Spin Waves in Synthetic Ferrimagnets

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Abstract: Chirality has been paid more and more attention as an information carrier. Considering the more abundant degrees of freedom inside the ferrimagnetic(FIM) structure, we verify and try to propose several means to regulate the chirality of moment precession in ferrimagnet, including external field, temperature and acoustic waves. And we find that the chirality is dependent on the external drive well.

1 Modeling

The spin dynamics of synthetic ferrimagnets can be illustrated by the Landau-Lifshitz-Gilbert (LLG) equation, where the effective filed includes exchange interaction, anisotropy, Dzyaloshinskii-Moriya interaction (DMI), inter-layer coupling etc. Micromagnetic simulation is performed by COMSOL Multiphysics (Finite Elements Method).

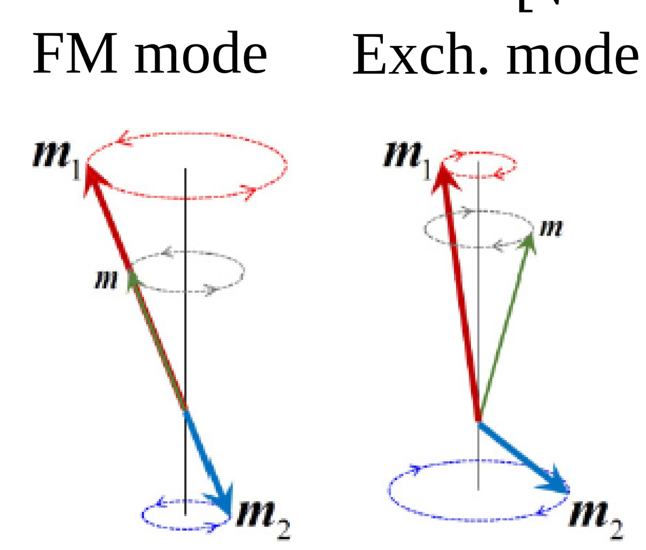
For macrospin without exchange interaction in each sublattice, there is ferromagnetic mode and exchange mode of the magnetic moment precession. They are right-handed and left-handed respectively. Ignore the Gilbert damping and don't effect the resonance modes.

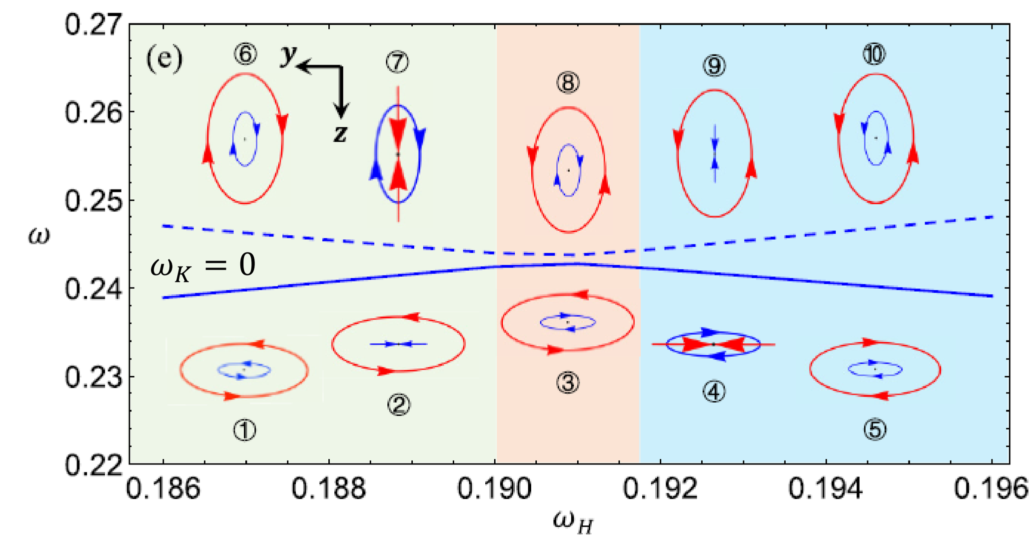
$$\frac{d\boldsymbol{m}_1}{dt} = -\gamma_1 \boldsymbol{m}_1 \times (\boldsymbol{H}_0 + KM_{1s}\boldsymbol{m}_{1z} - JM_{2s}\boldsymbol{m}_2)$$

$$\frac{d\boldsymbol{m}_2}{dt} = -\gamma_2 \boldsymbol{m}_2 \times (\boldsymbol{H}_0 + KM_{2s}\boldsymbol{m}_{2z} - JM_{1s}\boldsymbol{m}_1)$$

$$\omega_F = \omega_H + \left[\sqrt{\omega_K^2 + 2\omega_J\omega_K + \beta^2\omega_J^2} - \beta(\omega_J - \omega_K)\right]/2$$

$$\omega_{ex} = \omega_H - \left[\sqrt{\omega_K^2 + 2\omega_J\omega_K + \beta^2\omega_J^2} + \beta(\omega_J - \omega_K)\right]/2$$





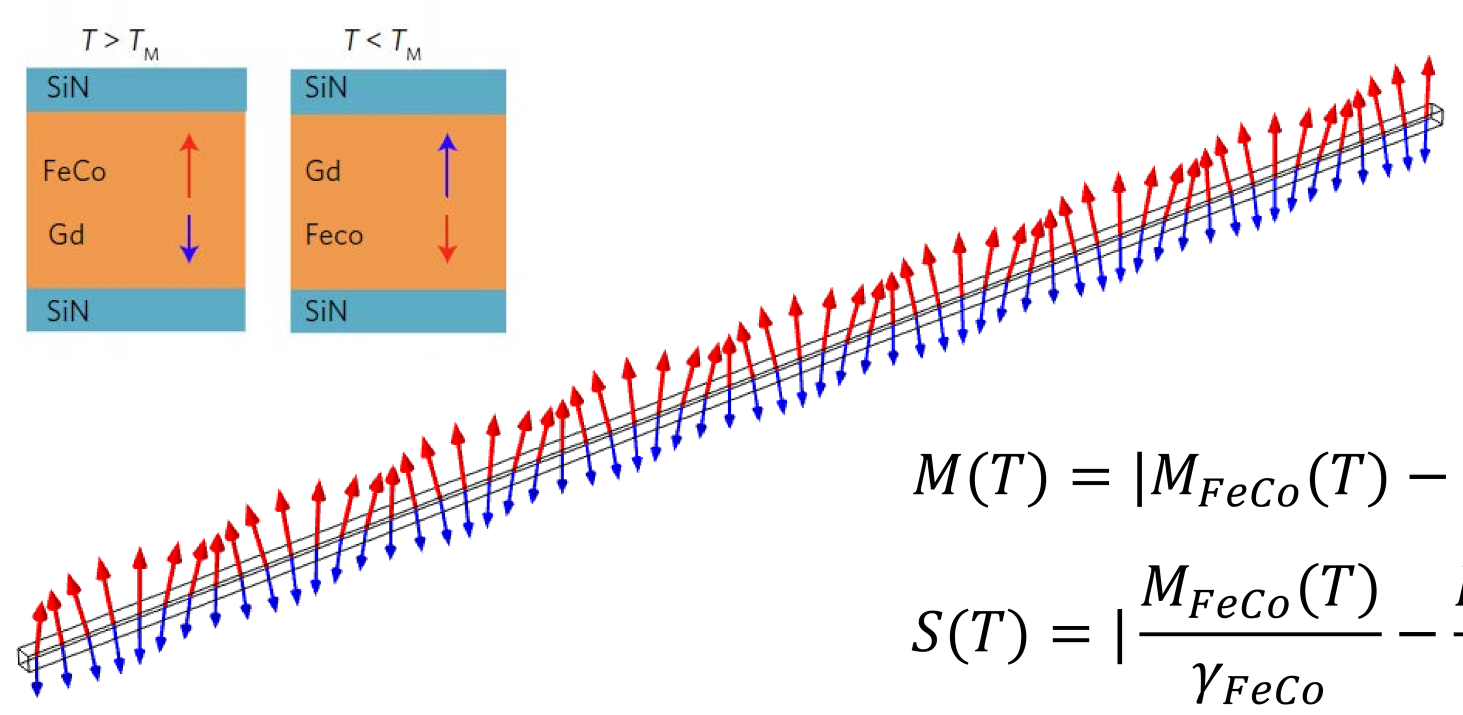
2 Manipulating Chirality by Temperature

Since the gyromagnetic ratio and saturation magnetization of each sublattices is different, we can change saturation magnetization by temperature around the angular momentum compensation point. And the chirality of spin waves (SWs) will exchange.

$$\omega = \frac{1}{2}\sqrt{(\omega_{1\mathrm{eff}} + \omega_{2\mathrm{eff}})^2 - 4\omega_{12}\omega_{21}} \pm (\omega_{1\mathrm{eff}} - \omega_{2\mathrm{eff}})$$

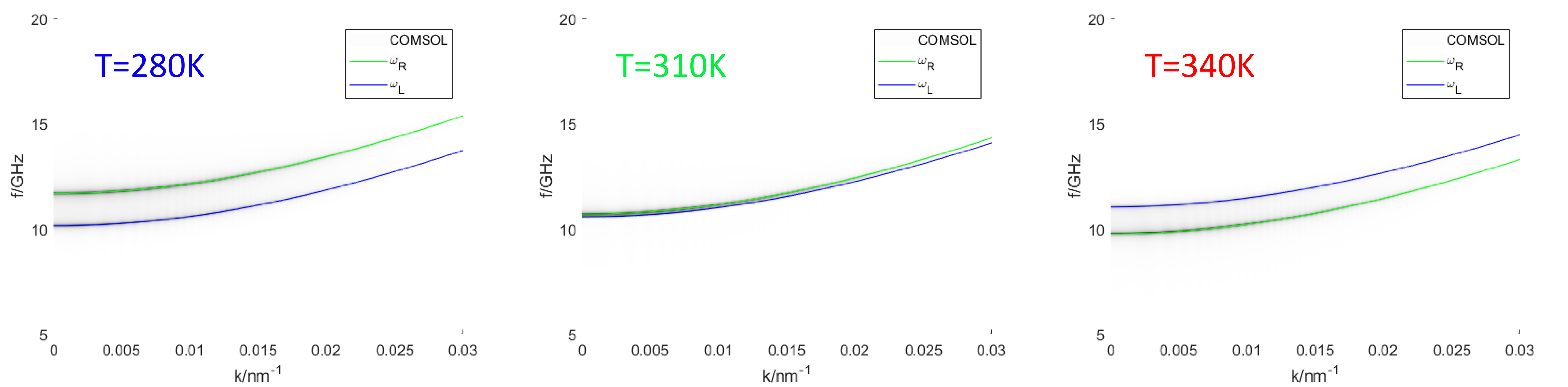
$$\omega_{1\mathrm{eff}} = \gamma_1(A_1k^2 + H_0 + K_1 + JM_{2s}(T))$$

$$\omega_{2\mathrm{eff}} = \gamma_2(A_2k^2 - H_0 + K_2 + JM_{1s}(T))$$



$$M(T) = |M_{FeCo}(T) - M_{Gd}(T)|$$

$$S(T) = \left|\frac{M_{FeCo}(T)}{\gamma_{FeCo}} - \frac{M_{Gd}(T)}{\gamma_{Gd}}\right|$$



3 Manipulating Chirality by Bulk Acoustic Wave

Owing to magnetoelastic coupling (MEC), the precession of spin is always accompanied with elastic deformation. Bulk transverse acoustic waves have two kinks of chirality. The chirality can respond to magnons in ferrimagnet. If we inject right-handed phonons, we can get correspond magnons with the same chirality.

Except bulk acoustic waves, there are Rayleigh waves, Love waves, Stoneley waves and so on propagating on the surface. Surface acoustic waves (SAW) couple with SWs in different way from bulk acoustic waves.

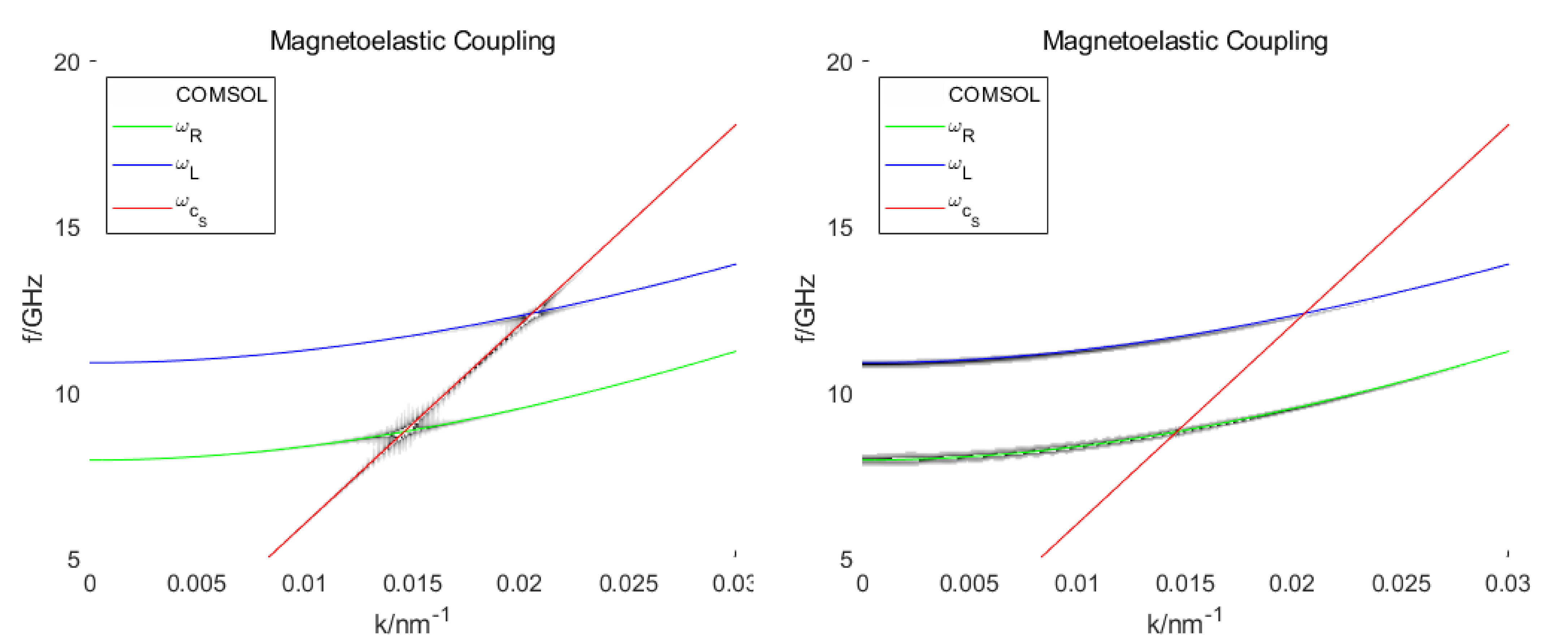
$$\dot{\boldsymbol{m}}_i = -\gamma_i \boldsymbol{m}_i \times \boldsymbol{H}_i + \alpha \boldsymbol{m}_i \times \dot{\boldsymbol{m}}_i$$

$$\rho\ddot{\boldsymbol{R}} = (\lambda + \mu)\nabla(\nabla\cdot\boldsymbol{R}) + \mu\nabla^2\boldsymbol{R} + \boldsymbol{f}$$

$$E_{\mathrm{mec}\_i} = b_1 \sum_\alpha m_{i\alpha}^2 \frac{\partial R_\alpha}{\partial x_\alpha} + b_2 \sum_{\alpha\neq\beta} m_{i\alpha}m_{i\beta}\left(\frac{\partial R_\alpha}{\partial x_\beta} + \frac{\partial R_\beta}{\partial x_\alpha}\right)$$

$$\boldsymbol{H}_i = \boldsymbol{H}_0 + K_i\boldsymbol{m}_z + A_i\nabla^2\boldsymbol{m}_i - J\boldsymbol{M}_{\bar{i}} + \boldsymbol{H}_{\mathrm{mec}\_i}$$

$$\boldsymbol{H}_{\mathrm{mec}\_i} = -\frac{1}{\mu_0 M_s}\frac{\partial E_{\mathrm{mec}\_i}}{\partial \boldsymbol{m}_i}, \boldsymbol{f} = -\nabla_{\boldsymbol{R}} E_{\mathrm{mec}}$$



The Fourier transform of x component of displacement and magnetic moment of sublattice one.

Reference

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