LIGHT SCATTERING BY CHARGED CENTERS IN SEMICONDUCTORS WITHOUT INVERSION CENTER

A. A. Grinberg, N. I. Kramer, A. A. Patrin, S. M. Ryvkin, V. I. Fistul', I. M. Fishman, and I. D. Yaroshetskii
A. F. Ioffe Physico-technical Institute, USSR Academy of Sciences
Submitted 30 July 1968
ZhETF Pis. Red. 8, No. 8, 394 - 398 (20 October 1968)

Two of us considered theoretically [1] a new mechanism of light scattering without change of frequency, due to the presence of charged impurity centers in a semiconductor crystal. From the phenomenological point of view, this light-scattering process can be regarded as scattering by fluctuations of the dielectric constant, due to variation of the latter in the Coulomb field of the center (the Pockels effect). From the microscopic point of view, the scattering process is connected with virtual production of an electron-hole pair, accompanied by single scattering of the electron or hole by the Coulomb field of the center. In the dipole approximation, such a process is allowed only in crystals having no inversion center. At not too high charged-impurity-center concentration, when bound states still exist, the scattering may also be due to virtual transitions to bound states of the impurity centers.

The scattering due to interband virtual transition has characteristic polarization and angular properties, whereas the scattering due to the presence of bound states has a dipole character. The integral cross sections of these two scattering components, for a hydrogenlike acceptor center with ground-state energy E = 0.02 eV in GaAs at T = 300°K, are respectively equal to $\sigma = 10^{-23}$ cm^2 [1)] and $\sigma_j = 10^{-22}$ cm^2 for light of wavelength $\lambda = 1.06\ \mu$.

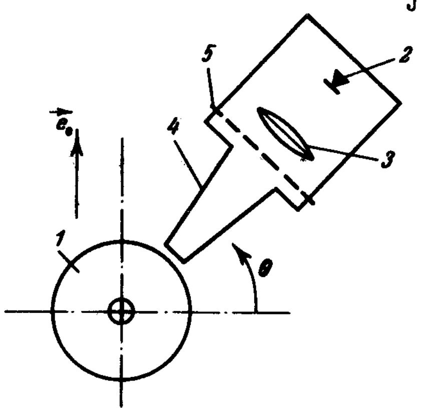

Fig. 1. Experimental setup

The experiment aimed at observing light scattering by charged centers was performed by us in GaAs crystals. The experimental setup is shown in Fig. 1. Polarized light from a Q-switched neodymium laser (operating on one transverse mode with beam diameter ~1 mm) was incident on the end face of cylindrical sample 1. The scattered light was recorded with a germanium high-speed photodiode 2 with a time constant $\tau \leq 10^{-9}$ sec. The scattered light was focused on the photodiode by lens 3, in front of which a black cone 4 was placed to decrease the parasitic light striking the

1) In estimating the cross section, we used the experimental value of the Pockels constant [2]. In [1], where we used tentatively the nonlinear susceptibility to the generation of the second harmonic, we obtained an overestimated value of σ.

receiver. The photodiode could be rotated together with the cone around the sample through 360°.

The sample dimensions, the crystallographic orientation of the end planes, and the mobilities and concentrations of the free carriers at 300°K are listed in the table.

Sample		Diameter mm	Length mm	Orien-tation	μ, cm^2/V-sec	n, cm^{-3}	N_d+N_a [1)]
1	End a	8	15	[111]	700	$4,3\cdot10^{14}$	$7,5\cdot10^{18}$
	End b				$2,9\cdot10^{3}$	$1,4\cdot10^{14}$	$1,2\cdot10^{18}$
2	End a	7	15	[100]	900	$1,4\cdot10^{16}$	$5,0\cdot10^{18}$
	End b				1000	$8,0\cdot10^{15}$	$4,5\cdot10^{18}$

To separate the effect of light scattering by charged centers from the "dipole" radiation (see below), the scattered light was polarized in the direction of the wave vector of the incident light by means of polaroid 5 (Fig. 1). At the given experimental geometry and the given direction of the polarization vector $\vec{e}_0$ of the incident light, as shown in Fig. 1, the theoretical formulas for the differential scattering cross section (without allowance for the bound states) are

$$d\sigma/d\Omega = 1/12\,(Z_e\,\omega/\epsilon_0 c_0 n)^2 A^2 \sin^2\theta$$

and

$$d\sigma/d\Omega = 1/4\,(Z_e\,\omega/\epsilon_0 c_0 n)\,A^2 \cos^2\theta$$

for sample end-surface orientations [111] and [100], respectively. Here Z_e - charge of center, ω - frequency of light, ϵ_0 - dielectric constant, $\vec{n}$ - refractive index of crystal, c_0 - speed of light in vacuum, and A - Pockels constant.

Experimental plots of $I_p(\theta) \sim d\sigma/d\Omega$ for both samples are shown in Fig. 2 in relative units, while the theoretical plots are shown dashed. It is seen that the angular distribution of the scattered-light intensity is different for samples with different crystallographic orientations, and agrees with the theoretical distribution. The absolute values of the intensity of light scattered from the different faces of sample 1 with different concentrations are different, and correlate

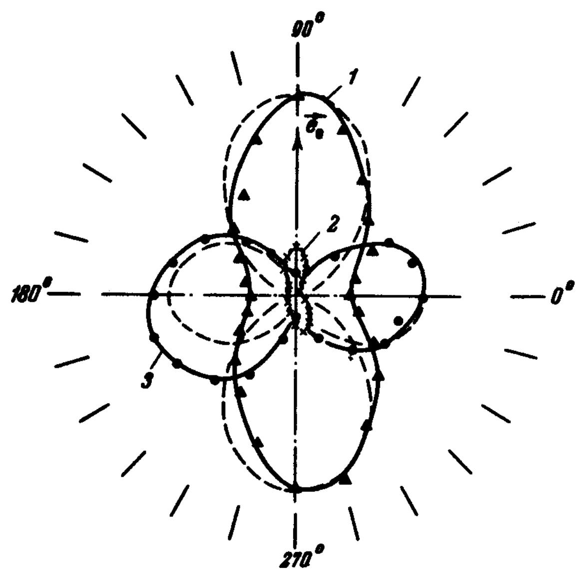

Fig. 2. Angular distribution of scattered-light intensity in plane perpendicular to incident-light wave vector, with scattered radiation polarized: 1 - sample 1, face a; 2 - sample 1, face b; 3 - sample 2.

1) The total concentration of the charged centers (N_d + N_a) was calculated in accordance with the Brooks-Herring formulas [3].

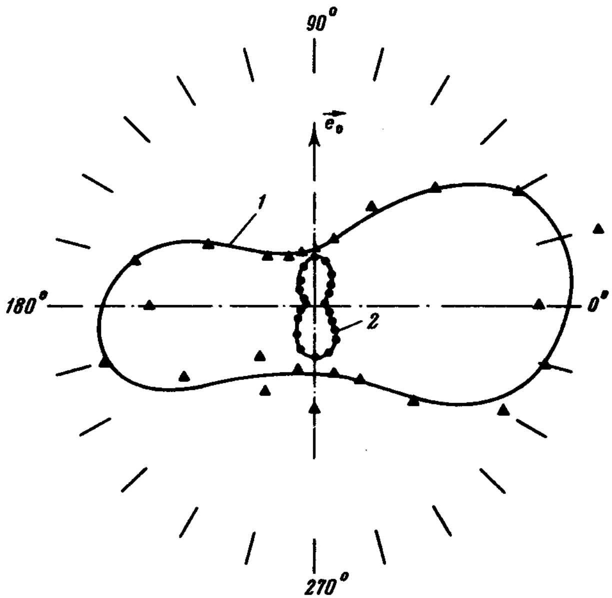

Fig. 3. Angular distribution of scattered-light intensity for sample 1: 1 - without polarization, 2 - with polarization of the scattered light.

with the values of the mobility. One of the reasons why the light intensity does not vanish at any value of the angle θ is that the scattering volume cannot be regarded as an infinitesimally thin filament in the sample.

The experimental value of the maximum differential scattering cross section is of the order of 10^{-24} - 10^{-25} cm^2, in satisfactory agreement with the theoretical estimate.

The results indicate that we have observed experimentally the effect of light scattering by charged centers.

Similar angle measurements were made for the case when the scattered light was recorded without a polarizing filter. It turned out that the angular distribution $I_p(\theta)$ does not depend on the crystallographic orientation of the sample and has a "dipole" character (curve 1, Fig. 3). Such a character of the scattering can be due, in principle, to either small structural inhomogeneities or sound waves in the crystal [4, 5], or else to scattering by charged impurities with account taken of the influence of virtual transitions to the bound states of the impurity centers. Favoring the latter explanation are the correlation of the absolute magnitude of the "dipole" scattering with the value of the mobility. The ratio of the integral intensity of the unpolarized scattered light to that of unpolarized light (Fig. 3, curve 2) is approximately 5, which is in satisfactory agreement with the theoretical estimate given by formula (29) of [1].

[1] A. A. Grinberg and N. I. Kramer, Fiz. Tverd. Tela 8, 583 (1968) [Sov. Phys.-Solid State 8, 463 (1968)].
[2] V. S. Bogaev, Yu. N. Berozashvili, and L. V. Keldysh, ZhETF Pis. Red. 4, 364 (1966) [JETP Lett. 4, 246 (1966)].
[3] P. P. Debye and E. M. Conwell, Phys. Rev. 93, 693 (1954).
[4] L. D. Landau and E. M. Lifshitz. Elektrodinamika sploshnykh sred (Electrodynamics of Continuous Media), Gostekhizdat, 1957 [Addison-Wesley, 1960].
[5] I. L. Fabelinskii, Molekulyarnoe rasseyanie sveta (Molecular Scattering of Light, 1965 (Consultants Bureau, 1968).