Threshold current for switching of a perpendicular magnetic layer induced by spin Hall effect

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Recently, several experiments have shown that it is also possible to switch the magnetization in current-in-plane(CIP) geometry [1 – 3]. Liu et al. [2,3] demonstrated that an in-plane current flowing in a heavy metal layer attached to a free layer can selectively switch the free-layer magnetization and reported that these results can be quantitatively explained by spin torque from the spin Hall effect. In ferromagnet/non-magnet bi-layer systems, an in-plane charge current passing through the non-magnet is converted into a perpendicular spin current due to the spin Hall effect [4].

The analytic expression for the threshold switching current of conventional spin torque case is well established. Such expression is of critical importance for both fundamental physics and applications. However, the threshold switching current for the switching of a perpendicular magnetic layer induced by the spin Hall effect is missing. In this work, we derive an explicit analytic expression of threshold switching current density[5] as

$$J_{\mathrm{C,perp}}^{\mathrm{SH}} = \frac{2e}{\hbar}\frac{M_{\mathrm{S}}t_{\mathrm{F}}}{\theta_{\mathrm{SH}}}\left(\frac{H_{\mathrm{K,eff}}}{2} - \frac{H_x}{\sqrt{2}}\right), \qquad (1)$$

where Θ_{SH} is an effective spin Hall angle of the system, $M_S$isthesaturationmagnetization, t_F is the thickness of ferromagnetic layer, $H_{K,eff}$ is the effective perpendicular anisotropy field, and an external in-plane field H_x.

We verify its applicability by testing various cases based on macro-spin simulations [5]. This expression for the threshold switching current will be useful since it can be used to estimate essential physical quantities such as spin Hall angle and to design practical devices utilizing the spin Hall effect. In the presentation, we will discuss in detail about this spin Hall based switching scheme in comparison to the scheme based on the conventional spin transfer torque.

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