

Ultrastrong coupling of on-chip magnon polaritons in a YBCO superconducting resonator

○ S. Yoshii^{1,2}, M. Müller³, R. Ohshima^{1,2}, Y. Ando⁴, M. Althammer³, H. Huebl³
and M. Shiraishi^{1,2}

Department of Electronic Science and Engineering, Kyoto University¹, CSRN, Kyoto University²,
Walther-Meissener-Institute, Bayerische Akademie der Wissenschaften³,
Osaka Metropolitan University⁴

E-mail: yoshii.shugo.88x@st.kyoto-u.ac.jp

Magnon polariton, a strong coupling between electromagnetic microwave (photons) and quantized spin waves (magnons), has been fascinating research with regard to the light-matter interaction. In the context of light-matter interaction, the achievement of the ultrastrong coupling regime represents a crucial milestone for exploration of the veiled quantum phenomena induced by counter-rotating terms (CRTs) [1]. Since the CRTs are capable of generating their squeezed states, there has been a strong anticipation that they will serve as the foundational physics in the next generation of quantum technologies. Despite the existence of multiple reports on the realization of ultrastrong coupling in magnon polaritons, the majority of studies have been constrained to bulk $\text{Y}_3\text{Fe}_5\text{O}_{12}$ [2, 3]. In this study, we demonstrate the achievement of ultrastrong coupling of magnon polariton within thin metallic ferromagnetic film on high- T_C $\text{YBa}_2\text{Cu}_3\text{O}_7$ (YBCO) resonator, where the Bloch-Siegert shift, the signature of the existence of CRTs, was successfully observed [4].

The ferromagnetic films of NiFe alloy (Py) with the stacking order of SiO_2 (10 nm) / MgO (2 nm) / Py (30 nm) / Ti (3 nm) / SiO_2 (20 nm) were mounted onto the superconducting resonator made of high- T_C YBCO, where the layers were deposited by using electron-beam deposition except for sputtered SiO_2 capping and buffer layer. The superconducting resonator with the ferromagnetic films is introduced into cryostat, which was cooled down to 10 K. The external magnetic field was swept between ± 145 mT, and a microwave was applied at a power of 0 dBm and with a frequency range of 4.8-5.4 GHz (Fig. 1). Figure 2 shows the normalized transmission spectra, ΔS_{21} , of magnon polariton for the sample, where the coupling strength (g) is estimated to be 674 MHz and the ratio, $\eta = g/\omega$, exceeds 0.1, entering ultrastrong coupling regime. The system also demonstrates the Bloch-Siegert shift, the energy shifts due to the existence of CRTs.

[1] A. F. Kockum *et al.*, Nat. Rev. Phys., **1**, 19-40 (2019). [2] M. Goryachev *et al.*, Phys. Rev. Appl. **2**, 054002 (2014). [3] A. Ghirri *et al.*, Phys. Rev. Appl. **20**, 024039 (2023). [4] S. Yoshii *et al.*, in preparation.

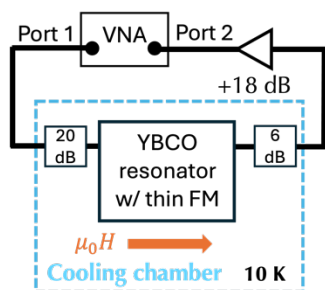


Fig. 1 Schematic of measurement.

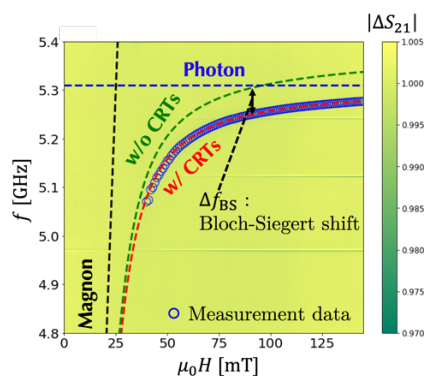


Fig. 2 Transmission spectra of magnon polariton within 30 nm-thick Py film.