Spin related phenomena in (Ga,Mn)As-based heterostructures

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An empirical tight-binding (TB) model was developed to describe the results of recent experiments: the interlayer exchange coupling (IEC) in (Ga,Mn)As-based trilayers and superlattices [1], the high tunneling magnetoresistance (TMR) in (Ga,Mn)As-based trilayers [2] and highly polarized spin injection (about 80%) in p-(Ga,Mn)As/n-GaAs Zener diode [3]. The TB approach is particularly well suited for these interface phenomena, because it takes automatically into account the asymmetry terms. For Ga and As ions we take sp3d5s* orbitals with the spin-orbit interactions. The used parameterization reproduces correctly the band structure and effective masses in GaAs [4]. To describe the (Ga,Mn)As magnetic structure within the virtual crystal and mean field approximations, the exchange integrals determined by bands' spin-splittings are included.

In order to describe the IEC in the (Ga,Mn)As-based SL, we built a tight-binding model in the spirit of the approach which has been used to explain IEC observed in other semiconductor magnetic multilayers, i.e., the antiferromagnetic (AFM) EuTe- and FM EuS-based SL [5]. The model is applied to the structures studied experimentally in Refs [1]. In qualitative agreement with the experiment, the obtained IEC for these structures is, in principle, FM. and decreases with the thickness of nonmagnetic layers, [6]. Importantly, our study indicates that in (Ga,Mn)As-based heterostructures also the AFM coupling could be achieved by a proper choice of constituent materials and an appropriate engineering of the SL (Fig. 1).

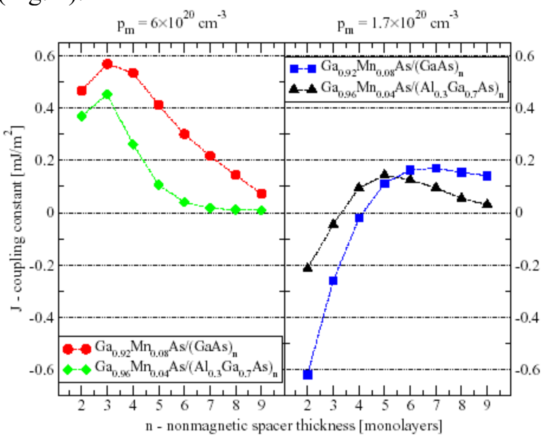

Fig. 1. Conditions for AFM interlayer coupling in GaMnAs-based semiconductor superlattices.

The tunneling current in the Zener and TMR structures is calculated using Landauer-Buettiker formalism combined with the TB matrix method. In this model we ignore the bending of the bands at the interfaces. In Zener structure the bending is, however, partially simulated by adding a thin GaAs spacer. For the Zener diode, the model leads to the spin current polarization of about 60% [7], which compares well with the observed in [3] values. The dependence of the polarization on applied bias is also described correctly (Fig. 2a). The calculated TMR ratio (about 300%) in the (Ga,Mn)As trilayer [8] agrees with the results of [2]. Our results explain not only the large values of TMR but also its strong decrease with the applied bias (Fig. 2b).

Moreover, prompted by experimental results on resonant tunneling (RTD) [9], and anisotropic magnetoresistance (TAMR) [10], we describe the applicability of our theory to asses the magnitude as well as angular dependence of the spin current in these devices. In particular, we present the dependence of resonant tunneling spectra on structure architecture such as the width of the layers. The model predicts the TAMR effect to be weak (less than 10%) as long as the hole concentration is large ($p > 10^{20}$ cm^{-3}). For smaller hole concentrations the model leads to very high anisotropy of TMR, *e.g.* for p=10^{19} cm^{-3} ca 200% though one could expect a perturbation from hole localization in this regime.

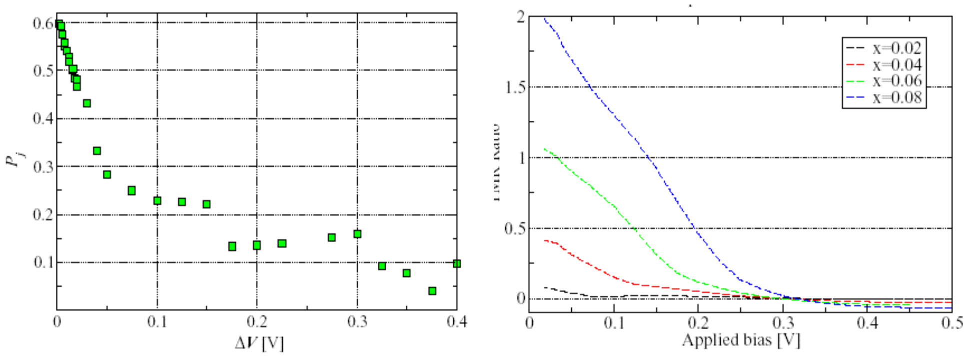

Fig. 2. The bias dependence of a) spin polarization of the tunneling current in a p-GaMnAs/n-GaAs Zener diode; b) TMR in $Ga_{1-x}Mn_xAs$/GaAs/ $Ga_{1-x}Mn_xAs$ structures with various x.

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