STUDING THE PROPERTIES OF GaAs, BOMBARDED BY IONS OF IRON AND MANGANESE WITH FOLLOWED PULSED LASER ANNEALING

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Diluted magnetic semiconductors (DMS), which have along with semiconductor also ferromagnetic properties, are one of the main materials of spin electronics. Their production requires the introduction of transition element impurities into the semiconductor up to concentrations of at least several at.%. This creates doping problems, since the equilibrium solubility limite of transition elements in the most common semiconductors (Si, GaAs), as a rule, does not exceed 10^{19} cm^{-3}. Low-temperature molecular beam epitaxy (LT-MBE) is usually used to obtain DMS in laboratory conditions, but the high cost of equipment and low productivity do not allow using this method for any large-scale production. A solution can be the use of ion implantation followed by pulsed laser annealing (PLA). In this work, we compare the properties of GaAs layers obtained by implantation of Mn and Fe ions and annealed with single pulses of an excimer laser.

EXPERIMENTAL TECHNIQUE

Semi-insulating GaAs (001) wafers were used as initial samples. The implantation was carried out on an ion accelerator "Raduga" using metal ion sources; A feature of the setup is the presence in the ion flow of three charged fractions with a predominance of doubly charged ions. Accelerating voltage = 80 kV. Implantation doses (D) were in the range of 1×10^{16} – 5×10^{16} cm^{-2}. Pulsed laser annealing (PLA) was carried out with use of an LPX-200 excimer laser (KrF) with a wavelength of 248 nm, a pulse duration of ~30 ns, and a pulse energy density (P) up to 400 mJ/cm^2.

EXPERIMENTAL RESULTS

Studies of optical reflection in the photon energy range 2 - 6 eV for layers irradiated with both Fe and Mn ions showed that the shape of the spectra significantly differed from the spectrum of unimplanted GaAs. Peaks characteristic of single-crystal GaAs at E_1 = 2.90 eV and $E_1 + \Delta$ = 3.12 eV (doublet corresponding to interband transitions), as well as peak E_2 at 5.11 eV, are absent in GaAs irradiated with ions, which corresponds to its amorphization. The PLA (P > 200 mJ/cm^2) leads to a significant restoration of the reflection spectrum (crystal structure), a peak E_2 appears, although the doublet of peaks E_1 and $E_1 + \Delta$ is not resolved and the reflection coefficient is generally lower than the values for mono-GaAs. Probably, the introduction of more than 1 at.% impurity leads to some disordering of GaAs, associated with the formation of a solid solution of the impurity in the matrix.

Raman spectra (NTEGRA Spectra – NT MDT, 473 nm laser, 0.5 mW, backscattering geometry, resolution of 0.7 cm^{-1}) for as-implanted and annealed samples are shown on Fig.1.

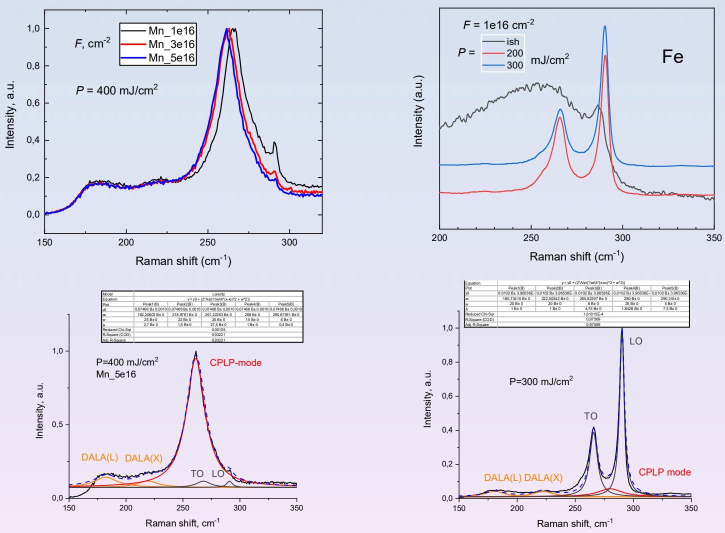


Fig. 1. Raman spectra for GaAs samples, implanted by ions of Mn (left) and Fe (right).

The annealed layers exhibited p-type conductivity. Hall effect measurements at 300 K showed a decrease in the layer resistance with an increase in the ion dose from 1 to 5×10^{16} cm^{-2} and a monotonic increase in the layer concentration up to 2.9×10^{15} cm^{-2} (Mn implantation) and 5.2×10^{14} cm^{-2} (Fe). The hole mobility ranged from 4 to 17 cm^2/V×s. Temperature dependence of the resistance has a semiconductor character (Fig. 2).

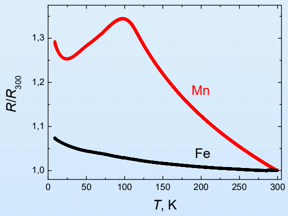


Fig.2
Note the appearance on the dependence for Mn of a peak of about 100 K. Usually, its appearance is associated with the position of the Curie point for the "ferromagnetic-paramagnetic" phase transition. The absence of a pronounced peak in the resistance for Fe implantation most likely indicates different mechanisms of exchange interaction in these DMSs.

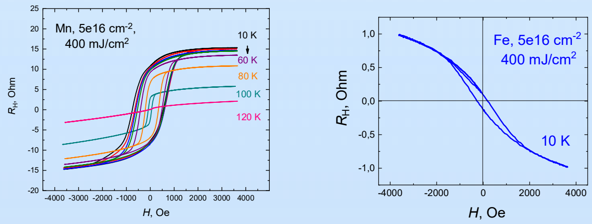


Fig. 3. Hall effect at various measurement temperatures for the samples obtained by Mn$^+$ (left) and Fe (right) ion implantation with a dose of 5×10^{16} cm^{-2} and PLA.

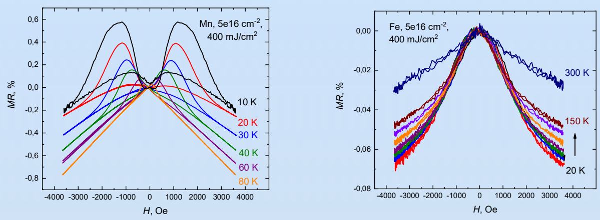
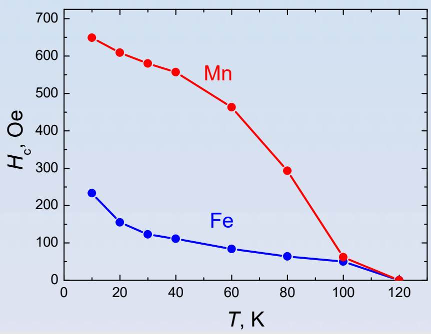


Fig. 4. Magnetoresistance at various measurement temperatures for the samples obtained by Mn (left) and Fe (right)$^+$ ion implantation with and a dose of 5×10^{16} cm^{-2} and PLA. The magnetic field is normal to the surface.

Fig.5. The temperature dependence of the coercive field for the GaAs:Fe and GaAs:Mn layers. Implantation dose = 5×10^{16} cm^{-2}, P = 400 mJ/cm^2.



It was shown that layers formed by Mn and Fe ion implantation into GaAs and subsequent annealing by an excimer laser pulse with an energy density to 300–400 mJ/cm^2 feature the properties of the p-type semiconductor. Hysteresis loops in the magnetic field dependences of the Hall effect and the negative magnetoresistance suggest that the layers are ferromagnetic compounds. The Curie temperature of this materials (up to 120 K) is not below than that for the LT-MBE material. We assume that non-equilibrium recrystallization with superfast cooling at short laser pulse promotes the effective incorporation of implanted Mn and Fe atoms into Ga sites, that leads to a high concentration of holes and magnetic moments, causing ferromagnetic ordering in laser-annealed Mn and Fe implanted GaAs layers.

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