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Tunnel magnetoresistance in asymmetric double-barrier magnetic tunnel junctions

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ABSTRACT

The spin-polarized tunnel conductance and tunnel magnetoresistance (TMR) through a planar asymmetric double-barrier magnetic tunnel junction (DBMTJ) have been calculated using quasi-classical model. In DBMTJ nanostructure the magnetization of middle ferromagnetic metal layer can be aligned parallel or antiparallel with respect to the fixed magnetizations of the top and bottom ferromagnetic electrodes. The transmission coefficients of an electron to pass through the barriers have been calculated in terms of quantum mechanics. The dependencies of tunnel conductance and TMR on the applied voltage have been calculated in case of non-resonant transmission. Estimated in the framework of our model, the difference between the spin-channels conductances at low voltages was found relatively large. This gives rise to very high magnitude of TMR.

1. Introduction

Spin-polarized conductance and tunnel magnetoresistance are two striking effects in layered nanostructures where metallic ferromagnetic layers are separated by thin insulating barriers. If thickness of a layered nanostructure is comparable with the mean free path of conduction electrons, conditions of ballistic transport are satisfied, and mutual quantum-mechanical penetration of magnetism of the adjacent layers becomes important. As a result, nanoscale ferromagnet-insulator heterostructures acquire unusual properties which can find useful practical applications [1]. The ways to get functionality in heterostructures are to manage transport properties by means of non-uniform magnetism and/or applied voltage. High TMR, desired for magnetic read heads or sensors, is achieved using single MgO barrier, however, it drops steeply with increasing the bias voltage, which limits its application in the high bias-voltage region.

Double-barrier magnetic tunnel junctions were studied theoretically and experimentally as well with a special emphasis to quantum well (QW) states in the middle metallic layer [2–8]. It was argued that there QW states may enhance TMR significantly at resonant voltages. In our paper we develop a theory of spin-dependent transport and tunnel magnetoresistance in asymmetric planar double-barrier magnetic tunnel junctions. We apply our model at non-resonant regime of conductance to explain experimental observation of ~200% values of the TMR in DBMTJs.

1.1. Model of asymmetrical double-barrier magnetic tunnel junction

As shown in Fig. 1, the double-barrier structure consists of three planar ferromagnetic layers of thicknesses t, m and b, respectively, separated by two nonmagnetic insulators of thicknesses t_1 and t_2 of around dozen of angstroms. This makes up three-dimensional model of the double-barrier magnetic tunnel junction $FM^t/I_1/FM^m/I_2/FM^b$. Typical examples for the constituents of the junction are Co, CoCr, CoFeB, Fe, and NiFe for ferromagnets, and Al_2O_3 and MgO for insulating nonmagnetic barriers. Note that in this paper we assume FM^m layer having lower coercivity compared with the FM^t and FM^b layers. If the voltage is applied to the nanostructure $FM^t/I_1/FM^m/I_2/FM^b$ the spin-polarized tunnel conductance arises. This conductance is induced by quantum tunneling through the barriers. It is very small and decays exponentially with increasing the thickness of the insulators. The FM^m layer can be considered as a quantum well. Then, the motion of electrons in the FM^m layer is quantized. For some parameters of the structure $FM^t/I_1/FM^m/I_2/FM^b$, the resonant conditions can be fulfilled. Then, the spin-polarized tunneling conductance rapidly increases at specific values of the applied voltage. Since the magnetization direction of the FM^m layer can be easily changed (for example, in the case of a soft magnetic alloy), it takes either parallel (P) or antiparallel (AP) alignment with respect to the magnetization direction of the FM^t and FM^b electrodes. Now, if the system is transformed by an external magnetic field from the state with

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