TABLE I. Conduction-band splitting $\Delta E_c^i - \Delta E_c^0$ for uniaxially stressed Si and Ge. T is the stress (positive for tensile stress), Ξ_u is the deformation potential, and S_{11}, S_{12}, and S_{44} are compliance coefficients.

Material / Stress direction	Si: Valley direction	Si: $\Delta E_c^i - \Delta E_c^0$	Ge: Valley direction	Ge: $\Delta E_c^i - \Delta E_c^0$
[001]	[001] [00$\bar{1}$] [100] [010] [$\bar{1}$00] [0$\bar{1}$0]	$\frac{2}{3}(S_{11}-S_{12})\Xi_u T$ $-\frac{1}{3}(S_{11}-S_{12})\Xi_u T$	Any	0
[111]	Any	0	[111] [11$\bar{1}$] [1$\bar{1}$1] [$\bar{1}$11]	$\frac{1}{3}S_{44}\Xi_u T$ $-\frac{1}{9}S_{44}\Xi_u T$
[110]	[100] [010] [$\bar{1}$00] [0$\bar{1}$0] [001] [00$\bar{1}$]	$\frac{1}{6}(S_{11}-S_{12})\Xi_u T$ $-\frac{1}{3}(S_{11}-S_{12})\Xi_u T$	[111] [11$\bar{1}$] [$\bar{1}$11] [1$\bar{1}$1]	$\frac{1}{6}S_{44}\Xi_u T$ $-\frac{1}{6}S_{44}\Xi_u T$

e magnitude of the stress and its direction with spect to the k vector of the valley. These shifts are scribed by the deformation potentials Ξ_d and Ξ_u of erring and Vogt.[1]

Experimentally, intrinsic properties and free-carrier fects in strained Si and Ge have been studied by ectrical,[6–8] optical,[9,10] and microwave[11] techniques. he results of these measurements seem to verify the bove theories, but the magnitudes of the deformation otentials obtained by the different methods deviate ore than it seems possible to ascribe to experimental ncertainties.

In this paper we shall describe an independent xperimental method for determining the deformation otential constants based on an analysis of the change n the indirect absorption edge due to uniaxial stress.

The structure of the indirect absorption edge in train-free silicon and germanium crystals has been iscussed in detail by several authors.[12,13]

This structure is characterized by certain threshold nergies corresponding to the creation of an electron-ole pair with simultaneous emission or absorption of phonon in order to fulfill the condition of momentum onservation.

Owing to the lifting of the energy degeneracy with hear strain of the valence- and conduction-band edges hese thresholds will split up. An analysis of the fine tructure of the thresholds and its dependence on irection and magnitude of uniaxial stress makes it possible to determine the deformation potentials of the two band edges.

2. BAND STRUCTURE OF STRAINED SILICON AND GERMANIUM

The energy degeneracy in a many-valley cubic semiconductor is in general lifted by shear strain. Herring and Vogt[1] have applied symmetry arguments in the studies of this phenomena and found that the energy shift ΔE_c^i of valley i for an arbitrary homogeneous deformation described by the second-rank strain tensor $\boldsymbol{\varepsilon}$ can be expressed as

$$\Delta E_c^i = [\Xi_d \mathbf{1} + \Xi_u \{\mathbf{a}_i \mathbf{a}_i\}] : \boldsymbol{\varepsilon}, \tag{2.1}$$

where $\mathbf{1}$ is the unit tensor, $\mathbf{a}_i$ is a unit vector parallel to the $\mathbf{k}$ vector of valley i, and $\{\ \}$ denotes a dyadic product. The shift of the mean energy of the band extrema is

$$\Delta E_c^0 = (\Xi_d + \tfrac{1}{3}\Xi_u)\mathbf{1} : \boldsymbol{\varepsilon}, \tag{2.2}$$

nd the quantity $\Delta E_c^i - \Delta E_c^0$ is given in Table I for Si and Ge in case of uniaxial stress parallel to the crystal directions [001], [111], and [110].

Without strain and spin-orbit coupling the valence-band edge in silicon and germanium is a sixfold degenerate p multiplet with symmetry Γ_{25}'. The spin-orbit coupling partially lifts the degeneracy into a fourfold $p_{3/2}$ multiplet and a $p_{1/2}$ doublet with a separation $\Lambda = 0.044$ eV in Si and $\Lambda = 0.3$ eV in Ge. The edge, the upper $J = \frac{3}{2}$ state, is for $\mathbf{k} \neq 0$ a pair of Kramers doublets designated as "light" and "heavy" holes. $\mathbf{k}\cdot\mathbf{p}$ perturbation applied to this edge yields energy surfaces of the form[14]

$$E(\mathbf{k}) = Ak^2 \pm [B^2k^4 + C^2(k_x^2k_y^2 + k_x^2k_z^2 + k_y^2k_z^2)]^{1/2}, \tag{2.3}$$

where A, B, and C are inverse mass parameters related to the elements of the Shockley matrix[14] by

$$\begin{aligned} A &= \tfrac{1}{3}(L+2M) + (\hbar^2/2m_0), \\ B &= \tfrac{1}{3}(L-M), \\ C^2 &= \tfrac{1}{3}(N^2 - (L-M)^2). \end{aligned} \tag{2.4}$$

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