Thin Solid Films 519 (2011) 2193–2200

Contents lists available at ScienceDirect

Thin Solid Films

journal homepage: www.elsevier.com/locate/tsf

The interfacial roughness effect on spin-dependent transport in nonplanar junctions with double magnetic barriers

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ARTICLE INFO

Article history:
Received 12 January 2010
Received in revised form 4 November 2010
Accepted 5 November 2010
Available online 12 November 2010

Keywords:
Spin polarized transport
Tunneling
Magnetic tunnel junctions
Interface roughness
Transfer matrix
Ferromagnetic semiconductor

ABSTRACT

In this paper, we use the transfer matrix method to study the effect of roughness with nonplanar interfaces on spin-dependent transport properties in a magnetic tunnel junction, which consists of two ferromagnetic semiconductor barriers separated by a nonmagnetic (NM) layer. This trilayer is sandwiched between two NM electrodes. The roughness is modeled as a periodic corrugation interface. Based on the effective mass approximation, the spin-dependent transmission probability, and also the dependence of tunnel magnetoresistance (TMR) and electron spin polarization (SP) on the center nonmagnetic layer quantum well width are studied, theoretically, at several different temperatures. The numerical results show that the SP and TMR have an oscillatory behavior as a function of NM layer thickness and the interface roughness/islands degrade the transmission probability. Our results may be useful for the development of nanoelectronic devices.

1. Introduction

In the past few years, spin-dependent transport in magnetic tunnel junctions (MTJs) has opened the field of spintronics, which involves the study of active control and manipulation of electron spin and charge degrees of freedom [1–3]. A common MTJ consists of two ferromagnetic (FM) material separated by a thin nonmagnetic (NM) insulator spacer, in which the insulating spacers increase the resistance of the structure to the order of megaohms. This is known as tunneling magnetoresistance (TMR) effect. The TMR effect was first expressed by Julliére in 1975 [4] and describes the change in resistance as the magnetic alignment of the magnetic electrodes switches between parallel and anti-parallel. The effect was explained in terms of the spin polarization (SP) extracted of spin-split density of states in the electrodes [1,5]. During recent years, the large magnetoresistance of MTJs has attracted much attention due to the possibility of its application in magnetic random access memory, magnetic field sensors and quantum computing devices [6–8]. In general, the transport properties in the MTJs depend on the properties of the potential barrier height, the barrier thickness, the interfacial roughness and the types of disorder in the barrier, which affects TMR in a critical way [9–13]. Also, the effect of the disorder on oscillatory conductance and TMR due to quantum well has been studied within the single site coherent potential approximation and the tight-binding model for FM/I/NM/FM junctions [14].

The interface roughness which is inevitable in all surfaces, leads to fluctuations in the barrier thickness that strongly alter the tunneling transmission. Some researchers have used the X-ray diffraction and cross-sectional transmission electron microscopy for measurement and receive the information about the roughness [15]. In order to study the effect of interface roughness on the tunneling of electrons and holes, the photoluminescence technique is used in quantum wells [16]. Gobato et al. have implied that typical quantum well photoluminescence spectra present a splitting attributed to the growth island formation in the quantum well [17]. Experimentally, it has been observed that the TMR depends critically on the conditions of preparation of the tunnel barrier, in particular on the interface roughness between the metal and the barrier layer. However, in the MTJs, the scattering due to scattering potential at the interface (especially the interfacial roughness) have definitely a strong influence on the spin-dependent tunneling currents and TMR.

Among several methods which have been used to model the interface roughness, the transfer matrix method is the usual method [18,19]. Björn and Rudberg have showed that the roughness gives rise to a small asymmetry in the current–voltage using a perturbation theory and the Golden Rule [20]. In some works, the tight-binding model Hamiltonian has been used in the nearest-neighbor approximation [21,22]. In this method which is used in heterostructures, somewhat the spatially varying of effective mass is considered [23]. In

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0040-6090/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.tsf.2010.11.010