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LETTER TO THE EDITOR

THE PHOTOEXCITATION SPECTRA AND EXCITATION TRANSFER FROM N TO NN_1 IN GaP-N

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The GaP-N crystals were grown by vapour phase epitaxy. There is an energy shift between the nitrogen bound exciton luminescence and its excitation spectrum at 30 K. The main transfer mechanism of excitons from N to NN_1 at low rates of excitation in temperature > 35 K was due to thermal ionization. The value of binding energy of electron and hole was determined.

The energy transfer are of great interest to many fields of semiconductors and solid state physics. The dominant role of the tunnel transfer of excitons from N to NN_1 centers in GaP-N at $T \sim 1.6$ K explains the high efficiency of NN_1 at low temperature[1]. The concentration quenching of shallow bound excitons in A^{III}-B^{V} semiconductor compounds gives evidence of energy transfer[2]. The energy transfer was detected also in the dipole — dipole interaction in some laser materials[1]. The energy transfer in GaP-N has not been studied in detail[1,3].

The aim of this work is to compare between excitation and luminescence of N excitations in GaP and also to study the energy transfer from N to NN_1 centers.

The properties of the studied GaP-N samples were similar to films investigated in Ref. 4. The nitrogen concentration estimated from the optical absorption data was 5×10^{18} cm^{-3} and the residual impurity concentration was $< 10^{16}$ cm^{-3}.

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The photoexcitation spectra and excitation transfer from N to NN_1 in GaP-N were recorded using the method of crossed monochromators. In this case a different source was used from an incandascent lamp with a power density W which decreased by more than 40% when $\hbar\omega$ increased from 2.31 to 2.43 eV.

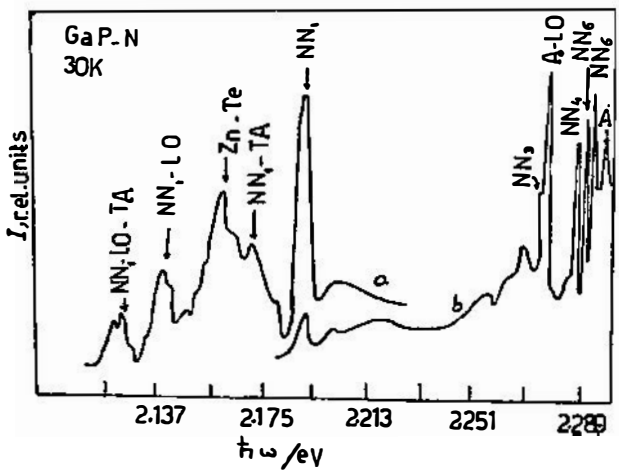

Fig. 1. a) Photoexcitation lines at E_g ($\lambda \approx 5 \cdot 10^{-5}$ cm) of GaP-N at 30 K and excitation power density $W \approx 10^{-4}$ W/cm^2. b) Photoluminescence lines of GaP-N at 30 K and excitation power density $W \approx 10^3$ W/cm^2.

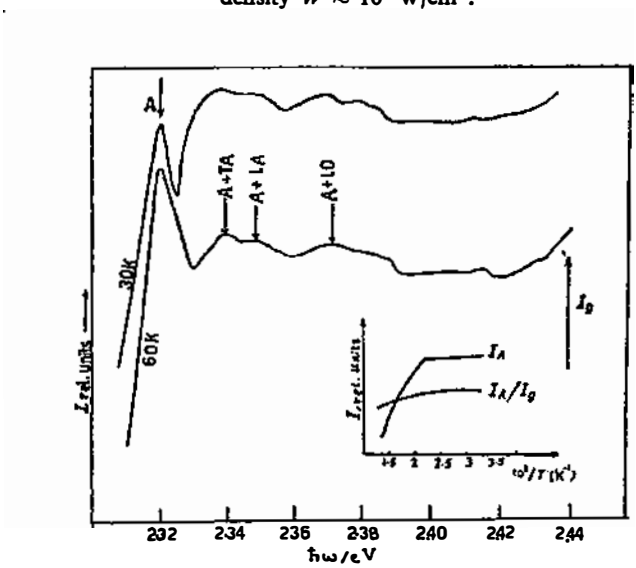

Fig. 2. The normalized (to the excitation power) photo-excitation spectrum of NN_1 line at 30 and 60 K. Excitation power density $W \approx 10^{-4}$ W/cm^2. The inset shows the temperature dependences of the intensities of the NN_1 (I_A and I_g/I_A) photoexcitation lines.

Fig. 1 shows the photoexcitation and photoluminescence spectra of GaP-N at 30 K; the photoexcitation was at E_g ($\lambda \approx 5 \cdot 10^{-5}$ cm). The spectra reveal the exciton bound to NN_1 pairs and its phonon replicas TA (15 meV), LA (29 meV) and LO (49 meV). In comparison with photoluminescence spectra (curve b), there is an energy shift toward lower energy. Fig. 1 shows that A and NN_{2-7} lines in excitation spectra were undetectable.

Fig. 2 shows the photoexcitation spectra at 30 and 60 K, the excitation power density $W \approx 10^{-4}$ W/cm^2. The luminescence intensity of I_A/I_g decreased with temperature as shown in Fig. 2. The intensity of A-line is less than NN_1, this fact may be due to tunneling or thermal ionization.

The decrease of intensities of A and A-LO with temperature confirms the thermal rejection equation,

$$G = C_P P_{1t} \tag{1}$$

where P_{1t} is defined from the following equation:

$$P_{1t} = N \cdot \exp(-E_h/KT). \tag{2}$$

Fig. 2 shows that the increase in temperature caused I_A to decrease slowly and also the ratio I_g/I_A decreased by a factor of 2 when temperature was increased from 30 to 80 K. The decrease of temperature caused the thermal release of carriers from A-line to decrease and A-LO to increase, which confirms Eq. (2).

These behaviours indicated that the main transfer mechanism at low rates of excitation in temperature > 35 K was thermal ionization of excitons from N centers followed by their capture by NN_1 centers.

The decrease of I_A/I_g can be studied by statistical recombination of carriers.

The statistical rate of recombination through isoelectronic centers can be written in the form[5].

$$U_t = C_1 C_2 \frac{n p}{C_1 (n + n_{1t}) + C_2 p + \tau_x C_1 C_2 [np + p_{1t} (n + n_{1t})]}, \tag{3}$$

where n_{1t} and p_{1t} are the equilibrium concentration of electrons and holes, τ_x radiative lifetime of an exciton at any N center, $C_1 = 1/\tau_{0n}$, $C_2 = 1/\tau_{0p}$ where τ_{0n}, τ_{0p} are the lifetime of electrons and holes in heavily doped GaP-N where energy of Fermi level is lower than conduction band but higher than the energy of recombination trap states.

The recombination rate of impurity centers with concentration N_s can be written in the form,

$$U_s = C_1 C_2 N_s \frac{n p}{C_1 (n + n_{1s}) + C_2 (p + p_{1s})}. \tag{4}$$

At stationary recombination, equations (3) and (4) are independent of time τ, so the recombination will be written in the form:

$$U_t = \frac{a}{1 + b p_{1t}}, \tag{5}$$

where a and b are constants, $P_{1t} = T^{3/2} \cdot \exp(-E_h/KT)$. Substituting for p_{1t} in Eq. (5), one gets

$$(a/U_t - 1)\, T^{-3/2} = \exp(-E_h/KT). \tag{6}$$

a/U_t is determined from the intensity changes of I_A with temperature.

Fig. 3 shows the relation between $(a/U_t - 1)\, T^{-3/2}$ vs. $1/T$. The value of the hole binding energy E_h is equal to 40 meV from the slope of the relation in Fig. 3. The binding energy of the electron is determined from the following equation:

$$E_e = E_{ex\,(NN1)} - E_h = 165 - 40 = 125 \text{ meV}. \tag{7}$$

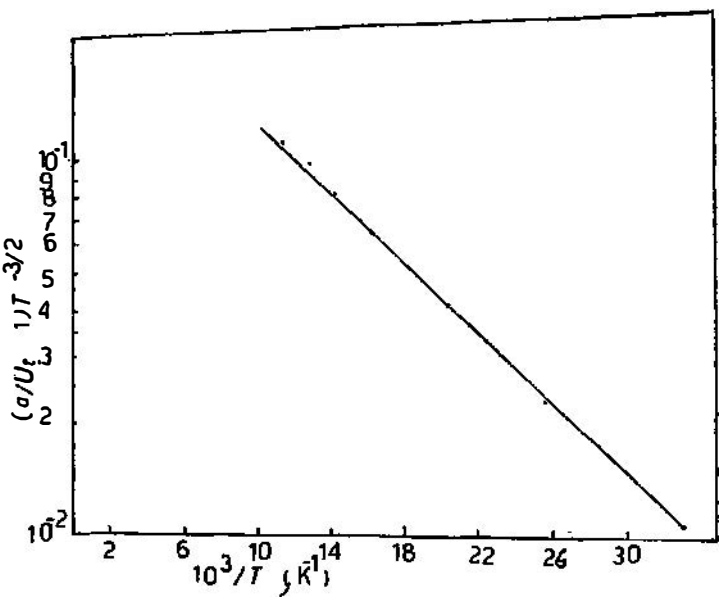

Fig. 3. The relation between $(a/U_t - 1)\, T^{-3/2}$ vs. $1/T$.

The variation of this value may be due to tunnel transfer mechanism pointed out in Ref. 1.

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SPEKTRI OPTIČKOG POBUĐENJA I POBUĐENI PRIJELAZ OD N U NN_1 U GaP-N

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Originalni znanstveni rad

Kristali GaP-N dobiveni su epitaksijom plinske faze. Postoji pomak u energiji između luminiscencije vezanog eksitona dušika i njegovog spektra pobuđenja na 30 K. Glavni mehanizam prijelaza eksitona iz N u NN_1 kod malog broja pobuđenja na temperaturama većim od 35 K je termička ionizacija. Određena je i vrijednost energije veze elektrona i šupljine.