Application of ion implantation to create a magnetically controlled light-emitting diode

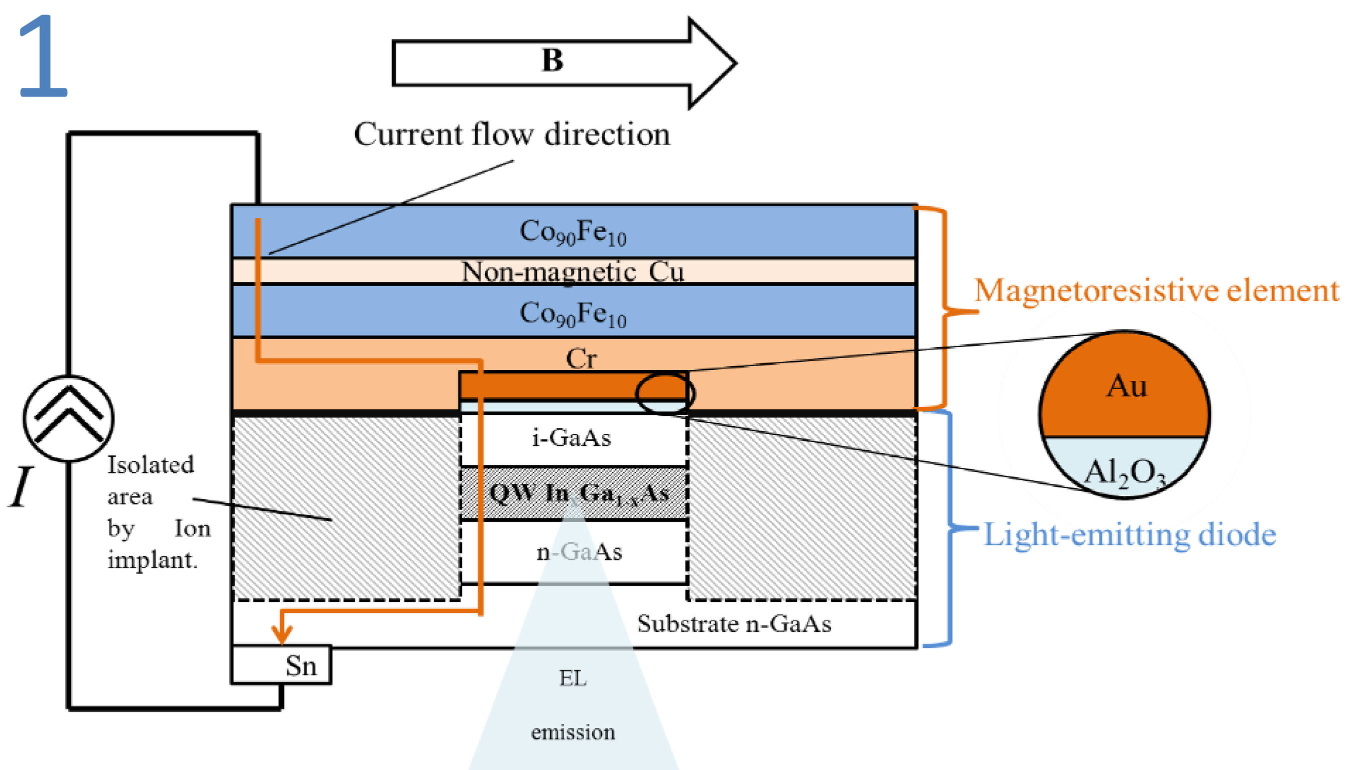
A.V. Zdoroveyshchev, M.V. Ved, Yu.A. Danilov, P.B. Demina, M.V. Dorokhin, Yu.A. Dudin, D.A. Zdoroveyshchev, A.V. Kudrin, V.E. Kotomina, Yu.M. Kuznetsov

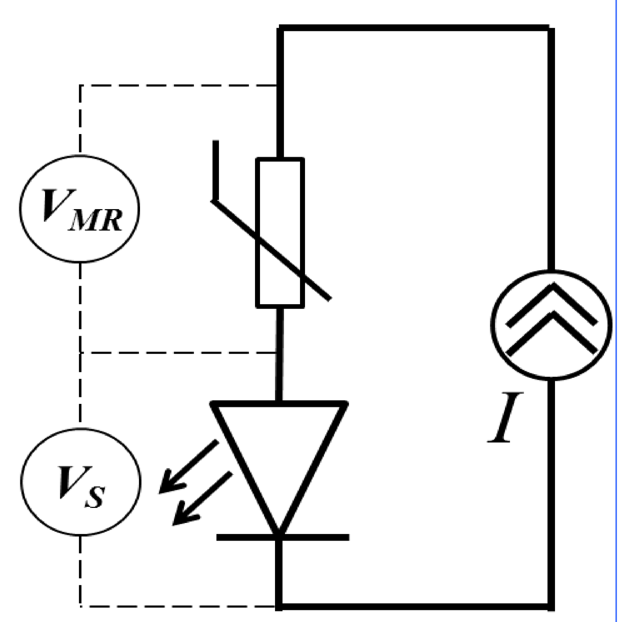
603950, Russia, N. Novgorod, Gagarin ave., 23/3, NIFTI NNSU, e-mail: zdorovei@nifti.unn.ru

The development of light-emitting devices with the ability to control the intensity of electroluminescence by applying an external magnetic field is an actual problem of spintronics. Such LEDs can be applied, for example, as high-speed magnetic field sensors with opto-decoupling, magnetic field visualizers or optical devices for reading magnetoresistive random access memory. One of the variant for creating such a device is the constructive combination of a magnetoresistive element (spintronic device) and a light-emitting diode [1,2]. In this device, the magnetoresistive element controls the current through the structure (by switching its state with an external magnetic field), and the current through the structure sets the intensity of the LED radiation, while the circuit is powered from the EMF source. The maximum percentage of the photoluminescence intensity modulation by the magnetic field in the works [1,2] was in the range of 10-60%.

[1] I. Appelbaum, K.J. Russel, D.J. Monsma et al. // Appl. Phys. Lett., V. 83, 4571 (2003).
[2] D. Saha, D. Basu, P. Bhattacharya. // Appl.Phys.Lett., V. 93, 194104 (2008).

1

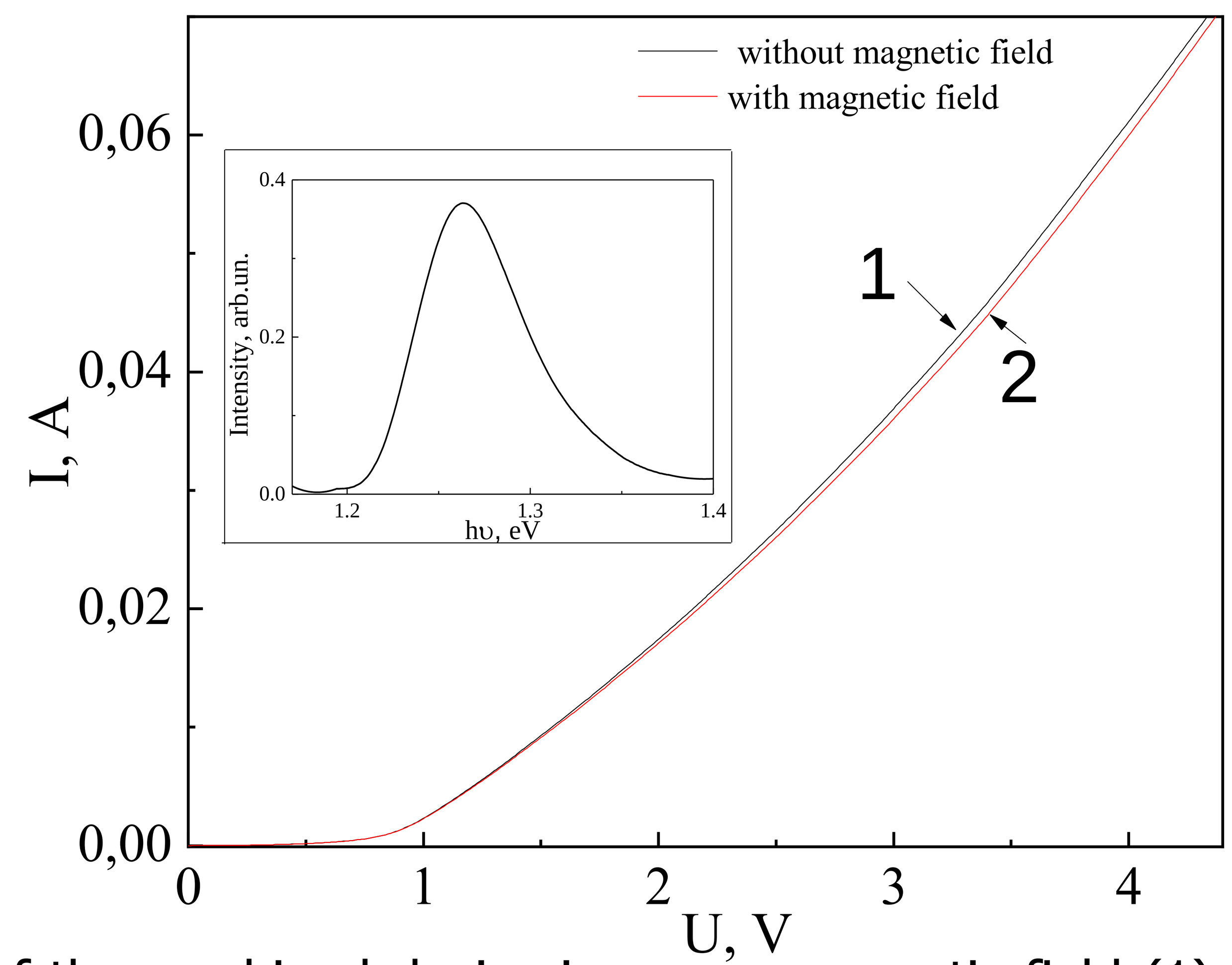




A magnetoresistive LED is a combination of an emitting part based on a heterostructure with an InGaAs/GaAs quantum well with an Al_2O_3/Au Schottky contact connected in series with a spin valve consisting of Cr/$Co_{90}Fe_{10}$/Cu/$Co_{90}Fe_{10}$ layers. The base contact to the n-type GaAs substrate was formed by the spark firing of the Sn foil. The electric power supply of the diode was carried out in the current source mode. For the electrical insulation of the semiconductor structure around the mesocontacts, the parts of the structure that were not closed by the injection contacts were bombarded with He^{++} ions (40 кВ, D~10^{14} cm^{-2}) before applying magnetoresistive layers [3]. According to the simulation, a near-surface layer with a thickness of 0.5 microns was exposed.

[3] J.P. de Souza, I. Danilov, H. Boudinov. // Appl. Phys. Lett., V. 68, 535 (1996).

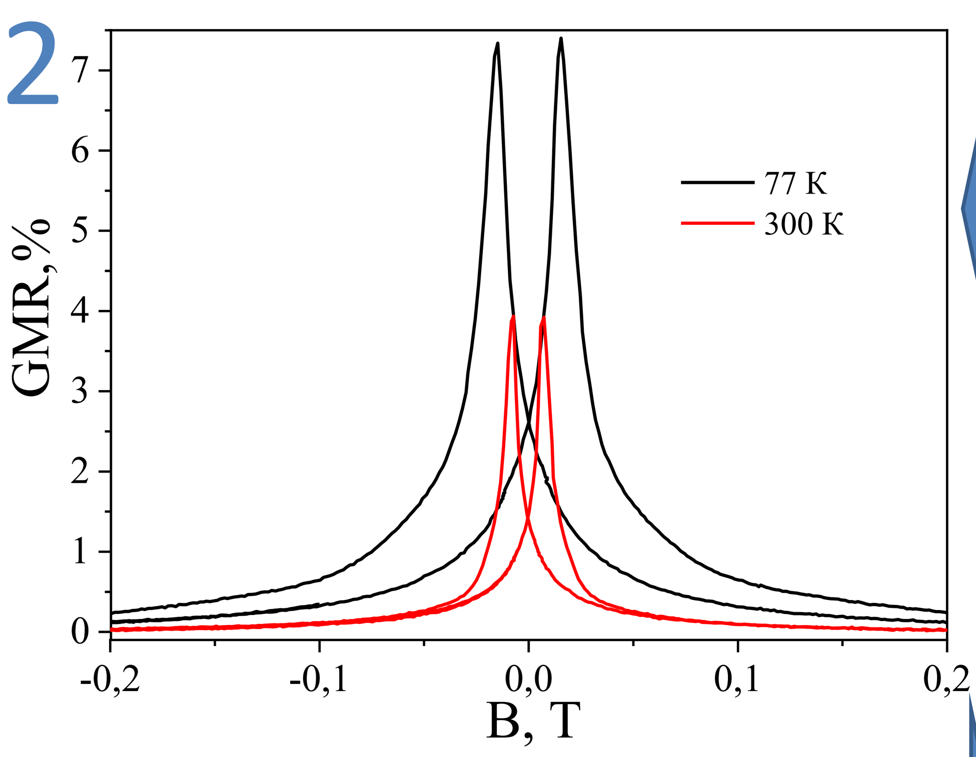
3



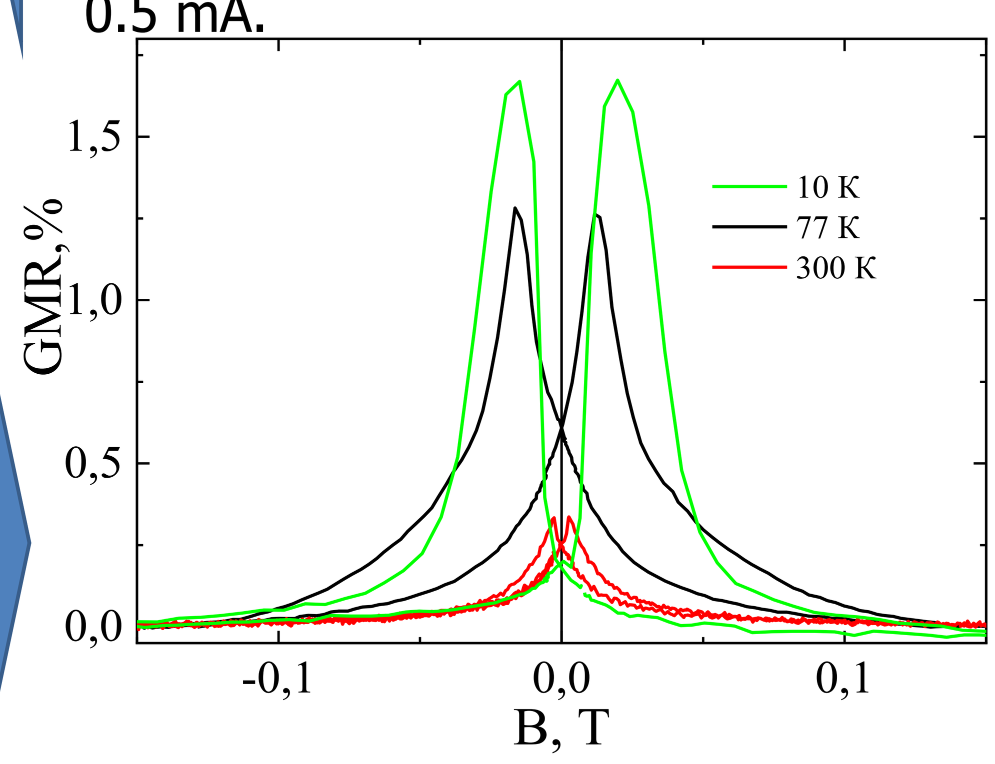
VAC of the combined device in a zero magnetic field (1) and in a magnetic field corresponding to the maximum resistance of the structure (2). The measurement temperature is 10K. The insert to the figure shows the EL spectrum measured at 300K.

When the structure is introduced into an external magnetic field, the value of the current through the structure decreases at the same voltage values

2



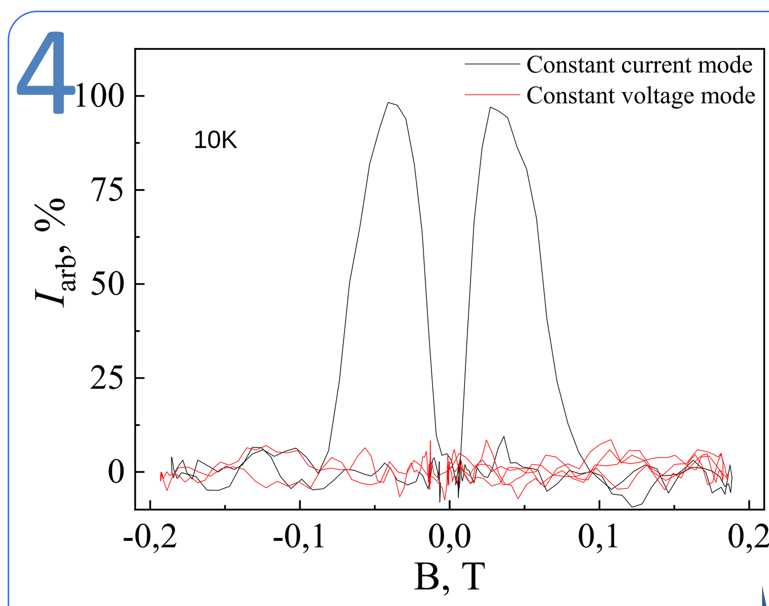
Magnetic field dependences of resistance for a separate magnetoresistive element. The current through the structure is 0.5 mA.



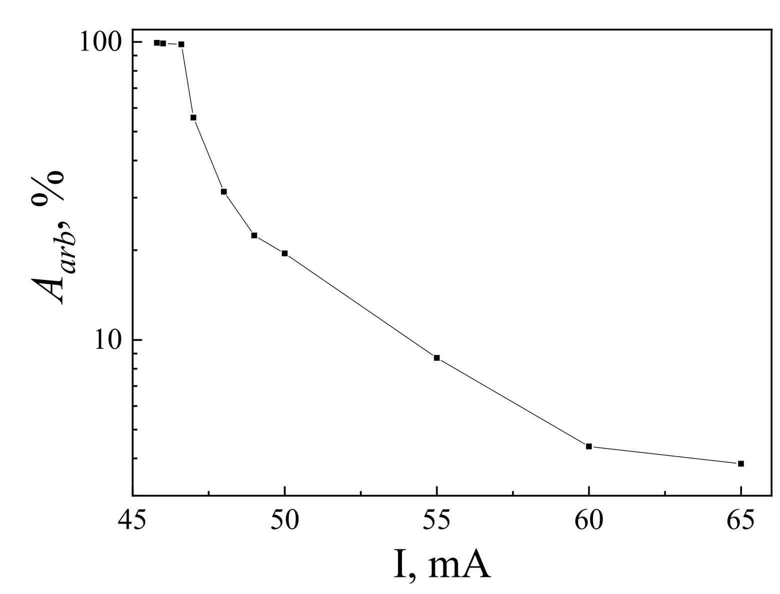
Magnetic field dependences of resistance for a combined device with horizontal transport. Voltage - 3 V.

The magnetoresistance curves view of the combined device are similar to the magnetic field dependences of resistance of a separate magnetoresistive element.

4



Magnetic field dependences of the electroluminescence intensity of the combined structure in the constant voltage (3.5 V) and direct current (46 mA) modes.

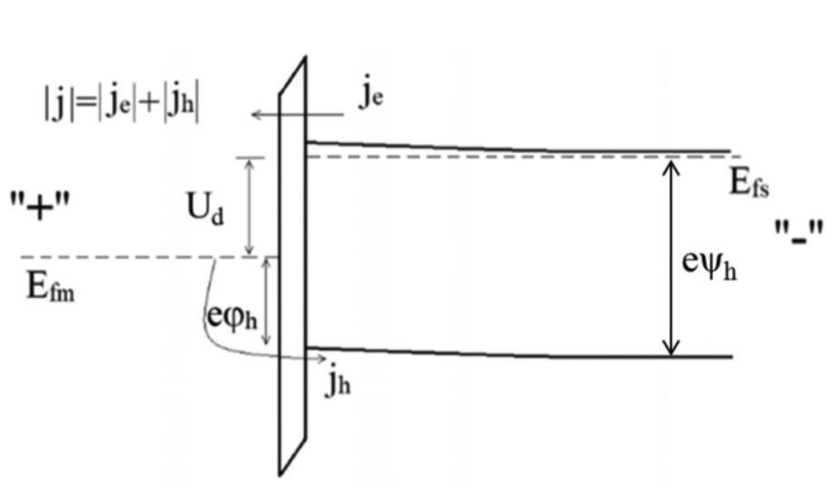


The function of changing the intensity of electroluminescence in a magnetic field from the operating current.

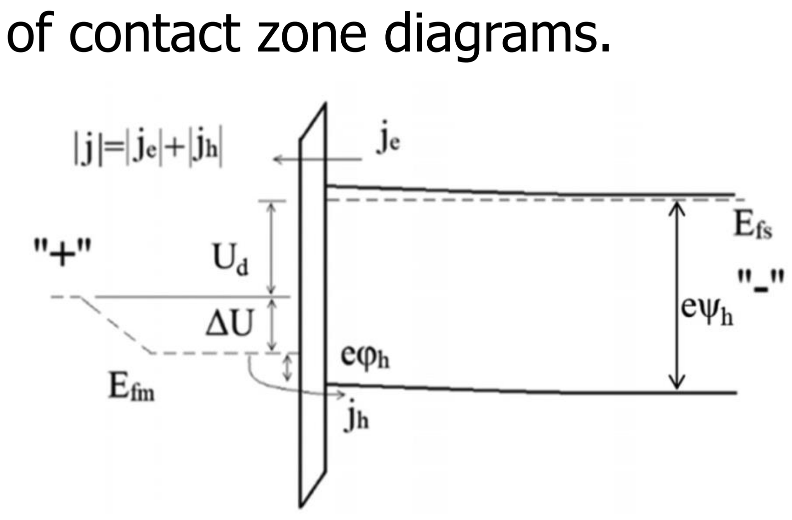
When measuring electroluminescence in the constant voltage mode, modulation of the electroluminescence intensity by a magnetic field is not observed. In the case of a constant current mode with a current equal to 46 mA, the structure operates in a key mode. With increasing current, the relative change of the electroluminescence intensity decreases.

5

The injection mechanism of minority charge carriers into a metal / tunnel dielectric / n-type semiconductor Schottky diode. Schematic representation of contact zone diagrams.



Diode forward bias mode; the voltage U_d across the dielectric layer leads to a shift of the Fermi level in the metal and a decrease in the potential barrier for holes ($\varepsilon\phi_h$).



Additional shift of the Fermi level due to some voltage drop ΔU on the magnetoresistive layer in the metal contact. It leads to a further decrease in $\varepsilon\phi_h$.

This work was supported by the RFBR (grants 18-29-19137mk, 20-38-70063- Stability, 20-02-00830a, 20-32-90032-Postgraduate students), a grant from the President of the Russian Federation (MK-445.220.2), the RSF (project No. 21-79-20186), state assignments (project 075-03-2020-191 / 5).

The results of the work are published in: Switching of magnetoresistive light-emitting diode by external magnetic field / M. Ved, Yu. Danilov, P. Demina, M. Dorokhin, Yu. Dudin, V. Kotomina, A. Kudrin, Yu. Kuznetsov, A. Zdoroveyshchev and D. Zdoroveyshchev // Appl. Phys. Lett. 118, 092402 (2021).

Докладчик:

с.н.с. НИФТИ ННГУ, к.ф.-м.н.,

Здоровейщев Антон Владимирович

zdorovei@nifti.unn.ru

+7-(910)-898-68-24