of the group of lines LiII* with $h\nu \approx 60$ eV is estimated to be small, and is therefore indistinguishable against the recombination background. The spectrum in the region 0 - 10 eV was taken from [8] and makes it possible to determine the energy of the recombination radiation of LiIII. Its share is 6¢ of the total emission energy 17 kJ, and corresponds to $T_e = 5$ eV in the central part of the discharge [11]. Thus, a plasma with $N \approx 10^{17} - 10^{19}$ cm^{-3} and $T_e = 2 - 10$ eV emits in the far-ultraviolet region mainly in energy intervals dictated by electron recombination to the ground states of doubly, triply, and more multiply charged ions. Such a plasma can werve as a powerful source in the far ultrviolet, and owing to the selective emission spectrum the required energy input is about one-hundredths the black-body value. The intensity of the investigated source, $\sim 10^{22}$ quanta-cm^{-2}sec^{-1} is much higher than that of the known sources (T-tubes, Penning discharge, etc. [1]).

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[1] Methods of Plasma Research, W. Lochte-Holtgreven, ed. (Russ. transl.), Mir, 1971.
[2] A. D. Klementov et al. Teplofiz. Vys. Temp. 8, No. 4 (1970).
[3] R. Lincke and T.P. Wilkerson, Rev. Sci. Instr. 33, 911 (1962).
[4] A. A. Vekhov, F. A. Nikolaev, and V.B. Rozanov, FIAN Preprint, 1973 (in press).
[5] L. G. Eliseenko, V. I. Shemelev, and M. A. Rumsh, Zh. Eksp. Teor. Fiz. 52, 329 (1967) [Sov. Phys.-JETP 25, 211 (1967)].
[6] A. N. Dobretsov and M. V. Gomoyunova, Emissionnaya elektronika (Emission Electronics), Nauka, 1966.
[7] V. Ya. Gol'din et al. Trudy, Inst. Appl. Math., Preprint No. 36, 1971.
[8] A. D. Klementov, F. A. Nikolaev, and V. B. Rozanov, Proc. 10th Internat. Conf. on Phenomena in Ionized Gases, London, 1971, p. 436.
[9] E. N. Savinov and A. P. Lukirskii, Opt. Spektr. 2, 303 (1967)
[10] N. Wainfan et al., J. Appl. Phys. 26, 1366 (1955).
[11] A. A. Vekhov, F. A. Nikolaev, and V. B. Rozanov, Teplof. Vys. Temp. 10, No. 4 (1972).

MODULATION OF LIGHT BY NONEQUILIBRIUM OPTICAL PHONONS IN n-GaAs

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Modulation of light near the direct-transition edge was observed in strong electric fields in doped n-GaAs with $n = 2.4\times10^{16}$ cm^{-3} at $T_0 = 77$°K. The experimental results are compared with a calculation based on the model of direct exciton transitions with participation of nonequilibrium LO phonons. It is shown that within the framework of the employed model it is possible to obtain qualitative and quantitative agreement between theory and experiment if the lifetime of the long-wave LO phonons is assumed to be 0.8×10^{-12} sec.

The main mechanism of energy transfer from the hot electrons to the lattice in polar semiconductors is emission of longitudinal optical (LO) phonons by the electrons. The number of phonons in the crystal then increases, and this can lead to an increased absorption in strong electric fields near the direct-transition edge with participation of LO phonons [1]. This phenomenon was observed and investigated in n-GaAs. The n-GaAs samples, with fused-in contacts, had a dumbell shape with thickness 200 μ along the light-propagation direction. The drift mobility of the electrons at $T_0 = 77$°K was $\mu = 7000$ cm^2/V-sec, the electron density was $N_e = 2.4\times10^{16}$ cm^{-3}, and the strong-field pulse duration was 0.1 μsec. In weakly-doped samples ($N_e \approx 10^{14}$ cm^{-3}), no modulation was observed. The experimental results for two fields are shown in Fig. 1. The absorption threshold lies at an approximate quantum energy $\hbar\omega_{thr} = \varepsilon_g - \varepsilon_{ex} - k_B\theta$ (θ is the temperature of the long-wave LO phonons, ε_{ex} is the exciton binding energy in the ground state).

Light absorption in CdTe in transitions to the exciton states with absorption of equilibrium LO phonons was investigated in [2]. In analogy with [2], we calculated the change in the absorption with participation of LO phonons. We first obtained the nonequilibrium distribution

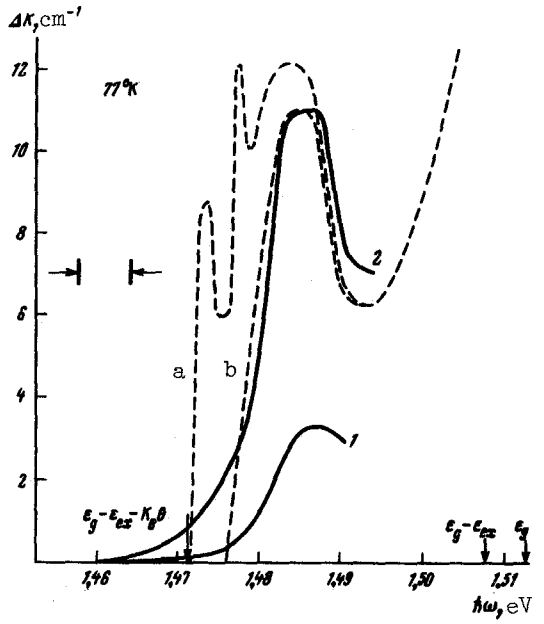

Fig. 1. Change of light-absorption coefficient of n-GaAs in strong electric fields. Solid curves - experiment at E = 470 V/cm (1) and 820 V/cm (2). Dashed curves - calculation for E = 820 V/cm and $\tau_q = 0.8\times10^{-12}$ sec. a) For transitions to the discrete and continuous exciton spectra, b) for transitions to the continuous spectrum only.

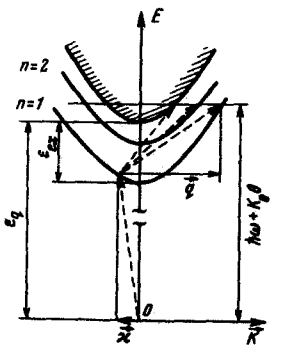

Fig. 2. Mechanism of light absorption by excitons with phonon participation.

function (DF) of the LO phonons in a strong electric field, in the manner used in [3] for LO phonons in n-Ge. The nonequilibrium increment to the distribution function of the LO phonons was calculated by assuming the lifetime τ_q of the latter to be independent of the wave vector $\vec{q}$, and the electron DF was assumed Maxwellian. The temperature T_e of the hot electrons was obtained from the power balance equation

$$ev_{dr}E = \left\langle \left(\frac{d\epsilon}{dt}\right)_{LO} \right\rangle_{DF}, \qquad (1)$$

where the left-hand side was known from experiment. If the constant of the interaction with the LO phonons is $E_0 = 6\times10^3$ V/cm at $\theta = 420°K$, then $T_e = 260°K$ at E = 820 V/cm. Although the true electron DF is not Maxwellian, since the tail of the DF is cut off at $\epsilon > k_B\theta$ because of LO-phonon emission, $T_e = 260°K$ gives the correct number of electrons in the active region, and therefore the total number of emitted photons at $T_e < \theta$. The phonon DF has a sharp maximum at $q \approx \sqrt{2m_e^* k_B\theta}/\hbar$. At $\tau_q = 0.8\times10^{-12}$ sec, the DF of the phonons reaches a value 0.062 at the maximum, which is three times larger than the equilibrium DF at $T_0 = 77°K$. As shown in [2], transitions to all the exciton states with absorption of equilibrium LO phonons, via intermediate states with n > 1 give a smaller contribution than those via an intermediate state with n = 1 in the greater part of the energy region. We therefore calculated the transitions to all possible unbroadened exciton states, including the continuous spectrum, via the intermediate n = 1 state (Fig. 2). Transitions to final states n = 1, 2, 3, 4 were calculated exactly, and to those with n > 5 in accordance with the approximate formulas for the wave function of the exciton with large n, followed by summation. The valence band was assumed isotropic with $m_p^* = 0.5m_0$. The results of the calculation are shown in Fig. 1 for $\tau_q = 0.8\times10^{-12}$ sec. The values of ϵ_g and ϵ_{ex} were taken from [4], and the momentum matrix element $|P_{cv}|$ was obtained from the experimental [4] and calculated values for the absorption coefficient in the continuous spectrum with allowance for the Coulomb attraction of the electron and hole [5]. All the maxima on the dashed curve "a" are due to the δ-like shape of the phonon DF and are connected with transitions to final states with n = 1 or n ≥ 2 and to the continuous spectrum. In transitions to the continuous spectrum, each value of $\hbar\omega$ corresponds to a transition with absorption of a phonon having a definite value of $\vec{q}$ (Fig. 2), so that the maxima almost duplicate the shape of the DF of the nonequilibrium LO phonons. If account is taken of the real structure of the valence band of GaAs near $\vec{K} = 0$ (small shift of the extremum of the heavy-hole band along [111]) [6], then one value of $\hbar\omega$ will correspond to an entire set of $\vec{q}$, and therefore the maxima on the $\Delta K(\hbar\omega)$ curve for transitions to the discrete spectrum, as shown by a semiquantitative calculation, should broaden strongly and decrease simultaneously in absolute value; at the same the splitting of the extremum of the heavy-hole band will hardly affect the shape of $\Delta K(\hbar\omega)$ curve for transitions to the continuous spectrum of the exciton. The shape of the absorption curve will therefore be close to the dashed line "b" of Fig. 1, which agrees

well with the experimental relation. It should be noted that the band-band transitions with absorption of nonequilibrium phonons [1], as shown by calculation, are less intense and produce no maximum on the $\Delta K(\hbar\omega)$ curve. The energy deficit incurred upon absorption of light with $\hbar\omega < \varepsilon_g$ can occur both as a result of the interaction of the electron-hole pair with the electron gas heated by the strong electric field [7]. However, as shown by calculation, this effect is weaker by more than one order of magnitude than the one described above in the case of transitions to a final exciton state with n = 1 via an intermediate state with n = 1 in interactions with free hot electrons, and cannot result in a maximum on the $\Delta K(h\omega)$ curve.

It should be noted in conclusion that the observed effect is quite sensitive to the band structure near small values of $\vec{K}$, of the order of $\sqrt{2m_e^* k_B\theta}/\hbar$. For this reason, it can be used as a method of investigating the band structure of III-V semiconductors in the vicinity of the Γ point when a more exact theory is constructed. In addition, this phenomenon can be used to determine the lifetimes of long-wave longitudinal optical phonons.

[1] W. P. Dumke, Phys. Rev. 108 1419 (1957).
[2] B. Segall, Phys. Rev. 150, 734 (1966).
[3] L. E. Vorobyov, V. I. Stafeev, and A. V. Sturbin, Phys. Stat. Sol. (B)53, 47 (1972).
[4] R. P. Seisyan, M. A. Abdullaev, and B. P. Zakharchenya, Fiz. Tekh. Poluprov. 6, 408 (1972) [Sov. Phys.-Semicond. 6, 351 (1972)].
[5] R. J. Elliott, Phys. Rev. 108, 1384 (1957).
[6] E. O. Kane, J. Phys. Chem. Solids 1, 249 (1957).
[7] S. M. Ryvkin, Fiz. Tverd. Tela 7, 1278 (1965)[Sov. Phys.-Solid State 7, 1038 (1965)].

ANISOTROPIZATION OF THE ELECTRIC CONDUCTIVITY IN ORIENTED SAMPLES OF VITREOUS SEMICONDUCTORS

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An appreciable anisotropy of the electric conductivity, attributed to orientation of the macromolecules, was observed in oriented samples of vitreous semiconductors of the As-Se-I system. The result proves the influence of the polymer structure on the conduction mechanism of vitreous chalcogenide semiconductors

The question whether chalcogenide glasses are inorganic polymers has been discussed in the literature many times [1 - 4]. An influence of changes of the polymer structure (joining or destruction of the macromolecules) on the electric and acoustic properties, and also on the energy spectrum of the local states in chalcogenide vitreous semiconductors of the As_2Se_3 type having branched two-dimensional frames (Fig. a) was noted in [5, 6]. From the point of view of establishing a correlation between the structure and the properties, it is of considerable interest to investigate chalcogenide vitreous semiconductors, for example the material AsSeI, which has a one-dimensional structure [7, 8] and is the analog of linear organic polymers (Fig. b).

We performed experiments on the orientation of chalcogenide glasses of the As-Se-I system and report here the first results on the electric properties of oriented samples. Glasses with composition $AsSeI_x$ with $0.1 \leq x \leq 0.1$ were synthesized by the known method of fusing the components in vacuum. Oriented samples in the form of strips 0.5 - 2.0 mm wide and 0.05 - 0.2 mm thick were prepared by drawing from a melt of reduced viscosity. The long strips were cut into pieces 1 - cm long, which were fastened on teflon plates and equipped with electrodes of silver paste, so that the resistance of the smaples could be measured both along and across the drawing direction (resistances $r_{\parallel}$ and $r_{\perp}$, respectively).

In most samples with appreciable iodine content ($0.25 \leq x \leq 1.0$), we observed a noticeable anisotropy of the electric conductivity ($r_{\perp}/r_{\parallel} \gg 1$), which increased with increasing iodine content. The resistances of some typical oriented samples with various compositions are listed in the table together with the data on the softening temperature T_g, obtained by the method described in [9]. In samples prepared by drawing from the low-viscosity melt, no noticeable anisotropy of the electric conductivity was observed ($r_{\perp}/r_{\parallel} \approx 1$).