2^{nd} Progress Meeting

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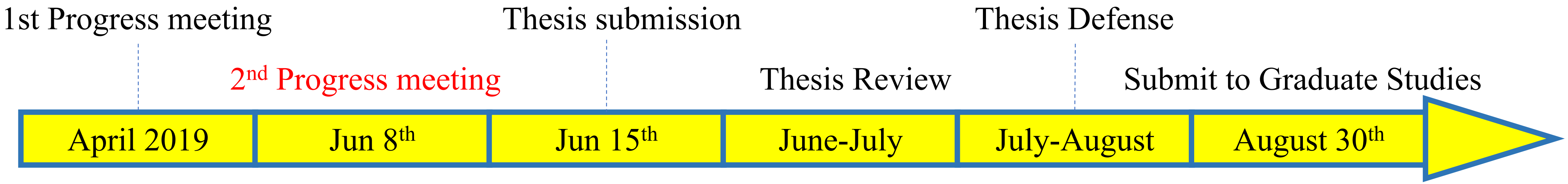
Outline

1. Research and academic progress
2. Introduction to dissipative coupling
3. Level attraction in metamaterials and its applications
4. Broadband nonreciprocal device in cavity magnon polaritons



- Coursework
  1. PHYS 7720 Quantum Mechanics 1 (A+)
  2. PHYS 7510 Condensed Matter Physics 2 (A)
  3. PHYS 7590 Electromagnetic Theory (A+)
  4. ECE 7440 Microwave Materials Measurement Techniques (A+)

- Publications

  1st Author:

  Physical Review Applied (received)

  Coauthor: (3 paper total)

  Nature communications, New Journal of Physics, Communications Physics

Research and academic progress

Course Work:

PHYS 7720
Quantum Mechanics 1 (A+)

2018

2018.09 Start of the program

Course Work:

PHYS 7510
Condensed Matter Physics 2 (A)
PHYS 7590
Electromagnetic Theory (A+)

2019

2019.04 1st Progress meeting
+ Thesis proposal

Course Work:

ECE 7440
Microwave Materials
Measurement Techniques (A+)

2020

2020.06 2nd Progress meeting + Thesis submission
2020.07 Published 1st paper
2020.08 Thesis defense + finial submission

Publications

[1]. Zhao, Y. T., et al. "Broadband nonreciprocity realized by locally controlling the magnon's radiation." Physical Review Applied, 2020, 14(1): 014035.

[2]. Rao, J. W., et al. "Analogue of dynamic Hall effect in cavity magnon polariton system and coherently controlled logic device." Nature communications 10.1 (2019): 1-7.

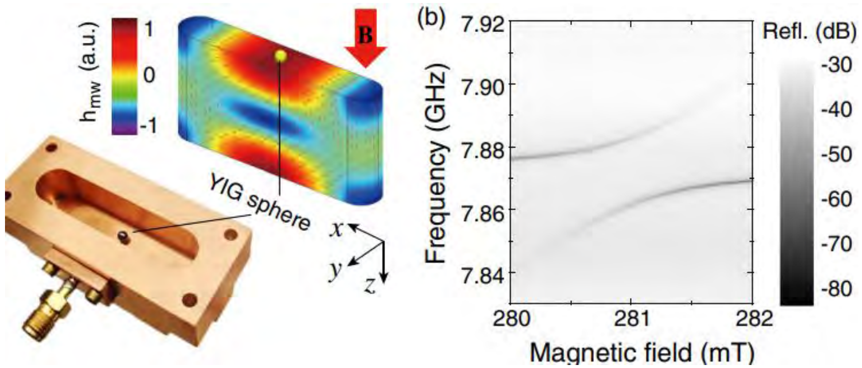
[3]. Yao, B.M., et al. "Coherent control of magnon radiative damping with local photon states", Communications Physics (2019):0482

[4]. Rao, J. W., et al. "Level attraction and level repulsion of magnon coupled with a cavity anti-resonance." New Journal of Physics 21.6 (2019): 065001.

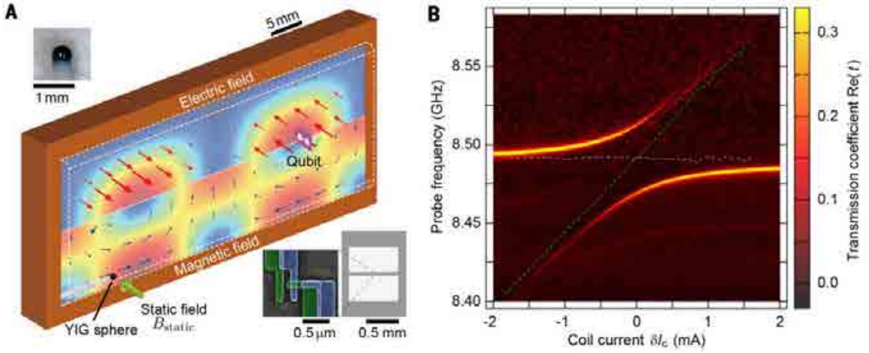
Introduction to cavity-magnon-polariton (CMP)

Coupling Mechanics of CMP

Coherent coupling



Physical review letters 113.15 (2014): 156401.

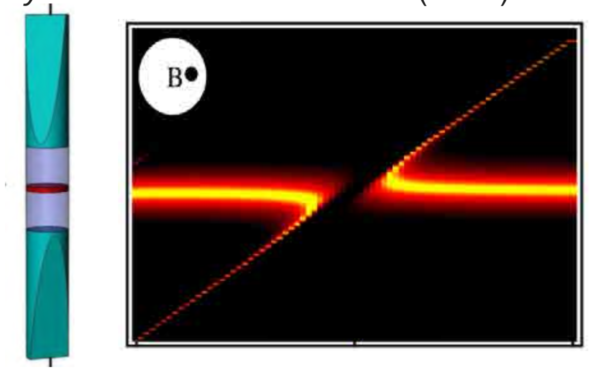


Science 349.6246 (2015): 405-408.

Level repulsion has been widely studied in CMP

Dissipative coupling

Physical review letters 121.13 (2018): 137203.

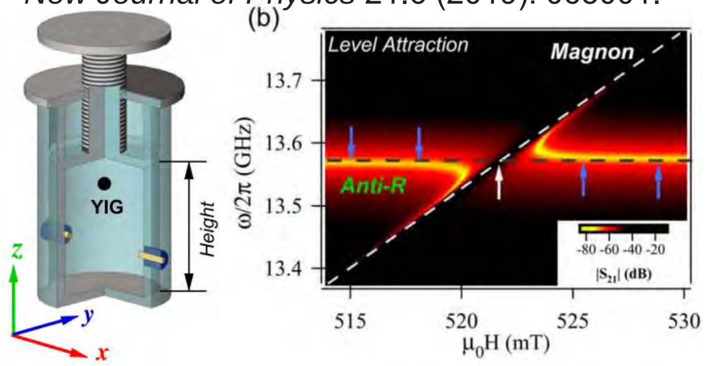


Discovery of **level attraction** in CMP

My research is focused on dissipative coupling.

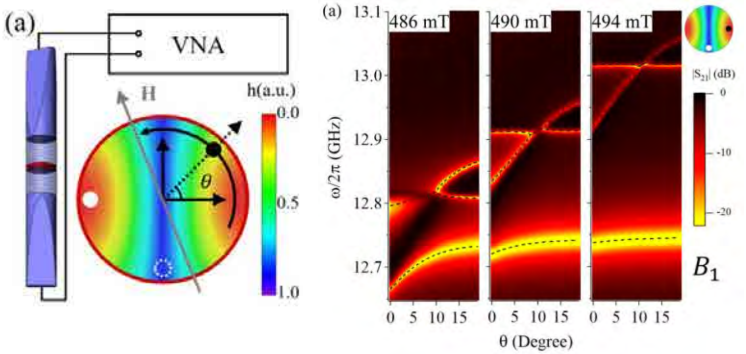
Why do we study dissipative coupling?

New Journal of Physics 21.6 (2019): 065001.



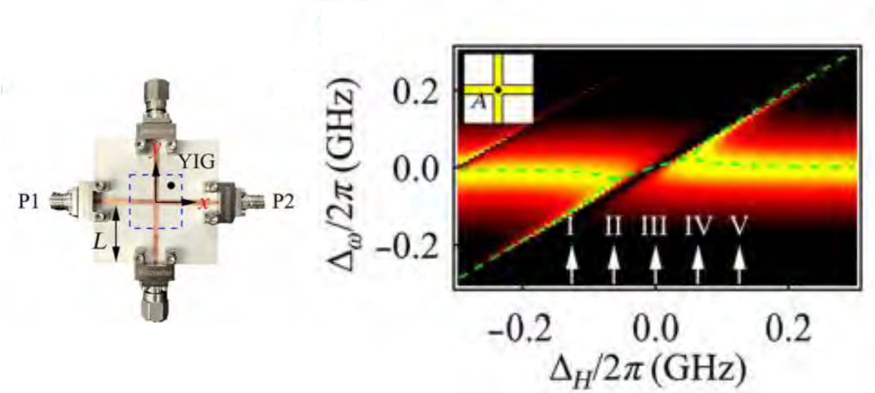
Level attraction in cavity anti-resonance

Physical Review B 100.1 (2019): 014415.



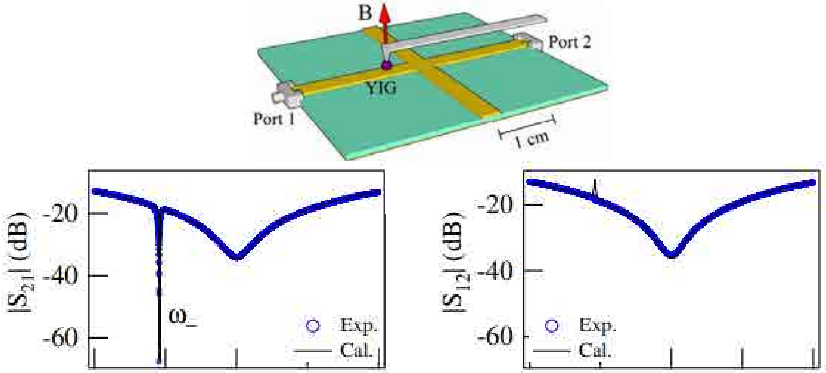
Cavity mediated level attraction

On-chip device utilizing level attraction



Physical Review Applied 11.5 (2019): 054023.

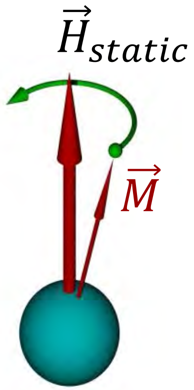
Nonreciprocal microwave transmission



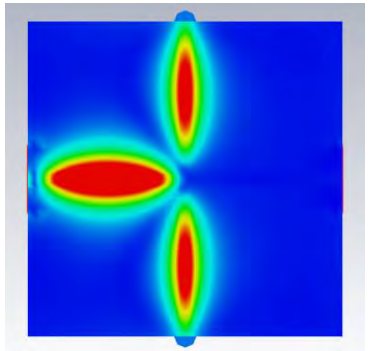
Physical review letters 123.12 (2019): 127202.

How do we understand CMP?

- Coupled photon and magnon

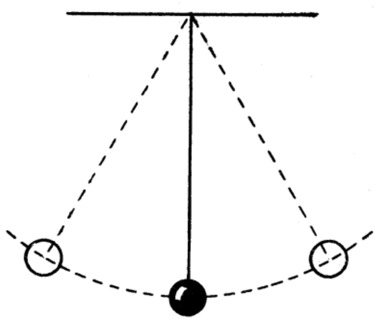


Ferromagnetic resonance



Photon cavity resonance

→ Periodic motion



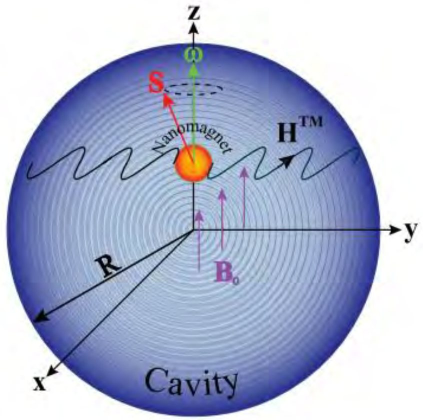
Simplified to Pendulum

Complex frequency

$$\widetilde{\omega}_1 = \omega_1 + i\gamma_1$$

Resonance (real) + damping (imaginary)

Why do we study?



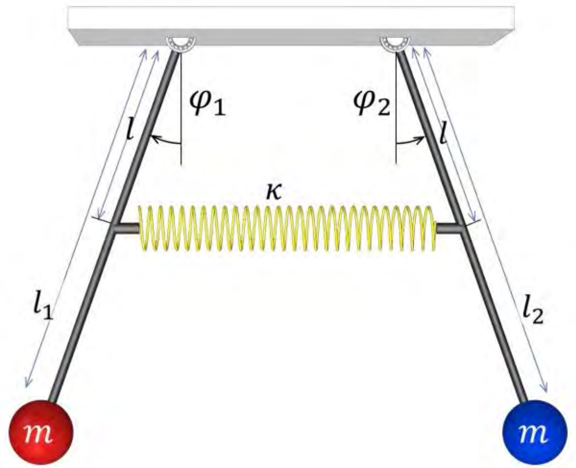
Physical review letters 104.7 (2010): 077202.

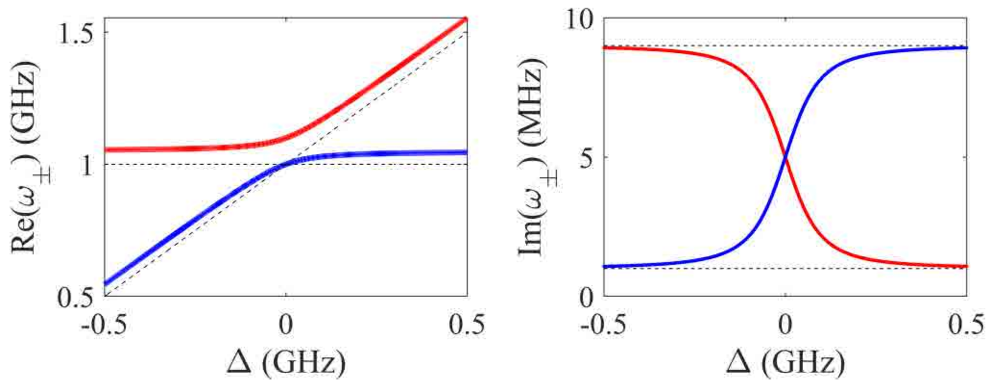
1. Spin-Photon interaction.
2. Nanosized structural elements
3. Quantum information procession

…

Coherent coupled pendulums

Schematic – Spring





Equation of motion:

$$\ddot{\varphi}_1 + 2\lambda_1\dot{\varphi}_1 + \omega_1^2\,\varphi_1 - 2\omega_1 J(\varphi_2 - \varphi_1) = 0$$

$$\ddot{\varphi}_2 + 2\lambda_2\dot{\varphi}_2 + \omega_2^2\,\varphi_2 - 2\omega_2 J(\varphi_1 - \varphi_2) = 0$$

Matrix form

$$\begin{bmatrix} \omega - \widetilde{\omega}_1 - J & J \\ J & \omega - \widetilde{\omega}_2 - J \end{bmatrix} \begin{bmatrix} |\varphi_1| \\ |\varphi_2| \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

Interpretation:

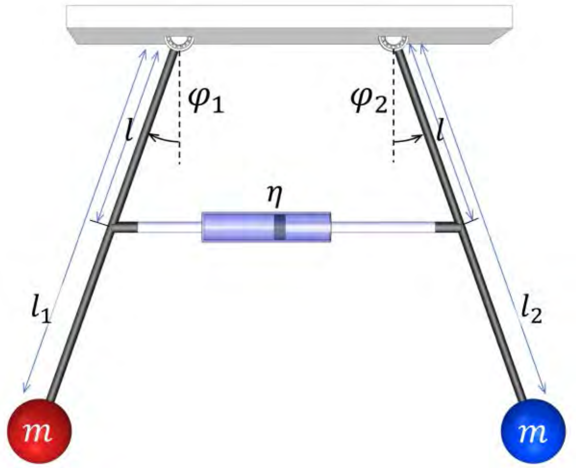
$$\begin{bmatrix} \text{Pendulum} - 1 & \text{coupling} \\ \text{coupling} & \text{Pendulum} - 2 \end{bmatrix}$$

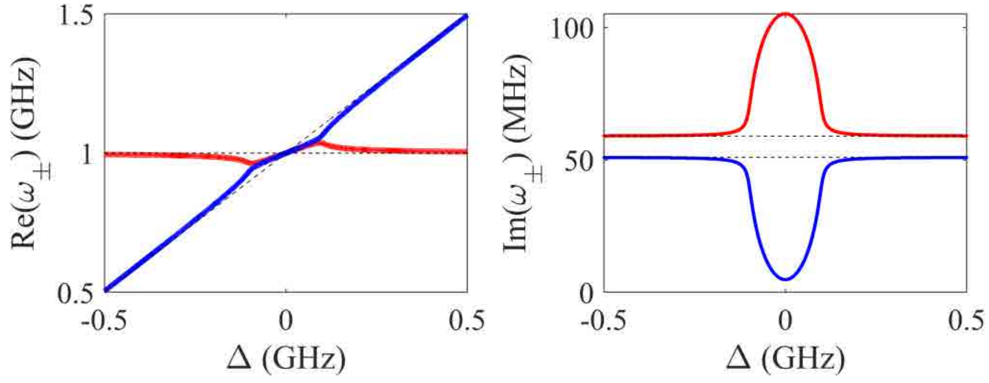
$$\text{coupling} = \text{Real}$$

→ Conservative force

Dissipative coupled pendulums

Schematic – Dashpot





Equation of motion:

$$\ddot{\varphi}_1 + 2\lambda_1\dot{\varphi}_1 + \omega_1^2\,\varphi_1 \;-2\Gamma(\dot{\varphi}_2 - \dot{\varphi}_1) = 0$$

$$\ddot{\varphi}_2 + 2\lambda_2\dot{\varphi}_2 + \omega_2^2\,\varphi_2 \;-2\Gamma(\dot{\varphi}_1 - \dot{\varphi}_2) = 0$$

Matrix form

$$\begin{bmatrix} \omega - \widetilde{\omega}_1 - i\Gamma & i\Gamma \\ i\Gamma & \omega - \widetilde{\omega}_2 - i\Gamma \end{bmatrix} \begin{bmatrix} |\varphi_1| \\ |\varphi_2| \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

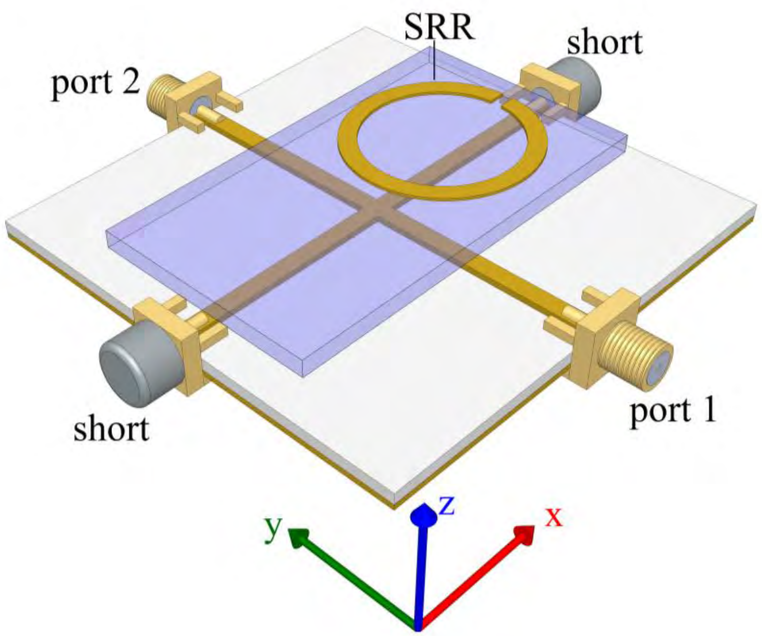
Interpretation:

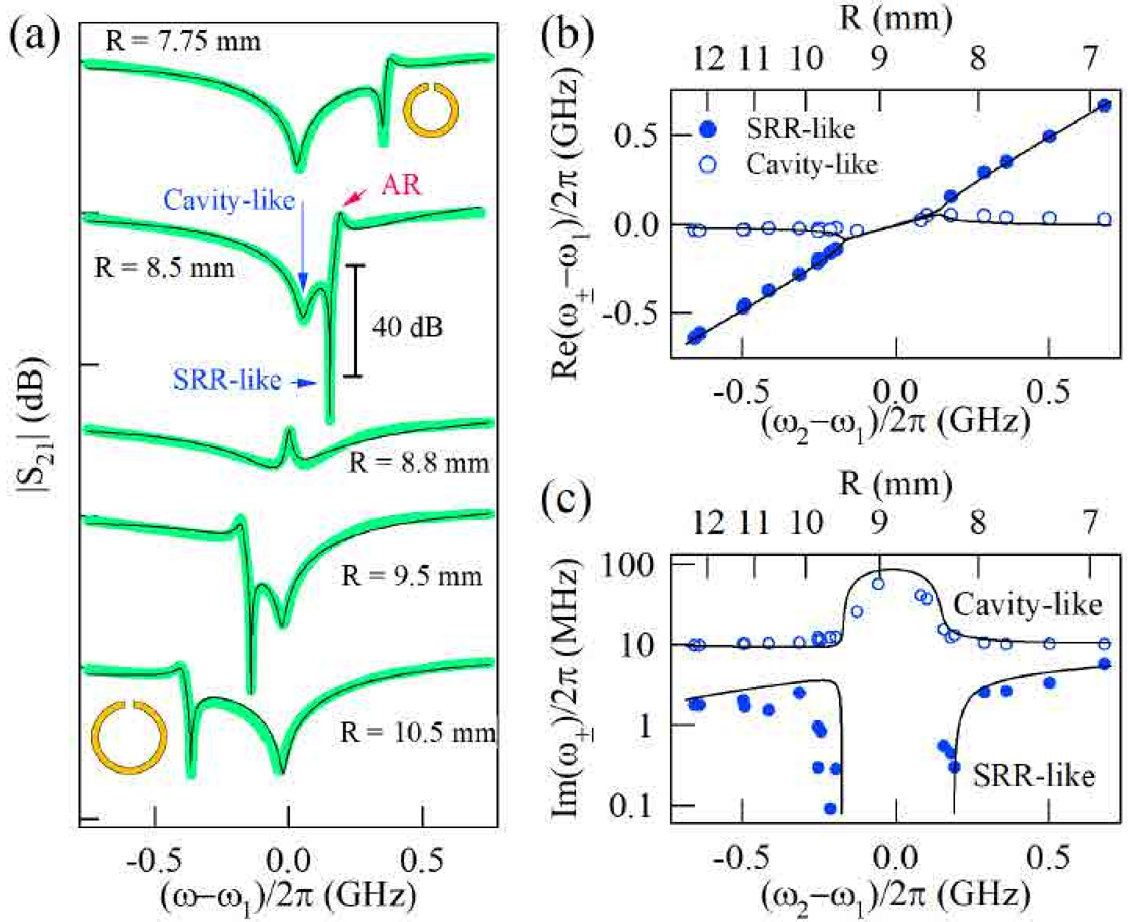
$$\begin{bmatrix} \text{Pendulum} - 1 & \text{coupling} \\ \text{coupling} & \text{Pendulum} - 2 \end{bmatrix}$$

$$\text{coupling} \;= \text{imaginary}$$

→ Nonconservative force

Dissipative coupling in metamaterials





Level attraction

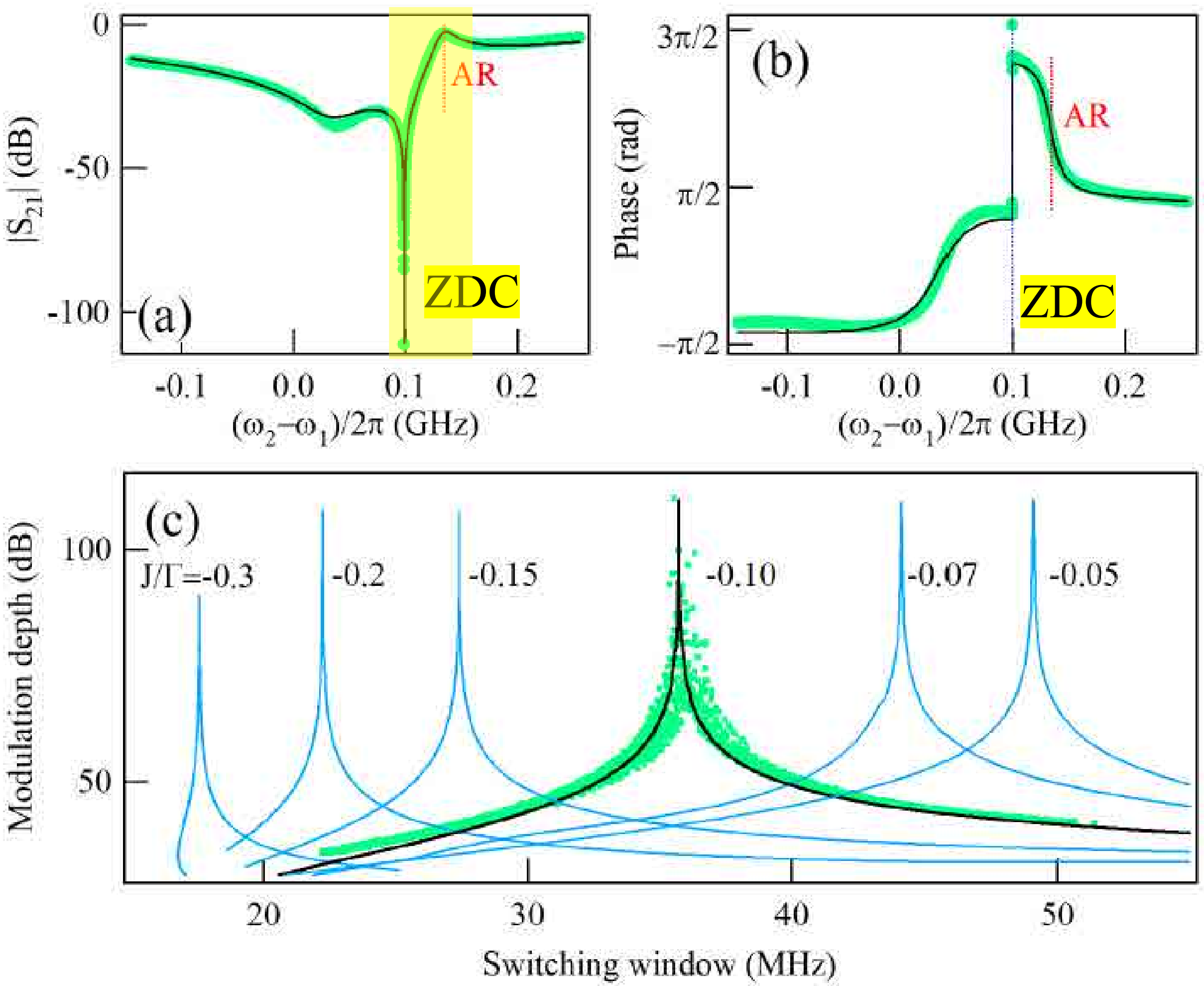
Linewidth Narrowing

Experiment Setup

Measured Spectra

Dispersion

Transmission transition from 0 to 1



Asymmetry resonance is a typical Fano resonance

We have observed a transition from 0 to 1 in transmission.

1 → on

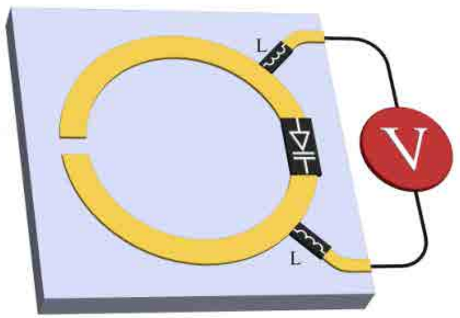
0 → off

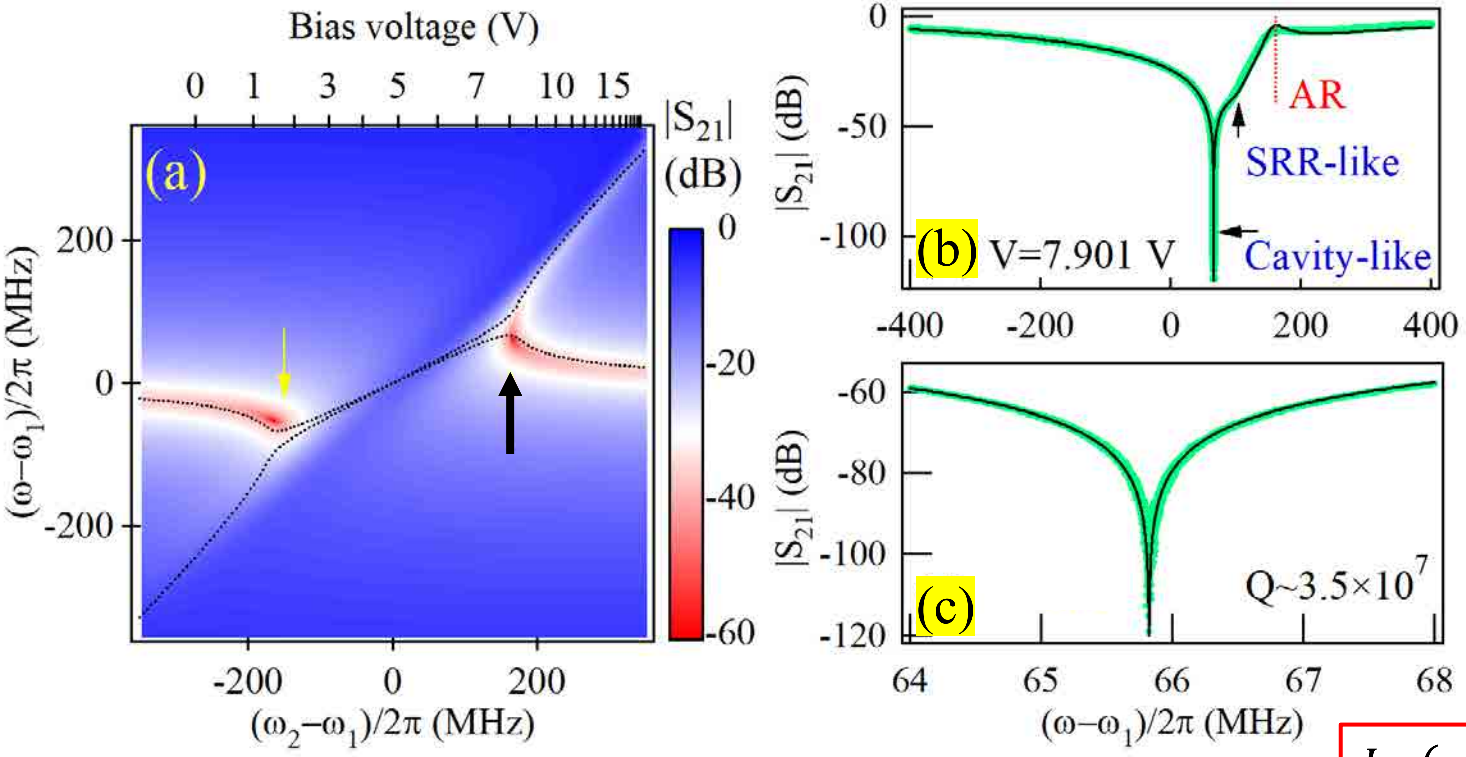
Potential to design switching device.

Voltage-controlled level attraction

Varactor loaded split-ring resonator

$$\omega_{ssr} = \frac{1}{\sqrt{L\textcolor{red}{C}}}$$



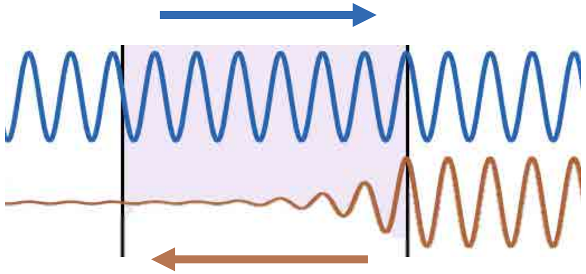


$\boxed{Im(\omega_c) = 30\ Hz!}$

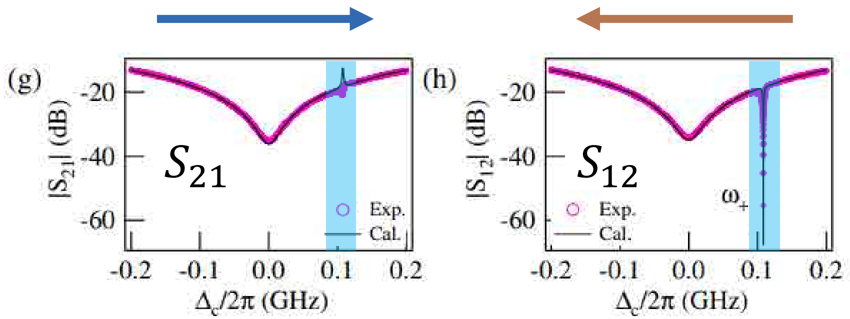
Ultra-high Quality factor → sensitive detection / sensor design

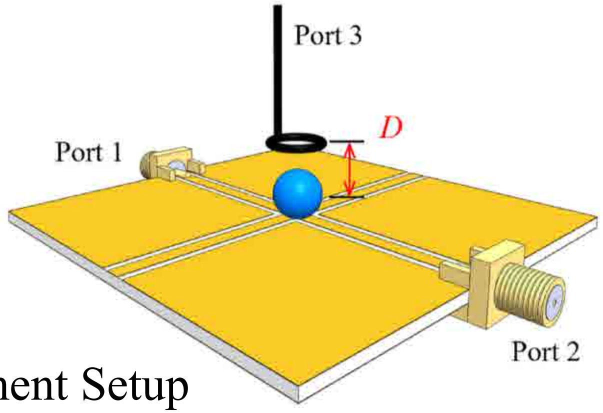
Nonreciprocity in cavity magnon polariton

Wang, Yi-Pu, et al. "Nonreciprocity and unidirectional invisibility in cavity magnonics." *Physical review letters* 123.12 (2019): 127202.

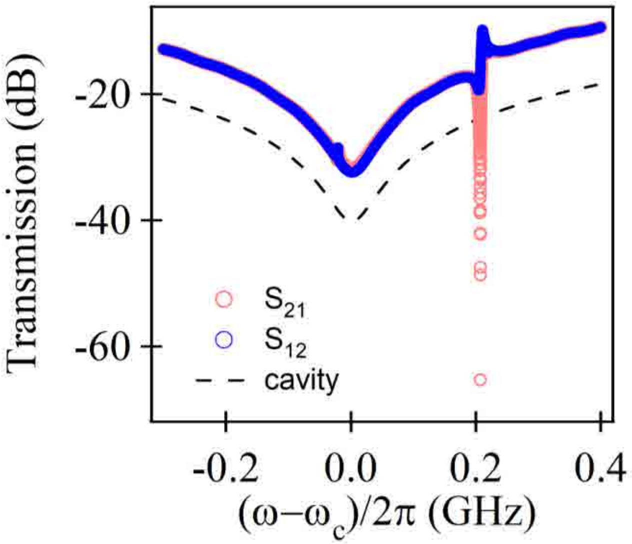


Unidirectional transmission





Experiment Setup



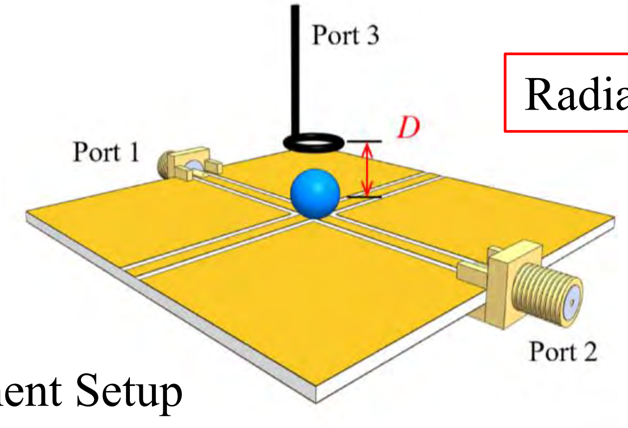
Nonreciprocal

Transmission:

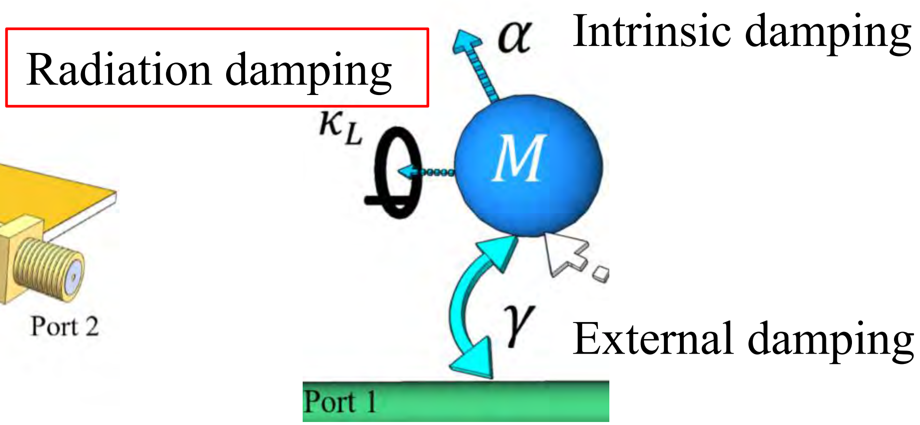
Bandwidth ~ 0.5 MHz

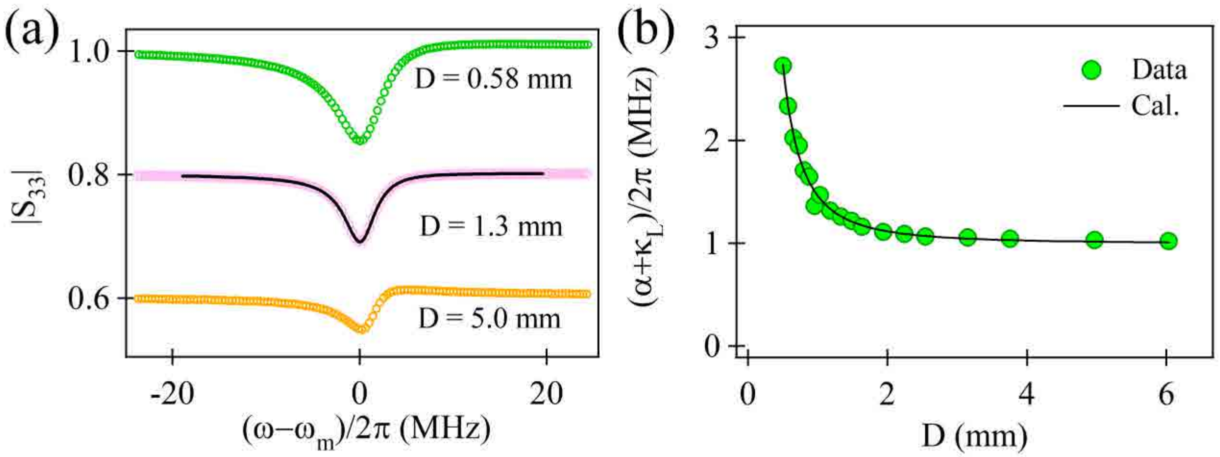
Limited by magnon linewidth

Local control of magnon damping

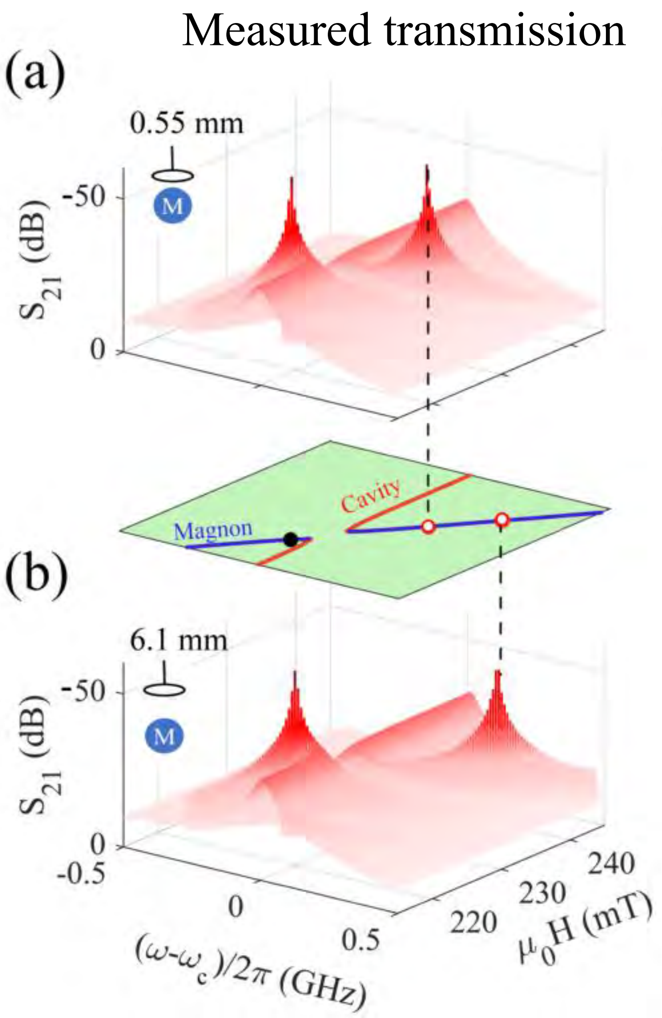


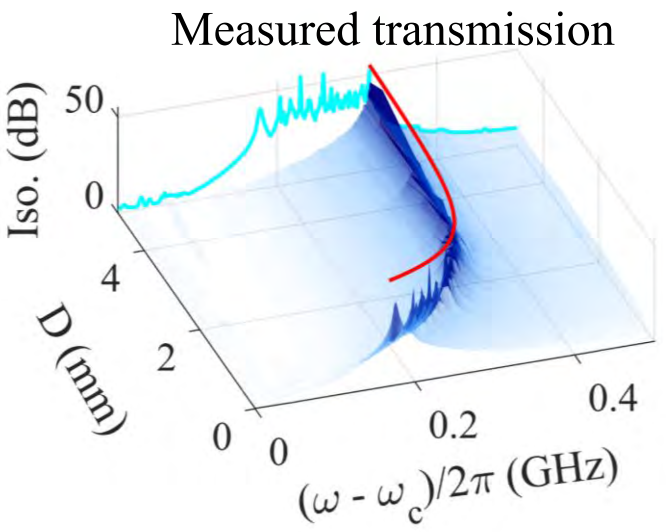
Experiment Setup

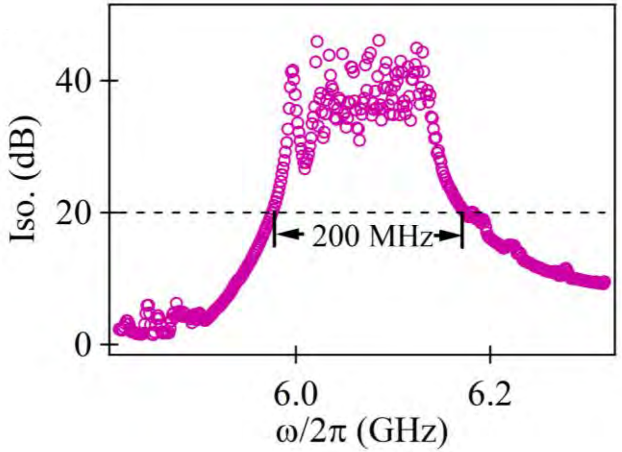




Broadband nonreciprocal device







Summary

- These research explores the application of dissipative coupling in microwave frequencies.
- Practical applications on sensitive detection, switch device, and broadband nonreciprocal device.

Timeline