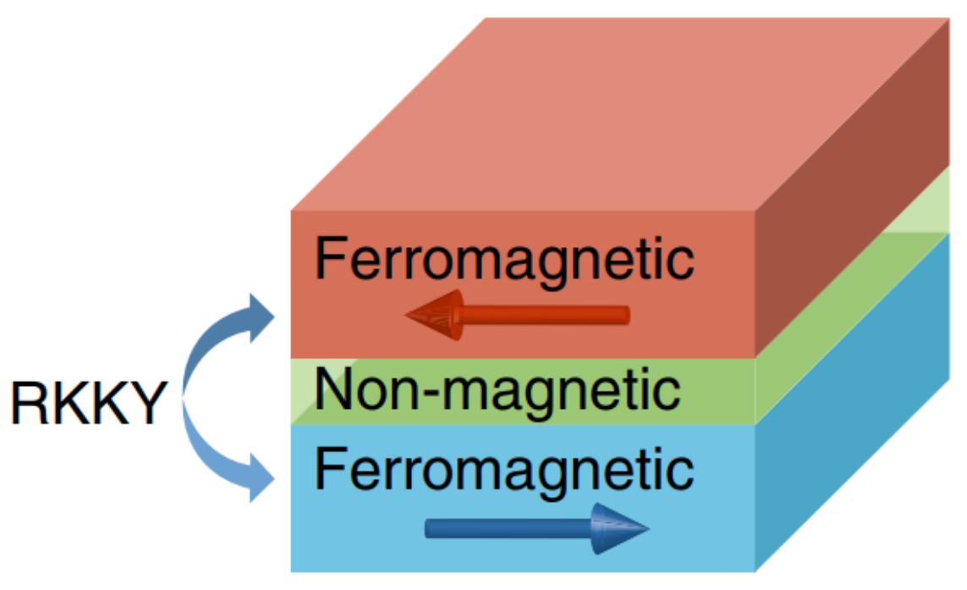
Observation of mode splitting by magnon-magnon coupling in synthetic antiferromagnets

D. Hayashi[1], Y. Shiota[1,2], M. Ishibashi[1], R. Hisatomi[1,2], T. Moriyama[1,2], T. Ono[1,2]

Institute for Chemical Research, Kyoto Univ.[1] *Center for Spintronics Research Network, Kyoto Univ.*[2]

Introduction

◆ Synthetic antiferromagnet (SAF)



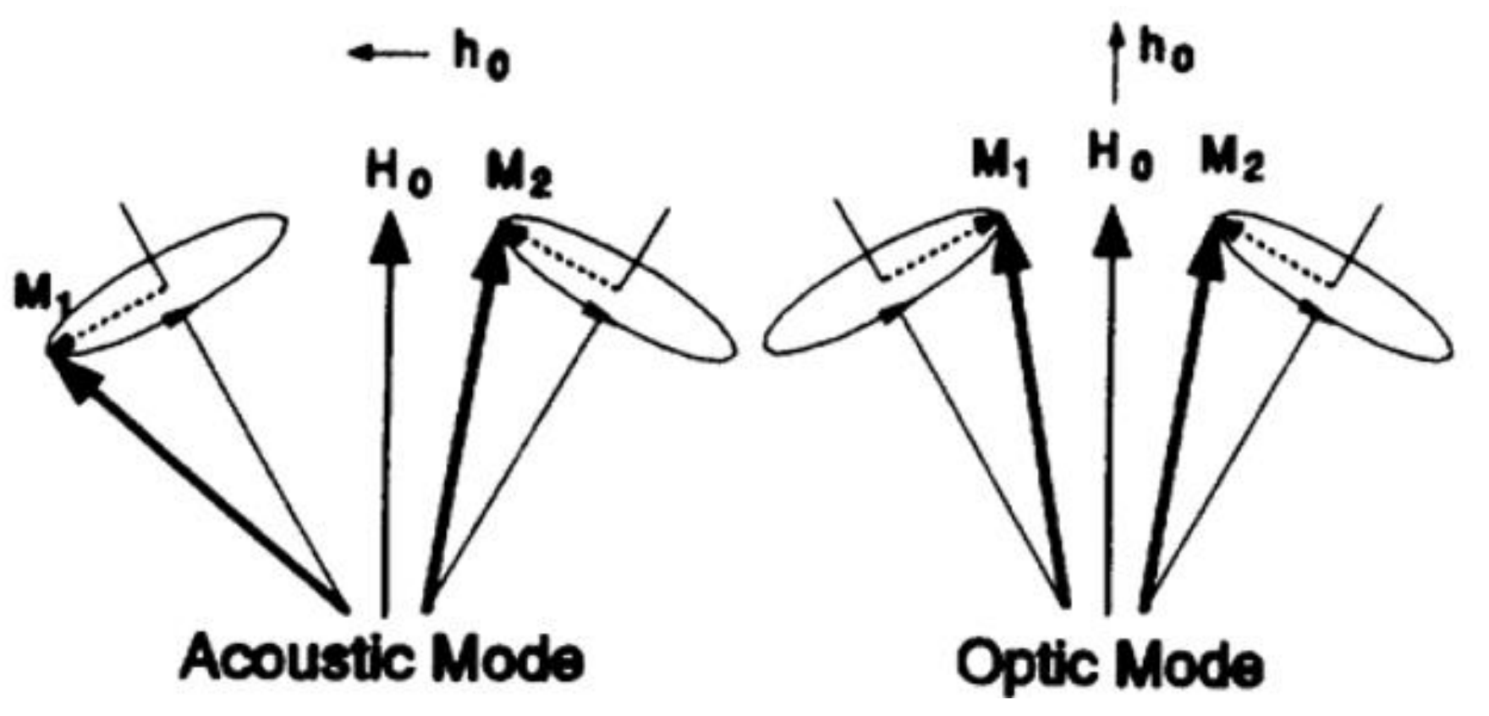
The magnetizations of the two ferromagnetic layers orient antiparallelly.

R. A. Duine *et al.*, Nature physics. 14, 3, 217-219 (2018)

✓ Resonant frequency of SAF is in GHz range.

✓ Easy to control the magnetization configuration by the magnetic field.

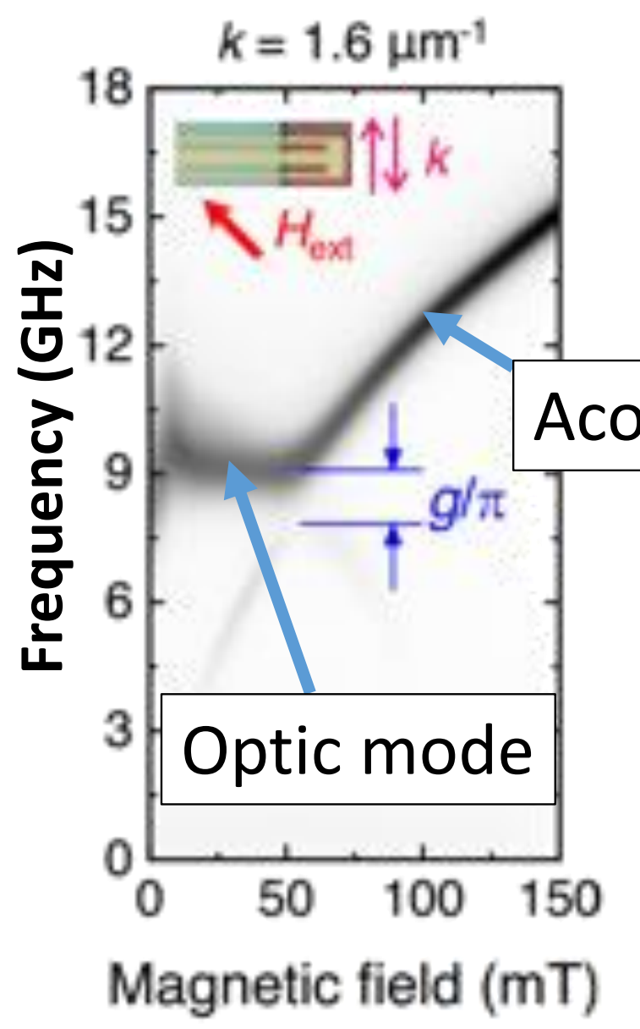
◆ Two modes of magnons in SAF



In-phase precession　Out-of-phase precession

Z. Zhang *et al.*, Phys. Rev. B 50, 6094 (1994)

◆ Magnon–magnon coupling



The resonance peaks of acoustic and optic modes exhibit a pronounced anti-crossing gap.

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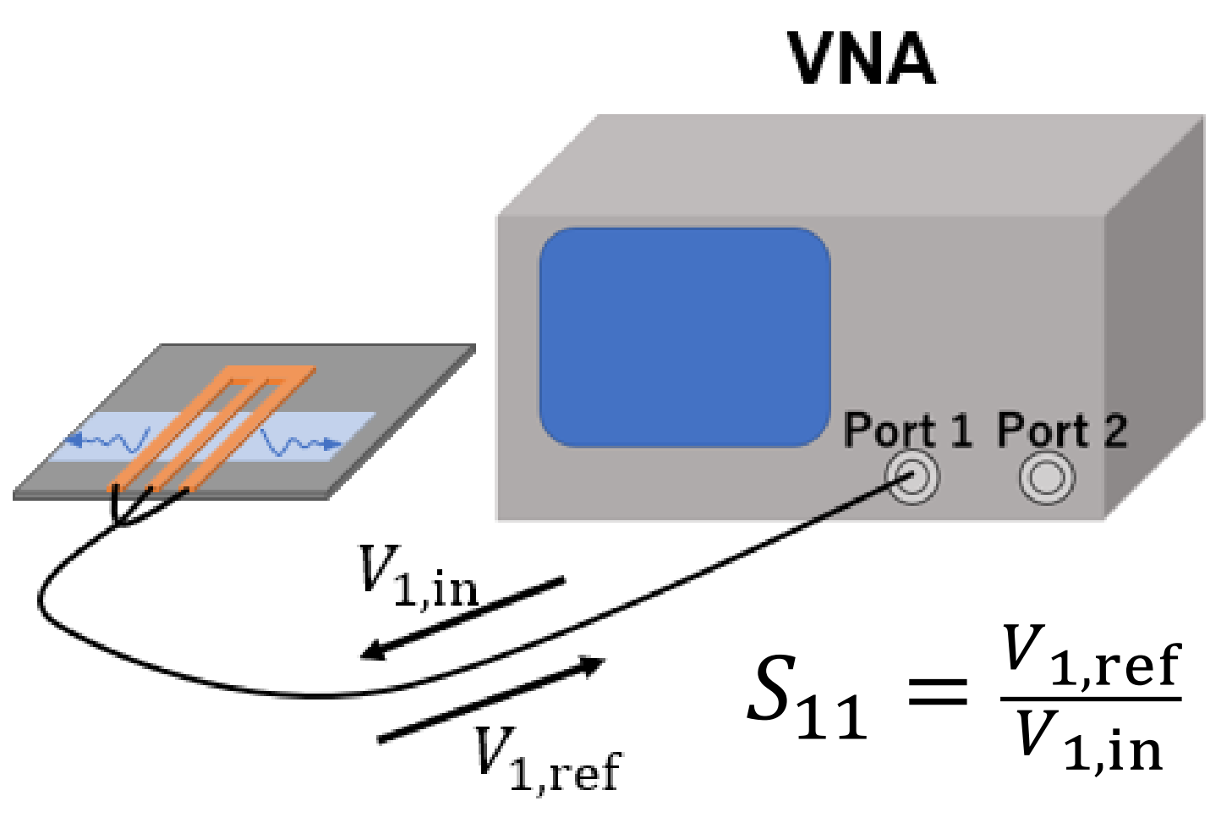
Two modes of magnons are hybridized by magnon-magnon coupling.

Y. Shiota et al., Phys. Rev. Lett. **125**, 017203 (2020).

Purpose: Obtaining dispersion relation of hybridized magnon to understand the magnon properties.

Method

◆Previous study



$$S_{11} = \frac{V_{1,\mathrm{ref}}}{V_{1,\mathrm{in}}}$$

Electrical spin wave spectroscopy technique with microwave reflection S_{11}

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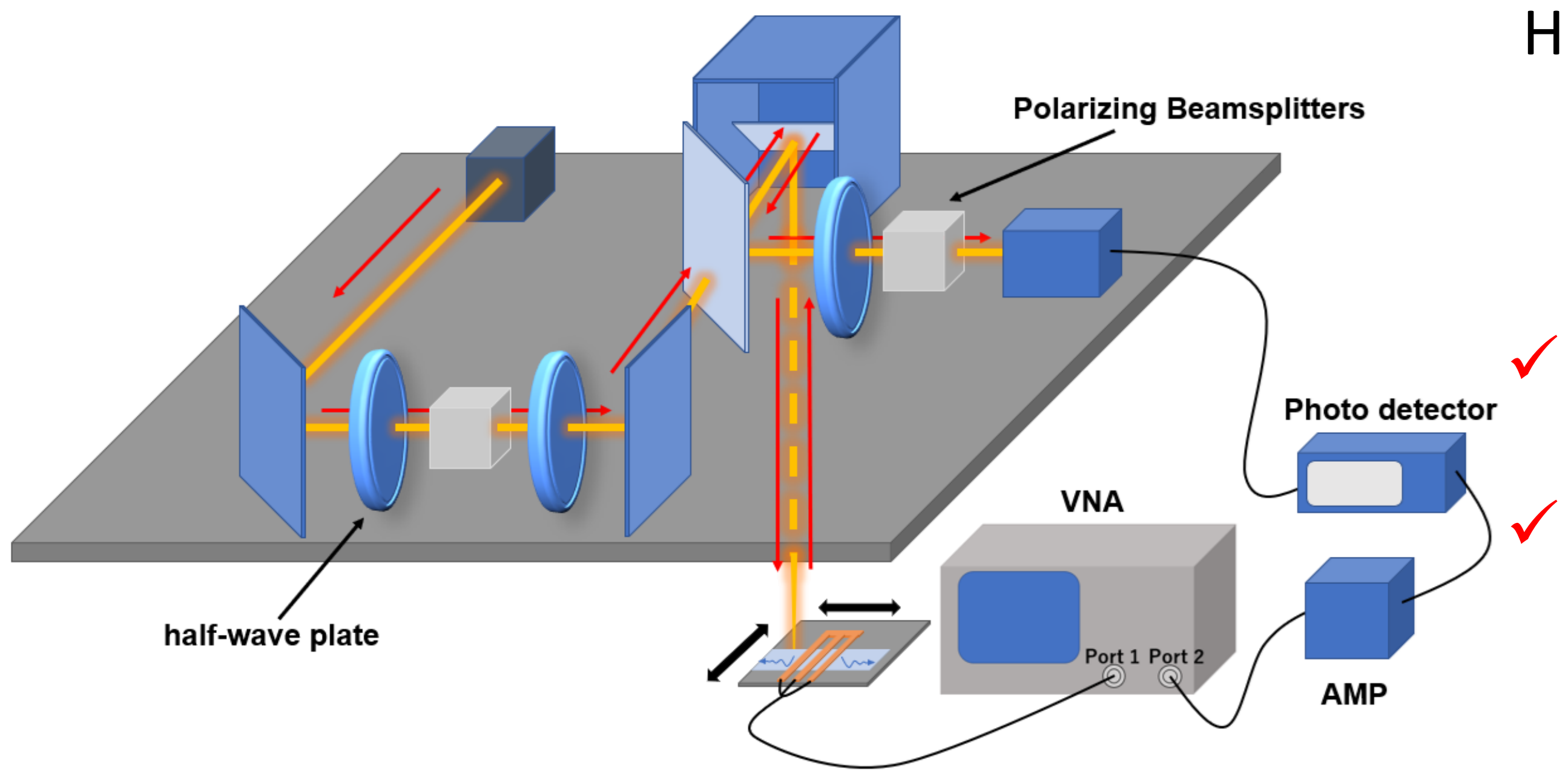
The magnon propagation characteristics cannot be evaluated.

Y. Shiota et al., Phys. Rev. Lett. **125**, 017203 (2020).

◆This study



Heterodyne-magneto-optical Kerr effect (MOKE) technique

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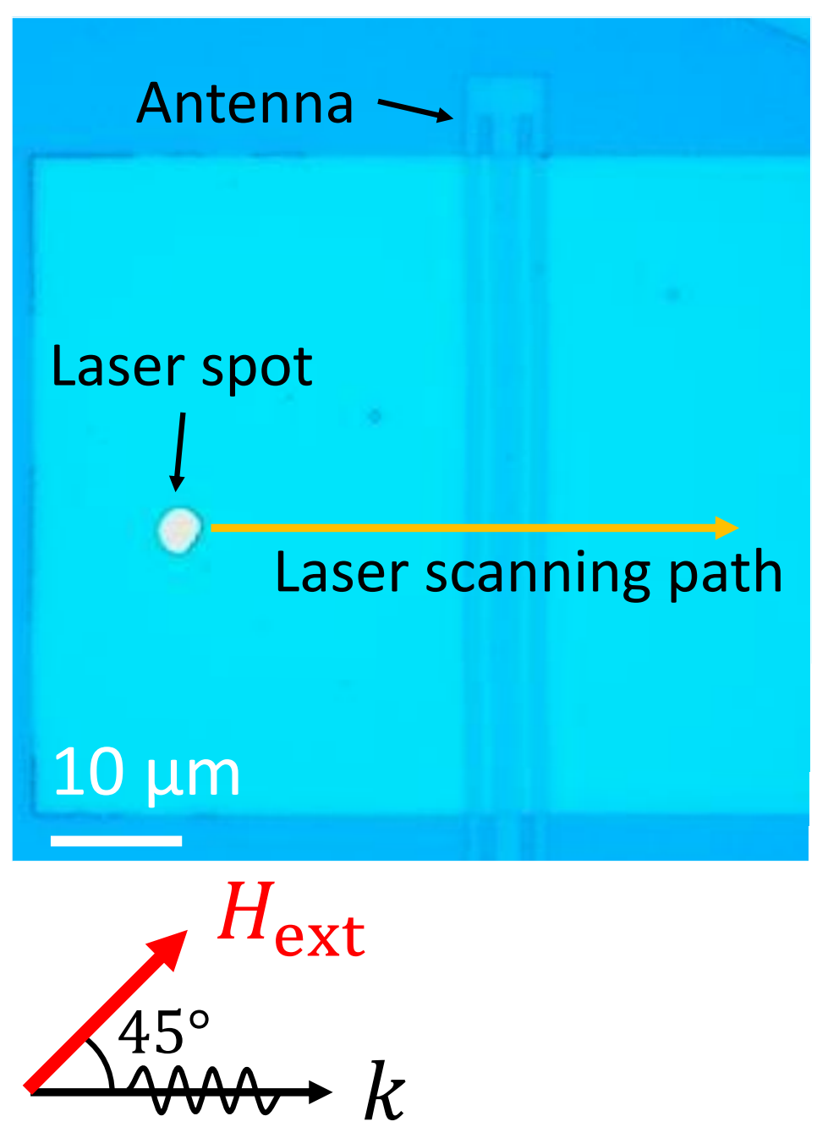
✓ Magnon propagation in real-space can be observed.

✓ Polar-MOKE configuration →Only acoustic magnon mode can be detected.

Y. Shiota et al., Appl. Phys. Lett. **116**, 192411(2020)
Y. Shiota et al., Phys. Rev. B **102**, 214440 (2020)

Experiment

◆Device and measurement condition



Film structure of SAF:
$Fe_{60}Co_{20}B_{20}$(15nm)/Ru(0.6nm)/$Fe_{60}Co_{20}B_{20}$(15nm)

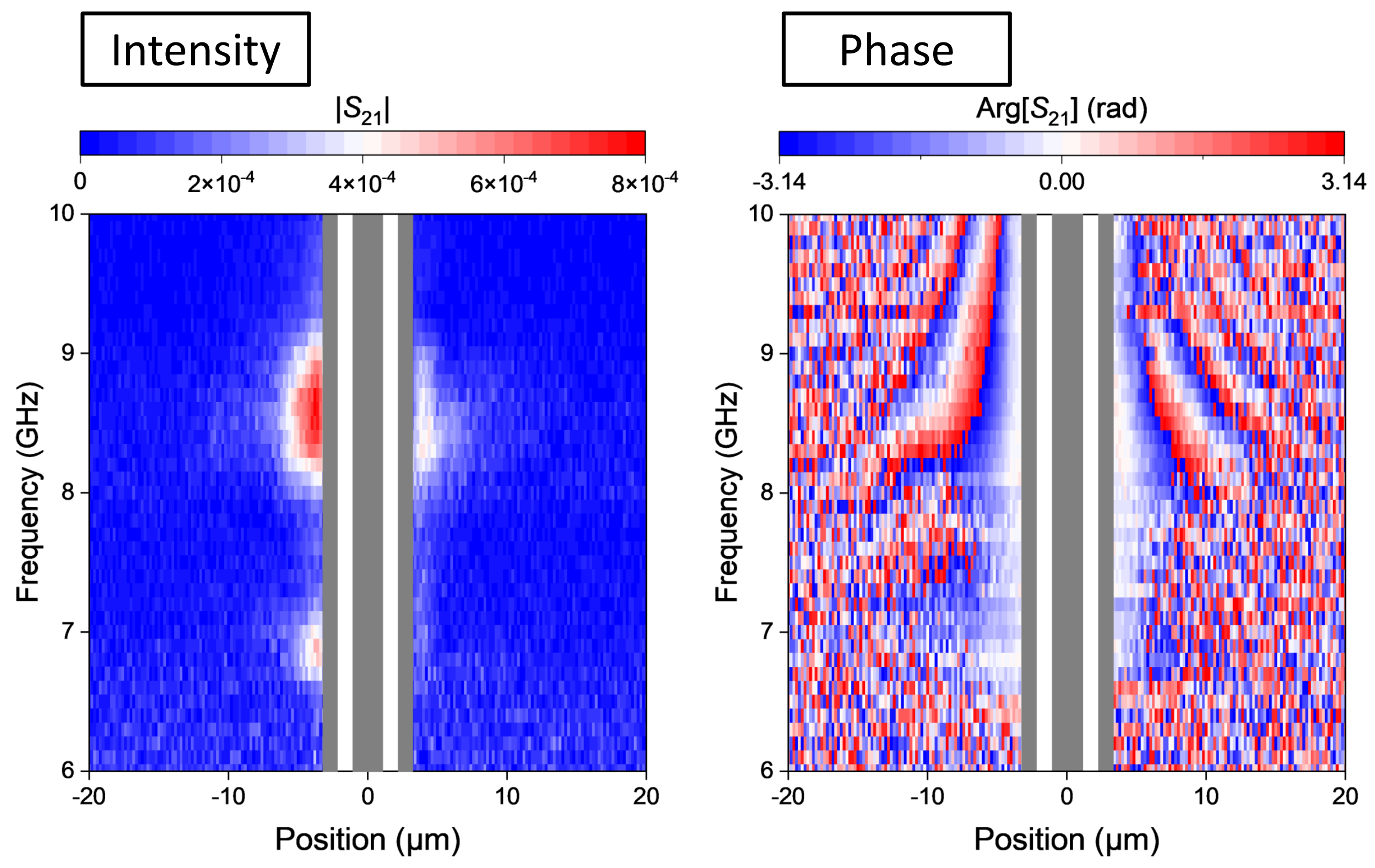
In-plane saturation field:
100 mT

Magnon excitation antenna:
GSG-type coplanar waveguide [1μm-2μm-1μm]

External in-plane magnetic field:
45° away from the magnon propagation direction

◆Imaging of propagating magnon

$\mu_0 H_{\mathrm{ext}} = 38.1\ \mathrm{mT}$

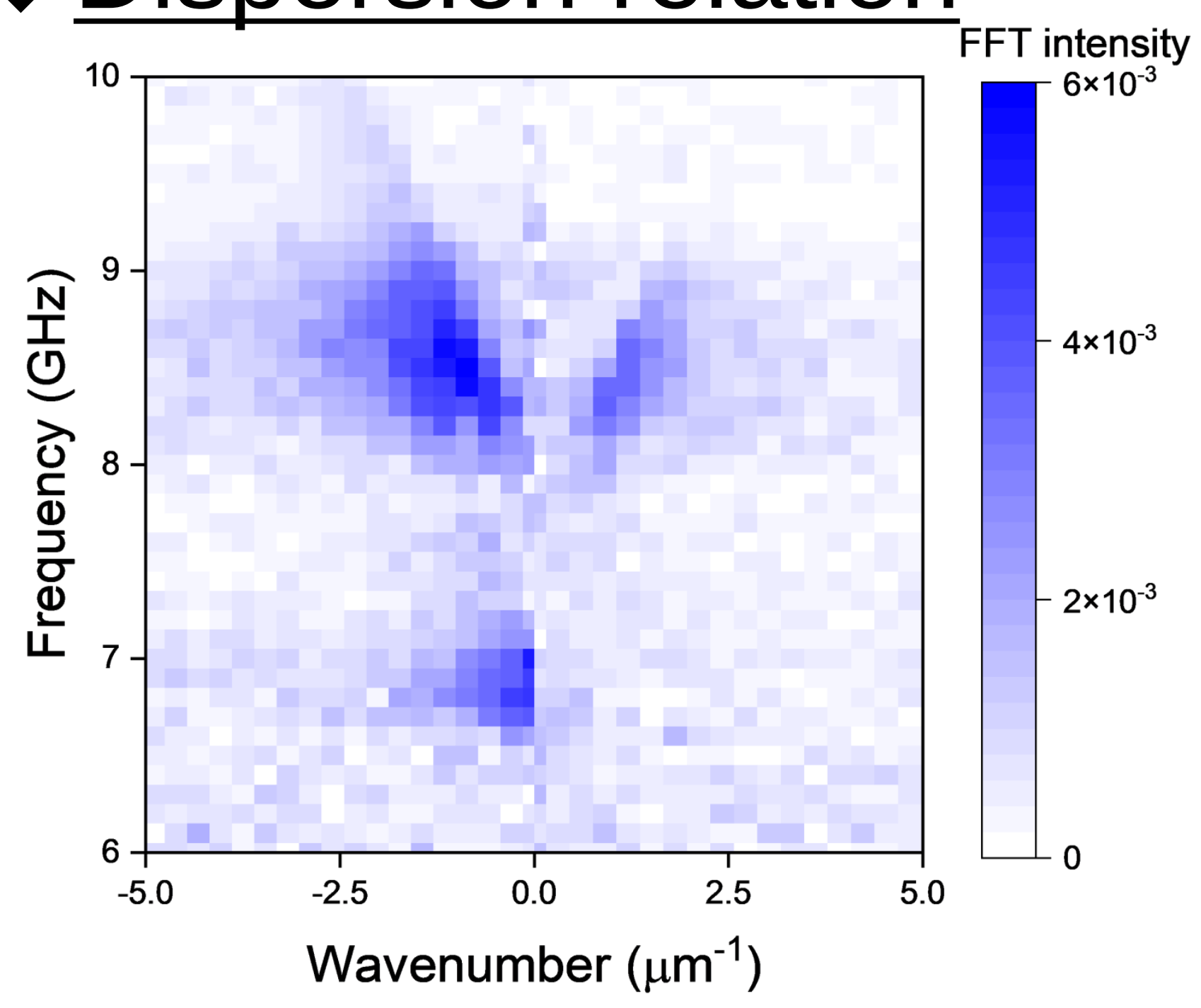


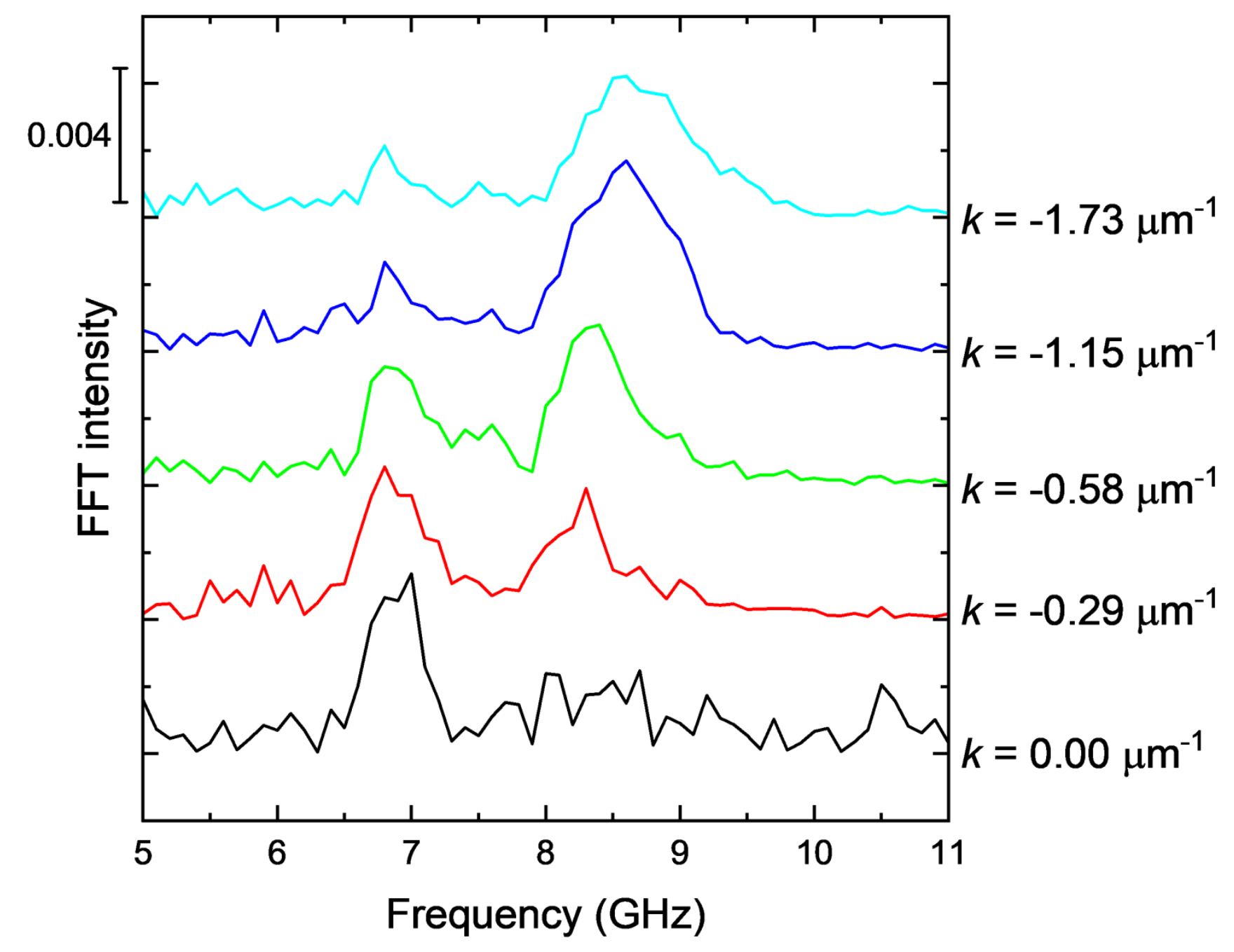
Heterodyne-MOKE signals as a function of frequency were measured by changing the position from the edge of the antenna.

✓ Direct measurement of the intensity and phase of magnons.

➡ One-dimensional real-space distribution of magnons was obtained.

◆Dispersion relation

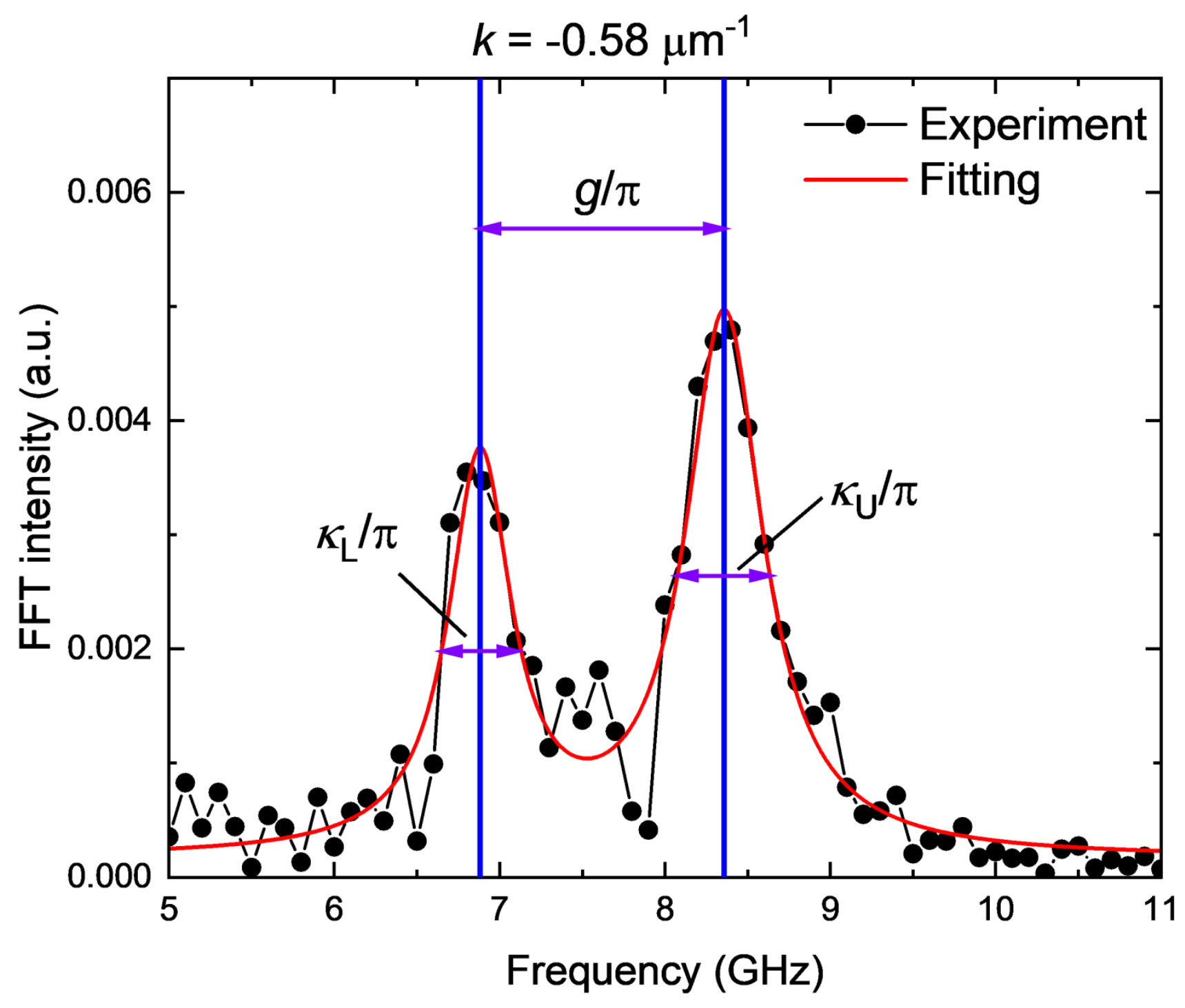




Magnon dispersion relation was reconstructed from complex fast Fourier transformation of the obtained signal.
To discuss hybridized magnon mode, we shows cross sections of it at several wavenumbers.

➡ Clear peak splitting was observed especially for $k = -0.58\ \mu\mathrm{m}^{-1}$.

◆Cooperativity parameter, C



Following parameters were obtained from multiple Lorentzian fit.

$$\frac{g}{2\pi} = 0.74 \pm 0.01(\mathrm{GHz})$$

$$\frac{\kappa_L}{2\pi} = 0.23 \pm 0.03(\mathrm{GHz}), \frac{\kappa_U}{2\pi} = 0.28 \pm 0.02(\mathrm{GHz})$$

Then, cooperativity parameter C can be evaluated.

$$\boxed{C = \frac{g^2}{\kappa_U \kappa_L} = 8.4 \pm 1.3}$$

The strong coupling with $C = 8.4 \pm 1.3$ was achieved.
This value was larger than the value obtained in the previous study, $C = 6.4$.

D. MacNeill *et al., Phys. Rev. Lett.* **123** 047204 (2019).

Summary

The magnon mode splitting in dispersion relation was observed.

◆Magnon propagation in in-plane magnetized SAFs was measured by the heterodyne-MOKE technique.
◆Mode splitting due to the magnon-magnon coupling was seen in the dispersion relation.
◆The cooperative parameter of 8.4 was obtained.

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