Magnetocurrent Anisotropy of (Ga,Mn)As/GaAs Esaki Diodes

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The magnetic anisotropy of (Ga,Mn)As has been intensively studied for the last years and this phenomenon has been comprehensively understood [1-3]. The application of (Ga,Mn)As as a heavily p-doped part of Esaki diode gives new possibilities of studying and tailoring its magnetic anisotropy [4,5] due to voltage-controlled scanning of the tunneling densities of states. As it has recently been shown, tunneling anisotropic magnetoresistance for forward bias shows biaxial anisotropy, in the band-to-band tunneling regime, whereas uniaxial anisotropy is observed when excess current prevails [6]. In this paper, we present the studies of Esaki diode under reverse bias, where new interesting observations were made.

We have measured current passing through Esaki junction as a function of magnetic field for different values of temperature and voltage bias. Magnetic field was applied in two configurations: 1) perpendicularly to the sample plane, i.e. along hard axis of magnetization and 2) in the sample plane, where a sample rotation allowed to cover full azimuthal angle.

We have observed very peculiar variation of the out-of-plane magnetocurrent ($MI_{out} = I(B_{out})/I(B = 0) - 1)$) as a function of temperature and voltage bias. At low temperature MI_{out} was positive, for higher temperatures it successively decreased, changed sign, reached minimum and finally it disappeared for temperatures in the vicinity of the Curie temperature (T_C). The low temperature part showed bias dependence, whereas starting from the temperature at which the minimum of MI_{out} was observed up to the T_C, magnetocurent did not depend on voltage bias (although the values of current did).

Such temperature variation is unexpected, as at the reverse bias electrons from (Ga,Mn)As valence band tunnel into GaAs conduction band states and those states are hardly altered by temperature. This effect could be related to reorientation of the in-plane magnetic easy axis, documented by SQUID measurements. Therefore we have systematically studied the changes of the current as a function of angle beetween the magnetic field and [100] axis of (Ga,Mn)As in the in-plane configuration. In the current dependence on azimuthal angle two apparently independent sets of maxima were observed, both showing uniaxial symmetry, but different temperature variation. Their amplitude was bias- and magnetic field-sensitive. We have applied the Stoner-Wohlfarth model to find anisotropy constants as a function of temperature and bias. We discuss possible origin of the observed peculiar current evolution.

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