2015 IEEE International Magnetics Conference, INTERMAG 2015, 2015

Tunnel magnetoresistance in magnetic tunnel junctions with embedded nanoparticles

Useinov A., Useinov N., Ye L., Wu T., Lai C.
Kazan Federal University, 420008, Kremlevskaya 18, Kazan, Russia

Abstract

© 2015 IEEE. We present a theoretical simulation to calculate the tunnel magnetoresistance (TMR) in magnetic tunnel junction with embedded nano-particles (npMTJ). The simulation is done in the range of coherent electron tunneling model through the insulating layer with embedded magnetic and non-magnetic nano-particles (NPs). We consider two conduction channels in parallel within one MTJ cell, in which one is through double barriers with NP (path I in Fig. 1) and another is through a single barrier (path II). The model allows us to reproduce the TMR dependencies at low temperatures of the experimental results for npMTJs [2-4] having in-plane magnetic anisotropy. In our model we can reproduce the anomalous bias-dependence of TMR and enhanced TMR with magnetic and non-magnetic NPs. We found that the electron transport through NPs is similar to coherent one for double barrier magnetic tunnel junction (DMTJ) [1]; therefore, we take into account all transmitting electron trajectories and the spin-dependent momentum conservation law in a similar way as for DMTJs. The formula of the conductance for parallel (P) and anti-parallel (AP) magnetic configurations is presented as following: $Gs^{P(AP)}$ = G0σk F, $s^2/4\pi \int$ Cos (θs) $Ds^{P(AP)}$ Sin(θ)dθsd, where Cos(θs) is cosine of incidence angle of the electron trajectory θs, with spin index s=(↑,↓), kF, s, is the Fermi wave-vector of the top (bottom) ferromagnetic layers; for simplicity the top and bottom ferromagnetic layers are taken as symmetric; $G0=2e^2/h$ and σ is area of the tunneling cell. The transmission probability $Ds^{P(AP)}$ depends on diameter of NP (d), effective mass m and wave-vector of the electron kNP attributing to the quantum state on NP (corresponding to the k-vector of the middle layer in DMTJs [1], and which is affected by applied bias V). Furthermore $Ds^{P(AP)}$) depends on Cos(θs), kF, s, barriers heights U1,2 and widths L1,2, respectively. The exact quantum mechanical solution for symmetric DMTJ was found in Ref.[1]. Here we employ parallel circuit connection of the tunneling unit cells, where each cell contains one NP with the average d less than 3 nm per unit cell's area (σ =20 nm^2), while tunnel junction itself has surface area S and consists of N cells (N=S/σ). The total conductance of the junction is G = Nx (G1↑+G2↑+G1↓+G2↓), where G1, s is dominant conductance with the NP (path I), G2, s is conductance of the direct tunneling through the single barrier (path II), and $TMR=(G^P-G^{AP})/G^{AP} \times 100\%$.

http://dx.doi.org/10.1109/INTMAG.2015.7157345