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Photoelastic Properties of Sapphire (α-Al_2O_3)†

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Recently Caddes and Wilkinson[1] have reported the observation of large photoelastic anisotropy in sapphire. They find that the ratio of the strain optical constants p_{33}/p_{13} to be ≥ 45, the largest value ever reported for any substance. In view of the low room-temperature microwave ultrasonic attenuation of sapphire, its good optical properties and the relative ease with which these crystals can be grown, they are of interest as a material for use as Debye–Sears light modulators at microwave frequencies. In this article the results of measurements on the variation of the refractive indices of sapphire with pressure to 7 kbar are reported and the possible reason for the above reported large anisotropy is discussed.

The experimental details and the mathematical expressions and the computations involved in measurements with such birefringent crystals have already been described in an article[2] dealing with similar measurements on α-quartz. In brief, the variation of the refractive indices with pressure was determined from the shift of the localized interference fringes across the specimen kept in an optical pressure vessel, for λ5893 Å appropriately polarized. Due allowance for the change in thickness of the specimen was made with the help of the recently determined values of the elastic constants of sapphire by Wachtman *et al.*[3] No computations involving the third-order elastic constants were made since such data are not available in the literature. Nevertheless, the results of the present measurements indicate that the elastic behavior of sapphire is quite linear in the entire pressure range (7 kbar) investigated. About twenty fringes were observed to shift with each crystal.

Figures 1 and 2 represent, respectively, the variation of the ordinary and extraordinary refractive indices of sapphire with pressure and volume strain. It is seen that both the refractive indices decrease linearly with pressure with slopes of $(1.0\pm0.2)\times 10^{-4}$/kbar and $(1.1\pm0.2)\times10^{-4}$/kbar for the ordinary and the extraordinary ray, respectively.

Similar computations for the change in the thickness of the sample were also performed using Bridgman's[4] compressibility data on α-Al_2O_3, and it was found that the final results on $\Delta n/\Delta P$ were essentially similar to that described above except that the numerical values were larger by about 25%. Since Bridgman has reported that some of his observations on sapphire were not quite reproducible, the present authors have used the more recent and accurate measurements of Wachtman *et al.* Waxler and Weir[5] have also made measurements of $\Delta n/\Delta P$ on sapphire but up to a maximum pressure of 1 kbar only, and they find that both the ordinary and extraordinary refractive indices decrease with pressure with a slope of 1.4×10^{-4}/kbar. This is in very good agreement with the present measurements when it is realized that these authors have used Bridgman's compressibility data for their computations.

It can be shown[6] that the observed changes in the refractive indices are related to the Lagrangian strains η_1 and η_3 by the relations

$$(n_0-n_0')=(n_0^3/2)[(p_{11}+p_{12})\eta_1+p_{13}\eta_3] \quad (1)$$

$$(n_e-n_e')=(n_e^3/2)(2p_{31}\eta_1+p_{33}\eta_3), \quad (2)$$

where p_{ij} are the Pockels' elasto-optic constants; and n_0' and n_e' are the final values of n_0 and n_e on deformation. Thus by combining the results of these measurements with those similar to that of Caddes and Wilkinson, one can evaluate the individual values of the elasto-optic constants.

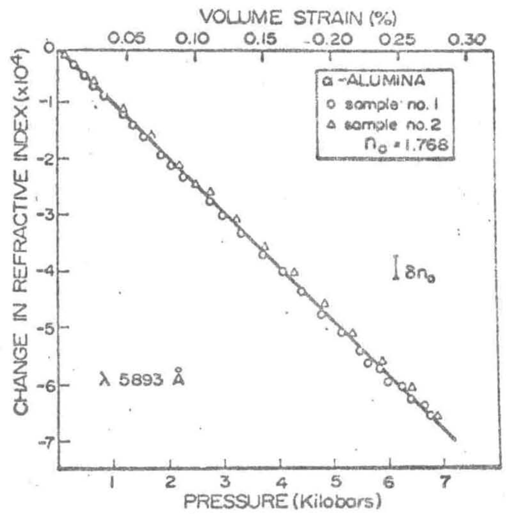

FIG. 1. Variation of the ordinary refractive index of sapphire with hydrostatic pressure and volume strain. $T=22°C$.

At this stage, it will be useful to consider the values of the elasto-optic constants of MgO, a cubic crystal whose elastic and optical properties are somewhat similar to that of α-Al_2O_3. Further, it may be mentioned that in both these crystals, the optical properties in the visible region of the spectrum are mainly determined by the oxygen ions. In the case of MgO, Vedam and Schmidt[7] find the values of the elasto-optic constants as $p_{11}=-0.25_9$ and $p_{12}=-0.01_1$ and hence the ratio $p_{11}/p_{12}=24$. As mentioned before, in the case of α-Al_2O_3, Caddes and Wilkinson report the ratio p_{33}/p_{13} to be 45. Taking the analogy from MgO, this implies that in sapphire, $p_{13}\approx0$. For the same reason, the other elasto-optic constants p_{12} and p_{13} can also be assumed to be negligibly small as a first approximation. In such a case, Eqs. (1) and (2) yield the values of the elasto-optic constants as $p_{11}=-0.27$ and $p_{33}=-0.30$; which compare well with $p_{11}=-0.25_9$ in the case of MgO. The implications of these values will be discussed elsewhere along with similar results on other oxides.

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