This work was made possible thanks to the support provided by the Physics of Solid Nanostructures Program (projects 98-1100 and 00-17-2F) and the Russian Foundation for Basic Research (projects 99-02-39051GFEN and 00-02-17885).

References

1. Jacak L, Hawrylak P, Wojs A *Quantum Dots* (Berlin: Springer-Verlag, 1998)
2. Ledentsov N N et al. *Fiz. Tekh. Poluprovodn.* **32** 385 (1998) [*Semiconductors* **32** 343 (1998)]
3. Pchelyakov O P et al. *Izv. Ross. Akad. Nauk Ser. Fiz.* **63** 228 (1999) [*Bull. Russ. Acad. Sci. Ser. Phys.* **63** 191 (1999)]
4. Vostokov N V et al. *Fiz. Tekh. Poluprovodn.* **34** 8 (2000) [*Semiconductors* **34** 6 (2000)]
5. Yakimov A I et al. *Philos. Mag. B* **65** 701 (1992)
6. Yakimov A I et al. *J. Phys.: Condens. Matter* **6** 2573 (1994)
7. Dvurechenskiĭ A V, Nenashev A A, Yakimov A I, in *Nanofotonika: Materialy Vseros. Soveshchaniya* (*Nizhniĭ Novgorod, Mart 2001*) [Nanophotonics: Proc. National Workshop (Nizhniĭ Novgorod, March 2001)] (Nizhniĭ Novgorod: IFM RAN, 2001)
8. Dvurechenskiĭ A V, Yakimov A I *Izv. Ross. Akad. Nauk Ser. Fiz.* **64** 288 (2000) [*Bull. Russ. Acad. Sci. Ser. Phys.* **64** 233 (2000)]
9. Dvurechenskiĭ A V, Yakimov A I *Izv. Ross. Akad. Nauk Ser. Fiz.* **65** 187 (2001) [*Bull. Russ. Acad. Sci. Ser. Phys.* **65** 205 (2001)]
10. Yakimov A I et al. *Zh. Eksp. Teor. Fiz.* **119** 574 (2001) [*JETP* **92** 500 (2001)]
11. Yakimov A I et al. *Phys. Rev. B* **62** R16283 (2000)
12. Wixforth A et al. *Phys. Rev. B* **43** 10000 (1991)
13. Sundaram M et al. *Appl. Phys. Lett.* **65** 2226 (1994)
14. Yakimov A I et al. *Phys. Rev. B* **62** 9939 (2000)
15. Yakimov A I et al. *J. Appl. Phys.* **89** 5676 (2001)

PACS numbers: 03.75.Fi, 71.35.Lk, 71.35.Ji

DOI: 10.1070/PU2001v044n12ABEH001058

Exciton Bose condensate control and the phonon laser

Yu E Lozovik

There exists a fruitful analogy between a system of quasi-particles, electrons and holes in excited semiconductors, on the one hand, and a system of 'true particles', electrons and protons (or, in a more general case, positive ions), on the other, since the laws of interaction in these systems are the same. The systems differ dramatically in the corresponding scales: the effective Bohr radius for excitons, which may be much larger than the Bohr radius, the exciton binding energy Ry*, which is much lower than the binding energy of the hydrogen atom, etc. This analogy opens an enticing possibility not only of predicting as yet undetected phases of the electron – hole system but, on the contrary, to model (via the electron – hole system) various phases of particle systems in extreme cosmological conditions [1], unattainable in laboratory experiments, in particular, in ultrahigh magnetic fields (e.g. for the detection of the anisotropic phase of polymer chains consisting of electric quadrupoles of atoms or excitons, extended along the magnetic field, or for magnetic dissociation and transformation of the type of molecular or excitonic bonds in ultrahigh magnetic fields, and so forth).

This analogy really exists. Indeed, the quasi-particle analogs of molecules are biexcitons, those of clusters are small electron – hole drops, and that of the liquid phase is the electron – hole liquid. The possibility of other phases is also being discussed.

However, there are important differences between these systems. Electrons and holes, in contrast to particles, usually 'exist' in an anisotropic (and largely 'random', due to defects) world of semiconductors and are often characterized by a complex (multivalley) dispersion law. This can lead to a phase diagram differing from that for a system of electrons and protons (e.g. stabilizing the metallic liquid phase, the electron – hole liquid [2]). Another bare parameter, the ratio of the masses of the positive and negative charges, also plays an important role: it controls the contribution of the zero-oscillation energy and determines whether there exists a crystalline phase as yet undetected in an electron – hole system.

In view of the amazing achievements in the technology of fabricating quite perfect nanostructures there has emerged another remarkable possibility, namely, to control the effective dimensionality and even the topology of the space where the quasi-particles 'exist'. This possibility broadens the variety of phase states and kinetic properties of the systems consisting of electrons and holes.

An interesting system in this respect is the quasi-two-dimensional system of spatially separated electrons and holes in coupled quantum wells [3] or the similar one-dimensional system in coupled quantum wires or in the zero-dimensional system of coupled quantum dots [4]. The quasi-zero-dimensional situation is also realized in an electron – hole system residing either in a single quantum well or in coupled quantum wells in quantizing magnetic fields [5 – 7] (however, the effective dimensionality in an interacting e – h system may depend on the occupancy of the Landau level).

When discussing the above systems with different dimensionalities, it must be kept in mind that here one is actually dealing with two radically different physical realizations.

The first realization corresponds to electrons and holes in a semiconductor's excited state that is generated, for instance, by laser radiation and exists over intervals shorter than the recombination times. The latter may be significantly increased, for instance, by virtue of a weak overlapping of the wave functions of the spatially separated electrons and holes in coupled quantum wells, and so on. This fact favors the possibility of establishing a partial thermodynamic equilibrium in the system and observing the different phase states of the electron – hole system in coupled quantum wells [3 – 13] (for similar phases in a three-dimensional system see Ref. [14]).

The second physical realization corresponds to an equilibrium system of spatially separated electrons and holes in coupled type II quantum wells (such a system in the coherent phase may manifest, due to particle tunneling through potential barriers between wells, several effects similar to the Josephson effect; see Ref. [15]).

I believe that there is one more system of keen interest: the disbalanced steady-state system of two identical coupled electron layers in a strong magnetic field [6]. The 'disbalance' of the two layers is achieved by applying a voltage V between them. Suppose that at $V = 0$ the two layers entirely fill a single (zeroth) Landau level. Then there is a system of excess electrons on the first Landau level in one layer and an equal number of unfilled positions (holes) on the zeroth Landau level in the other layer (or, when the disbalance is great, the electrons and holes are in different layers on the same Landau level). A situation that is even more curious

occurs when there is a small disbalance near a fractional occupancy of a Landau level. In this case there emerges a two-layer system of equilibrium electrons and holes with fractional charges.

Another interesting physical realization of the spatially separated electron – hole system is the electron system of two coupled quantum wells (or a double quantum well) placed in a strong transverse magnetic field, which resides in states with half-filled Landau levels in each layer. In each of these layers (when the hybridization between them is not too strong), the two-dimensional Fermi surface for quasi-particles (composite fermions) consisting of electrons with two attached flux quanta is 'restored' [16] (the shape of this surface is identical to that of the initial surface [17] in the absence of field).

Pairing of electrons and holes in all the above situations leads to a coherent phase that exhibits superfluid properties [3, 6, 8], specific optical properties (see Ref. [18] and the references cited therein), and Josephson type effects [15].

In recent experiments researchers observed intriguing optical phenomena that probably point to the presence of a coherent exciton phase [19, 20] (see also Refs [21, 22]). One would like, however, to analyze such optical effects that would suggest a coherent exciton phase not only quantitatively but also qualitatively, i.e. in a more unambiguous manner. Effects of this sort constitute the topic of the present report.

First, examples of such phenomena are the unusual stimulated two-photon emission and Raman scattering of light by two-dimensional Bose-condensed excitons, with the processes accompanied by coherent recombination or generation of two (overcondensate) excitons with opposite momenta [18]. Such stimulated two-photon emission and Raman scattering can be shown to be related to the emergence of spectral lines at frequencies $|\omega_0 \pm 2\Omega| - m\omega^s$, where ω_0 is the incident photon frequency, and ω^s is the frequency of a photon whose parallel momentum (in the quantum well plane) coincides with momentum of the lowest-energy exciton.

The intensity of these lines depends on the anomalous averages, with the result that these processes make it possible to directly study off-diagonal order and occur only if there is an exciton Bose condensate in the system. Hence they can be used for detecting a Bose condensate of excitons (or a 'quasi-condensate' in a two-dimensional system at $T \neq 0$). Numerical estimates have shown that the effect associated with these processes can be used to detect Bose condensation of spatially indirect excitons in a system of coupled AlAs/GaAs quantum wells.

Another vivid manifestation of exciton Bose condensation is a new optical phenomenon — stimulated back reflection of light in the case of (oblique) incidence of a laser beam onto a quasi-two-dimensional or semi-infinite exciton condensate [23]. The effect is caused by light-induced coherent recombination of two excitons from the Bose condensate, accompanied by the production of two photons with oppositely directed momenta. What is remarkable is that for a Q2D coherent system of excitons, in addition to the ordinary transmitted beam, there appears an anomalously transmitted beam whose direction is mirror-symmetric to that of the incident beam (see Fig. 1). It is interesting that these effects must also be present in a Bose condensate of excited Bose atoms (e.g. first cooled and then resonantly excited).

Note that in the absence of an incident laser beam two-exciton recombination leads to luminescence with a correlation between photon states with oppositely directed

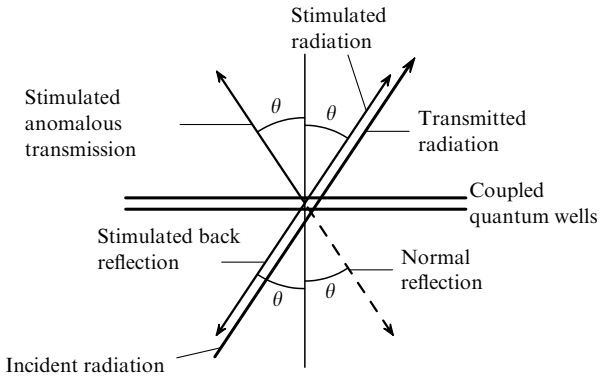

Figure 1.

momenta. Such a correlation can be detected in Hanbury – Braun – Twiss type experiments with two detectors placed on opposite sides of the exciton system.

Let us discuss in greater detail the possibility of controlling an exciton Bose condensate through the use of external fields and the phonon spectroscopy of the exciton Bose condensate.

In direct gap semiconductors, spatially indirect excitons in coupled quantum wells are direct excitons in the momentum space. Due to the weaker Coulomb attraction of an electron and hole, their level is above the level of a spatially direct electron. Since spatially indirect excitons have an electric dipole moment eD normal to the well plane, when an electric field E normal to the well plane is applied, splitting takes place, and the lower level shifts downward as eDE.

But a moving indirect exciton (an electric dipole eD) generates a magnetic moment $eDkh/(cM)$ in the quantum well plane, where k is the exciton momentum, and M is the exciton mass. When a magnetic field H is applied parallel to the quantum wells, there emerges an interaction (linear in the momentum k) between the magnetic moment and the magnetic field. Since this interaction is added to the exciton's quadratic dispersion law, it leads to a shift (sideways) in the dispersion law of the indirect exciton, and this shift is proportional to H. The shift can be interpreted differently, namely, as a manifestation of diamagnetism of the two-layer e – h system, i.e. the generation of currents flowing in opposite directions in the magnetic field parallel to the layers. This latter phenomenon corresponds to exciton motion (in the ground state) in the direction perpendicular to the field H [3, 15].

The displacement of the exciton's dispersion transforms the exciton into an indirect one in the momentum space and brings the exciton out of the radiation zone where recombination of the exciton accompanied by emission of a photon is possible: the exciton is transformed from 'light' to 'dark'. The described dispersion law engineering of spatially indirect excitons by means of applying a magnetic field parallel to the layers has been observed in the experiments described in Ref. [24].

The simultaneous control by an electric field E normal to the wells and a parallel magnetic field opens up even more remarkable possibilities. As noted earlier, an electric field shifts the energy level of indirect excitons. Hence it can be used to tune to resonance the recombination of indirect excitons via the level of spatially direct excitons through emission of an acoustic phonon, i.e. to the resonance of the

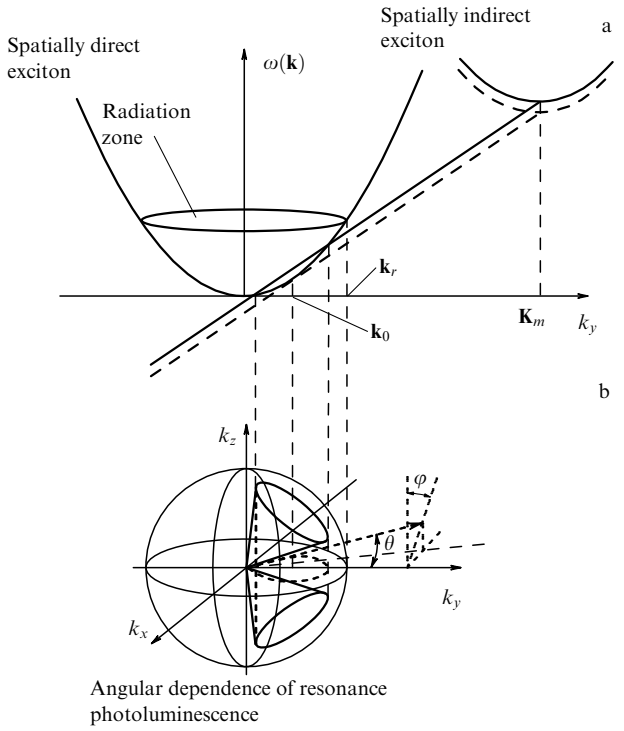

Figure 2.

process

indirect exciton → direct exciton + acoustic phonon.

In the process of tuning to resonance, the intensity of photoluminescence of the exciton condensate increases by several orders of magnitude and, as analysis of the laws of conservation of energy and momentum in the well plane shows, photoluminescence radiation turns out to be narrow-directed: it constitutes two oppositely directed beams propagating in the well plane (see Fig. 2). At the same time, the intensity of the phonon radiation also sharply increases, with this radiation forming a narrow beam, too. Furthermore, as shown by the analysis of the equation for the density matrix describing the photon and phonon generation process and of the integrals of motion for this equation, in realistic conditions the phonon radiation 'inherits', so to say, the statistics of the emitter, i.e. the system of indirect excitons [23]. This opens the possibility of phonon spectroscopy of an exciton Bose condensate. Moreover, the statistics of the phonons emitted by a (quasi-) condensate of indirect excitons is that of laser radiation, i.e. a phonon laser is realized. Clearly, the resonant process

indirect exciton → direct exciton + acoustic phonon

corresponds to the standard three-level lasing scheme with phonons acting as photons. Hence readily follow the conclusions concerning the attainability of conducting pulsed and continuous-wave operations for the phonon laser considered.

If there is a cavity for the phonons, phonon lasing is also achieved, naturally, through the use of an incoherent source (in our case, the source is a system of indirect excitons in an incoherent state), i.e. in the ordinary way, due to self-organization. In this connection I would like to point out some other possible schemes for a phonon laser. One is based on the employment of an indirect-narrow-gap semiconductor in which the gap is tuned (by applying pressure or a magnetic field) to resonance with a one-phonon emission [25].

Another possibility consists in the use of a scheme similar to the Capasso cascade laser, i.e. a superlattice of identical quantum wells manufactured from indirect-gap semiconductors and placed in an electric field such that the shift of the adjacent transverse quantization level is equal to the acoustic phonon energy.

This research was supported by grants from the Russian Foundation for Basic Research, INTAS, and the Physics of Solid Nanostructures Program.

References

1. Ginzburg V L *O Fizike i Astrofizike* (Key Problems of Physics and Astrophysics) (Moscow: Nauka, 1974)
2. Keldysh L V, in *Electron-Hole Liquid* (Amsterdam: North-Holland, 1986); Brinkman W F, Rice T M *Phys. Rev. B* **7** 1508 (1973)
3. Lozovik Yu E, Yudson V I *Pis'ma Zh. Eksp. Teor. Fiz.* **22** 26 (1975) [*JETP Lett.* **22** 11 (1975)]; *Zh. Eksp. Teor. Fiz.* **71** 738 (1976) [*Sov. Phys. JETP* **44** 389 (1976)]; *Solid State Commun.* **18** 628 (1976); **21** 211 (1977); *Physica A* **93** 493 (1978)
4. Lozovik Yu E, Verzakov S A, Willander M *Phys. Lett. A* **260** 400 (1999); Kaputkina N E, Lozovik Yu E *Phys. Status Solidi B* **221** 341 (2000)
5. Lerner I V, Lozovik Yu E *Zh. Eksp. Teor. Fiz.* **80** 1488 (1981) [*Sov. Phys. JETP* **53** 763 (1981)]; *Zh. Eksp. Teor. Fiz.* **82** 1188 (1982) [*Sov. Phys. JETP* **55** 691 (1982)]; *Zh. Eksp. Teor. Fiz.* **78** 1167 (1980) [*Sov. Phys. JETP* **51** 588 (1980)]; Dzyubenko A B, Lozovik Yu E *Fiz. Tverd. Tela* (Leningrad) **25** 1519 (1983); **26** 1540 (1984) [*Sov. Phys. Solid State* **25** 874 (1983); **26** 938 (1984)]; *J. Phys. A* **24** 415 (1991); Paquet D, Rice T M, Ueda K *Phys. Rev. B* **32** 5208 (1985)
6. Lozovik Yu E, Berman O L, Tsvetus V G *Phys. Rev. B* **59** 5627 (1999); Lozovik Yu E, Ruvinskiĭ A M *Zh. Eksp. Teor. Fiz.* **112** 1791 (1997) [*JETP* **85** 979 (1997)]
7. Yoshioka D, MacDonald A H *J. Phys. Soc. Jpn.* **59** 4211 (1990); Yoshioka D, Fukuyama H *J. Phys. Soc. Jpn.* **50** 725 (1978)
8. Lozovik Yu E, Berman O L *Pis'ma Zh. Eksp. Teor. Fiz.* **64** 526 (1996) [*JETP Lett.* **64** 573 (1996)]; *Zh. Eksp. Teor. Fiz.* **111** 1879 (1997) [*JETP* **84** 1027 (1997)]; Ivanov L N, Lozovik Yu E, Musin D R *J. Phys. C* **11** 2527 (1978); Lozovik Yu E, Berman O L, Willander M *Zh. Eksp. Teor. Fiz.* **115** 1786 (1999) [*JETP* **88** 980 (1999)]; Lozovik Yu E, Berman O L, Ruvinskiĭ A M *Pis'ma Zh. Eksp. Teor. Fiz.* **69** 573 (1999) [*JETP Lett.* **69** 616 (1999)]
9. Zhu X et al. *Phys. Rev. Lett.* **74** 1633 (1995)
10. Conti S, Vignale G, MacDonald A H *Phys. Rev. B* **57** R6846 (1998)
11. Schmitt-Rink S, Chemla D S, Miller D A B *Adv. Phys.* **38** 89 (1989)
12. Chen X M, Quinn J J *Phys. Rev. Lett.* **67** 895 (1991)
13. Bauer G E W *Phys. Scripta T* **45** 154 (1992)
14. Keldysh L V, Kopaev Yu V *Fiz. Tverd. Tela* (Leningrad) **6** 2791 (1964) [*Sov. Phys. Solid State* **6** 2219 (1964)]; Keldysh L V, Kozlov A N *Zh. Eksp. Teor. Fiz.* **54** 978 (1968) [*Sov. Phys. JETP* **27** 521 (1968)]; Kozlov A N, Maksimov L A *Zh. Eksp. Teor. Fiz.* **48** 1184 (1965) [*Sov. Phys. JETP* **21** 790 (1965)]; Halperin B I, Rice T M *Solid State Phys.* **21** 115 (1968); Lozovik Yu E, Yudson V I *Fiz. Tverd. Tela* (Leningrad) **17** 1613 (1975); Keldysh L V, in *Bose–Einstein Condensation* (Eds A Griffin, D W Snoke, S Stringari) (Cambridge: Cambridge Univ. Press, 1995) p. 246
15. Klyuchnik A V, Lozovik Yu E *Zh. Eksp. Teor. Fiz.* **76** 670 (1979) [*Sov. Phys. JETP* **49** 335 (1979)]; *J. Low Temp. Phys.* **38** 761 (1980); *J. Phys. C* **11** L483 (1978); Lozovik Yu E, Yudson V I *Pis'ma Zh. Eksp. Teor. Fiz.* **25** 18 (1977) [*JETP Lett.* **25** 14 (1977)]; Shevchenko S I *Phys. Rev. Lett.* **72** 3242 (1994); Lozovik Yu E, Yudson V I *Solid State Commun.* **22** 117 (1977); Lozovik Yu E, Poushnov A V *Phys. Lett. A* **228** 399 (1997)
16. Halperin B I, Lee P A, Read N *Phys. Rev. B* **47** 7312 (1993)
17. Balagurov D B, Lozovik Yu E *Phys. Rev. B* **61** 1481 (2000)
18. Lozovik Yu E, Poushnov A V *Phys. Rev. B* **58** 6608 (1998); Lozovik Yu E, Pushnov A V *Zh. Eksp. Teor. Fiz.* **115** 1353 (1999) [*JETP* **88** 747 (1999)]; Lozovik Yu E (to be published)
19. Butov L V, Filin A I *Phys. Rev. B* **58** 1980 (1998)
20. Larionov A V et al. *Zh. Eksp. Teor. Fiz.* **117** 1255 (2000) [*JETP* **90** 1093 (2000)]; *Pis'ma Zh. Eksp. Teor. Fiz.* **71** 174 (2000) [*JETP Lett.* **71** 117 (2000)]; **73** 342 (2001) [*JETP Lett.* **73** 327 (2001)]

21. Fukuzawa T, Mendez E E, Hong J M *Phys. Rev. Lett.* **64** 3066 (1990)
22. Cheng J-P et al. *Phys. Rev. Lett.* **74** 450 (1995)
23. Lozovik Yu E, Ovchinnikov I V *Solid State Commun.* **118** 2519 (2001)
24. Butov L V et al. *Phys. Rev. B* **62** 1548 (2000)
25. Lozovik Yu E, Merkulova S P, Ovchinnikov I V *Phys. Lett. A* **282** 407 (2001)

PACS numbers: 29.25.Bx, 29.27.Hj, 79.60.Jv
DOI: 10.1070/PU2001v044n12ABEH001058

Effective polarized electron emitters based on semiconductor nanostructures

A V Subashiev

High-energy beams of spin-polarized electrons have proven to be exceptionally useful in many experiments of elementary particle physics. By studying the scattering of polarized electrons by polarized and unpolarized targets it is possible to restore what is known as the nucleon spin structure functions and to investigate problems associated with the relative contribution of quarks and gluons to the observed value of nucleon spin, problems whose solutions are important for the development of quantum chromodynamics [1].

The second direction of research in this field is the study of CP symmetry violation in the electroweak interaction. The main result here is the exceptional accuracy (the relative error is about 0.1%) in measuring the electroweak mixing angle [2]. These measurements allowed the making of the most stringent (for the present) estimate of the maximum possible value of the Higgs boson mass. The value of 147 GeV c^{-2} obtained in this estimation was found to be within the range of energy attainable for modern accelerators, which makes the hope of discovering this particle in the near future quite realistic.

Less intensive is the expansion of polarized electron beam applications in materials science and, in particular, when investigating spin-dependent scattering, inverse photoemission, and spin-dependent absorption in thin films and surface layers of magnetic and semimagnetic materials [3].

The main achievements in the development and use of sources of highly polarized electrons have been made in the last decade, beginning with the experimental research in photoemission from highly strained semiconducting InGaAs and GaAs layers [4, 5], in which the possibility of creating a 75–85% electron polarization was demonstrated for the first time. Since that time semiconductor photocathodes with strained layers became the standard sources of electron beams in accelerators. Their main merit is the possibility of rapidly and precisely changing the orientation of the electron spin to the opposite, which makes it possible to specify the spin-dependent part of cross sections with ease.

The degree of the electron polarization of a beam determines the accuracy of measuring the spin-dependent effects, especially in the cases where there are limitations on the electron beam current, which are related to the properties of the target. The polarization of nearly 80% in the region of the targets is sufficiently high for the majority of experiments. A further increase in polarization and current density in the beam would make it possible to shorten the measurement times and would therefore reduce the cost of such experiments.

The development of research that uses the beams of polarized electrons has stimulated the study of polarized photoemission and the fabrication of new semiconducting materials with optimal photoemissive properties. In this report I will discuss the results and prospects of such research.

The operation of semiconductor photoemitters of polarized electrons leans upon two phenomena well-known in physics of semiconducting III–V compounds: optical orientation of electron spins as a result of excitation by circularly polarized light [6], and reduction of the work function of a p-doped semiconductor to negative electron affinity (when the vacuum level is below the edge of the conduction band in the crystal) in the process of activation of an atomically clean surface by a Cs(O) [or Cs(F)] deposition [7]. Here photoemission appears to be a consequence of the following processes: interband light absorption, trapping of electrons to the region of band bending at the surface (this region emerges because of the pinning of the Fermi level at the surface states within the forbidden band), and emission proper, i.e. the tunneling from the near-surface well into the vacuum through the residual surface barrier.

Such a pattern has been corroborated by experiments and calculations of the photoemission excitation spectra, the spectra of the energy distribution of the emitted electrons, and the dependence of these spectra on the photoemitter parameters (such as the doping level, layer thickness, temperature, and so forth) [3, 7].

Optical orientation is caused by the spin–orbit splitting of the valence band states, as a result of which the upper split-off states of the heavy and light holes have a total angular momentum $J = 3/2$ and are characterized by strong mixing of the orbital and spin movements. The difference between the probabilities for optical transitions to the conduction band from states of the multiplet with angular momentum projections $J_z = \pm 3/2$ and $J_z = \pm 1/2$, which are accompanied by the electron angular momentum change equal to unity (when the absorbed light is circularly polarized), results in unequal population of the two spin states of the conduction band: $|\uparrow\rangle$ and $|\downarrow\rangle$. The emerging optical orientation of the spins is characterized by the polarization $P = (n_\uparrow - n_\downarrow)/(n_\uparrow + n_\downarrow)$, where $n_\uparrow$, $n_\downarrow$ are, respectively, the concentrations of electrons with spins parallel and antiparallel to the direction of light propagation in the crystal [6].

Additional splitting of the multiplet with $J = 3/2$ into the subbands of heavy ($J_z = \pm 3/2$) and light ($J_z = \pm 1/2$) holes, when the crystal is under uniaxial strain, is used to make only one electron state populated. A fairly high strain is achieved by growing a $Ga_xIn_{1-x}As$ layer with a large lattice constant on a GaAs substrate. The best results have been achieved by growing GaAs (or $GaAs_{0.95}P_{0.05}$) layers on a $GaAs_xP_{1-x}$ (with $x = 0.28-0.32$) pseudosubstrate obtained, for instance, by growing a sequence of $GaAs_{1-y}P_y$ layers on a GaAs substrate with increasing concentration y. To reach the necessary photoemission current, the thickness of the photocathode's active layer must be no less than 0.1 μm, which is ten times the critical thickness for such strained layers and corresponds to dislocation-free growth. For this reason strained films prove to be partially relaxed and have a highly imperfect block crystalline structure. This in turn leads to a smearing of the absorption edge, hole scattering from defects in the process of absorption, and the filling of the second electron spin state, which reduces the initial polarization.

The above mechanism of polarization loss can be distinguished by calculating the dependence of the photoemission quantum yield Y and the polarization P of photoemission and photoluminescence radiations on the excitation energy and by