

zation ratios for the process 7 are somewhat lower. They differ, however, in different maxima, thus indicating that they have a different nature. The lower polarization ratio can be attributed to the overlap of the spectra of processes 7 and 8. For process 7, the experimentally obtained polarization ratio does not contradict the theory if account is taken of the short lifetime in the excited state.

An absolute calibration of the apparatus sensitivity with the aid of a standard lamp has enabled us to measure the cross section of the process 8. It turned out to be of the order of $10^{-27} - 10^{-28} \text{ cm}^2$. On the other hand, theoretical estimates of the cross section by means of the formula

$$\sigma \sim \frac{4\omega^2 d^4}{\hbar^2 c^4},$$

in which ω is the average cyclic frequency of the transitions and d the dipole moment, give values from 10^{-26} to 10^{-29} cm^2 . A theoretical estimate of the cross section can also be obtained by determining d^4 from the experimental results on two-photon absorption [4]. Such an estimate gives a cross section on the order of 10^{-27} cm^2 , which agrees well with our data.

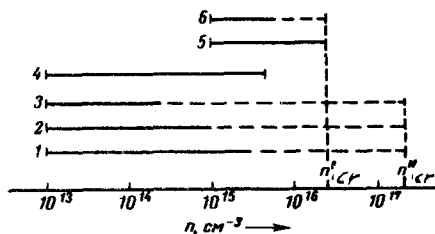
We must also point out some shortcomings of our interpretation. Thus, for example, all the short-wave maxima of the process 8 on Fig. 2 seem somewhat broader than the corresponding maxima of the one-quantum luminescence, and in the case of Fig. 2a the maximum 3 is even somewhat shifted towards the short-wave side. However, since these maxima overlap the maxima of processes 7, it is impossible to assess their actual width or exact position from the form of the curves of Fig. 2. A separation of the maxima is needed for this purpose. We indicate also that at the lifetimes characteristic of the processes in question, on the order of $10^{-11} - 10^{-13} \text{ sec}$, the relaxation of 2 is apparently incomplete, and this also can cause broadening and a shift in the short-wave direction.

- [1] W. E. K. Gibbs, Appl. Phys. Lett. 11, 113 (1967).
- [2] Ya. S. Bobovich, Usp. Fiz. Nauk 97, 37 (1969) [Sov. Phys.-Usp. 12, 20 (1969)].
- [3] J. Ducuing, G. Hanchecorne, A. Mysyrowicz, and F. Pradere, Phys. Lett. 28A, 746 (1969).
- [4] M. D. Galanin and Z. A. Chizhikova, ZhETF Pis. Red. 4, 41 (1966) [JETP Lett. 4, 27 (1966)].
- [5] L. D. Derkacheva, A. I. Krymova, V. I. Malyshev, A. S. Markin, ibid. 7, 468 (1968) [7, 362 (1968)]; L. D. Derkacheva, A. I. Krymova, A. F. Vompe, and I. I. Levkov, Opt. Spektrosk. 25, 723 (1968).

GIANT FLUCTUATIONS OF PHOTOCURRENT IN GERMANIUM

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The phenomenon of exciton condensation in germanium was discussed in [1 - 6]. This effect consists of formation of metallized "drops" surrounded in the semiconductor by a dielectric gas of excitons. The presently available proof of the existence of such "drops" in pure germanium at helium temperatures and at a sufficiently high excitation level is based on data obtained only from purely optical experiments, and there is still no meeting of minds concerning the density and heat of sublimation of the condensate. Thus, the authors of [4, 5]



Regions of existence of "drops" of exciton condensate and of biexcitons in germanium, from the data of: 1 - [4], 2 - [6], 3 - [5], 4 - [7, 8, 9], 5 - [2, 3], 6 - present work. Solid lines - concentration regions investigated in the cited papers, dashed - regions where the exciton condensate should exist in accordance with the cited papers (n'_{cr} - condensate density according to [2, 3], n''_{cr} - according to [4, 5]).

assume that the exciton condensate in germanium has a density $n \approx 2 \times 10^{17} \text{ cm}^{-3}$ and is produced at helium temperatures at rather low excitation intensities ($n \approx 10^{13} \text{ cm}^{-3}$). In [2, 3], to the contrary, arguments are presented favoring the assumption that the exciton-condensate density is lower by about one order of magnitude ($n \approx 2 \times 10^{16} \text{ cm}^{-3}$), and its production becomes possible only at an exciton concentration exceeding 10^{15} cm^{-3} . There is, finally, one more group of papers, in which the phenomena observed at low excitation level are attributed to the formation of biexcitons. The figure shows schematically the regions of existence of biexcitons and of the exciton condensate in accordance with the cited papers.

We present here some results of an experimental study of photocurrent fluctuations in a germanium p-i-n diode under conditions when the existence of an exciton condensate is expected according to the data of [2 - 6]. The drops of the exciton condensate (if they exist) will be attracted by the inhomogeneous electric field to the p-n junction, where their destruction will produce current pulses. By measuring the charge passing during the time of such a pulse, it is possible to determine the number of excitons in the "drop," and by using data on the condensate density it is possible to obtain the approximate drop dimensions.

The experiments were performed on pure germanium samples ($N_d \approx 10^{12} \text{ cm}^{-3}$) in the form of rectangular plates measuring $10 \times 40 \text{ mm}$ and about 1 mm thick. A fused p-i-n diode of approximate area 1 mm^2 was produced near one of the small sides of the rectangle. The non-equilibrium electrons and holes could be produced at different distances from the p-n junction with the aid of light pulses of duration $\approx 1.5 \text{ } \mu\text{sec}$ from an ISSh-100 flash lamp. The light-spot diameter was $\approx 3 \text{ mm}$. The measurements were made under short-circuit conditions. The photocurrent signal produced following the appearance of the free carriers in the p-n junction was registered on an oscilloscope screen.

Measurements made at $T \leq 4.2^\circ\text{K}$ have shown that when excitons with concentration exceeding $(2 - 3) \times 10^{15} \text{ cm}^{-3}$ are produced in a region close enough to the p-n junction, the waveform of the current pulse flowing through the p-n junction becomes irregular. Two types of fluctuations are observed in this case: long-duration, lasting several microseconds, and short ones of about 0.1 microsecond duration. The amplitude of these fluctuations, at maximum excitation levels close to $5 \times 10^{16} \text{ cm}^{-3}$, reached several milliamperes, corresponding to a charge of $10^{-8} - 10^{-10} \text{ C}$ passing through the p-n junction. Such large fluctuations can be attributed to the entrance of "drops" of exciton condensate into the field of the p-n junction. With

¹⁾ When the cited papers contained no data on the average exciton concentration [5, 6, 8] the latter was estimated by us on the basis of the described experimental conditions.

decreasing excitation level or with increasing distance from the excitation region to the p-n junction, the magnitude and duration of the fluctuations decreased rapidly. This fact is apparently connected with the rapid decrease of the "dimensions" of the drops falling in the p-n junction region. With increasing distance that the "drops" must traverse to the p-n junction, a time delay of the fluctuation appeared relative to the excitation pulse.

It is important that all these effect vanish at concentrations lower than $1 \times 10^{15} \text{ cm}^{-3}$ or when the temperature rises to about 6°K . The figure shows the region of concentrations where exciton condensate is observed in accordance with our results. Our data confirm the conclusions of [2, 3] that the condensate is produced in germanium under conditions when the density of the exciton gas is close enough to the density of the particles in the liquid phase, and that the heat of sublimation is close to 1 meV.

- [1] L. V. Keldysh, Proc. of 9th Internat. Conf. on Physics of Semiconductors, Moscow, 1968. p. 1384.
- [2] V. M. Asnin and A. A. Rogachev, ZhETF Pis. Red. 2, 415 (1969) [JETP Lett. 9, 248 (1969)]
- [3] V. M. Asnin and A. A. Rogachev, Proc. 3rd Int. Photoconductivity Conf., Stanford Univ. 1969 (in press).
- [4] Ya. E. Pokrovskii and K. I. Svistunova, ZhETF Pis. Red. 2, 435 (1969) [JETP Lett. 9, 261 (1969)].
- [5] V. S. Vavilov, V. A. Zayats, and V. I. Murzin, ibid. 10, 304 (1969) [10, 192 (1969)].
- [6] V. S. Bagaev, T. I. Galkina, O. B. Gogolin, and L. V. Keldysh, ibid. 10, 309 (1969) [10, 195 (1969)].
- [7] J. R. Haynes, Phys. Rev. Lett. 17, 860 (1966).
- [8] Benoit a la Guillaume, F. Salvan, and M. Voos, Proc. Internat. Conf. on Luminescence, Univ. of Delaware, 1969 (in press).
- [10] V. M. Asnin, A. A. Rogachev, and N. I. Sablina, Fiz. Tekh. Poluprov. 4, 1970 (Sov. Phys.-Semiconduct. 4, 1970) (in press).

POLARIZATION OF PROTONS PRODUCED IN INTERACTIONS BETWEEN 650 - 840 MeV PHOTONS AND Li^7 AND C^{12} NUCLEI

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Only a few investigations have been made to date of the polarization of the protons produced in the interactions between high-energy photons and nuclei.

The polarization of protons from the light nuclei Li^7 , Be^9 , B^{11} , and C^{12} at photon energies up to 335 MeV was investigated in [1, 2] in the kinematic region where the participation of real pions in the mechanism of the reaction is excluded. The results of these investigations are in satisfactory agreement with Levinger's quasideuteron model.

In this paper we present preliminary results of the measurements of the polarization of protons emitted at a lab angle 41° in reactions between 650 - 840 MeV photons and Li^7 and C^{12} nuclei. The measurements were made in a kinematic region admitting the photoproduction of pions on the free nucleon, as well as outside the region. The work was performed with the bremsstrahlung beam of a 2-GeV linear electron accelerator, using a magnetic spectrometer [3] with a subtended angle $\pm 2^\circ$ and a spark-chamber telescope.