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Quantum oscillation of TMR in tunneling junctions containing a non-magnetic spacer

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Abstract

In tunneling junctions containing a nonmagnetic spacer, a clear oscillation of tunneling magnetoresistance with respect to the spacer thickness has been observed recently. By using a simple tight-binding model and linear response theory, we show that the amplitude of the oscillation decreases in exponential with increasing spacer thickness and the rate of the decrease becomes larger as the mean free path of the spacer becomes shorter.

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Interfacial electronic structure of ferromagnetic tunneling junctions is an important ingredient for the tunnel magnetoresistance (TMR). Numerous experimental attempts have been made to show how TMR is affected by the spacer inserted at the interface of the junctions.

Recently, a clear oscillation of TMR with respect to Cu layer thickness has been observed in high-quality Co/Cu/Al_2O_3/NiFe junctions [1]. The characteristic features of the oscillation are (i) TMR ratio oscillates around zero, (ii) the period of the oscillations is determined solely by the Fermi wave vector of Cu, and (iii) the amplitude of the oscillation decays with increasing Cu thickness.

The purpose of our work is to give a theoretical explanation for the characteristic features of the observed oscillation in TMR by treating both the coherence of the electron and the effect of disorder properly. In our previous work [2], we have shown that new conduction mechanisms (momentum selection due to the insulating barrier and new conduction channel via quantum well states due to the disorder) are essential to explain experimental results. In this contribution, we clarify how impurity scattering in the nonmagnetic spacer affects the amplitude of the oscillation.

We consider a FM/I/NM/FM junction and adopt a single orbital tight-binding model, where FM, I, and NM are ferromagnetic lead, insulating barrier, and nonmagnetic spacer, respectively. By considering the electronic structure of Co and Cu, we choose parameters so that the quantum well is formed at NM for minority spin states. We treat disorder in amorphous Al_2O_3 simply as on-site potential randomness. Conductances G_P and G_{AP} for parallel and antiparallel alignments of magnetizations are calculated using the Kubo formula and CPA with vertex corrections [3,4]. TMR ratio is defined as $MR \equiv (G_P - G_{AP})/G_P$.

In Fig. 1, we first show results of TMR ratio in the absence of impurities in NM, i.e., the mean free path λ_{NM} of NM is ∞. TMR ratio is calculated for both junctions without and with disorder in I. In the clean junction, TMR ratio oscillates around a finite value with periods given by the cut-off k-point [5] and the Fermi wave vector k_F of NM. On the other hand, in the disordered junction, TMR ratio oscillates around zero

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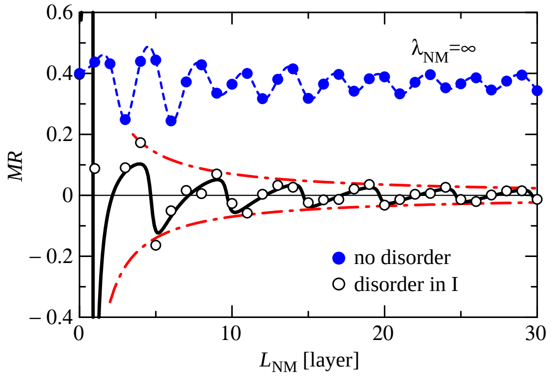

Fig. 1. TMR ratio calculated for clean (solid circles) and disordered (open circles) junctions. Solid curve is obtained by the stationary phase approximation. Chained curves denote $1/L_{\rm NM}$-dependence.

with $k_{\rm F}$-period. This result is qualitatively consistent with experimental results [1]. Physical mechanisms for vanishing of the average TMR ratio and selection of $k_{\rm F}$-period due to the disorder are fully explained in Ref. [2].

From the fact that the stationary phase approximation [6] describes the obtained TMR ratio in Fig. 1, we can see that the amplitude of the oscillation is inversely proportional to $L_{\rm NM}$. The experimental results, however, indicate a much faster decrease of the oscillation amplitude [1].

We, therefore, introduce impurities in NM layer and study how the amplitude of TMR oscillation is affected by the impurity scattering. By changing the impurity potential, we calculate the conductance for several values of $\lambda_{\rm NM}$. In Fig. 2, obtained results of TMR ratio are shown. The amplitude of the oscillation becomes small with decreasing $\lambda_{\rm NM}$. This is because the impurity scattering breaks interference effects caused by the quantum well at NM. We found that the amplitude can be fitted well by $1/L_{\rm NM}\exp(-L_{\rm NM}/\lambda_{\rm NM})$ except for thin NM layer region. By fitting experimental data [1] using this expression, we estimated the mean free path of Cu in the junction to be ~ 20 Å, which is consistent with a theory based on the Boltzmann equation [7].

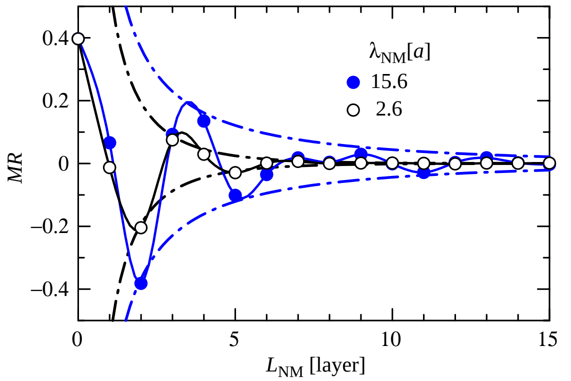

Fig. 2. TMR ratio calculated for junctions with disorder in both I and NM. Solid and open circles are results for $\lambda_{\rm NM} = 15.6a$ and $2.6a$, respectively. Chained curves denote $1/L_{\rm NM}\exp(-L_{\rm NM}/\lambda_{\rm NM})$-dependence.

In summary, we have studied how the impurity scattering in NM affects the amplitude of the TMR oscillation in FM/I/NM/FM junctions. It has been shown that the amplitude of the oscillation decreases as $1/L_{\rm NM}\exp(-L_{\rm NM}/\lambda_{\rm NM})$.

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