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PIEZOBIREFRINGENCE IN SILICON*

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ABSTRACT

A stress-birefringence investigation has been carried out on high purity silicon at a wavelength of 1.11 μ. Values have been obtained for the piezobirefringence constants ($q_{1111}-q_{1122}$) and $2q_{1212}$. The linearity of the stress-optical relationship in silicon has been established up to stresses of approximately 450 kilograms/cm^2. A qualitative indication has been obtained of the directions of change in the index of refraction of silicon under a stress applied parallel to [100]. Various transmission curves are given for World War II surplus infrared image converter tubes with Si, Si+H_2O, and Si+ Corning No. 5850 filters, respectively. An observation is noted on orders of interference resulting from the use of non-monochromatic infrared light analogous to the orders of interference colors commonly observed with visible white light.

INTRODUCTION

Thorough reviews of the field of study concerned with the stress-optical behavior of crystalline materials have been given by both Poindexter (1) and Giardini (2). The present paper reports on the stress-birefringence of high purity silicon at a wavelength of 1.11 μ.

The silicon used in this investigation was obtained from the Army Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey. The boule from which specimens were cut was elongated (pulled) parallel to [111]. Some spinel-type twinning was present in the boule; however, specimens were taken from areas free of twinning. The latter was determined both by visual inspection of specimen surface and by *x*-ray diffraction. No quantitative information is available on the purity of the silicon other than it is described as "high purity" material.

Since silicon possesses *m3m* symmetry, only constants q_{1111}, q_{1122} and q_{1212} are required for a complete description of stress-optical behavior (3, 4). Although definitions and derivations of these constants can be found in either reference (1) or (2) given above, they will be redefined here for the sake of completeness.

The stress-optical constant q_{1111} describes the relationship between a homogeneous stress directed along the crystallographic axis $X_1\overline{X}_1$ and the resulting retardation of light vibrating parallel to and traveling perpendicular to $X_1\overline{X}_1$. The stress-optical constant q_{1122} defines the relationship between a homogeneous stress directed along $X_1\overline{X}_1$ and the induced retardation of light vibrating parallel to $X_2\overline{X}_2$ and traveling parallel to $X_3\overline{X}_3$. The value ($q_{1111}-q_{1122}$) constitutes the stress-optical difference or piezobirefringence constant. The constant $2q_{1212}$ describes the relationship

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between a homogeneous stress directed along X_{12} (along $2/m$ for symmetry class $m3m$) and the resulting difference in retardation of light vibrating parallel to $X_1'\overline{X}_1'$* and $X_2'\overline{X}_2'$,* and traveling parallel to $X_3\overline{X}_3$. Constant $2q_{1212}$, therefore, constitutes a piezobirefringence constant for crystals possessing $m3m$ symmetry.

Values for both piezobirefringence constants $(q_{1111}-q_{1122})$ and $2q_{1212}$, at a wavelength of 1.11 μ have been determined and will be presented later in this report.

SPECIMEN PREPARATION

Polished oriented rectangular parallelepiped specimens are generally preferred for piezobirefringence investigation. The equipment and procedures which were used for orienting and cutting silicon are described in this issue on page 370.

For the measurement of the difference constant $(q_{1111}-q_{1122})$, a parallelepiped was prepared having all crystallographic cube faces, and dimensions 0.312 cm.×0.4145 cm.×0.518 cm. For the determination of $2q_{1212}$, a parallelepiped was cut having a zone of four dodecahedral faces terminated by a pair of parallel cube faces. The dimensions of the cube faces are 0.648 cm.×0.574 cm. and that common to the dodecahedral faces is 0.284 cm. The crystallographic orientation of both specimens is accurate to within 15 minutes of arc. The parallelism of opposing sides of the parallelepipeds are correct to within 1 minute of arc.

In order to investigate the absolute change in index of refraction as a function of stress applied parallel to [100], a silicon specimen was prepared in the form of a prism frustum. The right trapezium faces of the prism were crystallographic (100) faces with the following dimensions: base = 0.890 cm., altitude = 0.393 cm., second altitude = 0.160 cm., hypotenuse = 0.920 cm. The included prism angle, as determined by optical goniometry, is 14° 36.5′. The frustum is preferred to a right triangular type of prism because of its superior structural configuration.

Polishing of the oriented specimens was carried out with the following abrasive media in the order listed: 1) 350 grit SiC paper mounted on plate glass, 2) 500 grit SiC paper mounted on plate glass, 3) 8–25 micron diamond powder suspended in cold cream and spread on a sheet of index card paper which in turn is mounted on plate glass, 4) same as 3) but with 4–8 micron diamond powder, 5) same as 3) but with $\frac{1}{2}$–3 micron diamond powder. Each stage requires roughly about 1–2 minutes of polishing with a light hand pressure. Both the specimen and hands must be thoroughly cleansed before proceeding from one stage to the next.

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* Directions $X_1'\overline{X}_1'$ and $X_2'\overline{X}_2'$ are respectively parallel to and normal to X_{12} and in the plane of crystallographic directions $X_1\overline{X}_1$ and $X_2\overline{X}_2$.