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Photoelastic behaviour of KDP

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In the present communication all seven stress optical and seven strain optical constants of KDP are reported for the first time at 5890 Å. These values are obtained by subjecting a large number of orientations to stress birefringence and ultrasonic studies and by combining this information with other available data by the least squares method. The results are checked from different points of view and are discussed with reference to some of the earlier investigations.

1. Introduction

Potassium dihydrogen phosphate (KDP) belongs to the D_{2d} class of the tetragonal system in Schoenflies notation. This is a synthetic crystal grown for the first time during World War II. KDP has been studied widely with respect to its elastic [1] and piezoelectric [2] behaviour, but the photoelastic properties of this crystal have attracted the attention of very few investigators. KDP has seven stress-optical (q_{ij}) and seven strain-optical (p_{ij}) constants in the scheme of photoelastic constants developed by both Pockels and Bhagavantam. West and Makas [3] determined q_{66} and the order of magnitude of ($q_{11} - q_{12}$). Others to report q_{66} of KDP include Vasilevskaya [4], Vlokh and Lutsiv-Shumskii [5], Vasilevskaya and Sonin [6] and Vlokh *et al.* [7]. By studying the diffraction of light from an acoustic wave train Dixon [8] reported the numerical values of five out of the seven strain optical constants. Davis and Vedam [9] studied the effect of hydrostatic pressure on the refractive indices of KDP. They found that the refractive indices for both the ordinary and extraordinary rays increase under hydrostatic pressure. Thus the entire set of photoelastic constants of KDP is not available from the literature. Hence we have computed the most acceptable values for q_{ij} and p_{ij} by the least squares method by taking observations on a large number of orientations.

2. Experimental procedure and results

We have employed both static [10] and dynamic [11] methods for the experimental observations and also utilized data obtained by Davis and Vedam of the effect of hydrostatic pressure on the refractive indices. The axes for the crystal blanks are determined and they are cut, ground and polished as in the case of ADP [12]. The Brewster's constant, C_λ at 5890 Å was determined for seven orientations and the results are given in Table I along with the relevant expressions of piezooptical constants after correcting for the thickness change. The expressions at serial numbers 8 and 9 are derived from the observations of the change in refractive indices under hydrostatic pressure [9].

In the case of KDP, only one ratio, namely p_{33}/p_{13} has been found to be appreciably different from unity (Table II) and hence it is used in the calculations to compute q_{ij}. The magnitude of the ratio, whether less than or greater than unity, should be unambiguously known for reasons discussed earlier [12]. By combining this ratio with the expressions in Table I, the stress-optical constants q_{ij} (Table IIIa) are obtained at room temperature (21° C). p_{ij} are now calculated using the well known relations and are reported in Table IIIb. The results obtained are compared with some of the earlier results. The refractive indices used are those determined by Zernike [13] and the elastic constants those by Hearmon [14].

3. Discussion

The published data on the photoelastic behaviour of KDP are meagre. Also, from the literature it is evident that each of the investigators has studied this crystal with some particular aim in view. A systematic study of the piezooptic behaviour of

TABLE I

Serial no.	Direction		Expression for C_λ	$C_\lambda \times 10^{13}$ cm^2 dyn^{-1} at 5890 Å	Source
	Stress	Observation			
1	[100] or [010]	[010] or [100]	$\frac{1}{2}(n_x^3q_{11} - n_z^3q_{31})$	1.040	Serial nos. 1-7, present investigation
2	[100] or [010]	[001]	$\frac{1}{2}n_x^3(q_{11} - q_{12})$	0.281	
3	[001]	[100] or [010]	$\frac{1}{2}(n_z^3q_{33} - n_x^3q_{13})$	−1.541	
4	M	M′	$\frac{1}{8}n_{yz}^3(q_{11} + q_{13} + q_{31} + q_{33} + 2q_{44})$ $-\frac{1}{4}n_x^3(q_{12} + q_{13})$	−1.837	
5	L or L′	[001]	$\frac{1}{2}n_x^3q_{66}$	−18.14	
6	[100]	M or M′	$\frac{1}{2}n_x^3q_{11} - \frac{1}{4}n_{yz}^3(q_{12} + q_{31})$	0.876	
7	L	L′	$\frac{1}{4}n_x^3(q_{11} + q_{12} + q_{66}) - 2n_z^3q_{31}$	−6.436	
8			$(q_{11} + q_{12} + q_{13})$	7.110	Serial nos. 8 and 9, Davis and Vedam
9			$(2q_{31} + q_{33})$	8.152	

Note: M is a directional equally inclined to [010] and [001] in the *YZ* plane.
L is a direction equally inclined to [100] and [010] in the *XY* plane.
M′ and L′ are perpendicular to M and L respectively in the *YZ* plane and *XY* plane.

TABLE II

Serial no.	Direction		Expression for the ratio *R*	Ratio *R*
	Excitation	Observation		
1	[100]	[010]	p_{11}/p_{31}	1.08
2	[100]	[001]	p_{11}/p_{12}	1.16
3	[001]	[100]	p_{33}/p_{13}	0.70

TABLE IIIa

q_{ij} ($\times 10^{13}$ cm^2 dyn^{-1})	West and Makas [3]	Present study
q_{11}	$(q_{11} - q_{12})$ −0.30	4.15 ± 0.38
q_{12}		4.08 ± 0.31
q_{13}		1.12 ± 0.02
q_{31}		3.60 ± 0.32
q_{33}		0.44 ± 0.13
q_{44}		−1.47 ± 0.34
q_{66}	−11.25	−10.26 ± 0.23

TABLE IIIb

p_{ij}	Dixon [8]	Present study
p_{11}	0.251	0.287
p_{12}	0.249	0.282
p_{13}	0.246	0.174
p_{31}	0.225	0.241
p_{33}	0.221	0.122
p_{44}	—	−0.019
p_{66}	—	−0.064

Note: Dixon gives only numerical values of p_{ij}, since his method cannot yield the sign.

KDP has been undertaken which has yielded all the photoelastic constants for the first time. West and Makas have reported the value of q_{66} which agrees with the present value, but the sign of $(q_{11} - q_{12})$ observed is different while the magnitude is acceptable. In fact, it has been found for ADP and KDP that the fringes in the Babinet compensator shift in the same direction for stress parallel to [100] and observation parallel to [001], indicating that these two crystals have the same sign for $(q_{11} - q_{12})$, namely positive.

In the present studies, p_{33}/p_{13} is found to be much less than unity and hence this ratio has been taken as standard. When this ratio, with a positive sign, is combined with stress birefringence data, the stress-optical constants obtained are found to satisfy the observations of Davis and Vedam for hydrostatic pressure and also the other two ultrasonic ratios. When p_{33}/p_{13} is negative and combined with the stress birefringence data, q_{ij} obtained fail to satisfy not only the ultrasonic data but also the hydrostatic data. Hence a positive sign is given to the ratio p_{33}/p_{13} and this is combined with the seven expressions obtained from the stress birefringence studies and two from the hydrostatic studies. The stress optical constants thus obtained are used to calculate the other two strain optical ratios and values of these ratios are found to agree well with those observed experimentally. The sign of Equation 2 (Table I) is also found to be positive by using the remaining data, i.e. two equations from stress birefringence studies, two equations from hydrostatic data and one from the ultrasonic studies. This sign is the same as that observed experimentally. The results are thus checked from different points of view and are found to be acceptable.

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