ELECTRONIC STRUCTURE OF Cu

Strain tensor	Type of strain	Stress axis z'	$\Delta \epsilon_2$ with respect to x', y', z'	Components Δ_{ϵ_2} and $\Delta R/R$
$ \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} e/3 $	Hydrostatic	None	$ \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \Delta \epsilon_2 $	$\Delta \epsilon_2 = \frac{1}{3} (W_{11} + 2W_{12}) e \\ \Delta R/R = \frac{1}{3} (Q_{11} + 2Q_{12}) e$
$ \begin{pmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{pmatrix} e_{yz} $	Trigonal	[111]	$\begin{pmatrix} \Delta \epsilon_2^{\mathbf{I}} & 0 & 0 \\ 0 & \Delta \epsilon_2^{\mathbf{I}} & 0 \\ 0 & 0 & \Delta \epsilon_2^{\mathbf{I}} \end{pmatrix}$	$\Delta \epsilon_{2}^{II} = -2\Delta \epsilon_{2}^{I} = 4W_{44}e_{yz}$ $\Delta R/R^{II} = -2\Delta R/R^{I} = 4Q_{44}e_{yz}$
$\begin{pmatrix} -\frac{1}{2} & 0 & 0\\ 0 & -\frac{1}{2} & 0\\ 0 & 0 & 1 \end{pmatrix} e_{zz}$	Tetragonal	[001]	$\begin{pmatrix} \Delta \epsilon_2^{\mathbf{L}} & 0 & 0 \\ 0 & \Delta \epsilon_2^{\mathbf{L}} & 0 \\ 0 & 0 & \Delta \epsilon_2^{\mathbf{I}} \end{pmatrix}$	$\Delta \epsilon_2^{II} = -2\Delta \epsilon_2^{I} = (W_{11} - W_{12})e_{zz}$ $\Delta R/R^{II} = -2\Delta R/R^{I} = (Q_{11} - Q_{12})e_{zz}$

TABLE I. Definition of the piezo-optical constants.

be strain-induced change of ϵ at the surface. This ndition was always fulfilled in our measurements. The second contribution will be neglected here.

The phase-sensitive detector was locked to the andamental frequency of the vibration. Thus, only hanges of the reflectance proportional to odd powers of train were detected. Tuning to twice the frequency thich should pick up mostly the quadratic effect proaced a signal barely above the noise. Thus, only hanges linear in the strain components were detected a our measurements.

EXPERIMENTAL RESULTS

Symmetry Relations

The optical properties of a solid are determined by the complex second-rank dielectric tensor ε , which reluces to the unit tensor times the complex dielectric constant for cubic crystals, i.e., cubic crystals are ptically isotropic. A general strain applied to these crystals destroys the isotropy. Restricting the discussion to changes linear in the strain components, we may Frite

$$\Delta \epsilon_{ij} = W_{ijmn} e_{mn}. \tag{3}$$

Cu has the point symmetry O_h . In this case, Eq. (3) parallels the stress-strain relation ($\Delta \varepsilon$ replaces the stress tensor, W the stiffness tensor), i.e., the fourthtank piezo-optical tensor W has three independent complex elements.^{8,9,11} We adopt the matrix notation used for the stress-strain relation (see, e.g., Ref. 24). Table I shows the resulting relations for ε_2 , the imaginary part of the dielectric tensor. (W44 defined in Ref. 11 is four times that of Table I. Using the corresponding definition of the stiffness constant²⁴ might help to avoid confusion, which frequently arose at that point in the past.) Selecting special geometries, namely the stress axis, the normal to the reflecting plane, and the polarization of the light parallel to the principal axes of $\Delta \varepsilon$ eads to 8,9,11

$$\Delta R = (\partial R / \partial \epsilon_1) \Delta \epsilon_1 + (\partial R / \partial \epsilon_2) \Delta \epsilon_2, \qquad (4)$$

where $\Delta \epsilon_1$ and $\Delta \epsilon_2$ are the appropriate eigenvalues of

24 C. Kittel, Introduction to Solid State Physics (John Wiley & ^{Sons}, Inc., New York, 1956), 2nd ed., pp. 87, 89, and 91.

 $\Delta \varepsilon_1$ and $\Delta \varepsilon_2$. Thus we can define quantities Q_{ij} (similar to W_{ij}) that describe the relative change of the reflectance. The definition of Q_{ij} is also given in Table I.

Measurements and Piezo-Optical Constants

Figure 6 contains the measurements of the relative change of the reflectance per strain along the stress axis for three different samples, the stress axes being parallel to [001], [111], and [110], respectively. The surface of the samples was the $(1\overline{1}0)$ plane in all cases. For each stress direction, the reflectance for light polarized parallel and perpendicular to the stress axis is given. The independent information contained in



FIG. 6. The relative change of the reflectance per unit strain along the stress axis at room temperature for Cu crystals with the stress axes [001], [111], and [110], and with the reflecting surface (110). The curves are given for light, plane polarized parallel and perpendicular to the stress axes.

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nple contains two co: discontinuity of ϵ , the the surface. This coa sample with hom in at the surface of th due to the small vari on of the strain in the dicular to the surface mally several orders rst one, provided t h is small compared i