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ROLE OF EXCITON STATES IN THE PROCESS OF PHOTOCURRENT FORMATION IN GERMANIUM

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Submitted 2 May 1968
ZhETF Pis. Red. 8, No. 1, 15 - 18 (5 July 1968)

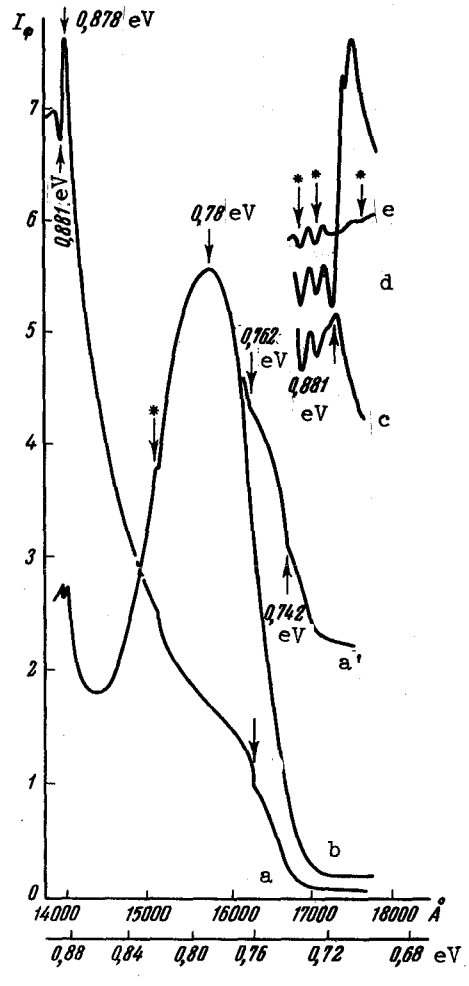
Germanium is one of the few semiconducting crystals in which the impurity content can be controlled with a high degree of accuracy. Particular interest attaches in this connection to research on exciton absorption of light in this crystal. The first to observe and to study exciton absorption in germanium, in indirect and direct transitions, were Macfarlane and his co-workers [1]. Recently Asnin, Rogachev, and Ryvkin [2] used exciton states to explain peculiar phenomena observed in the photoconductivity of germanium at low temperatures. We believe, however, that a direct proof of the part played by excitons in the production of free carriers can be obtained only by spectral investigations. This precisely was how Apker and Taft [3] demonstrated experimentally for the first time the role of excitons in the external photoeffect. We know of only one similar investigation of indirect exciton transitions in germanium [1]. Continuing a cycle of research initiated by us in 1956 on the role of excitons in photoelectric phenomena, we undertook a spectral investigation of the photoconductivity of pure germanium single crystals at 77°K, using an instrument with sufficiently large dispersion.

Free standing germanium single crystals measuring 5 x 2 x 2 mm, with ohmic contacts, were placed directly in a dewar with liquid nitrogen. The polished surfaces of the crystals were polished prior to the experiment in hydrogen peroxide or in CP-4. An MDR-2 monochromator with dispersion 80 Å/mm was used. The photocurrent was recorded at 600 Hz with an amplifier (28 IM) and was continuously plotted with an EPP-09 automatic recorder. The rate scanning the spectrum ranged in different experiments from 10 to 1 Å/sec.

The results are shown in the figure. Curve a is the spectrum of the photocurrent in the germanium immediately after etching the sample in H_2O_2. Similar curves were obtained

for the photoconductivity after etching the crystals in CP-4. The photocurrent curve shows clearly steps at energies 0.742 and 0.762 eV (Fig. 1a'), followed by a rise in the photocurrent up to 0.878 eV, where a maximum is observed. The photocurrent then drops sharply and has a narrow minimum at an energy 0.881 eV, which corresponds exactly to the energy of the free exciton (Figs. 1a, e). By varying the etching time and by investigating different parts and faces of the crystal, it is possible to observe curves on which the maximum value of the current is reached precisely in the exciton line (Fig. 1c). The steps near 0.742 and 0.762, as is known from the absorption spectra, correspond to indirect interband and exciton transitions.

Storing the etched crystal in the atmosphere at room temperature for a short time (10 - 30 min) decreases the photoconductivity in the short-wave part and causes formation of a maximum near 0.78 eV (Fig. 1b). Prolonged storage under the same conditions, or else polishing, greatly decreases the short-wave sensitivity and cause a relative increase of the photocurrent in the long-wave maximum. The position of this maximum in the spectrum is not constant and depends on the surface state. Similar phenomena are well known for germanium and can be attributed to an increase of the rate of surface recombination of the carriers [4]. A feature of the curve obtained in this investigation is the presence of a second rise of the photocurrent in the region of the direct exciton transitions (0.88 eV). Its origin (at a monotonic growth of the absorption coefficient) can be attributed to the existence of two different photocurrent mechanisms in these spectral regions (diffusion length, quantum yield). These questions are considered in [5].



a - d) Spectral distribution of the photocurrent in germanium single crystals at 77°K. e) Absorption in the atmosphere

We have thus observed in our experiments a fine structure in the excitation spectrum of the photoconductivity of germanium. Such a structure was known earlier in this crystal only for absorption. These experiments demonstrate directly that the exciton actually takes part in the production of carriers, and its contribution to the photocurrent is determined primarily by the state of the surface of the crystal. As shown by us earlier, the state of the surface is decisive in the photoelectric manifestations of excitons in other crystals, too [6]. It is precisely on the surface where the centers are located, which interact with the exciton during the photocurrent production when the exciton diffuses from within the

crystal. A study of the dependence of the photocurrent on the absorption coefficient makes it possible to estimate the diffusion length of the excitons, which in our experiments on germanium turned out to be ∿1 mm.

The authors are grateful to Professor V. P. Zhuze for supplying the samples of pure germanium and to G. P. Shcherbakov for collaboration in preparing the ohmic contacts.

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SELF-ISOLATION OF SURFACE OF A BODY IN A MEDIUM AGAINST INTENSE LIGHT FLUX. INDUCED MIRAGE

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Submitted May 5, 1968
ZhETF Pis. Red. 8, No. 1, 19 - 21 (5 July 1968)

Let us examine the effect of self-limitation of the access of intense light radiation to an absorbing surface situated in a transparent liquid or gas, or else bordering on a transparent solid medium.

We assume that a powerful light beam with flux density I_0 is incident at an angle ϕ to the tangent on the absorbing surface immersed in the transparent medium. The absorption coefficient α of the surface is given, but it can depend also on the light flux density and on the angle of incidence.

The flux density of the energy absorbed by a unit surface area

$$W \simeq \alpha I_0 \sin\phi$$

can be sufficiently large at large values of I_0 and α even if ϕ is small, and the temperature of the surface can therefor rise appreciably. (In order of magnitude

$$\Delta T \simeq W\sqrt{\tau}/(\rho_1 C_1 \sqrt{\kappa_1} + \rho_2 C_2 \sqrt{\kappa_2}) ,$$

where ρC and κ are the heat capacity per unit volume and the temperature conductivity of the surface material and of the medium bordering on it.)

Since the refractive index of the medium $n(\rho, T)$ decreases with decreasing density of the medium, heating produces on the absorbing surface a layer with decreased refractive index; this layer can change appreciably the conditions for the interaction between the light and the surface. In particular, at certain incidence angles the light beam can be refracted by this layer to such an extent that the approach of the light to the surface will change radically or will stop completely. We shall call this effect an induced mirage. Let us consider