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Studies of Magnetoresistance Effects in the Trilayer Junctions with Semi-Metallic Bismuth as Spacer Layer

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Since the discovery of giant magnetoresistance effect (GMR) in magnetic multilayers [1] separated by non magnetic metallic spacer layer have attracted a great deal of attention due to its diverse technological applications. The amplitude of the magnetoresistancedepends upon the exchange coupling between the ferromagnetic layers and the type of exchange coupling. The sign of exchange coupling is oscillating between ferromagnetic and antiferromagnetic with the progressive increase of spacer thickness up to 2~3 nm order. In the past, the investigations of new-type MR were limited to the samples with metal, insulator or semiconductor as the spacer material. Up to now there is no report using the semimetal as the spacer. Especially in our previous magnetic studies the trilayers with bismuth as a spacer layer exhibit oscillatory type exchange coupling with a very long period due to long Fermi wavelength of Bi [2]. Besides, an anomalous temperature dependence of interlayer exchange interaction has been observed [3]. Therefore, a detailed study of MR effect with semimetal Bi spacer is helpful to better understand the spin-dependent transport behaviors. In this work we investigated the magnetoresistance effect of NiFe/FeMn/NiFe/Bi/CoFe spin valves and varied the thickness of the semimetal (Bi) spacer layer to determine the contribution from Bi. The films with the structure of NiFe/FeMn/NiFe/Bi/CoFe was deposited by dc sputtering at room temperature. NiFe/FeMn/NiFe (seed layer/antiferromagnetic layer/ferromagnetic layer) trilayer structure has been widely used in the spin valve systems. The ferromagnetic electrode thickness was fixed to 15 nm and thickness of spacer layer Bi was varied between 1 to 60 nm. The contact masks were used to prepare the junction. The MR effect was determined by a conventional four-probe method. The dependence of MR effect on Bi thickness will be reported and discussed. Furthermore, the samples has been treated with post-annealing under different annealing conditions. This is because the low melting point of Bi enable to modify the interface of Bi/ferromagnetic layers easily so that the correlation of microstructure with MR effect can bestudied.

Acknoledgement
This work was supported by the National Science Council, ROC under Grant No. NSC95-2110-M002-002.

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A Theory of Temperature Dependence of Resistivity in Magnetic Semiconductors

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The coupling of conduction electrons with localized spins gives rise to a rich variety of transport properties, including the Kondo effect, critical scattering near the Curie temperature (T_C) in ferromagnets, and magnetoresistance (MR) in perovskite manganites and magnetic semiconductors.

Diluted magnetic semiconductors such as (Ga-Mn)As exhibit a peak in the electrical resistivity ρ near T_C [1], which may be attributed to the critical scattering of electrons by localized spins. It was argued before that the effect of the spin flip of localized spins caused by the scattering of conduction electrons may extend to an infinite distance due to the critical slowing down of spin fluctuations near T_C. As a result, ρ diverges at T_C in proportion to the magnetic susceptibility. This argument was modified such that the propagation of the effect of spin flip may be restricted to the length scale of the mean free path, leading to finite resistivity at T_C. The resistivity caused by the critical scattering may thus be crucially influenced by the presence of the other source of resistivity, impurities, phonons etc.

In diluted magnetic semiconductors may include, in addition to localized spins of magnetic ions, random potentials caused by impurities themselves and/or by imperfection of lattice structure. It raises an issue how much ρ due to the critical scattering is affected by a presence of random impurities. We will study the issue by calculating the self-energy of conduction electrons taking into account both spin flip scattering caused by a coupling between conduction electron spins and localized spins and spin-conserved scattering by impurities.

The self-energy of the conduction electrons has been calculated by applying the coherent potential approximation (CPA) to the random potentials due to impurities, and the Born approximation to the spin flip scattering. The formulation gives an important result that the self-energy due to spin flip scattering includes the effect ofrandom potentials. Since the self-energy is related to the life-time, we may estimate ρ adopting the Drude formula.

Numerical solution of the self-energy gives following results. 1) The magnitude of ρ due to critical scattering decreases as expected with increasing the magnitude of the random potential, however, the total ρ usually increases. 2) However, when the critical scattering is strong, the total ρ may decrease with increasing random potentials.

By adopting suitable parameter values for (Ga-Mn)As, $\rho(T)$ has been calculated, and the results are compared with experimental ones. A qualitative agreement between theoretical and experimental results has been obtained, however, the magnitude of ρ calculated is smaller by one order of magnitude, which may be attributed to a difference between carrier concentration used in the calculation and in the experiment.

We acknowledge financial support from the Next Generation Super Computing Project, Nanoscience Program, and the 21st Century COE Program "Frontiers of Computational Science".

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