Observation of Rashba magnetoresistance in metal films on magnetic insulators

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In the metallic thin films, the physical properties, such as resisitivity, behave very differently from that in bulk due to the interfaces. The Boltzmann method is a semiclassical decription applied in the metal with thickness range from ultrathin films to bulk.[1-3] For ultrathin Cu films, we make a smart quantum modification in the Boltzmann equation numerical process and obtain excelent agreement with the experimental data [4-5], as well as the theory [6]. A new type of magnetoresistance (MR) effect is observed in a bilayer structure Cu[Pt]/$Y_3Fe_5O_{12}$ (YIG), where the Cu/YIG interface is decorated with Nano size Pt islands. With the interface Rashba effect [7], we reproduce the Rashba magnetoresistance[7].

Basic Boltzmann equation:

Generalized spin dependent Boltzmann equation[1-3]

$$\mathbf{v}_0(\mathbf{k})\cdot\frac{\partial f_\alpha(\mathbf{r},\mathbf{k})}{\partial \mathbf{r}} - e\mathbf{E}\cdot\mathbf{v}_0(\mathbf{k})\delta_{\alpha,0} = -R_\alpha(\mathbf{k})\, f_\alpha(\mathbf{r},\mathbf{k}) + \sum_{\alpha'=0,x,y,z}\int_{\mathrm{FS}} d\mathbf{k}' P_{\alpha,\alpha'}(\mathbf{k},\mathbf{k}') f_{\alpha'}(\mathbf{r},\mathbf{k}'),$$

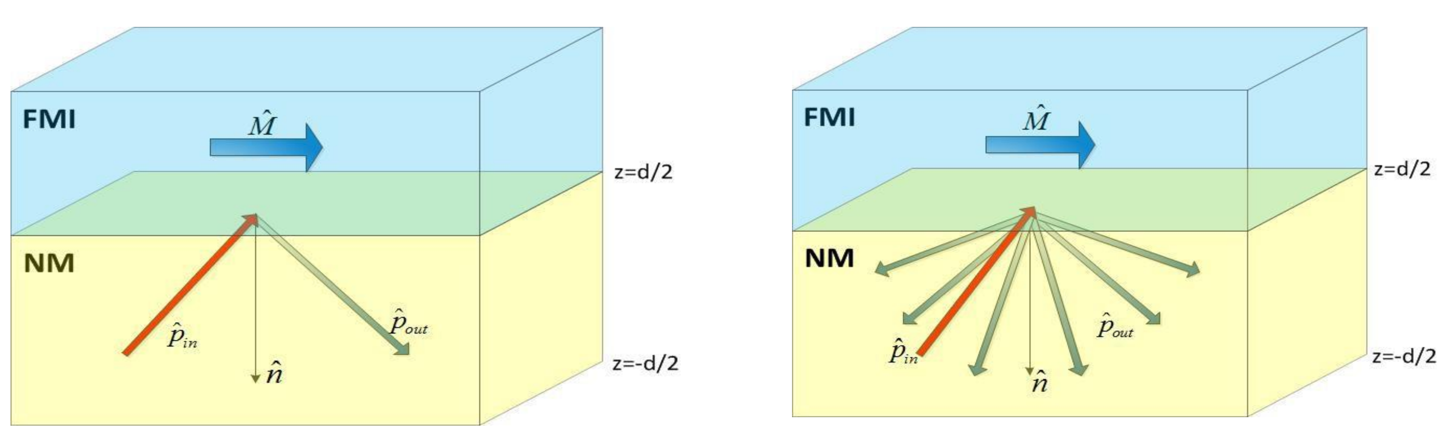
Boundary condition :

At the upper interface, the surface scattering matrix connects the impinging distribution function and the reflected distribution function:

$$f_\alpha(z_+,\mathbf{k},k_z>0) = \int_{\mathrm{FS}} d\mathbf{k}' S^+_{\alpha,\alpha'}(\mathbf{k},\mathbf{k}')\, f_{\alpha'}(z_+,\mathbf{k}',k_z'<0)$$

Similar boundary condition can be written down at the lower interface.

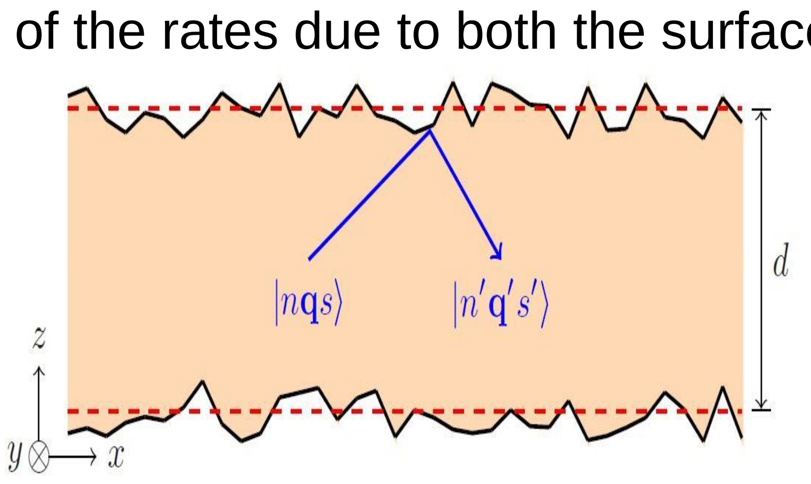
Typically, there are two types of boundary conditions, and other situation can be described as a combination of the two:

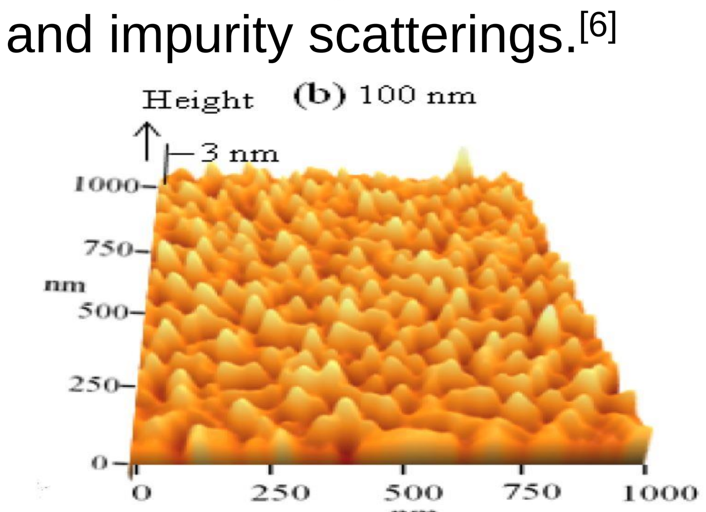


Top left is the specular process and top right is the diffusive case.

Roughness description:

We consider here that the surface roughness and the impurity distribution are uncorrelated.[6] The total scattering rate is the sum of the rates due to both the surface and impurity scatterings.[6]





$$\frac{1}{\tau_n} \equiv \frac{1}{\tau(\mathbf{k}_{m,n})} = \frac{1}{\tau_0} + \frac{n^2}{\tau'} = \frac{1}{\tau_0} + \frac{1}{\tau_n'}, \quad with\ \frac{1}{\tau'} = \frac{\delta^2}{\alpha^2}\frac{4S}{3n_c^2}\frac{E_F}{\hbar}$$

The bulk impurity relaxation time and the channel-dependent surface relaxation time is used here. And here α is the lattice constant and δ parameterizes the magnitude of the surface roughness. [6]

Rashba at interface:

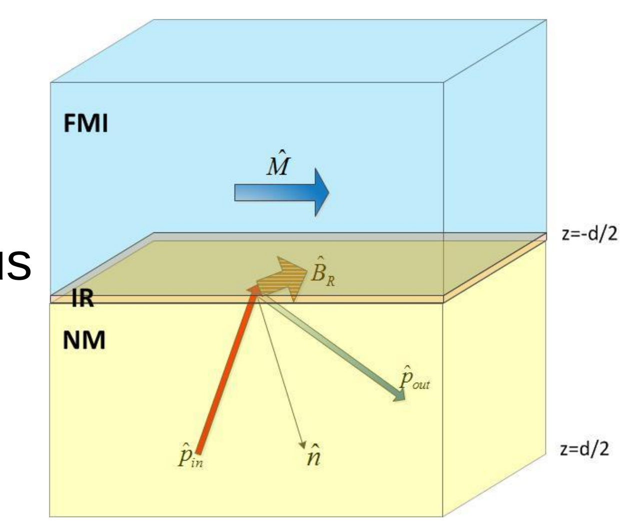
When there exists Rashba effect at Ferromagnetic insulator(FMI) side, interfacial Rashba-induced magnetoresistance will arise.[7]

Rashba at interface:

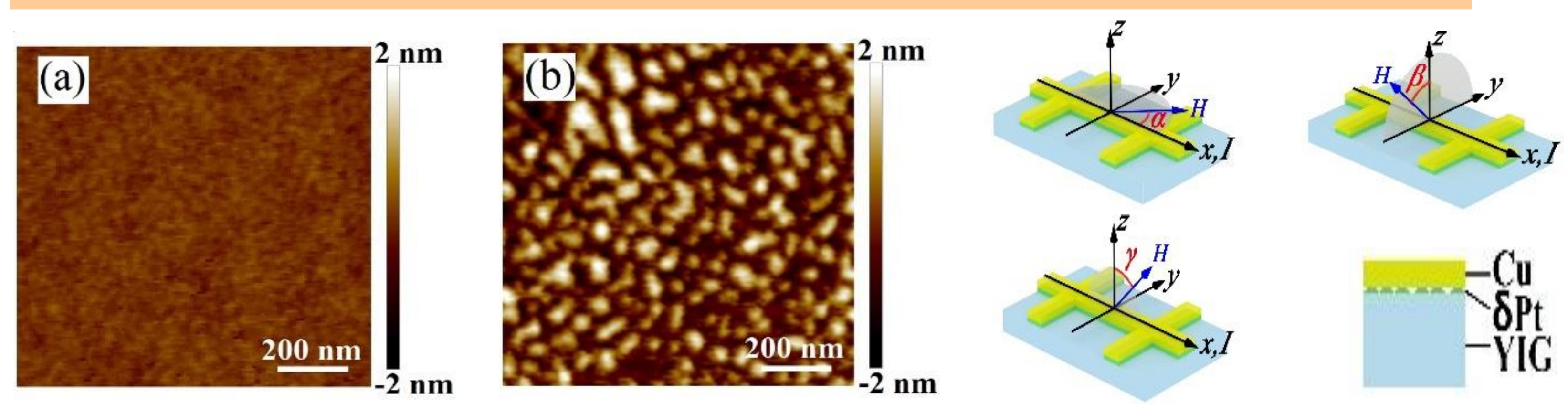
$$H_{\mathrm{R}} = \eta\hat{\boldsymbol{\sigma}}\cdot(\hat{\mathbf{z}}\times\hat{\mathbf{p}})\,\delta(z-z_+)$$

This gives rise to a spin-dependent anomalous velocity at the interface:

$$v'^{\beta}_{\alpha} = -\frac{i}{\hbar}[\mathbf{r},H_{\mathbf{R}}]_\beta\,\hat{\sigma}_\alpha = \eta\delta(z-z_+)(\hat{\boldsymbol{\sigma}}\times\hat{\mathbf{z}})_\beta\,\hat{\sigma}_\alpha \approx \eta\delta(z-z_+)(\mathbf{m}\times\hat{\mathbf{z}})_\beta\, m_\alpha$$

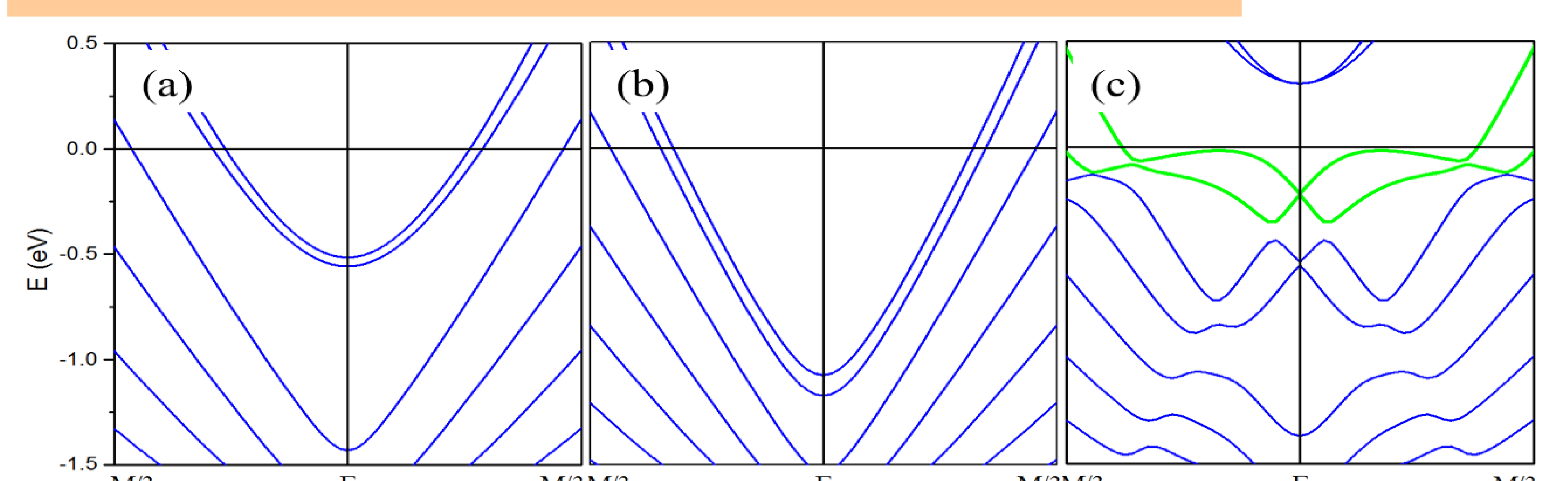


Experimental configuration of measurement:



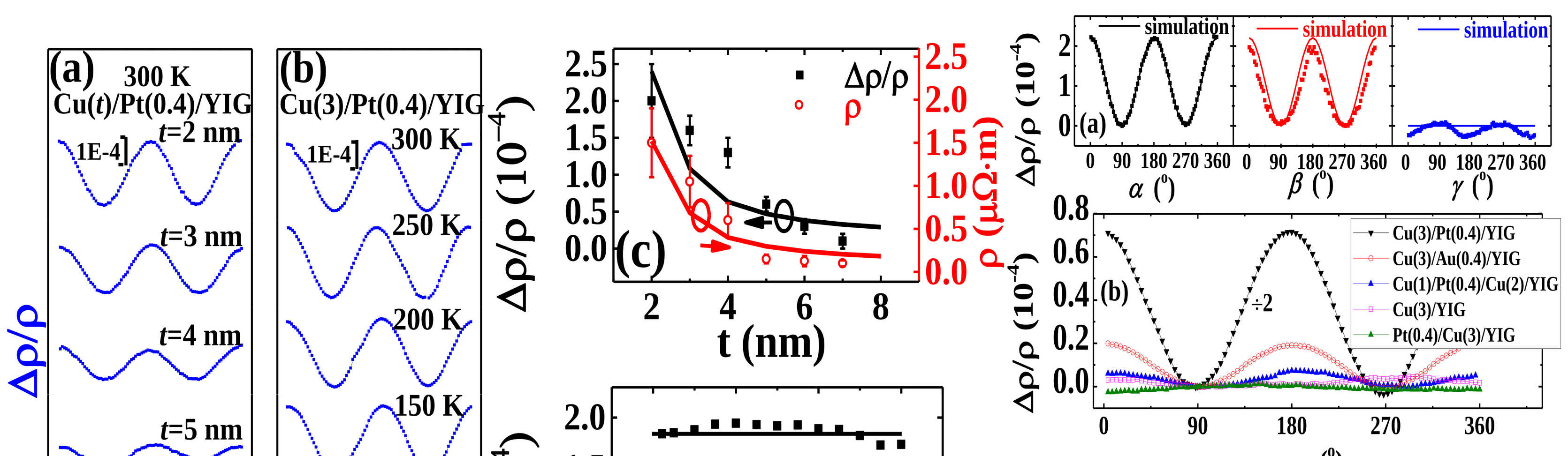
(a)AFM image of YIG(10)/GGG, the rms roughness is 0.127 nm. (b)AFM image of Pt(0.4)/YIG(10)/GGG, the rms roughness is 0.733 nm. (c)Geometric configurations of the MR measurements. The film plane defines the *xy* plane. The *x* axis is parallel to the current direction.

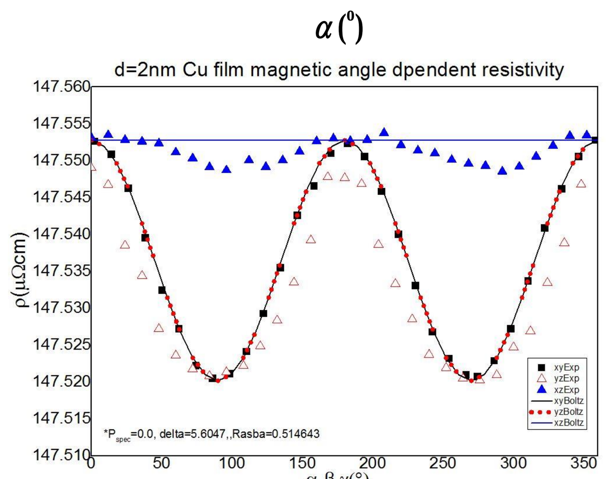
First principle calculation results:



The band structures of (a) the Cu ultra-thin film of 14 monolayers, (b) the same film covered by Au, (c) the same film covered by Pt. The bands marked by green bold lines indicate a Rashba splitting.

Boltzmann and Experimental numerical results:





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