Imfact of Orange Peel Coupling on Magnetization Switching in Nanopillar

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Introduction

- Recently magnetization switching in nanopillar devices has been a continuously growing topic, because of its potential applications in ultra-high density recording media, magnetic memory devices, magnetic sensors and read / write heads etc.
- The speed of switching of magnetization in magnetic trilayers is an issue of increasing importance for applications. Magnetocrystalline anisotropy, shape anisotropy and surface anisotropy play a vital role in reducing the switching time.
- There is an important magnetostatic coupling between the ferromagnetic layers in the nanopillar due to surface roughness referred as **Neel Coupling** or **Orange Peel Coupling** which is expected to contribute to the reduction of the switching time.
- In this work, we investigate the impact of orange peel coupling on magnetization switching time in Co/ Cu/ NiFe (Py) nanopillar device.

Geometry: Co/Cu/NiFe Nanopillar

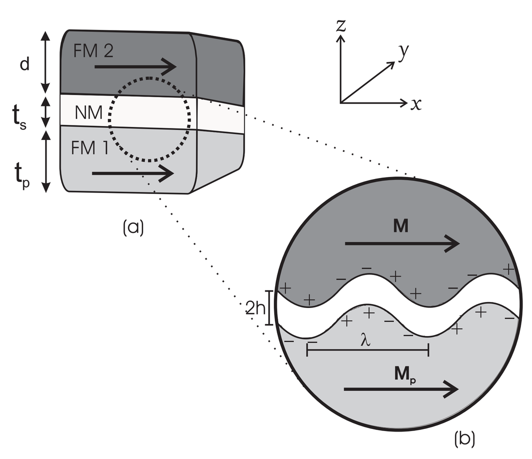

Fig.1: Schematic sketch of the Co/Cu/NiFe nanopillar device.

Magnetization Switching Dynamics

- The magnetization switching dynamics of the free layer is governed by the Landau-Lifshitz-Gilbert-Slonczewski(LLGS) equation

$$\frac{d\mathbf{M}}{dt} = -\gamma[\mathbf{M}\times\mathbf{H}_{eff}] - \frac{\alpha\gamma}{M_s}[\mathbf{M}\times(\mathbf{M}\times\mathbf{H}_{eff})] + \gamma a_j[\mathbf{M}\times(\mathbf{M}\times\mathbf{M}_p)], \quad (1)$$

where, $a_j = \frac{pJ\hbar}{\mu_0 e d M_s^2}$.

Effective field in the free layer

$$\mathbf{H}_{eff} = \mathbf{H}_{ma} + \mathbf{H}_{shape} + \mathbf{H}_{ext} + \mathbf{H}_{opc} \quad (2)$$

Magnetocrystalline Anisotropy : $\mathbf{H}_{ma} = h_a M^x \mathbf{e}^x$, where, $h_a = \frac{2k_a}{\mu_0 M_s^2}$

Shape Anisotropy : $\mathbf{H}_{shape} = -[N_x M^x \mathbf{e}^x + N_y M^y \mathbf{e}^y + N_z M^z \mathbf{e}^z]$

External Magnetic Field : $\mathbf{H}_{ext} = H_e \mathbf{e}^y$

Orange Peel Coupling Field : $\mathbf{H}_{opc} = h_n M^y \mathbf{e}^y$, where $h_n = \frac{\pi^2 h^2}{\sqrt{2}\lambda d}\exp\left(\frac{-2\sqrt{2}\pi t_s}{\lambda}\right)$

Total Effective Field : $\mathbf{H}_{eff} = h_a M^x \mathbf{e}^x - N_z M^z \mathbf{e}^z + H_e \mathbf{e}^y + h_n M^y \mathbf{e}^y$.

Numerical Results

The dimensionless LLGS equation is

$$\frac{d\mathbf{m}}{d\tau} = -[\mathbf{m}\times(h_a m^x \mathbf{e}^x + (h_e + h_n m^y)\mathbf{e}^y - N_z m^z \mathbf{e}^z)] \quad (3)$$
$$-\,\alpha[\mathbf{m}\times(\mathbf{m}\times(h_a m^x \mathbf{e}^x + (h_e + h_n m^y)\mathbf{e}^y - N_z m^z \mathbf{e}^z))] + a_j[\mathbf{m}\times(\mathbf{m}\times\mathbf{m}_p)].$$

Table: Values of various parameters

Parameters / Constants	Symbol	Value
Gyromagnetic ratio of the free electron	γ	$2.21\times10^5 mA^{-1}s^{-1}$
Polarization factor	p	0.4
Gilbert damping parameter	α	0.001
Magnetocrystalline anisotropy coefficient	k_c	$2\times10^3 Jm^{-3}$
Saturation magnetization of NiFe	M_s	$0.795\times10^6 Am^{-1}$
Thickness of the free layer	d	$4\times10^{-9}m$
Thickness of the spacer layer	t_s	$2\times10^{-9}m$
Amplitude of the interface waviness	h	$0.8\times10^{-9}m$
Wavelength of the interface waviness	λ	$40\times10^{-9}m$

Effect of orange peel coupling

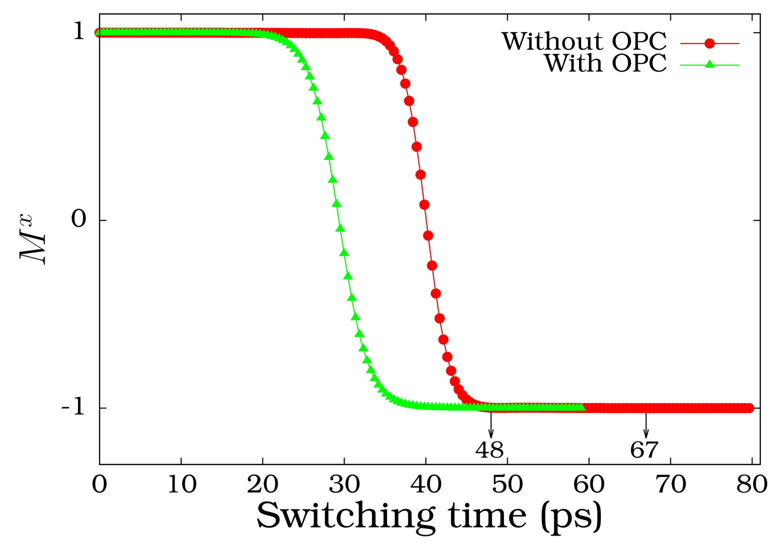

Fig.2: A plot of magnetization versus switching time for the Co/Cu/NiFe nanopillar in the presence and absence of the orange peel coupling for the applied current density $J = 4\times10^8 Acm^{-2}$. Presence of orange peel coupling reduces the switching time.

Effect of current density

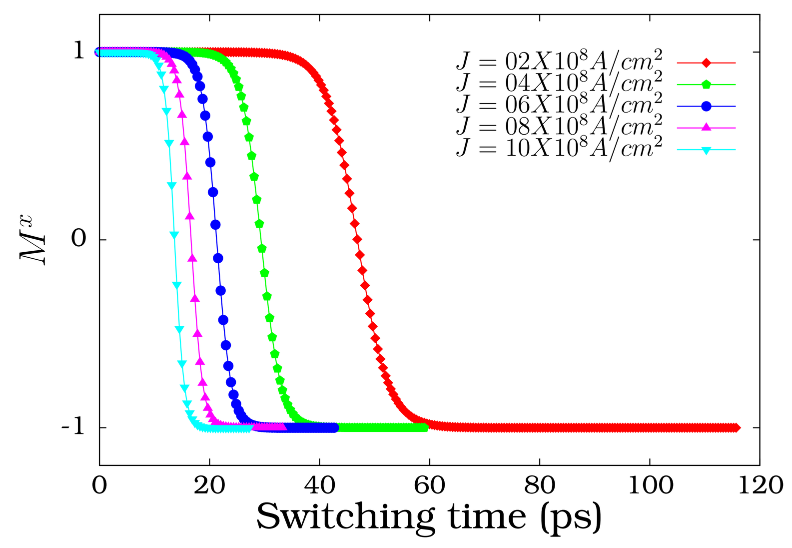

Fig.3: A plot of magnetization versus switching time for the Co/Cu/NiFe nanopillar for different current densities. The applied current density increases from $2\times10^8 Acm^{-2}$ to $10\times10^8 Acm^{-2}$ in the interval of $2\times10^8 Acm^{-2}$. Switching time decreases from 78 ps to 23 ps.

Effect of spacer and free layer thicknesses

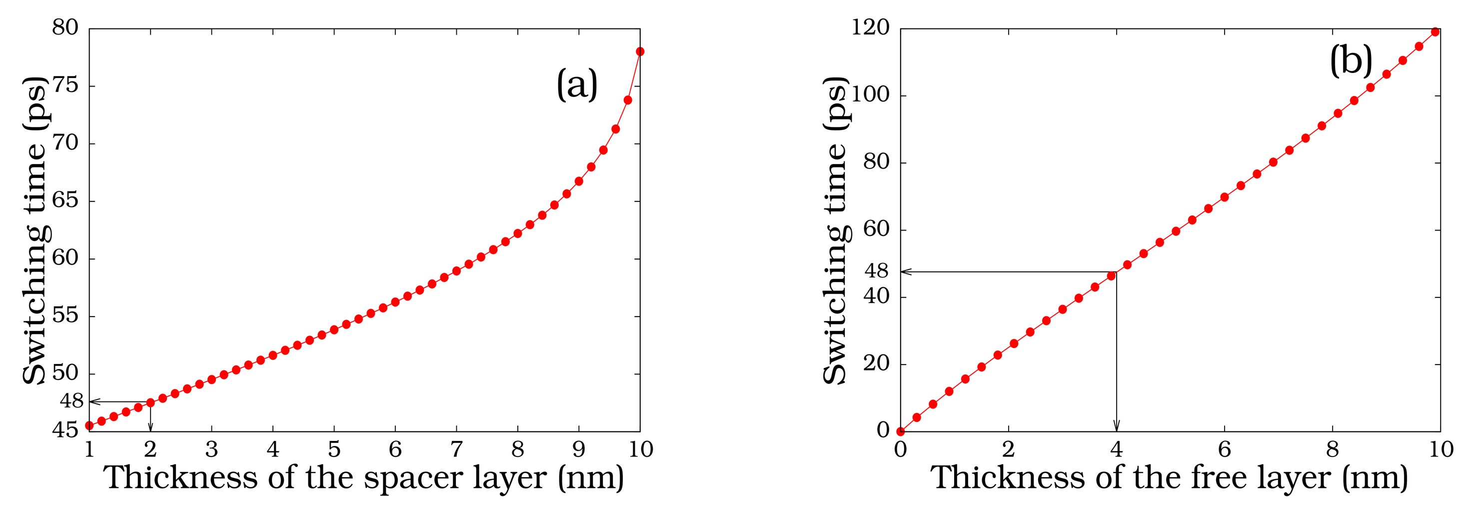

Fig.4: (a). A plot of thickness of the spacer layer versus switching time for the Co/Cu/NiFe nanopillar for the applied current density $J = 4\times10^8 Acm^{-2}$. (b). A plot of thickness of the free layer versus switching time for the Co/Cu/NiFe nanopillar for the applied current density $J = 4\times10^8 Acm^{-2}$.

Conclusions

- The spin current induced magnetization switching dynamics in Co/Cu/NiFe nanopillar with orange peel coupling is studied by solving the governing Landau-Lifshitz-Gilbert-Slonczewski equation numerically.
- The switching time of the nanopillar device reduces from 67 ps to 48 ps when there exists the orange peel coupling between the ferromagnetic layers.
- The switching time decreases, when the thickness of the spacer layer and also the free layer reduces.
- Thus, We can achieve fast switching by making the free layer and spacer layer in the nanopillar device with minimal thicknesses.

References

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