Impact of Biquadratic Coupling on Current Induced Magnetization Switching in Co/Cu/Ni-Fe Nanopillar

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Introduction

- Spin current induced magnetization switching in multilayers have found applications in microwave frequency generators, read/write heads, spin transfer torque random access memories(STTRAM) and etc.
- The speed of magnetization switching in magnetic multilayer is an important issue to develop potential applications.
- Growing ideal multilayer nanopillar without roughness is very difficult task. The resultant multilayers have certain interface roughness and they give rise to two different coupling mechanisms.
- First one is orange peel coupling which arises in situations where the spacer layer has a correlated roughness.
- Second one is biquadratic coupling (BQC) which occurs when the roughness of the free and pinned layers are uncorrelated.
- In this work, we investigate the impact of biquadratic coupling on magnetization switching time in the Co/Cu/Ni-Fe nanopillar device.

Model: Co/Cu/Ni-Fe Nanopillar

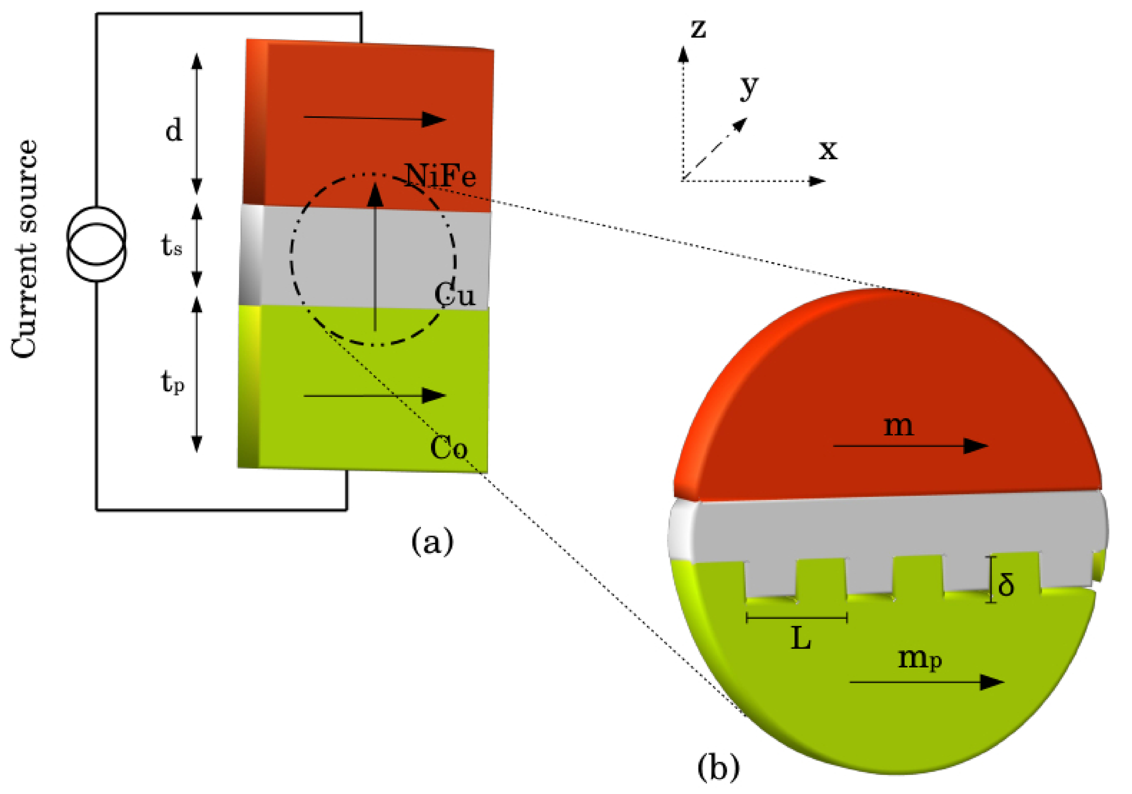

Figure: (a). Geometry of the Co/Cu/Ni-Fe nanopillar device. (b). In the zoomed view, we can see the pinned layer (Co) have the periodic interfacial terraces with a period L and a height δ.

Dynamical Equation

The magnetization switching dynamics of the free layer in the Co/Cu/Ni-Fe nanopillar is governed by the Landau-Lifshitz-Gilbert-Slonczewski(LLGS) equation & it can be written as,

$$\frac{d\mathbf{m}}{d\tau} = -[\mathbf{m} \times \mathbf{h}_{\text{eff}}] - \alpha[\mathbf{m} \times (\mathbf{m} \times \mathbf{h}_{\text{eff}})] + a_j[\mathbf{m} \times (\mathbf{m} \times \mathbf{m}_p)] \quad (1a)$$

$$\mathbf{m} = (m^x, m^y, m^z), \qquad \mathbf{m}^2 = m^{x^2} + m^{y^2} + m^{z^2} = 1. \quad (1b)$$

Where, $\tau = \gamma M_s t$, $\quad a_j = \frac{pJ\hbar}{\mu_0 e d M_s^2}$

Effective field acting on the free layer

Total Effective Field : $\mathbf{h}_{eff} = \mathbf{h}_{ma} + \mathbf{h}_{shape} + \mathbf{h}_{ext} + \mathbf{h}_{bqc}$.

Magnetocrystalline Anisotropy : $\mathbf{h}_{ma} = h_a m^x \mathbf{e}^x$

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 : $\mathbf{h}_{ext} = h_e \mathbf{e}^y$

Biquadratic coupling filed : $\mathbf{h}_{bqc} = h_b m^x \mathbf{e}^x$

Total Effective Field : $\mathbf{h}_{eff} = (h_a + h_b) m^x \mathbf{e}^x + h_e \mathbf{e}^y - N_z m^z \mathbf{e}^z$.

Where, $h_a = \frac{2k_a}{\mu_0 M_s^2}$, $h_b = \frac{\mu_0 M_s^2 \delta^2 L}{2\pi^3 A_{ex} d} \exp\left(\frac{-4\pi t_s}{L}\right)\left[1 - \exp\left(\frac{-8\pi d}{L}\right)\right]$.

Numerical Results

Values of various parameters

Parameters	Symbol	Value
Polarization factor	p	0.4
Gilbert damping parameter	α	0.001
Magnetocrystalline anisotropy coefficient of Ni-Fe	k_a	$2 \times 10^3 Jm^{-3}$
Saturation magnetization of Ni-Fe	M_s	$0.795 \times 10^6 Am^{-1}$
Thickness of the free layer (Ni-Fe)	d	$4 \times 10^{-9} m$
Thickness of the spacer layer (Cu)	t_s	$2 \times 10^{-9} m$
Height of the roughness of the pinned layer	δ	$0.8 \times 10^{-9} m$
Period of the roughness of the pinned layer	λ	$40 \times 10^{-9} m$
Exchange stiffness constant of Ni-Fe	A_{ex}	$2.1 \times 10^{-11} Jm^{-1}$

Table: Values of various parameters used in the numerical simulations.

Effect of Biquadratic Coupling on Switching Time

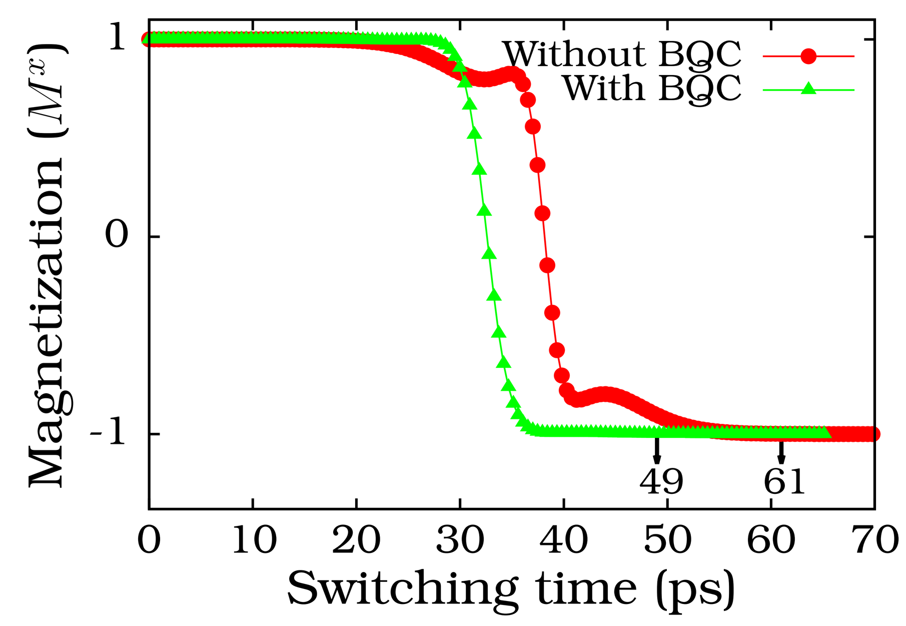

Figure: A plot of free layer magnetization versus switching time in the presence and in the absence of the biquadratic coupling (BQC) for $J = 5 \times 10^{12} Am^{-2}$.

Effect of Period of the Roughness on Switching Time

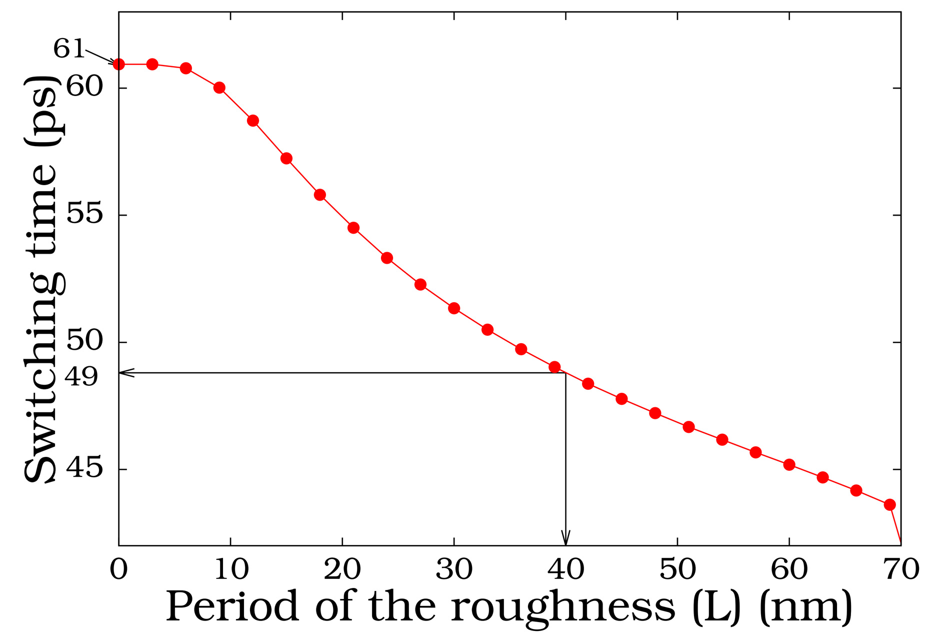

Figure: A plot of the period of the roughness versus switching time for an applied current density $J = 5 \times 10^{12} Am^{-2}$.

Conclusions

- The spin current induced magnetization switching in a Co/Cu/Ni-Fe nanopillar with biquadratic coupling is investigated by numerically solving the LLGS equation.
- Magnetization switching time in the absence of biquadratic coupling is 61 ps and in the presence of biquadratic coupling it reduces to 49 ps.
- The period of roughness effect on switching time also confirms the presence of biquadratic coupling reduces the switching time.

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