Anisotropy of the electron *g*-factor in the InSb conduction band

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The anisotropic correction to the *g*-factor of free electrons in indium antimonide has been measured for the first time. Its maximum value, $\Delta g = g(H \parallel [100]) - g(H \parallel [111])$, is 0.090 ± 0.004 in a magnetic field $H = 9434$ G. It thus becomes possible to determine the matrix element representing the interaction of the valence band (V) with the upper conduction band (C'), which lies 3.5 eV above the ordinary conduction band (C).

The three-band model of the band structure of indium antimonide[1] predicts an isotropic dispersion relation and thus an isotropic *g*-factor for the lowest conduction band, the C band. The reason is that this model is restricted to a consideration of the interaction of the C band in a *kp*-perturbation theory with terms up to k^2 inclusively, but only with the two light-hole valence bands V. When more remote bands, primarily the nearest of them, $C'(E_{C'} - E_C = 3.5$ eV$)$, are taken into account in the next order of the perturbation theory (with terms up to k^4), corrections are made to the *g*-factor which depend on the orientation of the crystal with respect to the magnetic field.[2] An attempt[3] to experimentally determine the magnitude of the anisotropic correction to the *g*-factor has not yielded reliable results.

By using a method of amplification during stimulated Raman scattering (stimulated Raman amplification) we have now found it possible to not only measure the maximum value of the correction but also to determine the orientational dependence of the *g*-factor as the crystal is rotated around the [110] crystallographic direction, perpendicular to the magnetic field. The method[4] is based on a resonant intensification of a test wave of frequency $\nu_2/c = 1821.0361$ cm^{-1} due to a pumping of energy from a strong wave with $\nu_1/c = 1842.8210$ cm^{-1} at the time at which the difference between the energies of the photons becomes equal to the spin splitting of the Landau level as the magnetic field is scanned:

$$\hbar\omega_1 - \hbar\omega_2 = g^* \mu_B H_0, \qquad (1)$$

where μ_B is the Bohr magneton, g^* is the measured *g*-factor, and $\omega_{1,2} = 2\pi\nu_{1,2}$.

Figure 1 explains the experimental geometry and procedure. We see that the beams of two lasers (carbon monoxide lasers) are brought into spatial coincidence and focused on the entrance faces of the oriented crystals. Measurements are taken for two samples, with free-carrier densities $n_e = 8 \times 10^{13}$ cm^{-3} and $n_e = 3.8 \times 10^{14}$ cm^{-3}. The resonance is detected from the change in the intensity of the wave of frequency ω_2. The magnetic field is modulated, and synchronous detection is used. At these light frequencies and with $H \parallel [111]$, resonance (1) is observed at a field $H_0 = 9434$ G. According to this equation, the *g*-factor is 49.46. The deviation of the *g*-factor from this value as

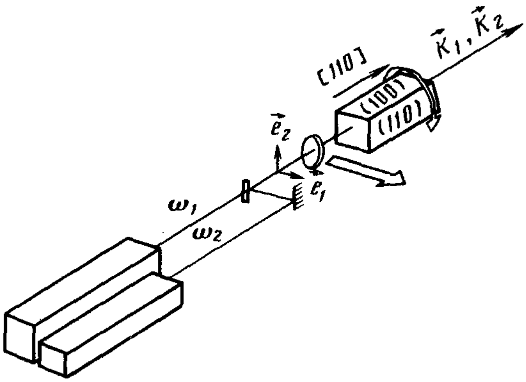

FIG. 1. The experimental arrangement. ω_1, $\mathbf{e}_1$, $\mathbf{k}_1$ and ω_2, $\mathbf{e}_2$, $\mathbf{k}_2$—Frequencies, polarizations, and wave vectors of the beams from the high-power laser and the test laser, respectively.

the sample is rotated 360° around the [110] direction is shown by the points in Fig. 2; the results are the same for the two samples. The maximum deviation, corresponding to $H \| [100]$, is 0.090 ± 0.004. With $H \| [110]$, there is a local maximum: $\Delta g_{110} = g[110] - g[111] = 0.022 \pm 0.004$. Along the four equivalent [111] directions we observe dips to zero. The solid line is the theoretical curve predicted by[2]

$$\Delta g = g(\theta) - g[111] = \gamma_0 \left[1 - \frac{3}{4}\sin^2\theta(1 + 3\cos^2\theta)\right], \tag{2}$$

where

$$\gamma_0 = \frac{2}{3}\frac{\mu_B H}{E_g}\frac{\mathscr{E}_P}{E_g}\frac{\mathscr{E}_Q}{E'_g}, \quad \mathscr{E}_P = \frac{2|P|^2}{m}, \quad \mathscr{E}_Q = \frac{2|Q|^2}{m},$$

$$E_g = E_C - E_V, \quad E'_g = E_{C'} - E_V,$$

and P and Q are the matrix elements of the momentum between the states V-C and V-C', respectively. The angle θ in Fig. 2 is shifted by $2\pi/3$ from θ in (2). The parameter γ_0 is found by fitting the theoretical curve to the experimental data by the method of

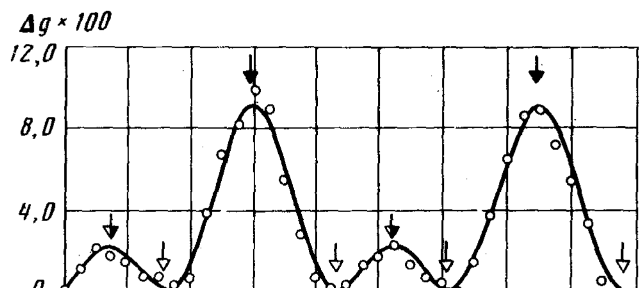

FIG. 2. Anisotropy of the g-factor of conduction electrons in n-InSb. $\Delta g = g(\theta) - g[111]$. The triangles show the angles at which the direction of the magnetic field is along a crystallographic direction: ▽—$H \| [111]$; ▼—$H \| [110]$; ▼—$H \| [100]$.

least squares. Since the precision in the orientation of the samples is 5°, the origin for the θ scale is also varied in the fitting procedure (the pattern is shifted along the abscissa). The mean square scatter in the experimental data is 0.004 for each of the samples. It follows from (2) that the magnitude of the anisotropy of γ_0 depends linearly on the magnetic field and tends toward zero in the limit $H \to 0$. The slope of the line is $\gamma_0/H = 9.5 \times 10^{-3}$ kG^{-1}. For $\mathscr{E}_P = 23.42$ eV, $E_g = 0.2368$ eV (Ref. 5), $H = 9.434$ kG, and $\gamma_0 = 0.09$ we find the value $\mathscr{E}_Q/E'_g = 5.92$ from the expression in (2) for γ_0. For comparison, $\mathscr{E}_P/E_g = 98.9$. If we take[6] $E'_g = 3.7$ eV, we find $\mathscr{E}_Q = 21.9$ eV. Comparing $\mathscr{E}_Q$ and $\mathscr{E}_P$, we see that the square matrix element $|Q|^2$ is not greatly different from $|P|^2$, and the reason why the C' band has a small effect on C in comparison with the V band is the remoteness of C'. We find the relative correction in the Hamiltonian to be $\Delta g \mu_B H \sigma / (1/2) g \mu_B H \sigma = 0.38\%$ (for a field of 9.4 kG), or 4% per 100 kG, in agreement with the estimate in Ref. 2.

These experimental data demonstrate the unique possibilities of the method of stimulated Raman amplification in terms of the sensitivity and accuracy of measurements of g-factors. The maximum value of Δg in Fig. 2, for example, is 0.18% of the absolute value of the g-factor, and the mean square error is 0.008%.

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