possible to find the inversion point of the crystal. The previous measurements on thick CdSe crystals (Wardzyński (1961), were able only to get the inversion point through extrapolating the curve.

The present method enables us to find this point directly. Fig. 9 shows the dependence of δn on wavelength in the region of inversion point for CdS and CdS—CdSe mixed crystals at room temperature.

Discussion

The smallness of the values of δn which may be measured by this method, depends on such factors as the resolving power of the instrument, sharpness of the fringes obtained when using the basic crystal, the quality of the basic crystal to quarantee the reproducibility of the interference fringes. Using a monochromator of high resolution one should choose for the basic crystal a crystal with a high birefringence to get fringes of a high order. The thickness of the basic crystal should be adjusted to its birefringence. Crystals of smaller birefringence should be thicker. On the other hand in the case of thicker crystals it is much more difficult to find crystals enough homogenous. Finally one should choose as a basic crystal such a crystal whose birefringence does not depend much on wavelength. In practice we find that for differenct wavelengths region CdS, CdSe and quartz crystals could be used. In the case of CdS and CdSe the homogeneity of the crystal makes it impossible to use crystals thicker than about 5 mm. In the case of quartz, crystal as thick as 20 mm could be used. The smallest δn measured with a 20 mm thick crystal and grating monochromator with reciprocal dispersion of 40 Å/mm was about 5.10^{-6}.

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