Scientific session of the Division of General Physics and Astronomy of the Academy of Sciences of the USSR (26–27 October 1988)

Usp. Fiz. Nauk **157**, 545–550 (March 1989)

A scientific session of the Division of General Physics and Astronomy of the USSR Academy of Sciences was held on October 26 and 27, 1988, at the S. I. Vavilov Institute of Physics Problems of the USSR Academy of Sciences. The following reports were presented at the session:

October 26

1. *Yu. E. Lozovik and S. M. Chudinov.* Drift resonance in a two-dimensional electron gas: the dynamic quantum Hall effect.
2. *P. S. Kop'ëv and I. N. Ural'tsev.* The energy spectrum of Coulomb states in a quantum well.

October 27

3. *A. M. Shalagin.* Light-induced drift and its manifestations, particularly in astrophysics.
4. *I. D. Novikov.* Physical properties of a time machine.

Brief summaries of three reports are presented below.

P. S. Kop'ëv and I. N. Ural'tsev. *The energy spectrum of Coulomb states in a quantum well.* Technological advances in the reproducible fabrication of ultra-thin semiconducting layers have led to the creation of model two-dimensional objects: heterostructures with quantum wells (QW) consisting of a narrow bandgap material (GaAs), separated by barriers (AlGaAs) of sufficient thickness (~ 100 Å) to suppress the interaction of different quantum wells (Fig. 1,a). In such structures, traditional magnetooptic techniques make it possible to study the properties of the two-dimensional energy spectrum created by exciton localization and the formation of an "impurity band," which appears because the binding energy of an impurity depends on its proximity to the heterojunction.

The low temperature photoluminescence spectrum of 100 Å wide GaAs–AlGaAs quantum wells is shown in Fig. 2. It consists of an exciton peak due to an electron and a heavy hole from the lowest dimensionally quantized subbands and an electron recombination band due to electrons recombining on shallow acceptors provided by unintentional carbon background doping of $\sim 10^{15}\,\mathrm{cm}^{-3}$ concentration. A characteristic property of the exciton radiation peak is its red shift with respect to the peak in the absorption spectrum or the line in the photoexcitation spectrum. This effect is a manifestation of the spectrum of localized states created by fluctuations in the quantum well width L_z (Fig. 1,b). As L_z decreases the magnitude of the Stokes shift E_s and the halfwidth of exciton luminescence line both increase as $1/L_z^3$. This makes it possible to determine the extent of well width fluctuations, which do not exceed one or two monolayers in perfect quantum well structures grown by molecular beam epitaxy. The filling of localized states via increased photoexcitation intensity or thermal activation results in a smooth transition to radiation from delocalized exciton states.[1] Since L_z changes discretely in monolayer steps the appearance of a continuous spectrum of localized states may indicate that the exciton localization energy depends on the spatial extent of QW width fluctuations, so long as the size distribution of these fluctuations contains islands comparable to the characteristic exciton size. The position of the localized exciton peak is determined by the singularity in the density of states due to the characteristic size of islands which localize the excitons. Exciton localization can be tuned by reducing the exciton radius with a magnetic field oriented perpendicular to the plane of the quantum wells. The localized exciton line shifts faster in a magnetic field than its delocalized counterpart. An analysis of this effect makes it possible to determine the characteristic size of islands which localize the excitons. It is found to exceed the exciton radius by a factor of 2.5. Generally speaking, the observed suppression of the Stokes shift by a magnetic field indicates exciton delocalization. The situation is unique in that the magnetic field usually increases the localization energy. Since the magnitude of the localizing potential (fluctuation depth) in QW is fixed for all islands, large fluctuations have greater binding energies than small ones. The magnetic field favors localization in smaller islands, which are more numerous, and thus effectively lowers the exciton localization energy[2]—an unusual property of exciton localization due to QW width fluctuations.

The behavior of impurity states in QW structures is governed by the theoretically predicted dependence of impu-

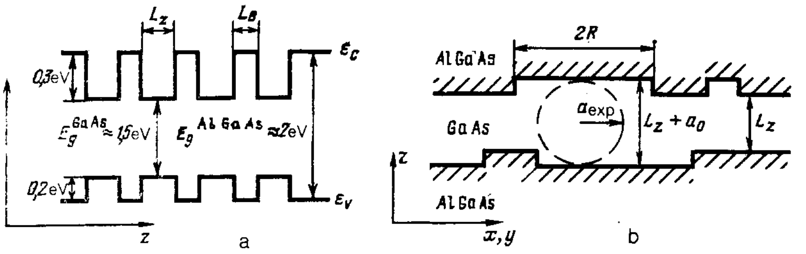

FIG. 1. Band diagram of a GaAs–$Al_{0.4}Ga_{0.6}As$ quantum well structure (a) and schematic view of well width fluctuations (b).

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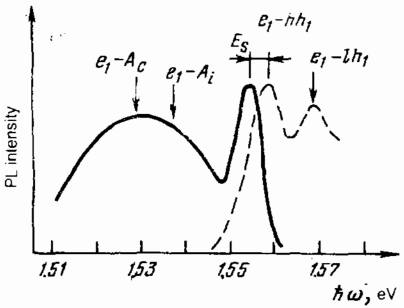

FIG. 2. Photoluminescence (PL) (solid line) and luminescence excitation (dashed line) spectra for a QW structure with $L_z = 100$ Å at $T = 1.6$ K and excitation intensity of 0.1 W/cm^2. The arrows mark light and heavy hole exciton transitions, and transitions via acceptors located in the middle of the QW and at a heterojunction.

rity binding energy E_A on its location in the quantum well.[3] If the acceptor Bohr radius a_0 is somewhat smaller than L_z ($a_0 = 15$ Å for a shallow acceptor), the impurity states form a continuous spectrum determined by the maximum binding energy E_{Ac} of an acceptor located near the QW center and the minimum E_{Ai} of an acceptor at the heterojunction. The difference which the impurity location in QW makes is most clearly observed in the spectral dependence of the degree of circular polarization in a magnetic field,[4] which is determined by the thermal orientation of holes in the acceptor Zeeman sublevels. An analysis of this dependence yields the g-factor and the relative oscillator strength of acceptor transitions as a function of the acceptor location in the QW. These quantities can also be related to changes in the hole wavefunctions as the acceptor moves closer to the heterojunction.

The observed lower bound of the "impurity band" (E_{Ai}) at a heterojunction is lowered by transitions due to acceptors in the barrier which bind holes of the narrow bandgap material.[5] The potential profile created in the QW by charged deep impurities in the barrier material is smoothed by weak above-barrier illumination, which increases the exciton recombination efficiency.[6]

The effects described above have been successfully employed in characterizing the smoothness of heterojunctions, determining the concentration profile of shallow impurities, and controlling the carrier mobilities in quantum well heterostructures.

[1] P. S. Kop'ëv, B. Ya. Mel'tser, I. N. Ural'tsev, A. L. Éfros, and D. R. Yakovlev, Pis'ma Zh. Eksp. Teor. Fiz. **42**, 327 (1985) [JETP Lett. **42**, 402 (1985)].

[2] P. S. Kop'ëv, I. N. Ural'tsev, A. L. Éfros, D. R. Yakovlev, and A. V. Vinokurova, Fiz. Tekh. Poluprovodn. **22**, 424 (1988) [Sov. Phys. Semicond. **22**, 259 (1988)].

[3] G. Bastard and J. A. Brum, IEEE J. Quantum Electron. **QE-22**, 1625 (1986).

[4] P. S. Kop'ëv, V. P. Kochereshko, I. N. Ural'tsev, and D. R. Yakovlev, Fiz. Tekh. Poluprovodn. **22**, 597 (1988) [Sov. Phys. Semicond. **22**, 373 (1988)].

[5] Zh. I. Alferov, A. M. Vasil'ev, P. S. Kop'ëv, V. P. Kochereshko, I. N. Ural'tsev, A. L. Éfros and D. R. Yakovlev, Pis'ma Zh. Eksp. Teor. Fiz. **43**, 442 (1986) [JETP Lett. **43**, 569 (1986)].

[6] P. S. Kop'ëv, V. P. Kochereshko, I. N. Ural'tsev, and D. R. Yakovlev, Pis'ma Zh. Eksp. Teor. Fiz. **46**, 74 (1987) [JETP Lett. **46**, 89 (1987)].