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A New Light Beam Deflector Using Spin Waves at Microwave Frequencies in YIG Crystals

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1) Introduction

For possible use of such optical information processings as hologram memories, the need for a light beam deflector is increasing. Especially, an electrically controllable deflector having a large deflection angle is required. To utilize such a deflector by acoustic waves in crystals, a high power oscillator and an efficient ultrasonic transducer at high frequencies are necessary. However, at microwave frequencies it is quite difficult to make such an ultrasonic transducer.

On the other hand, spin waves such as magnetostatic waves, exchange spin waves and magnetoelastic waves at microwave frequencies can be excited efficiently in a magnetized Yttrium Iron Garnet (YIG) single crystal. Spin waves are excited by the direct conversion of electromagnetic energy at the end of a YIG rod [1),2)], and they interact with the infrared light, deflecting the light beam. Especially, the interaction is enhanced in the instability state of highly excited spin waves. The wave number of these spin waves can be varied electrically by changing the external magnetic field or the microwave frequency. Then, the deflection angle of a laser beam can be varied electrically in a YIG crystal.

Using these phenomena of spin waves, we propose a new electrically tunable light deflector with its fundamental experiments of spin waves excited in microwave fields.

2) Properties of Microwave Spin Waves

The samples used in the experiments are a [110]-axis YIG circular rod (2 mm dia× 7.33 mm length) and a [110]-axis YIG rectangular rod ($1.5\times2\times10$ mm^3). The excitation of spin waves in a YIG rod was made at 4.09 GHz at room temperature. Figure 1 shows a typical reflected microwave power. In the external magnetic field strength H_0 from 1300 to 1500 Oe the absorption peaks of magnetostatic waves were observed. Also, from 1500 to 2400 Oe the broad absorption peaks ($n=1,2,\cdots$) of magnetostatic waves and the fine absorption peaks of magnetoelastic waves (admixture of exchange spin waves and elastic waves) were clearly observed. Figure 2 shows the experimental curves of the delay times versus the field H_0 of magnetostatic and magnetoelastic waves. At H_0=1500 Oe the turning point exists at the center of the YIG rod. It is seen from Fig. 2 that near the turning point the wave number k of spin waves becomes large and varies rapidly.

With increasing the input power above a threshold value, the amplitudes of the peaks $n=1,2,\cdots$ became extremely large and then the instabilities were observed near each resonance peak. Figure 3 shows a typical frequency spectrum when the instabilities were observed near the n=1 peak. It is seen that the lower sidebands are highly generated. The mechanism of the instabilities is clarified to be due to the second-order parametric process [3)].

3) Light Deflection due to Spin Waves

As well known, YIG crystals are transparent in the near infrared light from 1.15 to 4.5-μ at room temperature and 1.05 to 4.5-μ at 77 K [4)]. The optical attenuation constant (to the base 10) of the YIG rod used in our experiments was about 0.1 cm^{-1} at 1.153-μ laser radiation. Then, the light interacts with spin waves and its beam is deflected efficiently without absorption loss. The angle of Bragg diffraction (θ_B) is given by [5)]

$$\sin\Theta_B = \frac{k}{2\,k_{op}} = \frac{\omega}{2\,k_{op}\,v}$$

where k and k_{op} are respectively the spin and optical wave numbers, and ω and v are the frequency and the velocity of travelling spin waves, respectively. The velocity v is a function of the internal magnetic field strength, which can be varied by the external field H_0, and it becomes quite small ($v \sim 10^6$ cm/s) at the place near a turning point in the YIG rod. Then, by increasing the frequency ω or by setting the laser beam near the turning point we can increase the deflection angle largely. The theoretical value of Θ_B at 1.153-μ and 4 GHz is about 13°. It is noted that a relatively small change in the field H_0 produces an appreciable change in Θ_B. In the state of the instability of spin waves it is expected that the intensity of the deflected light beam is enhanced.

The experiments of the laser beam deflection are done in the arrangement as shown in Fig. 4, using a 1.153-μ He-Ne laser radiation with a power of 1 mW in a 0.1 mm dia beam. The position of the laser beam can be moved along the YIG rod. The deflected beam is detected with a S-1 type photomultiplier or a Ge avalanche diode. From these experiments the propagation properties of spin waves and the origin of the instability are studied at first, and then we can get a efficient light beam deflector with the most suitable conditions. The detailed results will be presented at the conference.

References

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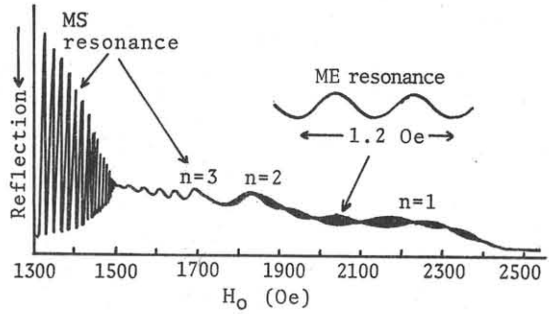

Fig. 1 Resonance absorption peaks of magnetostatic (MS) and magnetoelastic (ME) waves in the reflected microwave power.

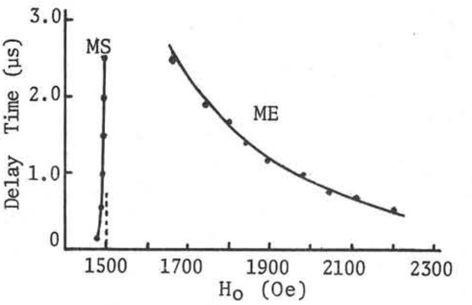

Fig. 2 Experimental curves of the delay times versus the field H_0 of magnetostatic (MS) and magnetoelastic (ME) waves.

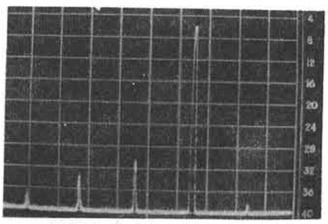

Fig. 3 Spectrum analyzer trace of the instability. f: 4.09 GHz, Δf: 1.9 MHz Vert.: 4 dB/div, Hori.: 1 MHz/div

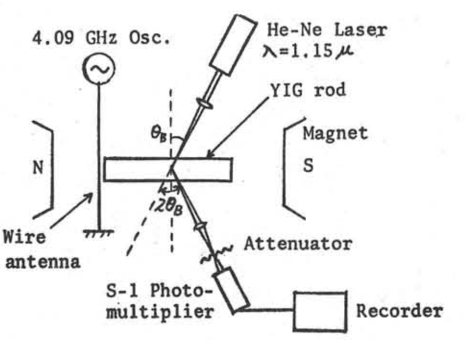

Fig. 4 Experimental arrangement of the laser beam deflection.