Electrical properties of ZnO:Mn/n-GaP structures

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Transparent conductive pure and doped by magnetic impurities oxide films are widely used for the fabrication of various kinds of heterostructures and spintronic devices, respectively. This research is focused on the analysis of current transport through the structure diluted magnetic semiconductor (ZnO: Mn) – semiconductor.

As the base material (substrate) we used single crystal GaP (ρ = 4 Ohm·cm) with the n-type of conductivity. There was established that the ZnO:Mn thin films with optimal structural perfection and electrical properties are prepared by the spray pyrolysis technique using zinc acetate salts $Zn(CH_3COO)_2$ and manganese chloride $MnCl_3$ (0,2 M aqueous solution) in proportions that provide a 3% atomic content of Mn in the thin films. Electrical resistivity of ZnO:Mn thin films (3at. % Mn) at the substrate temperature T = 623K is equal to 80 ÷ 130 Ohm·cm.

Electrical contacts to the structures ZnO:Mn/n-GaP were formed using indium in order to investigate electrical properties. Before the indium deposition the surface of the n-GaP substrate was covered by copper thin film by means of the reduction from the aqueous solution of Cu_2SO_4.

The ZnO:Mn/n-GaP (3at. % Mn) structures possess pronounced rectifying properties. The sharp increase of the current is observed at positive bias U = 1.8 V. The breakdown is observed on the reverse branches of I-V characteristics at bias |U| > 20 V. The estimated value of the height of the potential barrier φ_k samples ZnO:Mn/n-GaP (3at. %Mn) is in the range 1 ÷ 1.4 eV, depending on the oxidation conditions of the GaP surface before the deposition of the ZnO thin film. Additional growing of the native oxide film on the surface of the GaP surface before the pyrolysis process leads to the increase in the height of the energy barrier in the structures under investigation.

Within the direct bias range 0.05 < U <0.25 V for the structures ZnO/n-GaP and 0.25 < U <0.45 V for the structures ZnO:Mn/n-GaP (3 atm. % Mn) the current transport is dominated by recombination mechanism of the injected charge carriers through the energy barrier. The nonideality factor of the I-V characteristics n = 2 under these conditions. At positive voltages higher than 0.25 V for the structures ZnO/n-GaP and U > 0.45 V for the structures ZnO:Mn/n-GaP (3at. % Mn) appear tunnel mechanisms current flow with the nonideality factor of the I-V characteristics n > 2. Observation of tunneling into a specified range of voltages caused by the presence of a thin dielectric layer at the interface between the ZnO thin film and GaP substrate. The analysis of the current-voltage characteristics at reverse bias from 0 to -2 V indicates the domination of the generation mechanism of charge carriers' transport through the energy barrier.

The total capacity of the heterostructure ZnO:Mn/n-GaP with an intermediate layer P_2O_3 is determined by the capacitance of the depleted region C_j and dielectric layer C_d: $1/C = 1/C_j + 1/C_d$. At voltages U > 1.3 V the equality $1/C = 1/C_d$ is true. It means the the total capacitance is determined by the voltage independent capacitance of the thin dielectric layer.

The energy diagram of the heterojunction ZnO:Mn/n-GaP was built using the experimental data on the electrical properties of the contacting materials and data on the energy parameters of ZnO (E_g = 3,2 eV, χ = 4,35 eV) and GaP (E_g = 2,27 eV, χ = 3,8 eV). The calculated height of the potential barrier $e\varphi_k \leq 1{,}45$ eV. Actually, the measured values of the height of the potential barrier $e\varphi_k$ = 1,6 eV indicates on the influence of the intermediate dielectric layer at the heterojunction interface.