for the investigated calcite line. The sensitivity can be increased further by narrowing down the line and increasing the power of the PLG; this also increases the resolution.

5. The maximum effect is reached along the synchronism direction ($\Delta k = 0$). However, the requirements with respect to the accuracy with which the beams are set are in many cases not too stringent. The table lists the values of the coherent scattering length $L_{coh} = (\Delta k)^{-1}$ far from the exact synchronism for different media and different frequencies of the pump and of the probing signal. It is seen that in gases $L_{coh} \gtrsim 10$ cm and in general there are no problems connected with the exact synchronism. In strongly dispersive media, $L_{coh} \sim 1$ cm is reached by having the pump and probing-signal frequencies close. Of course, the possibility of using exact synchronism remains in all cases.

The choice of a green probing beam with wavelength $\lambda_{pr} = 532$ nm is convenient because it makes it possible to use the recording apparatus of the commercial Raman spectrograph with the argon laser serving for the excitation of the RS spectra.

[1] J.A. Giordmaine and W. Kaiser, Phys. Rev. 144, 676 (1966).
[2] F. deMartini and J. Ducuing, Phys. Rev. Lett. 17, 117 (1966).
[3] J.P. Coffinet and F. deMartini, Phys. Rev. Lett. 22, 60 (1969).
[4] M. Papoular, Solid State Commun. 4, 129 (1966).
[5] S. Biraud-Laval and G. Chartier, Opto-electronics 1, 172 (1969).
[6] P. Maker and R. Terhune, Phys. Rev. 137, A801 (1965).
[7] D. von der Linde, A. Lauberau, and W. Kaiser, Phys. Rev. Lett. 26, 954 (1971).
[8] R.R. Alfano and S.L. Shapiro, Phys. Rev. Lett. 26, 1247 (1971).
[9] N.I. Koroteev, Usp. Fiz. Nauk 106, No. 4 (1972) [Sov. Phys.-Usp. 15, No. 2 (1972)].
[10] W.J. Jones and B.P. Stoicheff, Phys. Rev. Lett. 13, 657 (1964).
[11] V.S. Gorelik and M.M. Sushchinskii, Fiz. Tverd. Tela 12, 1475 (1970) [Sov. Phys.-Solid State 12, 1157 (1970)].

FAST-NEUTRON-COMPENSATED n-GERMANIUM AS A MODEL OF AMORPHOUS SEMICONDUCTORS

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As is well known, transport phenomena in amorphous (vitreous) semiconductors differ significantly from those in crystals: in particular, they exhibit an anomalously small "Hall" mobility, a nonlinear S-shaped current-voltage characteristic, and a conductivity activation energy that decreases continuously with decreasing temperature [1]. According to recently developed concepts, the physical properties of amorphous semiconductors are determined by the presence in them of random potential fluctuations whose scale is comparable with the width of the forbidden band [2, 3]. A similar potential relief exists, as is well known, also in crystalline semiconductors if they are strongly compensated by randomly distributed charged impurities. By varying the degree of doping and compensation it is possible, as shown in [4], to produce a controllable model of amorphous semiconductors, for in this case changes take place both in the amplitude and dimensions of the regions of the potential fluctuations and in the position of the Fermi level.

We note, however, that if fluctuations are produced as a result of a Poisson distribution of point defects and impurities, a rigid connection is

established between the averaged dimensions and the mean-squared values of the fluctuation amplitudes. In this sense, the method of producing a model of amorphous semiconductors by random distribution of point defects is subject to limitations. New possibilities for developing a controllable model of amorphous semiconductors are afforded by the use of bombardment with high-energy nuclear particles, which produce local clusters of defects. By using nuclear particles of different types and energies it is possible to produce structures with different relations between the average potential-variation amplitude and the dimensions of the disturbed regions.

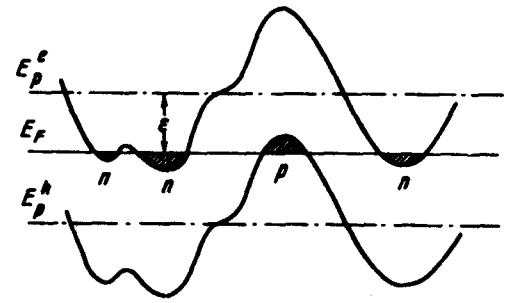

Fig. 1. Variation of potential along an arbitrary direction. The shaded regions denote electron (n) and hole (p) drops. The dimension of the p-region corresponds to the cluster dimension R_0.

We have investigated from this point of view strongly doped n-type germanium bombarded with fast neutrons. As is well known, fast neutrons absorbed in germanium produce spherical (in first approximation) regions of "disorder" with linear dimensions R_0 of approximately 50 - 100 Å, inside of which the germanium exhibits properties of a p-type material with average acceptor concentration on the order of 10^{19} cm^{-3}. Thus, randomly disposed p-type regions surrounded by insulating layers of n-p junction space charge are produced when n-Ge with donor density up to 10^{19} cm^{-3} is bombarded with fast neutrons. At first, when the concentration N of such regions is small, they are simply "excluded" from the conductivity and lead to bending of the current lines, but when NR_0^3 becomes of the order of unity, these regions begin to overlap so that the germanium sample becomes a three-dimensional network of randomly spaced electron and hole regions and of n-p junctions between them. In this case the swing of the potential fluctuations slightly exceeds the width of the forbidden band.

Figure 1 shows schematically the variation of the potential along an arbitrary direction. Here E_F is the Fermi level, and $E_p^{e,h}$ are the "percolation" levels for the electrons and holes, i.e., the values of the energy required for the charge to be able to go first from electrode to electrode in "classical" fashion without tunneling through the potential peaks, but bending around them. It follows from this model that the conductivity σ should have an activation character, and at high temperatures the activation energy is equal to the energy difference between the "percolation" level and the Fermi level, and can approach half the width of the forbidden band of the semiconductor. At sufficiently low temperatures the predominant conductivity mechanism should be tunneling over states that are closer and closer to the Fermi level. The activation energy ε should in this case decrease continuously with temperature T in accordance with Mott's law $\varepsilon \sim T^{3/4}$ or $\ln \sigma \sim T^{-1/4}$ [5, 6]. It is clear also that, owing to the strong inhomogeneity of the sample, the product $R\sigma$ of the Hall constant by the conductivity has nothing in common with the mobility and can assume arbitrarily small values. Such a system should have, in addition, a nonlinear current-voltage characteristic with S-shaped section. Breakdown or at least its initial stage can be determined by the mechanism described in [7].

Our experiments have fully confirmed the foregoing assumptions. n-Ge samples with arsenic concentration 8×10^{18} cm^{-3} were bombarded with fast neutrons. The conductivity of such samples had a metallic character, i.e., it depended little on the temperature. The resistivity and the mobility in the entire temperature interval were of the order of 2×10^{-3} ohm-cm and 5×10^2 cm^{2}V^{-1}sec^{-1}, respectively. With increasing fast-neutron dose, the mobility decreased sharply, and the Hall emf could no longer be measured in the strong-

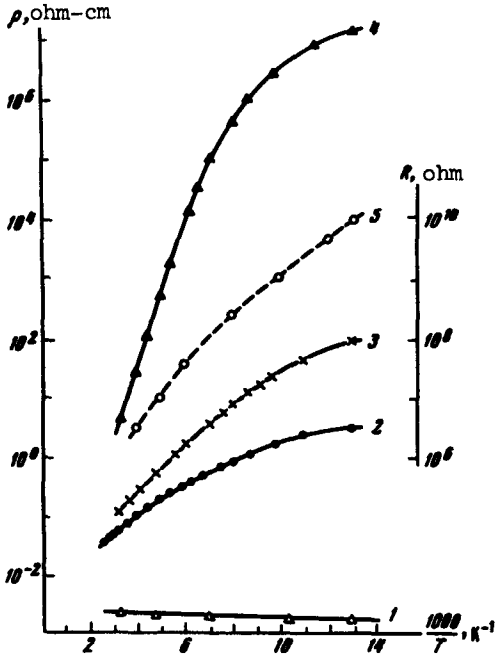

Fig. 2

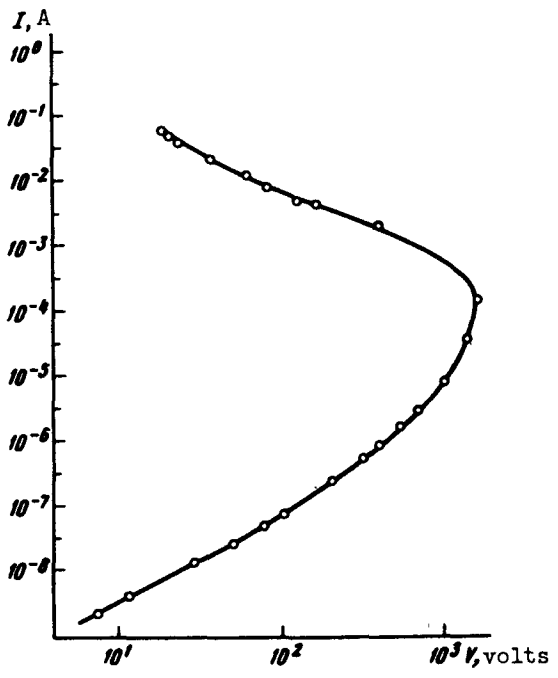

Fig. 3

Fig. 2. Temperature dependence of the resistivity: 1) initial sample of strongly doped germanium; 2 - 4) samples compensated with different doses of neutron bombardment; 5) resistance of film of amorphous germanium (right-hand scale) [8].

Fig. 3. Static current-voltage characteristic of the most compensated sample at 77°K.

compensation region. Figure 2 shows the temperature dependences of the resistivity of samples obtained with different radiation doses. For comparison the figure shows the temperature dependences of the resistivity of the initial sample, and also of a film of amorphous germanium [8]. It can be seen that the conductivity has acquired an activation character, and in the most compensated sample at high temperatures we have $\varepsilon = 250$ meV, i.e., close to half of the width of the germanium forbidden band. Reduction of the curves plotted in the $T^{-1/4}$ scale shows that Mott's law is well satisfied at low temperatures. Figure 3 shows the current-voltage characteristic of the most compensated sample, plotted by a stationary method at T = 77°K. It can be seen that the characteristic has an S-shape with a considerable negative-differential-resistance section.

Thus, our investigation has shown that n-germanium bombarded by fast neutrons exhibits the main features possessed by an amorphous semiconductor, and can be regarded in this sense as a model of such a semiconductor.

In conclusion, the authors are grateful to B.I. Shklovskii for a discussion of the results.

[1] N. Mott, Phil. Mag. 24, 190, 911 (1971).
[2] H. Fritzsche, J. Non-Cryst. Sol. 6, 49 (1971).
[3] B.I. Shklovskii, ZhETF Pis. Red. 14, 397 (1971) [JETP Lett. 14, 269 (1971)].
[4] B.I. Shklovskii and A.L. Efros, Zh. Eksp. Teor. Fiz. 62, 1156 (1972) [Sov. Phys.-JETP 35, No. 3 (1972)].
[5] N. Mott, Phil. Mag. 19, 835 (1966).

[6] I.S. Shlimak and E.I. Nikulin, ZhETF Pis. Red. 15, 30 (1972) [JETP Lett. 15, 20 (1972)].
[7] S.M. Ryvkin, ibid. 15, 632 (1972) [this issue, p. 448].
[8] A. Clark. J. Non-Cryst. Sol. 2, 52 (1970).

APPEARANCE OF FINE STRUCTURE IN FLUORESCENCE SPECTRA OF LASER-EXCITED COMPLEX MOLECULES

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1. It is well known that the absorption and luminescence spectra of polyatomic organic molecules in solutions usually consist of one or several broad bands. In a large number of cases, at low temperatures, it is possible to obtain spectra with a fine structure by introducing the investigated molecules into a suitably chosen crystal n-paraffin matrix (the Shpol'skii effect [1]). Narrow phononless lines in these spectra are accompanied by phonon wings occurring in transitions with creation or annihilation of the matrix phonons [2, 3].

In most solvents, however, particularly in a vitreous medium, the spectra remain smeared down to helium temperatures.

In the present communication we present the first results of our investigations of the nature of broad bands in spectra of organic molecules in solid solutions, using laser excitation of the fluorescence in the region of a purely electronic 0-0 transition. During the course of these investigations we have observed that in a number of compounds, under definite excitation conditions, a spectrum with a fine structure can be obtained practically in any solvent.

2. Figures 1a and 2a show the flourescence spectra of an aromatic hydrocarbon (perylene) at 4.2°K in two solvents having essentially different

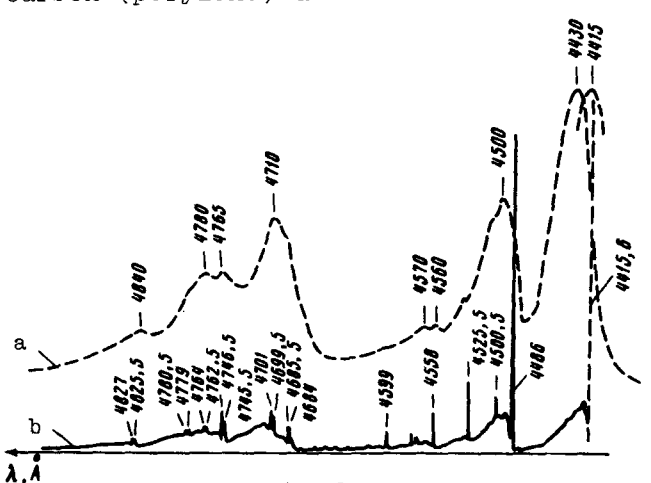

Fig. 1

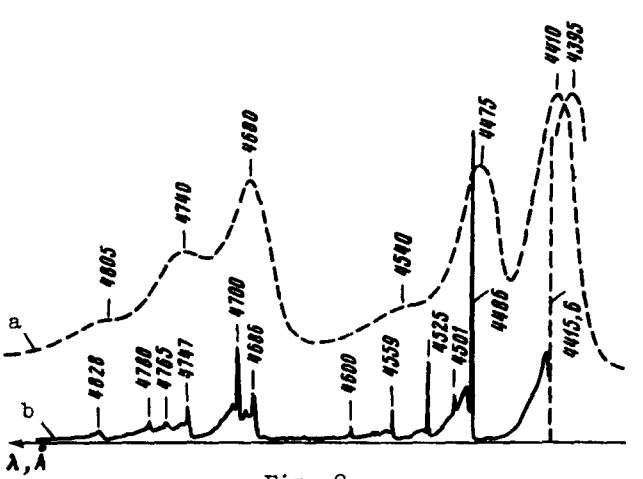

Fig. 2

Fig. 1. Fluorescence spectra of perylene in n-undecane at 4.2°K: a - ordinary excitation (λ = 365 nm, DRSh-1000 lamp); b - laser excitation at λ = 4415.6 Å. The 4415 Å maximum belongs to the longest-wavelength absorption band. Concentration ∿2 × 10^{-5} mole/liter. DFS-12 spectrometer.

Fig. 2. Fluorescence spectra of perylene in ethanol at 4.2°K: a - ordinary excitation, b - laser excitation.