Photon-magnon coupling in a YIG-film split-ring resonant system

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1. Introduction

The study of light-matter interaction is a central subject in quantum information and communication science and technology. In order to be useful for quantum application, a proposed technology has to be able to exchange information with preserved coherence [1-3]. Recently hybrid systems consisting of resonantly coupled spin ensembles and microwaves have received much attention [4-5]. In this present work, we have proposed a simple hybrid structure consisting of yttrium iron garnet (YIG) film and split ring resonator (SRR) to study the interaction of magnetic resonances in YIG film with microwave photon resonances in SRR.

2. Methods and Results

A SRR structure along with microstrip line (shown in Fig. 1a) has been fabricated using lithographic techniques on a standard duroid (**RT/duroid 5870**) substrate of dielectric constant 2.3. The dimensions of the split ring and the microstrip line are (Fig. 1a): a = 8.5 mm, b = 7.5 mm, and g = 0.06 mm (the distance between the microstrip line and the SRR is also g), w = 3 mm. The split ring is inductively coupled to a microstrip feeding line. For the measurements, coaxial adaptors have been soldered at the two end of the stripline. The characterization of this structure has been carried out using a calibrated two port vector network analyzer (VNA).

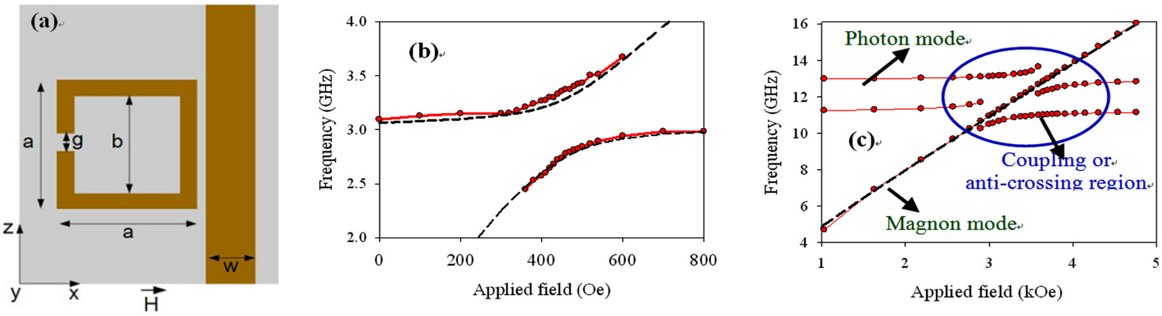

Fig. 1. (a) Sketch of the split ring resonator structure with geometrical parameters. Frequencies of the peaks as functions of the applied field (b) when YIG film covers only SRR and (c) when YIG film covers both an SRR and a section of the microstrip line

During measurements, an epitaxial YIG film (grown on GGG substrate) with the dimensions 8 mm × 15 mm × 25 μm is placed on top of the split ring with the YIG layer facing the SRR. A dc magnetic field (H) is applied (using electromagnet) in the plane of the film in the direction perpendicular to the microstrip line (along X direction). The input and the output of the microstrip feeding line have been connected to the ports of a VNA and its reflection (S_{11}) and transmission (S_{21}) characteristic have been measured as a function of microwave frequency and the strength H of the applied field. A microwave current flowing through the microstrip feeding line (along Z direction) excites a (photon) resonance in the SRR. At resonance, significant microwave current flows through the SRR. Its Oersted field drives the magnetization precession in the YIG film.

The microwave transmission |S21| as a function of microwave frequency (f) measured at different applied magnetic field. At H=0 Oe only one resonance mode (which is purely SRR resonance mode) was observed. When magnetic field is applied two peaks were observed out of which one peak is very strongly dependent on the applied field. Essentially, it moves across the displayed frequency range with an increase in field.

3. Discussion

The variation of resonance peak positions are plotted as a function of applied magnetic field and is presented in Fig. 1b. This clearly shows strong anti-crossing of the two lines, which suggests strong coupling between two modes. In order to identify the resonances peaks observed in Fig 1b, another set of measurements were performed. During the measurement the YIG film was placed such that it covered not only the SRR but also a section of the feeding microstrip line. These measurements were taken on a different SRR structure. The shape of the SRR for this structure was the same as in Fig.1a, but its sizes were slightly smaller, therefore the frequencies of the resonances in Fig.1c do not coincide with the ones in Fig.1b. Here we observed that for this YIG film placement one extra a resonance peak was appeared and is located in between two peaks of the type shown in Fig.1b. This extra mode shows a smooth and monotonous variation with the magnetic field and fitted well to the Kittel formula for the in-plane position. We will call it "magnon mode or Kittel mode". The variation of other two modes as a function of magnetic field can also be seen in Fig1 c. These modes show anti-crossing behavior independently at two different frequency regions when they came closer to Kittel mode. Importantly, far away from the "anti-crossing" with the Kittel mode the frequencies are almost the same and the line slope is practically vanishing. This implies the horizontal sections of these lines are uncoupled (pure) SRR resonances (photon modes). The sections of these lines with significant slopes (close to the anti-crossing region) are SRR resonances coupled to the magnon mode of the YIG film. The strong anti-crossing between the photon and magnon modes seen in Fig 1(b) and (c) suggests a strong coupling between them.

The strength of coupling of the SRR mode to the magnon mode can be determined by using the equation used for two coupled resonators [5]. From the fit, we obtain Δ = 270 MHz or = 9 %. In order to understand the process of anti-crossing of the SRR and magnon modes numerical simulation was carried out to calculate the radiation impedance (Zr) of spin waves excited by the microwave current in the split-ring resonator. It was shown that the SRR resonator experiences additional energy losses due to excitation of spin waves and also storage of oscillation energy in the spin system of the YIG film within the area of localization of the microwave magnetic field of the microwave current in SRR. It represents the physical mechanisms of coupling of the SRR resonances to magnon excitations in the YIG film.

4. Conclusion

By using the frequency-domain VNA–FMR spectroscopy we have demonstrated a strong coupling regime of magnons to microwave photons in the planar geometry of a lithographically formed split-ring resonator loaded by a single-crystal epitaxial YIG film. This interaction manifests itself as a strong anti-crossing between the photon and magnon modes. The numerical simulations of the microwave field structure of the SRR and of the magnetization dynamics driven by the microwave currents in the SRR reveals the physical origins of the effect of anti-crossing.

5. References

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