ELECTRONIC STRUCTURE OF Cu

Strain tensor	Type of strain	Stress axis z'	$\Delta_{\epsilon_2} \text{ with respect} \\ \text{to } x', y', z'$	Components $\Delta \epsilon_2$ 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]	$\begin{pmatrix} \Delta \epsilon_2^{\mathbf{I}} & 0 & 0 \\ 0 & \Delta \epsilon_2^{\mathbf{I}} & 0 \\ 0 & 0 & \Delta \epsilon_2^{\mathbf{I}} \end{pmatrix}$	$\Delta \epsilon_2^{II} = -2\Delta \epsilon_2^{I} = 4W_{44} \epsilon_{yz}$ $\Delta R/R^{II} = -2\Delta R/R^{I} = 4Q_{44} \epsilon_{yz}$
$ \begin{pmatrix} -\frac{1}{2} & 0 & 0 \\ 0 & -\frac{1}{2} & 0 \\ 0 & 0 & 1 \end{pmatrix} e_{zz} $	Tetragonal	[001]	$\begin{pmatrix} \mathbf{\Delta} \epsilon_2^{\mathbf{L}} & 0 & 0 \\ 0 & \mathbf{\Delta} \epsilon_2^{\mathbf{L}} & 0 \\ 0 & 0 & \mathbf{\Delta} \epsilon_2^{\mathbf{H}} \end{pmatrix}$	$\Delta \epsilon_{2}^{II} = -2\Delta \epsilon_{2}^{I} = (W_{11} - W_{12})e_{zz}$ $\Delta R/R^{II} = -2\Delta R/R^{I} = (Q_{11} - Q_{12})e_{zz}$

TABLE I. Definition of the piezo-optical constants.

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

The phase-sensitive detector was locked to the undamental 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 profuced a signal barely above the noise. Thus, only hanges linear in the strain components were detected in 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 optically isotropic. A general strain applied to these crystals destroys the isotropy. Restricting the discussion to changes linear in the strain components, we may write

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

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 fourthrank 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. (W_{44} 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 $\Delta \varepsilon$ leads 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.

ance. 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

 $\Delta \varepsilon_1$ and $\Delta \varepsilon_2$. Thus we can define quantities Q_{ij} (similar

to W_{ij}) that describe the relative change of the reflect-

axis for three different samples, the stress axes being parallel to [001], [111], and [110], respectively. The surface of the samples was the (110) 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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ements

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nple contains two condiscontinuity of ϵ , the surface. This conin a sample with homin at the surface of the due to the small varion of the strain in the dicular to the surface mally several orders of rst one, provided the h is small compared to