Hole distribution in a film of a ferromagnetic semiconductor in the presence of an external electric field

A.E.Aminova, V.M.Chetverikov

Department of Applied Mathematics MIEM NRU HSE, Moscow

The electrical manipulation of magnetism and magnetic properties has been achieved across a number of different material systems. For example, applying an electric field to a ferromagnetic material through an insulator alters its charge-carrier population.

The possibility of changing the spontaneous magnetization of a ferromagnetic semiconductor by applying an electric field. A thin film of a ferromagnetic semiconductor $(In_{0.97}Mn_{0.03})As$ 5 nm thick was placed on a substrate of other semiconductors.

In such a system, at a sufficiently high concentration Mn (on the order of several percent), the wave functions of the holes associated with neighboring ions begin to overlap, and a hole impurity band arises. Ferromagnetism is provided by the exchange interaction of holes with manganese ions by the Zener mechanism, i.e. indirect ferromagnetic interaction between ions is provided due to the *sd* - exchange of Vonsovsky-Ziner between holes and ions. The dependence of the density of states of a hole gas in the impurity band of energy, which overlaps noticeably with the valence band, is rather complicated. And for simplicity in the model calculation it was assumed that this dependence is the same as in a gas with some effective mass.

Denote by ε_{ex} the elementary energy of the exchange interaction of holes with the manganese ion, referred to the density of the particles. Then, in the model under consideration, the energy of the exchange E_{ex} interaction per unit area of the film surface is represented as:

$$E_{ex} = -\varepsilon_{ex} \cdot L \cdot \int_0^1 \left(n_+^{1/2}(z) - n_+^{-1/2}(z) \right) \cdot \left(n_-^{5/2}(z) - n_-^{-5/2}(z) \right) dz, \quad \varepsilon_{ex} > 0 \tag{1}$$

Numerical solution of the system of equations (2), (3) considering boundary conditions (4):

$$\begin{gathered} \Delta(z) = \Omega\left(\psi(z), a(z)\right) \cdot \text{Tanh}[(b/T) \cdot \Delta(z)] / q(z), \\ \Omega\left(\psi(z), a(z)\right) = \delta \cdot \{\left((3/2) \cdot (1-\psi(z)\right)^2 + (1/2) \cdot (a(z))^2\}. \end{gathered} \tag{2}$$

$$\begin{gathered} \frac{d^2}{dz^2}\psi = -\gamma \cdot L^2 (q(z) - 1), \quad z \in (0,1), \quad \gamma = \frac{4\pi \cdot n_-}{\chi \cdot \varepsilon_F}, \\ q(z) = (1/2) \cdot \left((1 - \psi(z) + a(z))^{3/2} + (1 - \psi(z) - a(z))^{3/2} \right), \\ a(z) = \delta \cdot \text{Tanh}[(b/T) \cdot \Delta(z)]. \end{gathered} \tag{3}$$

$$\frac{d\psi}{dz}\Big|_{z=0} = \frac{d\psi}{dz}\Big|_{z=1} = -A \cdot L, \quad A = \frac{E}{\chi \cdot \varepsilon_F} \tag{4}$$

These equations are solved using an iterative procedure.