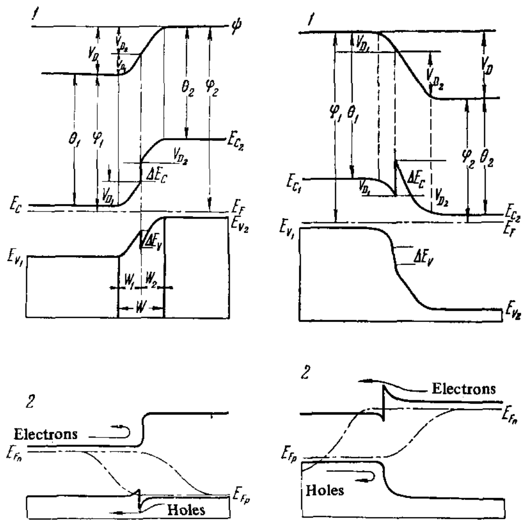

FIG. 1. A p-n heterojunction (on the left) in thermal equilibrium (1) and with a bias applied in the forward direction (2). V_D is the contact potential difference; W, the width of the space-charge region; θ, the electron affinity φ, the work function; ΔE_c and ΔE_v, the discontinuities of the conduction and valence bands. On the right: n-p heterojunction (the n-part is the wide-gap region).

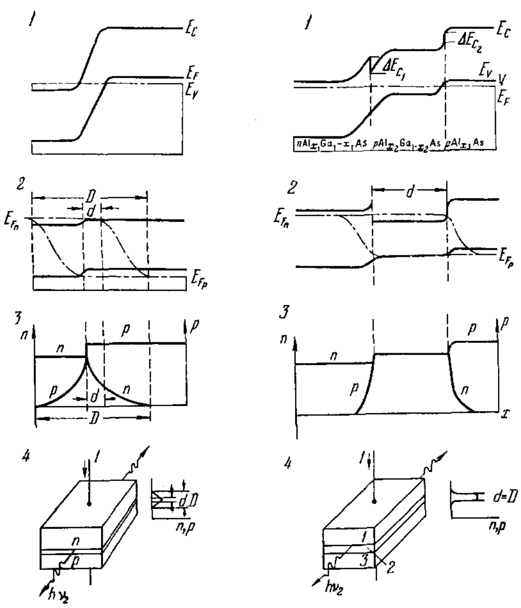

FIG. 2. An injection laser with a p-n junction (on the left) and a heterojunction laser (on the right). 1)–2) energy diagrams in thermal equilibrium and with a bias applied in the forward direction; 3) current carrier density distribution; d is the thickness of the active zone and D, that of the recombination zone.

We publish below summaries of some of the reports.

Zh. I. Alfërov. Semiconductor Devices with Heterojunctions. In the last two decades the development of the physical investigations of semiconductors has largely been, while the development of solid-state electronics has almost totally been connected with the use of p-n junctions (homo-p-n junctions), and has been based on the possibility of a controlled introduction of diverse impurities into the semiconductor crystal. The development of methods for preparing and purifying new materials and the investigation of their properties (after germanium and silicon, the $A^{III}B^{V}$ compounds) created new possibilities for improving the parameters of the already known devices (diodes, transistors, photocells) and the realization of new ones (thyristors, laser, photodiodes). Their basic element and the important tool for investigating their properties remained, however, the traditional homo-p-n-junction.

Advances in the epitaxial growth of semiconductor crystals allowed the transition ten years ago to the systematic investigation of single-crystal heterojunctions in semiconductors, i.e., of the contacts between two chemically different semiconductors realized in the same single crystal. The possibility arose of controlling inside the structure of the device the width of the forbidden band and other fundamental properties. The application of heterojunctions enables us to considerably improve the main parameters of the majority of semiconductor devices and, in a number of cases, to construct completely new ones. It was, however, necessary for the practical use of heterojunctions, to produce heterojunctions that are close in their properties to the ideal heterojunction whose interface is free from trace concentrations of defects, harmful impurities, etc., and to demonstrate the possibility of their application in semiconductor devices. To the solution of these problems have been devoted the investigations during the last decade of the group working on contact phenomena in semiconductors at the A. F. Ioffe Physico-Technical Institute of the USSR Academy of Sciences; the results of these investigations are briefly described in the present report.

At an ideal heterojunction, owing to the presence of additional potential barriers for electrons and holes (Fig. 1), we can control in a new way the injection of nonequilibrium current carriers, a phenomenon which is the basis of the operation of the majority of devices. Thus, in the case shown in the figure, there is a one-way injection of charge carriers from the wide-gap semiconductor to the narrow-gap semiconductor, and at sufficiently high biases in the forward direction, the concentration of the injected carriers should exceed by far their equilibrium concentration in the wide-gap emitter. This distinctive feature of injection at a heterojunction, (the "superinjection effect") makes it unique in its effectiveness as an emitter and especially promising for laser and electroluminescence diodes.

The realization of an ideal heterojunction not only required a felicituous choice of the pair of contiguous materials satisfying many conditions of mutual "compatibility" in their mechanical, crystallo-chemical, and thermal properties, and in their crystal and electronic structures, but also the development of a method for fabricating heterojunctions and the devices based on them. Gallium arsenide—one of the most important present-day semiconductor materials—and aluminum arsenide turned out to be such "ideal partners," and the universal method for their preparation is liquid epitaxy.

Among the various new devices, one of the most successful examples of the realization of the advantages of heterojunctions is the heterojunction laser (Fig. 2). Population inversion in a heterojunction laser is achieved, thanks to the "superinjection effect," by a pure injection method without the necessity of using high-level doping and degenerate p-n junctions. Owing to the potential barriers and the wave guide symmetry of the structure ($n_2 > n_1$ and n_3), there are practically no recombination and light losses, as a result of which the threshold generation currents are drastically reduced and the efficiency increased (at 300° K, $j_{thr} \approx 10^3$ A/cm^2, the differential quantum yield $\eta_d \approx 70\%$, the efficiency $\eta = 25\%$ instead of $j_{thr} \approx 50 \times 10^3$ A/cm^2, $\eta_d \approx 10-15\%$, and $\eta = 1-2\%$ for lasers with p-n junctions). The performance parameters of a number of other devices (solar converters, photodiodes, phototransistors, switching diodes) have also been considerably improved and completely new devices, which could not be realized on the basis of homo-p-n junctions, have been constructed: converters of infrared radiation to visible radiation, selective picture receivers, etc. The spectral band of emitting and photoelectric devices can be considerably broadened into both the visible and the infrared regions, since the possibility of producing ideal heterojunctions based on other $A^{III}B^{V}$ compounds (AlSb – GaSb, AlP – GaP, and some others) has now been demonstrated.

Zh. I. Alfërov, Inzhektsionnye geterolazery (Injection Heterojunction Lasers), in: Poluprovodnikovye pribory i ikh primenenie (Solid-State Instruments and Their Application), No. 25, Sov. Radio, M., 1971; Zh. Alfërov, Proc. of the Intern. Conference on Heterojunctions, (Budapest, October 1970), Vol. 2, Académiai Kiadó, Budapest, 1971; Sov. Sci. Rev. 2, 147 (1971).

V. S. Vavilov and E. A. Konorova. Semiconductor Diamonds. Diamond is structurally one of the simplest and, with respect to physical properties, one of the most interesting nonmetallic crystals. The high thermal conductivity and the chemical and thermal stability of diamond, as well as the high mobility of the charge carriers—electrons and holes[1]—make the production, study, and practical application of semiconducting diamonds a pressing problem. Advances in the synthesis of insulating and semiconducting diamonds under laboratory conditions[2,3] and the increase in the output of natural diamonds suggest that in the next decade, besides the traditional industrial applications, diamonds will also become a valuable material in electronics. The investigation into the possibility of an ionic implantation of electrically active donor (lithium, phosphorus, antimony) and acceptor (boron) impurities in plates of natural diamond carried out at the P. N. Lebedev Physics Institute of the USSR Academy of Sciences in collaboration with the I. V. Kurchatov Institute of Atomic Energy[4,5] has led to the production of n- and p-type semiconducting layers which are stable right up to 1400°C and have highly mobile carriers.

It was established in the course of the indicated investigations that for implanted-ion doses not exceeding certain critical values, annealing leads to the restoration of the diamond lattice structure. It has been demonstrated that we can, using the ion-implantation method, fabricate p-n junctions which possess diode volt-ampere characteristics and exhibit the barrier-layer photoeffect in the spectral range corresponding to the interband electron transitions in diamond ($h\nu > 5.4$ eV)[6]. It has been established that upon increase in the concentration of the implanted impurity (in particular, boron and antimony), the conductivity realized in the conduction or valence band is changed into conductivity of the "hopping" type. Using the ion-implantation method, we can realize not only structures consisting of n- and p-type semiconducting layers on the surface of or inside an insulating diamond plate, but also heterogeneous structures—in particular, layers of silicon carbide SiC implanted in diamond[7].

Further investigations should be directed towards the production of low-resistance contacts based on n-type semiconducting diamonds and the investigation of the electron processes near the surface of semiconducting diamonds, after which we can, in principle, realize electronic devices characterized by the ability to operate at high temperatures and by stability. As an example of a diamond-based electronic device which has already found practical application, we can cite the nuclear-particle and photon detectors constructed at FIAN[8].

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L. N. Kurbatov. Photoelectric Solid-State Receivers and New Methods of Optical-Radiation Reception. The development of instrument manufacture and the working out of optico-electronic systems have led in the last decade to a rapid growth of interest in the reception of radiation in the optical band. A considerable impetus to the investigations and the development of receivers was given by quantum electronics, the attainment of which allowed the production of high-power radiation fluxes with a high degree of coherence. The characteristics of coherent radiation made it possible to carry over to the optical band certain principles of reception which had been known for a long time in radio engineering—in particular, heterodyne reception.

Still another circumstance, connected with the appearance of lasers, is the necessity for the broadening of the frequency band, i.e., for the construction of receivers with a high speed of response.

Radiation receivers have been the subject of an ex-