## CU04

# Attenuated Oscillation of the Tunneling Magnetoresistance in a Ferromagnet-metal-insulator-ferromagnet Tunneling Junction

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We apply the spin-polarized free-electron model [1] to study the tunneling magnetoresistance (TMR) in a ferromagnet-metal-insulator-ferromagnet ($FM_1$-$M_2$-$I_3$-$FM_4$) tunneling junction. Firstly, our calculation shows that the effective spin polarization $P_{FM_4\text{-}I_3}$ of the $FM_4$-$I_3$ bilayer is the same as Slonczewski's, but $P_{FM_1\text{-}M_2\text{-}I_3}$ of the $FM_1$-$M_2$-$I_3$ trilayers is modified by $P_{FM_1\text{-}M_2\text{-}I_3} = P_{FM_1} \times \cos(2k_{\xi,2}t + \phi_{M_2\text{-}I_3} + \pi)$ under one reasonable approximation. The trem $P_{FM_1}$ is the spin polarization of the $FM_1$ layer, $k_{\xi,2}$ within the $M_2$ layer is the out-of-plane wave vector, $t$ is the thickness of the $M_2$ layer, and the phase change $\phi_{M_2\text{-}I_3}$ is from the phase difference between the incident and the reflected electrons at the $M_2$-$I_3$ interface. Clearly, $P_{FM_1\text{-}M_2\text{-}I_3}$, and also the TMR ratio, oscillates with the amplitude of $P_{FM_1}$ and with the period related to $2k_{\xi,2}t$. Secondly, our calculation finds that not only electrons with the out-of-plane energy $E_\xi$ close to the Fermi energy $E_F$ but also electrons with $E_\xi$ below $E_F$ can tunnel sufficiently through the $FM_1$-$M_2$-$I_3$-$FM_4$ tunneling junction. This is due to the coherence multiple reflective scatterings within the $M_2$ layer; therefore, the range of $E_\xi$ is bounded between $E_F$ and Elow. Thirdly, Fig. 1 in our calculation indicates that the out-of-plane energy dispersion $\Delta E_\xi$ of tunneling electrons both attenuate the TMR amplitude and increase the oscillatory period, which is in good agreement with the reported experimental data [2].

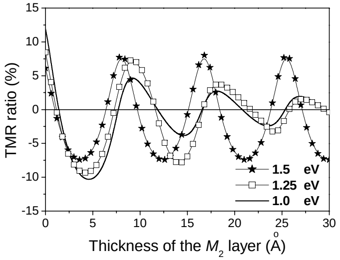

**Fig. 1.** The TMR ratios with the thickness of the $M_2$ layer in three $E_{low}$ and $E_F$=1.5 eV.

## REFERENCES

[1] J. C. Slonczewski, Phys. Rew. B 39 (1989) 6995.
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## CU05

# The Shape Dependency of Magnetic Energy Barrier in Nanostructured Magnetic Thin Film

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As the lateral dimension of the magnetic cell in the MRAM approaches to nano scale range, thermal stability ($E_M/kT$) of magnetic cell is of significant importance, as the magnetic energy barrier ($E_M$) of nanostructured cell approaches to the thermal energy ($kT$). Recently, Ikeda et al. reported the results for $E_M/kT$ in single magnetic thin films and an exchange coupled trilayer [1]. The value of $E_M/kT$ is much smaller in single magnetic thin films than that in exchange coupled trilayers. In an effort to understand the origin which causes the large difference in $E_M/kT$, we calculated $E_M/kT$ in nanostructured single magnetic thin films.

The thin films having lateral dimensions of 160 × 80 nm$^2$, which are similar to those reported in the literature, was considered [1]. The thickness ($t$) is varied within 2 to 2.5 nm. In order to consider the effect of edge rouding during fabrication, the shape of thin film was varied from the complete rectangle to complete ellipse by changing the values of $a$, $b$ ($a = 2b$) as seen in Fig. 1. The magnetic parameters used were: a saturation magnetization of 1034 emu/cc, an induced anisotropy of 10 Oe.

The results for the $E_M$ are shown in Fig. 2 as a function of $t$ and $b$. Expectedly, $E_M$ increases with increasing $t$ over the whole rangle of $b$. More importantly, there is a significant difference of $E_M$ depending on the shape of the cell. This result indicates that the $E_M/kT$ can be largely changed with fabrication process condition in the mass production. The shape dependency of $E_M/kT$ in magnetic thin film can acts as another demerit in actural device application.

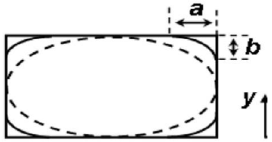

**Fig. 1.** The shape of thin films.

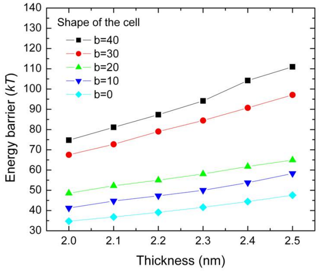

**Fig. 2.** The $E_M$ as a function of the shape and thickness of thin film.

## REFERENCES

[1] S. Ikeda *et al.*, IEEE Trans. Elec. Device. **54**, 991 (2007).