TUNNELING AND MAGNETORESISTANCE IN FERROMAGNET/WIDE-GAP SEMICONDUCTOR/FERROMAGNET NANOSTRUCTURE

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I. INTRODUCTION

Ferromagnet/wide-gap semiconductor/ferromagnet (FM/WGS/FM) nanostructures attract a great interest during the last decade regarding their prospects for creating information-processing devices, including spintronic devices. Previously, the tunneling magnetoresistance (TMR) in such nanostructures was calculated using one-band insulator model. In this article the charge carrier transport model in the ferromagnet/wide-gap semiconductor/ferromagnet based on two-band Franc-Keine model (FKM) and phase function model is proposed [1]. It is taken into account that tunneling barrier with the width d, which was founded by the band gap, does not represent the potential step, but the energy band-gap. Its upper border is the bottom of the conduction band E_C, and the bottom part is the top of the valence band E_V. Inside this area the wave vector of the electron is an imaginary value.

II. MODEL

In FKM in order to calculate tunnel current density following equation is used [1,2]:

$$J(V) = \frac{4\pi q m_i}{h^3}\int_0^{\infty} dE[f_L(E) - f_R(E,V)]\int_0^{(m/m_i)E} dE_p T_\sigma(E,E_p,V), \qquad (1)$$

where E is the full electron energy, E_p is the electron energy component which is parallel to the tunneling barrier surface, m and m_i are the electron effective masses in electrode and WGS, q is the electron charge, $f_L(E)$, $f_S(E)$ are the Fermi- Dirac distribution functions for left and right electrodes, $T_\sigma(E,E_p,V)$ is the tunnel transparency of the barrier, σ is the spin index (spin –up and spin-down).

To find the transmission coefficients we develop a model on the basis of phase functions [3]. The model takes into account the barrier parameters, the image force potential and allows including the potential relief at the interfaces and in the volume of the wide-gap semiconductor. The main feature of the phase function method is that to obtain the transmission coefficients, so it is not necessary to approximate the potential barrier by rectangular potentials and to link the Schrödinger equation solutions from different regions. This process is too laborious for the potential of complex shape, besides it is very difficult to estimate faults of the results. In the phase function method not a wave function, but only its changes, as a result of potential actions, are calculated. Using phase function method it is possible to calculate tunneling transmission for potentials of any complexity, including complex and potentials depending from energy.

The tunneling transmission coefficient is [3]:

$$T_\sigma = \exp\left[\frac{1}{k_\sigma}\int_0^d U_{eff}(z)[b_\sigma(z)\cos(2k_\sigma z) - a_\sigma(z)\sin(2k_\sigma z)]dz\right]. \quad (2)$$

Here U_{eff} – effective potential which defines the potential relief of the structure, a_σ and b_σ functions are defined by the equations based on the Phase function method, *a,b* are WGS layer coordinates, k_σ is the wave number, его величина $k_\sigma^2 = (2m_i/h^2E_G)[(E-E_c)(E-E_V)]-k_p^2$. Where k_z, k_p are wave number components which are perpendicular and parallel to the barrier, correspondingly, E_G is the band-gap width, *h* is the Planck constant. According to the dispersion law, states located in the midgap sustain the largest attenuation in the barrier. Therefore if Fermi level of the observed nanostructure is located near the bottom of the band-gap, the bias voltage *V* shifts the levels of the tunneling electrons to the area of the lower barrier transparence. This shifting is the reason of the tunneling current decrease.

III. RESULTS AND DISCUSSION

Tunneling transmission coefficient depending from applied bias V at the variation of the layer thickness (WGS *d)* was calculated, Fig .1. Received dependences are oscillating and characterized by the maximums (picks) shiftings and changings of their amplitude at the variation of the thickness *d*. When thickness value increases from *d*=1nm to 2 nm first pick is moving from *V*=1 V to 2 V, and the second pick from *V*=2 to 4 V. And opposite at decreasing thickness value up to *d* =0.5 nm 3 picks are observed: at 0.45, 1.9 and 4 V. Picks amplitude also depends on *d*. At thickness value rising from c 1nm to 2nm first pick amplitude increases, but the second pick amplitude falls. At *d*=0.5 nm, vice-versa, first pick amplitude is the lowest, but the third pick amplitude has the maximal value.

We have also calculated dependencies of tunneling current at fixed WGS thickness and changeable value of band, Fig.2. In this case no picks moving is observed, only picks amplitude is changed. Picks' maximums are at 1 V и 3.9 V accordingly. So, at increasing E_G from 7.5 eV to 8.5 eV current density at the first pick is changed from 125 A/m^2 to 180 A/m^2, but at the second pick from 120 A/m^2 to 175 A/m^2, Fig.2. Tunneling magnetoresistance (TMR) from WGS thickness was also calculated. Its value is 3-8 %, Fig.3.

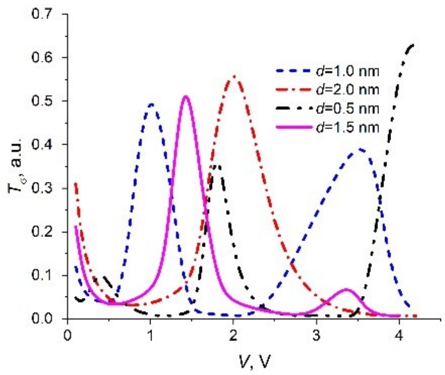

Figure 1. Transmission coefficient vs applied bias *V*: *d*=0.5-2 nm, E_G=8 эВ

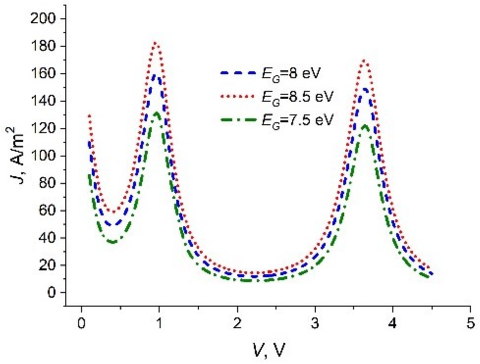

Figure 2. Current density vs applied bias V: E_G =7.5-8 эВ, *d*= 2 nm

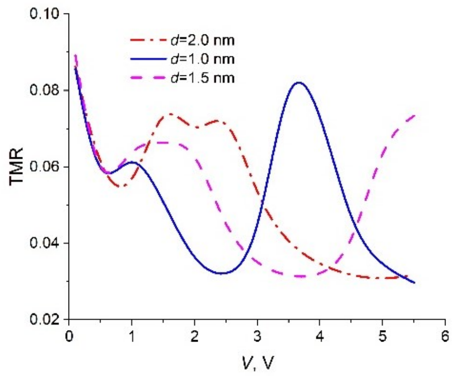

Figure 3. TMR vs WGS thickness, *d*=1-2 nm

TMR dependences at different thicknesses *d* are non-monotonous, first maximums are shifted to the areas of the higher biases at increasing WGS thickness. Amplitude of the first maximums rises from 6 to 7.5 %. Second maximums shift to the areas of the higher bias V with d increasing, but the values of their amplitudes are falling. Maximum TMR value is 8 % at *d*=1nm and *V*=3.9 V (line 2).

III. CONCLUSIONS

Tunneling coefficient, current density and TMR in FM/WGS/FM structure based on two-band Franc-Keine model and phase function method were calculated. It was shown that parameter oscillates at applied bias increasing. It explains by the presence of the alternate areas with the high and low tunneling transparency, where tunneling electrons layers exist. This area burst because of the changing of the Fermi quasi-layer position and generation of the additional tunneling channels in two-band wide gape semiconductor. Oscillation of the transmission coefficient sustain phase and amplitude changings, При этом осцилляции коэффициента прохождения претерпевают фазовые и амплитудные изменения, conditioned by the height and thickness of the WGS potential barrier. Represented dependencies of the TMR from the applied bias are explained by the combination spin polarization of the tunneling electrons and non-monotonous dependence transmission coefficient from energy.

REFERENCES

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