[4] V.E. Balakin, A. Bukin, E. Pachtusova, et al., Phys. Lett., 1971 (in print).
[5] V.N. Baier and V.S. Fadin, Phys. Lett., 1971 (in print).
[6] V.N. Baier, V.A. Khoze, and V.S. Fadin, Zh. Eksp. Teor. Fiz. 50, 156 (1966) [Sov. Phys.-JETP 23, 104 (1966)].
[7] V.E. Balakin, G.I. Budker, et al., Kiev Conference, 1970.
[8] B. Bartoly et al., G. Barbellini et al., Kiev Conference, 1970.
[9] J. Sakurai, Acta Phys. Hung., 1971 (in print).

LIGHT SCATTERING BY DROPS OF THE CONDENSED PHASE OF NONEQUILIBRIUM CARRIERS IN GERMANIUM

Ya.E. Pokrovskii and K.I. Svistunova
Institute of Radio Engineering and Electronics, USSR Academy of Sciences
Submitted 11 February 1971
ZhETF Pis. Red. 13, No. 6, 297 - 301 (20 March 1971)

It was noted in [1] that a direct confirmation of the existence of a condensed phase of nonequilibrium carriers in semiconductors, in the form of droplets, would be the observation of scattering of light by such droplets. In fact, drops of an electron-hole plasma of radius r_0 with a concentration p_0 of nonequilibrium carriers, have a complex refractive index m, which differs from the refractive index n of the crystal lattice of the semiconductor as a result of the absorption of the light by the carriers:

$$m = n - in^* ; \quad n^* = Sp_0 \lambda / 4\pi . \tag{1}$$

Here S is the cross section for the absorption of the light by the carriers, and λ is the wavelength of the light in vacuo. If $n^*/n \ll 1$ and $Sp_0r_0 \ll 1$, then the Rayleigh-Gans scattering theory is valid [2]. If furthermore, the dimension of the drops is large, $2\pi r_0 \gg \lambda/n$, then scattered at small angles will predominate. In this case the strength of the light scattering in the sample at an angle θ/n and emerging through a flat face of the crystal at an angle θ to the beam of incident light, can be represented in the form [2]

$$u_p(\theta) = I_0 d(2\pi)^2 NV^2 \lambda^{-4} (n^*)^2 G^2(r_0\theta),$$
$$G(r_0\theta) = 3\left(\sin\frac{2\pi}{\lambda}r_0\theta - \frac{2\pi}{\lambda}r_0\theta\cos\frac{2\pi}{\lambda}r_0\theta\right)\left(\frac{2\pi}{\lambda}r_0\theta\right)^{-3}. \tag{2}$$

Here I_0 is the flux of the sounding light, $V = 4\pi r_0^3/3$ is the volume of the drops, N is their concentration, and d is the thickness of the layer in which the scattering takes place. Integrating (2) with respect to θ and assuming that the bulk of the nonequilibrium carriers is concentrated in the condensed phase, $NVp_0 = gr_0$, we obtain, when account is taken of (1), the integral flux of the scattered light

$$I_p = \frac{3}{8} I_0 dS^2 p_0 r_0 g r_0 \tag{3}$$

Here g is the excitation rate, and τ_0 the lifetime of the condensate. The light flux absorbed by the carrier in the condensed phase can be written in the form

$$I_n = I_0 dS g r_0 \tag{4}$$

from which it follows that

$$I_p/I_n = \frac{3}{8} S p_0 r_0 . \tag{5}$$

Thus, the radius r_0 of the drops can be determined either from the angular distribution of the scattered light from (2), or from relation (5), if p_0 and S are known.

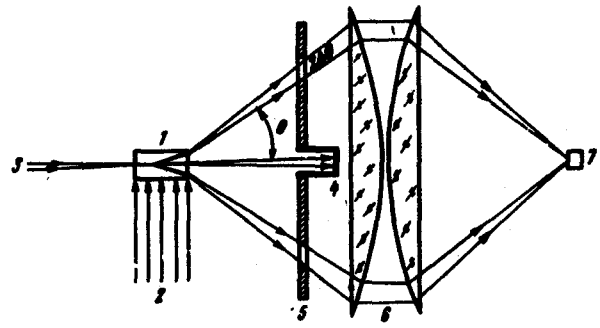

Fig. 1. Diagram illustrating the method of investigating light scattering.

The scattering of light by drops of the condensed phase in germanium was observed experimentally. A sample of pure germanium 1 (Fig. 1) measuring 2 × 4 × 10 mm and having optically polished faces was excited by modulated radiation 2 from an incandescent lamp. The rate of volume excitation g decreased with increasing sample thickness, owing to the indirect intrinsic absorption. We investigated the scattering of light from a helium-neon laser with $\lambda = 3.39\ \mu$, corresponding approximately to the maximum light absorption by the free holes in germanium ($S = 2 \times 10^{-16}$ cm^2 at 77°K [3]). A beam of light 3 with approximate diameter 0.2 mm passed through the sample parallel to the face on which the exciting radiation was focused. The light passing through the sample without scattering was blocked by a cup 4. To separate the light scattered at angles $\theta \pm \Delta\theta$ ($\Delta\theta \sim 1°$), annular windows of interchangeable disks 5 were used. A set of eight disks with windows corresponding to different θ made it possible to determine the angular distribution $u_p(\theta)$ of the scattered light. The scattered light was then focused with a quartz condenser 6 on the receiving area 7 of a cooled lead-sulfide photoresistor, shielded with a filter against the action of the exciting and recombination radiations.

For effective cooling of the sample 1, its upper half was soldered into the cavity of the cryostat and flushed continuously with liquid helium, while the lower half was kept in a vacuum. Under the experimental conditions, the sample temperature hardly differed from the temperature of the helium bath, and at the same time the parasitic scattering of light by bubbles of boiling helium was completely eliminated.

At the employed excitation levels g, the characteristic recombination radiation of the condensed phase of the nonequilibrium carriers [1] occurred at a temperature ∿2.1°K. This was simultaneously accompanied by scattered radiation modulated at the frequency of the exciting light and in phase with the excitation. This signal appeared only if the exciting and sounding beams 2 and 3 were simultaneously acting on the sample. The response of the photoresistor to the integrated scattered radiation I_p, measured with disks 5 removed, exceeded the noise by 2 - 3 order of magnitude.

To determine r_0 from (5), we measured the relative values of I_p, I_n, and I_0. To determine I_n we measured the response of the photoresistor, with cup 4 removed, to the ac component of the radiation 3, which, as expected, was in antiphase with the excitation. In the first case, when the sounding beam 3 passed at a distance 0.5 mm from the illuminated surface of the sample, we obtained $I_p/I_n = 1.75 \times 10^{-2}$ and $I_n/I_0 = 7.2 \times 10^{-3}$. If we assume $p_0 = 2.6 \times 10^{17}$ cm^{-3} [4], $\tau_0 = 2 \times 10^{-5}$ sec [1, 4], and $S = 2 \times 10^{-16}$ cm [3], then it follows from (4) and (5) that $r_0 = 8.8 \times 10^{-4}$ cm and $g = 4.5 \times 10^{18}$ cm^{-3}sec^{-1}. When the sounding beam is moved 1 mm away from the illuminated surface of the sample, corresponding to a decrease in the generation rate g, the result was $r_0 = 3.8 \times 10^{-4}$ cm and $g = 1.8 \times 10^{18}$ cm^{-3}sec^{-1}. Thus, the dimension r_0 of the drops decreased with decreasing g, in agreement with the concept developed in [1].

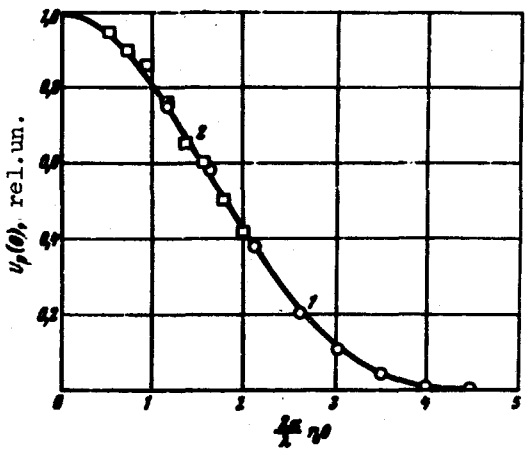

Fig. 2. Angular distribution of the strength of the scattered light $u_p(\theta)$: 1 - sounding light beam at a distance 0.5 mm from the illuminated surface of the sample, $r_0 = 7.6 \times 10^{-4}$ cm (light circles); 2 - sounding light 1 mm away, $r_0 = 3.4 \times 10^{-4}$ cm (light squares). Solid line - the function $G^2(r_0\theta)$.

An independent determination of r_0 was made also by comparing the experimental data on the angular distribution of the strength $u_p(\theta)$ of the scattered light with the theoretical formula (2). To this end, the strength of the light scattered at angles $\theta \pm \Delta\theta$ was plotted as a function of $(2\pi/\lambda)r_0\theta$ (Fig. 2), with $u_p(\theta)$ assumed proportional to the photoresistor response normalized to the area of the annular windows of disks 5. The parameter r_0 was chosen from the condition that the experimental points fit best the function $G^2(r_0\theta)$ characterizing the angular distribution is shown by the solid line in Fig. 2. It is seen from the figure that it is possible to choose values of r_0 such that good agreement is observed between experiment and calculation. At the first position of the sounding beam $r_0 = 7.6 \times 10^{-4}$, and at the second position $r_0 = 3.4 \times 10^{-4}$. These values of r_0 are in good agreement with the values determined from (5) for the same positions of the light probe. We note that when r_0 is determined from the angular distribution of the scattered light there is no need to know the carrier density in the condensed phase p_0 and the absorption cross section S. The obtained drop dimensions agree also with the value $r_0 \simeq 10^{-3}$ cm determined at the same temperature and under analogous excitation in [5] from the absorption of submillimeter radiation of the condensed phase in germanium.

The authors are grateful to S.G. Kalashnikov for a discussion of the results.

[1] Ya.E. Pokrovskii and K.I. Svistunova, Fiz. Tekh. Poluprov. 4, 491 (1970) [Sov. Phys.-Semicond. 4, 409 (1970)].
[2] H.C. van de Hulst, Light Scattering by Small Particles, Wiley, 1957.
[3] W.E. Pinson and R. Bray, Phys. Rev. 136A, 1449 (1964).
[4] Ya.E. Pokrovskii, A.S. Kaminskii, and K.I. Svistunova, Proc. Tenth. Internat. Conf. Phys. Semicond. 504, 1970.
[5] V.S. Vavilov, V.A. Zayats, and V.N. Murzin, ZhETF Pis. Red. 10, 313 (1969) [JETP Lett. 10, 199 (1969)].

SUPPRESSION OF (n,γ) REACTION IN RESONANT SCATTERING OF NEUTRONS BY A PERFECT CdS CRYSTAL

S.Sh. Shil'shtein, V.A. Somenkov, and V.P. Dokashenko
Submitted 11 February 1971
ZhETF Pis. Red. 13, No. 6, 301 - 305 (20 March 1971)

It was shown in an earlier paper [1] that for neutrons whose energy is comparable with the excitation energy of the resonant level of Cd^{113} (0.178 eV), in accord with the predictions of the theory [2], the inelastic channels of the nuclear reactions are suppressed, i.e., if the Bragg conditions are satisfied a perfect absorbing crystal becomes anomalously transparent. This effect was