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Influence of Spin-polarized Current on Spin Waves in Ferromagnets

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It has been recently established that spin-polarized current can have a direct influence on the magnetization dynamics in conducting ferromagnets. This effect has quantum origin and is of great interest from both fundamental and applied viewpoints. In particular, it can be useful for developing magnetoresistance random access memory, magnetic logic elements and microwave devices, to name a few.

Under certain conditions, the dynamics of magnetization $\mathbf{M} = \mathbf{M}(x,t)$ ($|\mathbf{M}| = M = \mathrm{const}$) in such ferromagnets is described by the equation [1]

$$\frac{\partial \mathbf{M}}{\partial t} = -\gamma \mathbf{M} \times \mathbf{H}_{\mathrm{eff}} + \frac{\alpha}{M} \mathbf{M} \times \frac{\partial \mathbf{M}}{\partial t} - \frac{b_J}{M^2} \mathbf{M} \times \left(\mathbf{M} \times \frac{\partial \mathbf{M}}{\partial x} \right) - \frac{c_J}{M} \mathbf{M} \times \frac{\partial \mathbf{M}}{\partial x}. \quad (1)$$

Here, $\gamma (> 0)$ is the gyromagnetic ratio, $\alpha (> 0)$ is the dimensionless damping parameter, and the parameters b_J and c_J (measured in units of velocity) account the influence of spin-polarized current. To study spin waves in these materials, we assume that the effective magnetic field $\mathbf{H}_{\mathrm{eff}}$ is given by $\mathbf{H}_{\mathrm{eff}} = H\mathbf{e}_z + A\,\partial^2 \mathbf{M}/\partial x^2$, where $H (> 0)$ is the magnetic field magnitude, $\mathbf{e}_z$ is the unit vector along the z axis, and $A (> 0)$ is the exchange constant. Then, representing $\mathbf{M}$ in the form $\mathbf{M} = M\mathbf{e}_z + \mathbf{m}_0 \exp(ikx - i\omega t)$, where $|\mathbf{m}_0| \ll M$ and k and ω are the wave number and frequency, respectively, from Eq. (1) one gets the dispersion relation

$$\omega = \gamma H + \gamma M A k^2 - b_J k - i[\gamma \alpha H + \gamma \alpha M A k^2 - (b_J \alpha - c_J) k]. \quad (2)$$

According to this result, spin waves always decay in ferromagnets without spin-polarized current. In contrast, in ferromagnets with spin-polarized current spin waves may increase, if the conditions

$$b_J \alpha - c_J > 0, \quad H < \frac{(b_J \alpha - c_J)^2}{(2\gamma\alpha)^2 M A} \quad (3)$$

hold simultaneously. This occurs for those spin waves whose wave numbers belong to the interval (k_-, k_+), where

$$k_\pm = \frac{b_J \alpha - c_J}{2\gamma\alpha M A} \pm \sqrt{\left(\frac{b_J \alpha - c_J}{2\gamma\alpha M A} \right)^2 - \frac{H}{MA}}. \quad (4)$$

1. S. Zhang and Z. Li, *Phys. Rev. Lett.* **93**, 127204 (2004).