Three-dimensional mapping of the anisotropic magnetoresistance in Fe single crystal thin film

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Anisotropic Magnetoresistance (AMR) in ferromagnet is a well-known and fundamental issue which is believed to originate from spin-orbit coupling. Most of the previous works about AMR mainly focused on polycrystalline thin films, only few works studied the AMR of single crystal thin films [1]. On the other hand, Most of the previous works studied the planar-AMR with a magnetic field applied in the film plane. The spatial distribution of AMR as a function of three-dimensional (3D) magnetization orientation and its dependence on the current direction in single crystalline ferromagnetic thin films are only partly understood.

In this contribution, we investigated three-dimensional distribution of magnetoresistance (MR) as a function of orientation of the magnetization in single crystalline Fe (001) film at 300k. A Fe (001) film with thickness of 50nm was epitaxially grown on single crystalline MgO (001) substrate using molecular beam epitaxy (MBE). In order to study the influence of current direction on the anisotropic behavior of MR, we patterned two Hall bars using photolithograph with current (I) directions along [010] and [110] direction of iron (001) film, respectively. Magnetoresistance was measured using commercial physical properties measurement system (PPMS) with a fixed-magnitude magnetic field applied along arbitrary directions with respect to the crystal axis. The orientation of magnetic field was transformed to that of magnetization (M) by considering the demagnetizing effect. The 3D-AMR as a function of the orientation of M (under 6T magnetic field) is shown in figure 1 for two current directions. The AMR is defined as:AMR $= (\rho - \rho_{min})/\rho_{min}$, ρ_{min} is the minimum value among spatial resistivity. It's clear that the 3D distribution of AMR shows strong anisotropy for both current directions. A minimum AMR was found when M oriented in the film plane and being perpendicular to the current direction. On the other hand, the current direction affects the magnitude and symmetry of 3D-MR, the maximum AMR ratio for [110] direction current (~0.67%) is larger than that for the [010] direction current case (~0.36%).

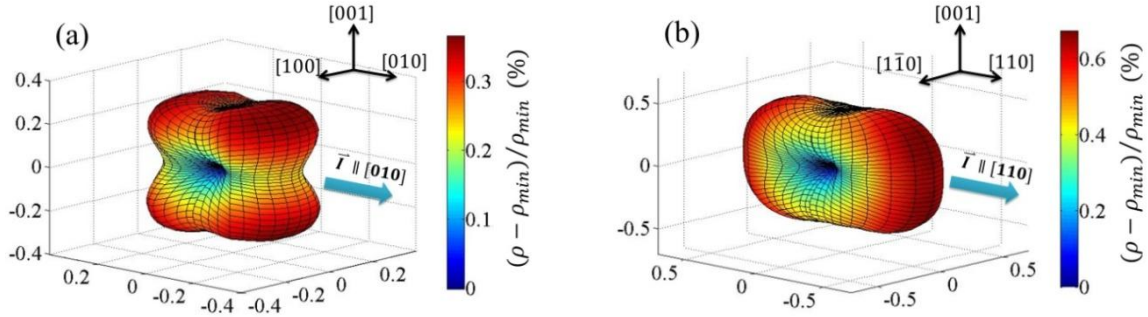

Figure1. Three-dimensional MR mapping of epitaxial Fe film with current along (a) [010] direction and (b) [110] direction. The black arrows indicates crystal axis.

Another interesting feature of AMR is the field dependence behavior. An almost linear and non-saturating negative MR was found under specific-direction-applied high magnetic field at high temperature in single crystal ferromagnetic thin films by other researchers [2]. However, it's still not clear that whether this linear-decreasing MR dependent on magnetization orientation relative to crystal axis or not. So we did the 3D-MR mapping measurements under high magnetic field from 4T to 9T at room temperature. For certain magnetization orientation, we can get the resistivity slope through linear fitting every field-dependent MR, the slope give us information about the response of the electron-magnon scattering to external magnetic field at certain orientation of M. Our analysis indicates that the resistivity slope also show dramatic anisotropy when M oriented along different directions in the space, and this behavior is also current direction dependent, the linear-decreasing-MR slope is maximum when M parallel to the current direction for both current-direction cases.

In summary, we found that both the magnetization spatial orientation and current direction have significant influence on the three-dimensional distribution of AMR for 50nm-thick epitaxial Fe (001) film at room temperature. For further understanding, the thickness and temperature dependence of AMR in epitaxial iron film will be investigated in the future.

References:

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