Spin Cavitronics: Spintronics Meets Microwave Cavity

Weichao Yu (余伟超),[1] and Jiang Xiao (肖江)[2]

1 Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan

2 Department of Physics and State Key Laboratory of Surface Physics, Fudan University, Shanghai 200433, China

Introduction Spin cavitronics is a newly developing interdisciplinary field that combines spintronics with cavity quantum electrodynamics, and its purpose is to realize quantum information processing via photon-magnon interaction. A typical configuration of spin cavitronics is a YIG sphere (magnetic insulator with low damping) inside a microwave cavity. Avoided level crossing of the transmission spectrum indicates the strong coupling between magnons and photons.

Simulation in time domain

Dynamics of spin precession inside the YIG sphere is governed by the Landau-Lifshitz-Gilbert equation

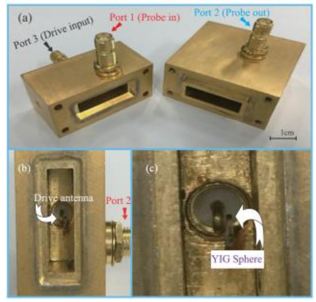
$$\frac{\partial \mathbf{m}}{\partial t} = -\gamma \mathbf{m} \times \mathbf{H_{eff}} + \alpha \mathbf{m} \times \frac{\partial \mathbf{m}}{\partial t}$$

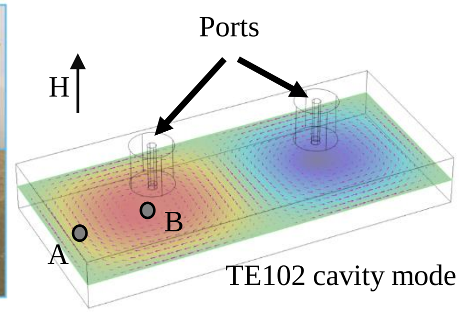
with eigenmode (Kittel mode) $\omega_H = \gamma H$

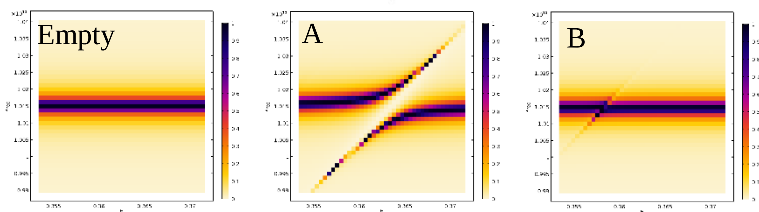
Dynamics of the microwaves is governed by the Maxwell's equation

$$\mu_0 \varepsilon_0 \frac{\partial}{\partial t}\left(\varepsilon_r(\mathbf{r}) \frac{\partial \mathbf{A}}{\partial t}\right) + \nabla \times \left(\mu_r^{-1}(\mathbf{r}) \nabla \times \mathbf{A}\right) = 0$$

with the constitutive relationship $\mathbf{B} = \mu_0(\mathbf{H} + \mathbf{M})$







Simulation in frequency domain

The time-dependent LLG equation can be written down in frequency domain in linear approximation

$$i\omega \mathbf{m} = \hat{\mathbf{z}} \times (\omega_M \mathbf{H} - \omega_K \mathbf{m} + i\alpha\omega \mathbf{m})$$

which can be transformed to the form $\mathbf{m} = \mu_0 \overline{\zeta} \mathbf{H}$ indicating that the dynamics of magnetization can be treated as a material with special permeability

$$\overline{\mu}_M = \bar{\mathrm{I}} + \overline{\zeta} = \begin{pmatrix} 1+u & -iv & 0 \\ iv & 1+u & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

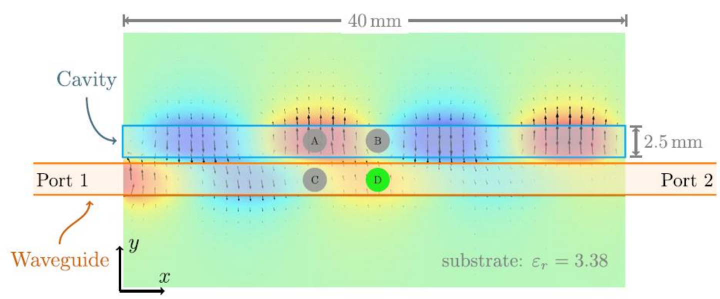
$$u = \frac{(\omega_K - i\alpha\omega)\omega_M}{(\omega_K - i\alpha\omega)^2 - \omega^2}, \quad v = \frac{\omega\omega_M}{(\omega_K - i\alpha\omega)^2 - \omega^2}.$$

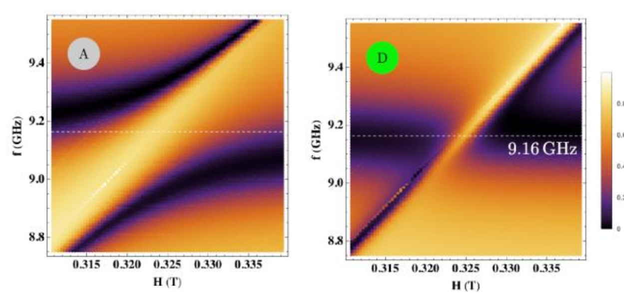
We can now simulate the hybrid system by solving only Maxwell's equations in frequency domain.

$$\nabla \times [\mu_r(\mathbf{r})^{-1} \nabla \times \mathbf{E}] - k^2 \varepsilon_r(\mathbf{r})\mathbf{E} = 0$$

Prediction of attractive level crossing

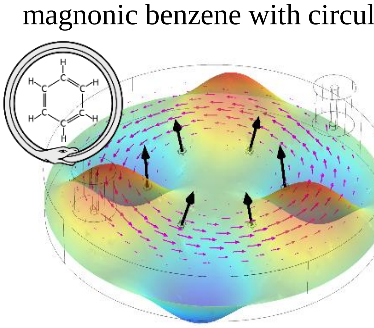
Magnon-photon coupling usually gives rise to the level anti-crossing (level repulsion), where two levels repel to each other. By simulating the directional-coupler-like cavity, it's possible to induce an extra dissipative mode and realize novel attractive level crossings (level attraction).

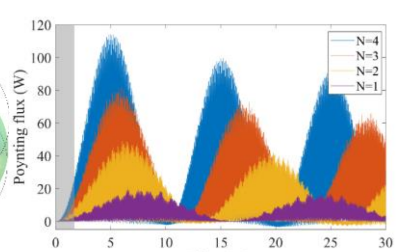




Design of magnonic molecules

Each magnetic sphere can be treated as a magnonic atom, and multiple atoms form magnonic molecules mediated by cavity photons. Chiral magnonic molecules can be designed such as magnonic benzene with circulating photonic current.





Reference

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wcyu@imr.tohoku.ac.jp