Scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics, USSR Academy of Sciences (23–24 June 1976)

Usp. Fiz. Nauk **120**, 706–709 (December 1976)

A joint scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics of the USSR Academy of Sciences was held on June 23 and 24, 1976 at the Conference Hall of the P. N. Lebedev Physics Institute. The following papers were delivered:

1. *M. M. Zaripov, I. B. Khaybullin, and E. I. Shtyrkov,* Annealing of Ion-Implanted Layers Under the Action of Laser Radiation.
2. *I. A. Smirnov,* Rare-Earth Semiconductors.
3. *L. P. Pitaevskiĭ,* Superfluid He^3.
4. *E. P. Velikhov,* Controlled Thermonuclear Fusion. Present State and Prospects.
5. *Yu. B. Khariton, V. N. Mokhov, V. K. Chernyshev, and V. B. Yakubov,* Operation of Thermonuclear Targets with Magnetic Pinching.
6. *B. B. Kadomtsev,* The Physics of Quasistationary Thermonuclear Systems.

We publish below brief contents of two of the papers.

M. M. Zaripov, I. B. Khaybullin, and E. I. Shtyrkov. *Annealing of Ion-Implanted Layers Under the Action of Laser Radiation.* The basic shortcoming of ion implantation of semiconductors is the formation of an enormous number of radiation-induced defects during bombardment, which may totally amorphize the irradiated layer. As we know,[1,2] the ion-implanted layer (IIL) is subjected to thermal annealing to eliminate the radiation damage and to obtain electrical activation of the implanted impurity, i. e., the specimen is heated and held at the optimum temperature for the particular semiconductor either during or after ion bombardment. In either case, this operation has a whole series of undesirable consequences: deterioration of certain electrophysical parameters of the original semiconductor, uncontrollable diffusive redistribution of the implanted impurity, contamination of the IIL by extrinsic impurities, etc. These deficiencies of thermal annealing interfere with practical realization of a whole series of interesting and even unique possibilities of ion implantation and thereby hinder expansion of its use in semiconductor electronics.

Since 1973, a fundamentally new method of eliminating radiation-induced damage was proposed and tested in the course of research done at the Kaztan' Physicotechnical Institute of the USSR Academy of Sciences Kazan' Branch on the interaction of powerful coherent-radiation pulses with IIL; we refer here to laser annealing,[3,4] which has a whole list of important advantages over the traditional thermal-annealing process. It is based on a photostimulated-recrystallization effect that we observed in disordered ion-implanted layers. It was shown in the case of IIL produced by bombarding Si, Ge, and GaAs with B$^+$, C$^+$, Ne$^+$, P$^+$, S$^+$, Ar$^+$, Zn$^+$, In$^+$, and Sb$^+$ ions at doses of $6\cdot10^{12}$–$6\cdot10^{16}$ ions$\cdot$cm^{-2} and energies of 10–370 keV, using electrical, optical, electron-diffraction, and electron-microscopic measurements, that when a short ($\lesssim 10^{-7}$ sec), powerful ($\sim 10^5$–10^8 W/cm^2) pulse of coherent radiation whose wavelength lies in an absorption band of the irradiated layer is directed at a disordered IIL, the disturbed crystalline structure recovers rapidly (for all practical purposes during the laser pulse). Calculation of the temperature of laser heating of the layer and experimental study of the recrystallization kinetics pointed to the conclusion that the laser-annealing mechanism cannot be equated to the purely thermal mechanism and is essentially of nonequilibrium nature. Additional factors come into play here: the high degree of photoionization of the IIL (~10^{18}–10^{19} cm^{-3}), a powerful shock wave ((1–2) · 10^3 atm), strong light fields (~10^4–10^5 W/cm), etc. and may significantly accelerate the diffusion of the radiation-induced defects and, on the whole, stimulate the recrystallization of the disordered layer.[5] It was established that the photostimulated-recrystallization effect is observed in a certain range of intensities for each semiconductor. The lower limit is determined by the recrystallization threshold and the upper limit by the threshold of light damage to the particular semiconductor. Both limits depend on the finish of the layer's surface, the ion-implantation conditions, and the wavelength and duration of the laser pulse.

Comparison of results from studies of implantation effectiveness, the distribution of electrically active impurity atoms, and the degree of recovery of crystalline structure as a function of depth in layers made with laser and thermal annealing brought out a number of distinctive features of laser annealing.

First, a higher (by factors of up 6–8) degree of electrical activation of the implanted impurity is obtained if the laser-radiation parameters are appropriately chosen. Here this effect is more strongly in evidence the larger the dose of the implanted impurity. It has been established experimentally that the higher electrical activation of the implanted impurity results from stimulated transition of impurity atoms from interstitial positions to substitutional positions. Owing to the strongly nonequilibrium nature of laser annealing, it is possible to obtain impurity-atom concentrations at lattice sites that are above the solubility limit of the impurity in solid silicon.

Second, the profile of the electrically-active impurity-atom distribution is determined not only by the distribution profile of the implanted impurity, but also by the distribution of the absorbed laser radiation through the depth of the layer.

Third, diffusive redistribution of the implanted impurity is practically eliminated in the process of photostimulated recrystallization.

Fourth, given appropriate selection of the laser-radiation parameters, there is practically no thermal heating of the original backing material, so that undesirable changes in its electrophysical parameters are prevented.

Fifth, three-dimensionally local annealing can be obtained by using the known methods to shape a predetermined spatial distribution of the luminous radiation intensity.

These features of ion-laser doping of single crystals can be used to greatest advantage primarily in semiconductor micro- and optoelectronics to make solid-state structures and devices. The photostimulated-recrystallization effect also opens up another area for practical application of the IIL. Namely, the observed effect in which there are significant changes in the optical properties of strongly disordered IIL in the visible and especially in the infrared when they are acted upon by powerful laser pulses suggests the possibility of using these layers as promising new materials with high resolution (~3000 lines/mm) and serviceability in a broad temperature range to record and store optical information, e.g., holograms.[5–7]

The materials of the paper have been published as follows: Annealing of ion-implanted layers under powerful laser radiation, Dep. VINITI No. 2061-74 (1974); Local laser annealing of ion-implanted semiconductor layers, Fiz. Tekh. Poluprov. 9, 2000 (1975) [Sov. Phys. Semiconductors 9, 1309 (1976)]; the ion-implanted layer—a new material for recording holograms, Opt. Spektrosk. 38, 1031 (1975) [Opt. Spectrosc. (USSR) 38, 595 (1975)]; Laser annealing of implantation layers, *in:* Trudy *mezhdunarodnoĭ konferentsii* po ionnomu vnedreniyu poluprovodnikov (Proceedings of International Conference on Ion Implantation of Semiconductors), Budapest, 1975, p. 212; The mechanism of laser annealing of implantation layers, *ibid.*, p. 247, and have been reported on at the following All-Union and international conferences: a) On Optoelectronic Holographic Storage Devices, Penza, 1974 (two papers); b) On the Physics of the Interaction of Optical Radiation with Condensed Media, Leningrad, 1974 (one paper); c) On Holography, Kiev, 1975 (one paper); d) On Ionic Implantation of Semiconductors, Budapest, 1975 (two papers); e) On Nonlinear Optics, Tiflis, 1976 (one paper).

[1] J. Mayer *et al.*, Ion Implantation. Academic Press, 1970.
[2] E. I. Zorin, P. V. Pavlov, and D. I. Tetel'baum, Ionnoe legirovanie poluprovodnikov (Ion Doping of Semiconductors), Énergiya, Moscow, 1975.
[3] I. B. Khaĭbullin, E. I. Shtyrkov, M. M. Zaripov, M. F. Galyautdinov, and R. M. Bayazitov, Dep. VINITI No. 2061-74, Moscow, 1974.
[4] E. I. Shtyrkov, I. B. Khaĭbullin, M. M. Zaripov, M. F. Galyautdinov, and R. M. Bayazitov, Fiz. Tekh. Poluprov. 9, 2000 (1975) [Sov. Phys. Semiconductors 9, 1309 (1976)].
[5] I. B. Khaĭbullin, E. I. Shtyrkov, M. M. Zaripov, V. V. Titov, V. P. Strashko, and K. P. Kuz'min, in: Trudy Mezhdunarodnoĭ konferentsii po ionnomu vnedreniyu v poluprovodniki (Proceedings of International Conference on Ion Implantation in Semiconductors), Budapest, 1975, p. 212.
[6] I. B. Khaĭbullin, E. I. Shtyrkov, M. M. Zaripov, M. F. Galyautdinov, and E. A. Guriyanskiĭ, Soviet Patent No. 490 368 with priority from 25 February 1974.
[7] E. I. Shtyrkov, I. B. Khaĭbullin, M. M. Zaripov, and M. F. Galyautdinov, Opt. Spektrosk. 38, 1031 (1975) [Opt. Spectrosc. (USSR) 38, 595 (1975)].