Magnon-photon coupling in a planar resonator-YIG thin film configuration

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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 been received much attention [4-5]. In the present work, we report on the exploration of the interaction of magnetic resonances in YIG films with microwave photon resonances in a complementary split ring resonator (CSRR) structure.

2. Methods and Results

A CSRR structure along with microstrip line has been fabricated using lithographic techniques on a standard duroid (TLC RF Substrate) substrate of a dielectric constant of 3.2.The dimensions of the CSRR are: size = 5 mm, width = 0.6 mm and split gap = 0.4 mm. The CSRR is capacitively coupled to a microstrip feeding line of a width of 1.85 mm. For the measurements, coaxial connectors have been soldered at the two ends of the stripline. The characterization of this structure has been carried out using a calibrated two- port vector network analyzer (VNA).

In our measurements, an epitaxial YIG film (grown on a GGG substrate) with a dimensions of 3 mm × 3 mm × 25 μm is placed on the top of the microstrip line with the YIG layer facing the strip line. 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 the transmission (S_{21}) characteristics have been measured as a function of microwave frequency and the strength H of the applied field. When a microwave current flowing through the microstrip feeding line (along Z direction) the CSRR essentially behaves as an electric dipole and excited by an axial electric field.

The microwave transmissions |S21| are measured as a function of microwave frequency (f) for different applied magnetic field strengths. At H=0 Oe only one resonance mode (which is purely SRR resonance mode) was observed. When the magnetic fields were applied, two peaks (F_1 and F_2) were observed, one with low dB and the other with high dB. Out of these two modes, one resonance mode is strongly dependent on the applied field and continuously shifts towards the higher frequency side with increasing magnetic fields.

3. Discussion

The variation of resonance peak positions are plotted as a function of applied magnetic field. This clearly shows strong anti-crossing of the two lines, which suggests strong coupling between two modes. Importantly, far away from the “anti-crossing” the frequencies are almost the same within and the line slope is practically vanishing. This identifies the almost horizontal sections of the line as uncoupled (pure) CSRR resonances ("photon modes"). The sections of these lines with significant slopes (close to the anti-crossing area) are CSRR resonances coupled to the magnon mode of the YIG film. The strong anti-crossing between the photon and magnon modes suggests a strong coupling between them.

At the resonant condition of $H=H_{RES}$, the frequency gap, F_{GAP}, between F_1 and F_2 is directly linked to the coupling strength of the system ($F_{GAP}/2=g_{eff}/2\pi$). The coupling strength of the SRR and the magnon mode can be determined using the harmonic oscillator model of two coupled resonators [5-6] for which we can define the upper (F_1) and lower (F_2) branches

$$F_{1,2}=\frac{1}{2}\left\lfloor (F_0+F_r)\pm\sqrt{(F_0-F_r)^2+k^4F_0^2}\right\rfloor \quad \cdots\cdots (1)$$

where F_0 and F_r are the resonance frequencies in the absence of coupling. F_0: CSRR resonance mode or photon mode and F_r: FMR frequency or magnon mode (modelled by the Kittel equation) which describes the precession frequency of the uniform mode (without taking into account spin wave distribution) [5]. The parameter k used in Eq. (1) corresponds to the coupling strength, which is linked to the experimental data $g_{eff}/2\pi$ by the equation: $F_{GAP} = F_2 - F_1 = k^2F_0$. From the fit, we obtain $g_{eff}/2\pi$ = 180 MHz and k = 0.31. The value of k obtained from the present study is significantly higher than the 3D-cavity/YIG sphere systems [2-4].

4. Conclusion

Using the frequency-domain VNA–FMR spectroscopy we have demonstrated a strong coupling regime of magnons and microwave photons in the planar geometry of a lithographically formed complementary split-ring resonator loaded on a single-crystal epitaxial YIG film. This interaction manifests itself as a strong anti-crossing between the photon and magnon modes. This thin film/CSRR hybrid geometry can be integrated with other planar electronic and optical devices and therefore is a very promising candidate as an information transducer that connects MHz, GHz, and THz frequencies.

5. References

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