Refractive Index, Dispersion, and Birefringence of Silicon Carbide Polytypes

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The refractive index of each of the four common silicon carbide polytypes has been measured over the visible range. The data were analyzed in an attempt to relate the birefringence to the relative hexagonal character of the polytype. A general relationship exists, namely, that the birefringence increases with increasing hexagonal character of the polytype. This relationship is not sufficiently precise to use for the identification of polytypes.

Introduction

The optical properties of various silicon carbide polytypes[1] have not been systematically determined previously, largely due to the difficulty of obtaining thick optically perfect crystals composed entirely of a single polytype. The object of this study was to determine the optical properties of several of the more common polytypes, to determine whether or not there exists a simple relationship between birefringence and polytype, and to determine whether such a relationship might be used to identify various polytypes.

Experimental

Optically perfect crystals, grown by sublimation, were oriented and cut into 20° prisms such that the *c* axis was oriented parallel to the prism edge. Refractive indices were measured throughout the visible range by the method of minimum deviation[2] using a Stöe two-circle goniometer. Monochromatic light was provided by the use of a xenon light source and a calibrated Leitz monochromator.

Each datum point was the result of at least two separate measurements by each of two operators. The estimated error was less than 1 min of angle, corresponding to less than 0.001 in calculated refractive index values. Computer analysis of each set of data showed typical variations in the slope and intercept of a dispersion curve of $N = A + (B/\lambda^2)$ to be less than 0.0003 in the intercept and 0.00001 in the slope. Typical data for each polytype are presented in Tables I and II and Figs. 1 and 2.

After measurement, each prism was reexamined under the polarizing microscope to verify the absence of extraneous layers of other polytypes. After a careful cleaning, the prisms were analyzed by x-ray diffraction to verify the polytype present and by emission spectroscopy to verify the purity. Data from any crystal not satisfying both structural homogeneity and <100 ppm impurity limits were omitted. Typical analyses of both alpha and beta SiC crystals are shown in Table III.

Discussion

Earliest measurements[4–7] showed that silicon carbide had extremely high refractive indices and dispersion, greater even than diamond, however no consideration was given to the possible relationship to structure. The first reference to this possible relationship to structure was by Thibault,[8] who suggested that differences in refractive index between two polytype zones within one crystal were due to impurity variations rather than to structure.

A preliminary study by the writer[9] showed that the relative retardation between zones of different polytypes within single crystals was, within experimental error, a constant. The relative birefringences of various polytypes are not only constant at a particular wavelength but show consistent changes with varying wavelengths. In Table IV the relative birefringences and their wavelength dependences, determined from retardation measurements, are summarized and compared with values determined from refractive index data. The comparisons are within the errors of measurements. However, these measurements are not sufficiently accurate to permit a direct determination of polytype from simple refractive index data.

The relationship between birefringence and various other properties has been studied in the structurally analogous system, zinc sulfide. Contrary to earlier reports,[10] it was found by Brafman and co-workers[11] that

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Table I. Refractive Index of Silicon Carbide Polytypes

Wavelength (mμ)	Polytype: Beta[a] (cubic)	6H[b]	15R	4H
		N_E[c]		
467		2.7553	2.7609	2.7771
498		2.7331	2.7402	2.7548
515		2.7236	2.7297	2.7450
568		2.6979	2.7043	2.7192
589		2.6911	2.6968	2.7119
616		2.6820	2.6879	2.7033
691		2.6639	2.6676	2.6834
		N_0[c]		
467	2.7104	2.7074	2.7081	2.7186
498	2.6916	2.6870	2.6894	2.6980
515	2.6823	2.6789	2.6800	2.6881
568	2.6600	2.6557	2.6572	2.6655
589	2.6525	2.6488	2.6503	2.6588
616	2.6446	2.6411	2.6429	2.6508
691	2.6264	2.6243	2.6263	2.6335
$N_E = A + (B/\lambda^2) \times 10^6$ A	—	2.5852	2.5889	2.6041
B	—	0.0368	0.0374	0.0375
$N_0 = A' + (B'/\lambda^2) \times 10^6$ A'	2.5538	2.5531	2.5558	2.5610
B'	0.0342	0.0334	0.0331	0.0340

[a] Ref. 3.
[b] Number of layers per unit cell, and symmetry.
[c] ±0.001 maximum.

Table II. Birefringence of Silicon Carbide Polytypes

Wavelength (mμ)	$N_E - N_0$: 6H	15R	4H	2H[a]
450				0.1024
467	0.0479	0.0528	0.0585	
498	0.0461	0.0508	0.0568	
500				0.0962
515	0.0447	0.0497	0.0569	
550				0.0962
568	0.0422	0.0471	0.0537	
589	0.0423	0.0465	0.0531	
600				0.0967
616	0.0409	0.0450	0.0525	
650				0.0973
691	0.0396	0.0413	0.0499	

[a] From retardation measurements on a whisker.

Table III. Spectrographic Analyses of Silicon Carbide Crystals (ppm)

	Alpha Crystal lot 439	Beta Crystal lot 538
Aluminum	10	≪10
Iron	<4	≪10
Magnesium	10	≪10
Titanium	<2	≪10
Vanadium	1	≪10
Copper	<3	N.D.[a]
Manganese	<2	N.D.
Zirconium	<2	N.D.
Calcium	<2	N.D.
Nickel	<2	N.D.

[a] Not detectable.

Table IV. Relative Birefringence of Silicon Carbide Polytypes

Wave-length (mμ)	Polytype: 6H[a]	15R: Ret.[b]	15R: $N_E - N_0$	15R: Thibault[c]	4H: Ret.[b]	4H: $N_E - N_0$	2H Ret.[d]
450	1.00	1.108			1.220		2.13
467			1.102	1.085		1.221	
498			1.086	1.092		1.232	
500		1.083			1.220		2.08
515			1.112	1.082		1.273	
550		1.094			1.237		2.24
568			1.116	1.095		1.272	
589			1.099	1.102		1.255	
600		1.095			1.224		2.32
616			1.100	1.100		1.283	
650		1.088			1.254		2.42
691			1.043	1.108		1.260	

[a] Arbitrarily set at unity for comparison.
[b] Determined by interference colors in crystals containing more than one polytype.
[c] From interpolated data of Thibault.[8]
[d] Approximate values from a whisker.

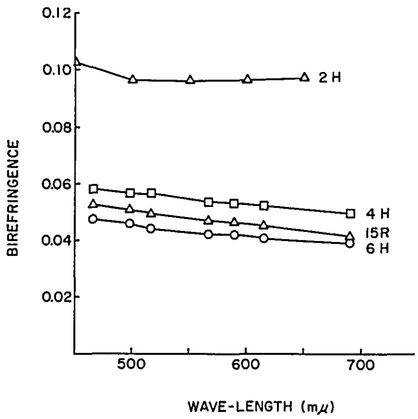

Fig. 1. Birefringence of silicon carbide polytypes.

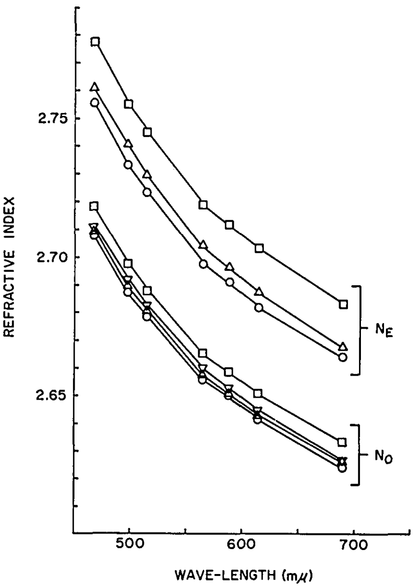

Fig. 2. Dispersion of silicon carbide polytypes: □ 4H, ▽ Beta, △ 15R, ○ 6H.

the birefringence of various zinc sulfide polytypes has a direct linear relationship with the electronic energy gap. No such simple relationship for silicon carbide has been found between birefringence and hexagonal fraction or energy gap. An apparent linear relationship seems to exist between log birefringence and log hexagonal fraction (Fig. 3).

Conclusions

The refractive indices, birefringence, and dispersion of the four common silicon carbide polytypes have been determined. They are each adequately described by the relation $N = A + (B/\lambda^2)$. While the birefringence increases with the more hexagonal polytypes, no simple relationship has been found. The measurement of birefringence is not sufficient to designate the polytype present.

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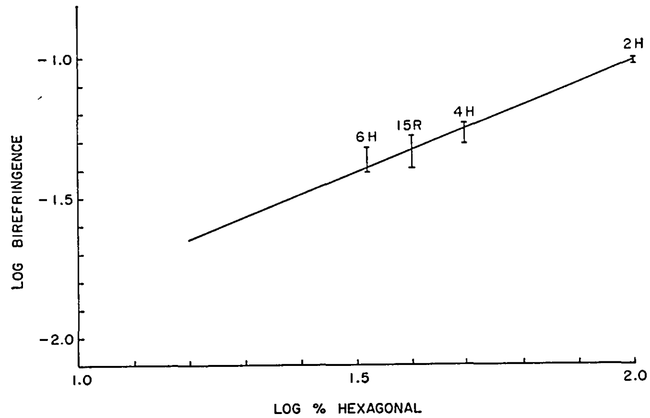

Fig. 3. (Log) birefringence of SiC polytypes vs (log) hexagonal character.

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A novel fiberscope for laser surgery has been described by H. Müssiggang and W. Katsaros of the University of Munich Medical School in Laser **2**, 60 (1970). The instrument, from the outside looking like a conventional fiberscope, has three separate, co-axial pathways: (a) a central cylinder, apparently a system of relay lenses, for observation; (b) surrounding this channel is a cylindrical sheath of optical fibers conducting light for illumination (with the interesting proposal of, if desired, blocking the light in half the circumference to make the target stand out better); (c) next follows a hollow cylinder through which air is forced for cooling the outer fibers and for inflating the cavity, such as the urinary bladder, if needed; (d) an outer cylindrical bundle of heavier fibers through which light from a neodymium-glass laser is conducted. With air cooling (water not necessary) and heat-resistant cements, more than 25% of the initial power output of 48 W has been transmitted, enough to obliterate or cut various tissues, except if under water. The outer fiber cylinder, which carries the laser light, is—near the end—made slightly wider and, at the end, narrow again, not unlike a truncated onion, providing good focusing without any lenses attached to the fibers.