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MAGNETOSTATIC WAVE DELAY LINES USING THE NONUNIFORMLY MAGNETIZED YIG FILM

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Abstract

This paper treats the group delay characteristics of the magnetostatic forward volume waves in a nonuniformly magnetized yttrium iron garnet film in the propagation direction of the wave. The long time delay more than 1 μ second with low propagation loss is observed by the pulse experiment at S band. The tapered transmission line model of the magnetostatic wave guide magnetized nonuniformly is also presented.

Introduction

Recently the authors have reported the non-dispersive magnetostatic wave delay line using a nonuniformly magnetized YIG slab in the transverse direction of the wave propagation(1). Stancil and Morgenthaler have investigated the propagation characteristics of the magnetostatic surface waves with nonuniform in-plane field. They suggest that nonuniform in-plane fields can be used to alter the dispersion characteristic of the waves(2).

This paper reports for the first time to our knowledge the characteristics of the magnetostatic forward volume wave delay line using a nonuniformly magnetized YIG film in the propagation direction of the wave.

Dispersion relation

The dispersion relation of the magnetostatic forward volume wave is given by(3)

$$\beta = \frac{2}{s}\sqrt{\frac{\omega_h^2 - \omega^2}{\omega^2 - \omega_o^2}}\tan^{-1}\sqrt{\frac{\omega_h^2 - \omega^2}{\omega^2 - \omega_o^2}} \qquad (1)$$

where $\omega_h = \gamma\mu_0 H_i$, $\omega_o = \gamma\mu_0\sqrt{H_i(H_i + M)}$, β is the propagation constant, s is the film thickness. γ, M and H_i are the gyromagnetic ratio, saturation magnetization and the internal DC magnetic field, respectively.

For simplicity the internal magnetic field is assumed to be parabolic for the propagation direction of the wave (y direction).

$$H_i = H_0 + a\,y^2 \qquad (2)$$

where H_0 and a are the constant.

Substituting Eq.(2) into (1), the group delay time to travel length L can be numerically evaluated by

$$\tau = \int_{-L/2}^{+L/2} \frac{\partial\beta}{\partial\omega}\,dy \qquad (3)$$

The magnetic field dependence of the group delay obtained from the solution of Eq.(3) is shown in Fig.1 where the frequency is chosen to be 3.678 GHZ. The $\Delta\bar{H}$ is the difference of the field intensity between the edge and the center of the YIG film. The dispersive characteristic of the time delay is found to be increase with increasing the nonuniformity of the internal magnetic field. Their characteristics are different from the case of the nonuniformity of the magnetic field of the transverse direction of the wave, where the dispersive characteristic decreases with increasing the nonuniformity of the magnetic field(1).

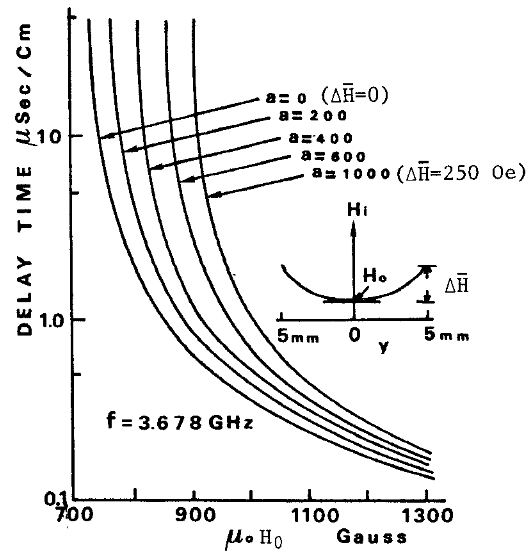

Fig.1 The group delay characteristic in a nonuiformly magntized YIG film.

Experiments

The main part of a magnetostatic wave delay line is shown in Fig.2. The dimensions of the YIG film are 10 micron thickness, 8 mm width and 12 mm

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length.The YIG sample is grown on gadolinium gallium garnet by liquid phase epitaxy.The input and output antennas placed on the surface of the film are fine wires of 100 micron diameters and separated by 9 mm from each other.The YIG film is magnetized non uniformly by means of auxiliary pole pieces placed close to the film.The center of the auxiliary pole piece is created mechanically in the concave form.

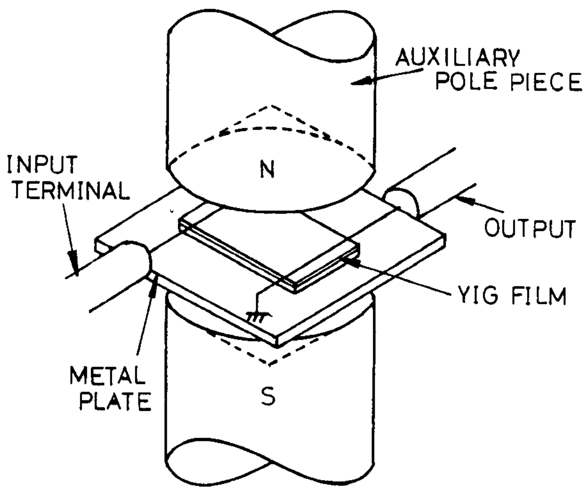

Fig.2 Geometry of the delay line

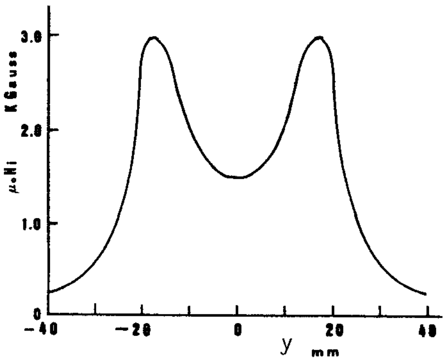

Fig.3 Measured bias field profile in the air gap.

The DC magnetic field profile is measured by the small Hall element.The result is shown in Fig.3 for the air gap of 7 mm.The DC magnetic field gradient estimated by the figure is an order of 100 Oe/cm near the center of the pole.

Measurements of the group delay characteristic of the magnetostatic wave are carried out at a S band frequency.The RF power of few mW modulated by 0.05 micro second pulse width is supplied through the input antenna.Fig.4 shows the typical magnetic field dependence of the time delay at 3.733 GHz.The long time delay more than 1 micro second is observed.On the contrary,for the case of the uniform

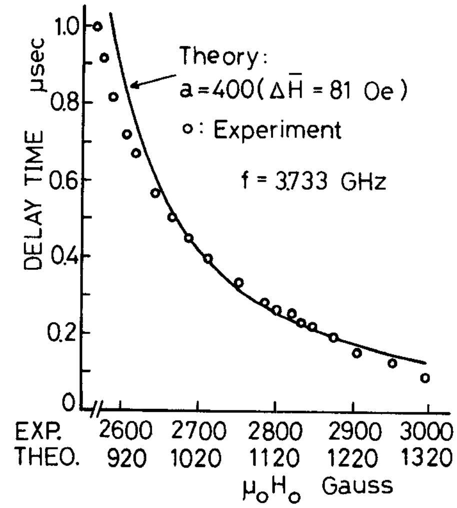

Fig.4 Measured and calculated group delay characteristic as a function of the magnetic field

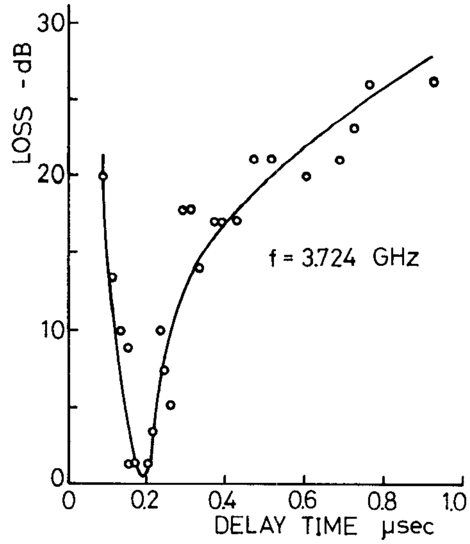

Fig.5 Propagation loss versus time delay characteristic.

magnetic field the time delay more than 300 nano second was difficult to observe for the same sample. The solution of Eq.(3) is also depicted in Fig.4 with the solid line.The experimental value coincides with the theoretical curve of a = 400 which corresponds to the field gradient of approximately 100 Oe/cm.

The insertion loss of the magnetostatic forward volume wave is measured as a function of the time delay as shown in Fig.5.The propagation loss is estimated to be 20 dB/μ second from the slope of the curve of the figure above 0.3 micro second. This value is lower 20 dB under the uniformly magnetized YIG film.However the insertion loss below

300 nano second varies rapidly with the magnetic field. The variation of the loss is estimated to be caused by the interference to different partial waves arising from reflection of the primary wave at the nonuniform magnetic field(4).

On the other hand we examined the effect on the nonuniform magnetic field for the magnetostatic surface wave, but the long time delay as well as the forward volume wave has not been observed at this time.

Tapered transmission line model

To explain theoretically the characteristic of Fig.5, the reflection loss of the magnetostatic wave by the nonuniform magnetic field is examined by using the transmission line model.

Integrating with the cross section of the magnetostatic wave guide, the complex poyinting vector is given by

$$P = \int (\mathbb{E} \times \mathbb{H}^*) \cdot n \, ds = \int j\omega\phi^* \mathbb{B} \cdot i_y \, ds \qquad (4)$$

where ϕ is the magnetic potential. B is the magnetic flux density and i_y is the unit vector of the propagation direction of the wave.

The following equivalent voltage and current can be defined regarding the power flow of Eq.(4).

$$j\omega B_y = V = A^+ e^{-j\beta y} + A^- e^{+j\beta y} \qquad (5)$$

$$\phi = I = (1/Z_0)(A^+ e^{-j\beta y} - A^- e^{+j\beta y}) \qquad (6)$$

The normalized characteristic impedance Z_0 of the magnetostatic wave guide may be defined with

$$Z_0 = \frac{|A^{\pm}|^2}{P} \qquad (7)$$

where $A^{\pm}$ is the amplitude of the magnetic potential. The characteristic impedance Z_0 is numerically estimated with the help of Eqs.(1) and (2). The Z_0 varies continuously in a tapered fashion along the length of the nonuniformly magnetized YIG film. The input reflection coefficient of the tapered transmission line is given by(5)

$$\Gamma_i = \frac{1}{2} \int_0^L e^{-2j\beta y} \frac{d}{dy}(\ln Z_0) dy \quad (8)$$

The Γ_i is numerically estimated as a function of the time delay as shown in Fig.6 where the a is chosen to be 400. The Γ_i is monotocally increases with increasing the delay time and varies sinusoidally with a very short periodicity. If we take the sampling point for a time delay on the curve of Fig.6, it may explain the interference effect which causes slow variation of the loss with the time delay of Fig.5.

Conclusion

Magnetostatic forward volume wave delay line using a nonuniformly magnetized YIG film was proposed. The long time delay characteristic with low propagation loss was experimentally observed.

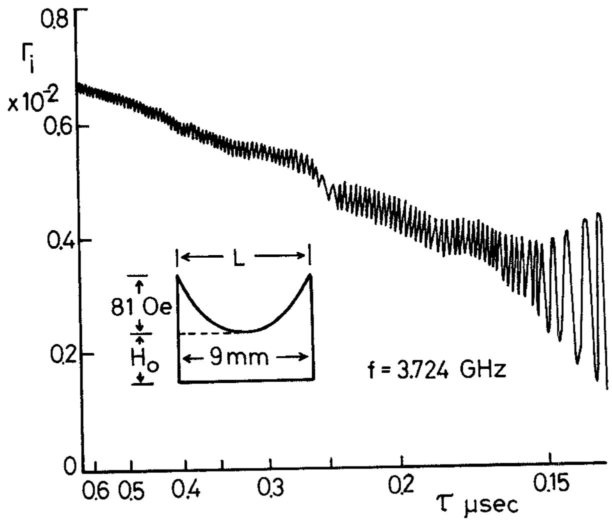

Fig.6 Reflection coefficient as a function of the time delay

Reflection loss caused by the nonuniform magnetic field was examined by the tapered transmission line model of the magnetostatic wave guide.

Since epitaxial film exhibits almost uniform internal field over more than 90 % of the film area, it has advantage to provide the desired internal magnetic field profile by means of the auxiliary pole piece.

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