MAGNETOSTATIC WAVE RESONATORS OF MICROSTRIP TYPE

Makoto TSUTSUMI+ and Tomoyuki TAKEDA++

+ Kyoto Institute of Technology,Matsugasaki Kyoto 606 Japan

++Osaka University,Yamada Kami Suita 565 Japan

ABSTRACT

We propose a new type of magnetostatic wave resonator using the Yttrium Iron Garnet (YIG) film with circular metal strips. Assuming the magnetic wall at a edge of strip,a simple dispersion relation is derived and estimated numerically to get the resonant frequency and quality factor as a function of resonator dimensions. Next more practical model of resonator is assumed and analyzed using mode matching technique. The best resonator characteristic is designed with the high concentration of magnetostatic wave energy within a circular strip.Finally resonant characteristic is demonstrated experimentally.

INTRODUCTION

Many type of magnetostatic wave resonators using YIG film have been reported extensively. For the rectangular shape resonator the straight edge resonance mode excited by comb transducer has been studied to get low insertion loss[1]. For the disk shaped resonator uniform precession mode excited by two orthogonal microstrips has been investigated to get high quality factor[2] .

This paper treats the magnetostatic wave resonator of microstrip disk type.Assuming the magnetic wall at a edge of circular strip, simple dispersion relation is derived. Secondly more practical geometry of the resonator is considered, and analyzed by making use of mode matching technique. Characteristics of the resonator are demonstrated experimentally.

ANALYSIS

A cross section of the microstrip resonator is shown in Fig.1. A microstrip disk

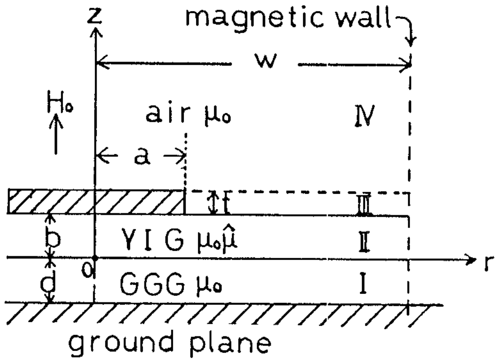


Fig.1 cross section of the magnetostatic wave resonator

having diameter a is put on the YIG film of the thickness b epitaxially grown on a Gadolinium Gallium Garnet (GGG) substrate. DC magnetic field H_0 is applied perpendicular to the YIG film.

From magnetostatic approximation the scalar magnetic potential satisfies with

$$\mu\left\{\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\psi}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2\psi}{\partial\theta^2}\right\}+\frac{\partial^2\psi}{\partial z^2}=0 \qquad (1)$$

where μ is the diagonal component of suceptibility tensor of the YIG.

The solution of (1) can be expressed as

$$\psi = A\, J_m(K_c r)\, e^{-jm\theta} \cos[K_z(z-b)]$$

where A is an arbitrary constant,phase constant K_z is given by

$$K_z = \sqrt{-\mu}\, K_c$$

The magnetic wall at r=a is assumed. Hence phase constant K_c is given by

$$K_c = \frac{y_{m\tilde{n}}}{a}$$

where $y_{m\tilde{n}}$ is the n th root of Bessel function of m th order. The magnetic potential and normal magnetic fields in the GGG and the YIG must be matched at the interface z =0. These boundary conditions reduce to a simple dispersion relatio as

$$K_z \tan(K_z b - n\pi) = K_c \tanh(K_c d) \qquad (2)$$

Dispersion relation (2) is evaluated numerically to get resonant chart as a function of aspect ratio a/b as shown in Fig.2. It is characterized with three integers (Υ.m.n) which signify the mode numbers in r ,θ and z directions,respectively.

We define resonant mode whose magnetic potential distributes exponentially in the direction of the magnetic field as the (110) mode. The RF magnetic field H_z of (110) mode which is obtained by differentiating Ψ with z, is bounded strongly at an interface between YIG film and GGG substrate. It may be a MSFVW(Magnetostatic Forward Volume Wave) mode influenced by metal plate,and dominant mode which is excited by the stripline transducer in the experimental configuration discussed later. While for (111) mode,the magnetic potential distributes sinusoidally,and its resonance characteristic is not in sensitive for the resonator geometries,i.e. aspect ratio as shown in Fig.2.

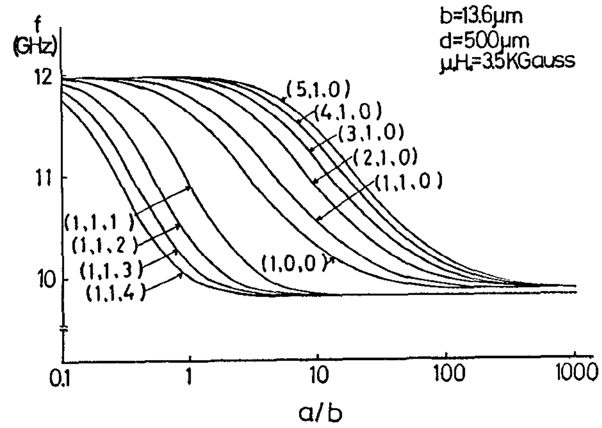


Fig.2 resonance frequency versus aspect ratio as a function of resonance mode

The quality factor of the microstrip resonator is examined. It consists of two factors. One is the quality factor due to the material loss and defined by

$$Q_{\Delta H} = \frac{2\pi f_0}{\gamma \mu_0 \Delta H}$$

where f_0 is the resonant frequency, and ΔH is the linewidth of the ferrimagnetic resonance of YIG film. Other factor is the quality factor Q_M defined by dissipatted energy P_d due to the surface resistance of two metals, and can be expressed as

$$Q_M = \frac{2\pi f_0 (U_1 + U_2)}{P_d} ,$$

$$U_1 = \frac{1}{2}\mu_0 \int_v \frac{\partial \hat{\mu}\omega}{\partial \omega} \mathbf{H}_I \cdot \mathbf{H}_I^* \, dv$$

$$U_2 = \frac{1}{2}\int_v \mu_0 \mathbf{H}_I \cdot \mathbf{H}_I^* \, dv \qquad (3)$$

$$P_d = \frac{1}{2}\int R_s \mathbf{H}_t \cdot \mathbf{H}_t^* \, ds$$

where $\mathbf{H}_t$ is the peak value of the tangential magnetic field and R_s is the surface resistance. U_1 and U_2 are the stored energy in the YIG film and GGG substrate,respectively.

Total quality factor is defined by the sum of two factors

$$\frac{1}{Q} = \frac{1}{Q_{\Delta H}} + \frac{1}{Q_M}$$

The Q_M for (110) mode is evaluated numerically from (3),and is shown in Fig.3 as a function of resonant frequency and for various values of GGG thikness d.The surface resistance R_s is assumed to be 2.61 $\times 10^{-7}\sqrt{f_0}$ (Ω). It is clear from the figure that the Q_M supports over 10^4 even if thickness d is decreased until 200 μm. Hence the quality factor of resonator proposed may be governed by the material loss rather than the metallic loss.

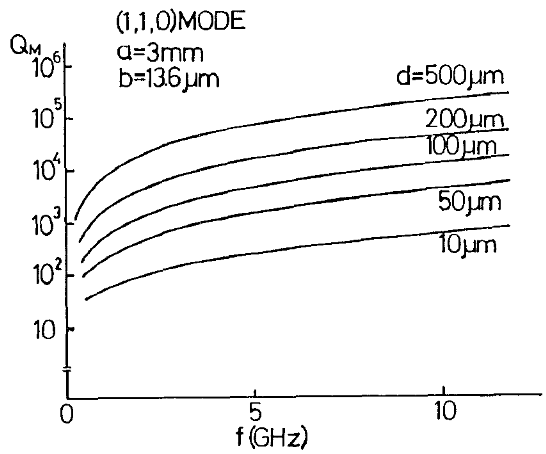


Fig.3 dependence of the resonance frequency on the quality factor as a function of the GGG thickness.

To analyze resonant characteristics in rigorous form, the mode matching technique is employed. Assuming the magnetic wall at r=w apart from a edge of the microstrip disk as shown in Fig.1, magnetic potentials in each regions are expanded in Fourier series in i th higher modes, and expressed as

$$\psi^{I}=\sum_{i=1}^{N1} A_i J_m(k_i r)\cosh[k_i(z+d)]\cdot e^{-jm\theta}$$

$$\psi^{II}=\sum_{i=1}^{N1} J_m(k_i r)\{B_i\sin(\beta_i z)+C_i\cos(\beta_i z)\}\cdot e^{-jm\theta}$$

$$\psi^{III}=\sum_{i=1}^{N2} B_m^{III}(\bar{k}_i,r)\{D_i e^{\bar{k}_i(z-b)}+E_i e^{-\bar{k}_i(z-b)}\}\cdot e^{-jm\theta}$$

$$(B_m^{III}(\bar{k}_i,r)\equiv N_m'(\bar{k}_i a)J_m(\bar{k}_i r)-J_m'(\bar{k}_i a)N_m(\bar{k}_i r))$$

and

$$\psi^{IV}=\sum_{i=1}^{N1} F_i J_m(k_i r)\, e^{-k_i(z-b-t)}\cdot e^{-jm\theta}$$

where upper suffixes denote the potentials of each regions, and

$$K_i=\frac{y_{mi}}{w}\ ,\qquad \beta_i=\sqrt{-\mu}\,K_i$$

y_{mi} is i th root of Bessel function $J_m(x_i)$. $\bar{K}_i$ is i th root of equation followed by

$$B_m^{III}(\bar{k}_i,W)\equiv N_m'(\bar{k}_i a)J_m(\bar{k}_i W)-J_m'(\bar{k}_i a)N_m(\bar{k}_i W)$$

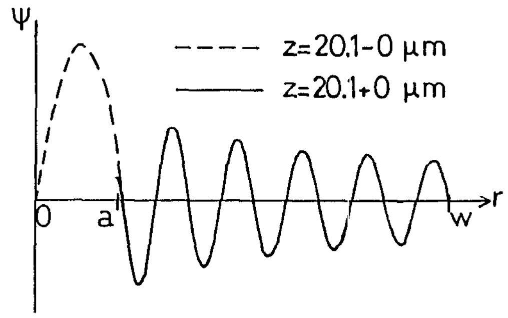
Matching the series expansions for tangential magnetic fields and normal component of magnetic flux at the boundaries z= b,0 and d, an explicit equation for the amplitude coefficients leads to a system of integral eigenvalue equation of an infinite number of N th modes.

Using orthogonal relation of modes, we obtain the homogeneous equation in the matrix form with $(2N_1)^2$ unknown amplitudes as

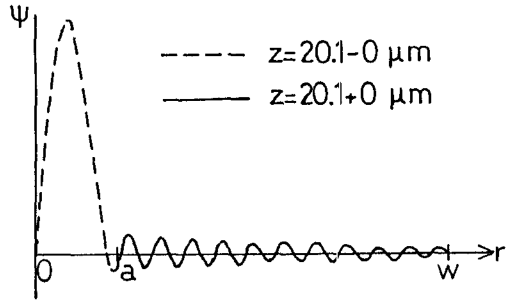
$$[M]\begin{bmatrix}C\\F\end{bmatrix}=0 \qquad (4)$$

The homogeneous equation (4) is evaluated by computer to get the dispersion relation. The numbers of mode must be chosen over N_1=20 to yield sufficiently convergence behavior of solution. Thus the matrix size is 1600.

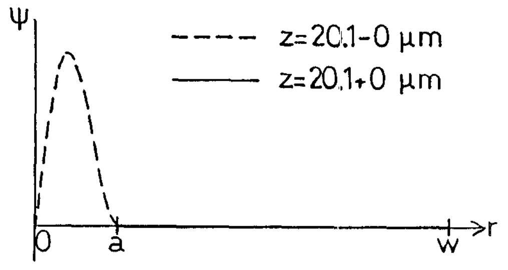
Fig.4 shows distributions of the magnetic potential ψ in the radial direction for (110) mode for various thickness of GGG. The material parameters used for the numercal calculations are 2a=3mm, b=20.1 μm, t= 1 μm, $\mu_0 M$=1640 Gauss and $\mu_0 H_0$=3500 Gauss. Signs of z+ and z- in the figure imply potentials of the upper and lower side of the microstrip, respectively. For large d value of Fig.6a, the potential ψ oscillates toward the magnetic wall w in



(a) GGG thickness 500 μm



(b) GGG thickness 200 μm



(c) GGG thickness 50 μm

Fig.4 magnetic potential distributions in the radial direction for various thickness of the GGG substrate.

the other side of microstrip. This behavior will prohibit the analysis of the simple resonator model discussed previous section because many magnetic walls are defined along radial direction, and also may cause large radiation loss in this case which results in low quality factor.

However if d is moderate as shown in figures 4b and 4c, ψ distributes sinusoidally in the microstrip disk and exponentially toward the magnetic wall w.

The high concentration of magnetostatic wave energy within the microstrip will result in a better resonance performance and also will give a correct solution for the simple model discussed in the preceding section.

EXPERIMENT

The structure of resonator consists of a microstrip disk placed on the center of a YIG film as shown in Fig.5. The YIG film dimension is 9 mm × 10 mm. Fine wire antennas have been used to excite MSFVW in the past, in our experiments wide microstrip transducer is designed to couple efficiently electromagnetic wave energy to magnetostatic wave energy. Several resonators were fabricated and tested with various diameter of circular strip.

Fig.6 shows a typical frequency response of the resonator using a 20 μm thick YIG film and 400 μm GGG substrate with 6 mm diameter disk evaporated by gold and 1 mm wide transducer. These geometries correspond to a aspect ratio a/b=150.

The resonator was tunned over the 1.8-4.2 GH_z range with 3 dB peak to peak amplitude ripples. Minimum resonator insertion loss was 14 dB. Maximum loaded Q_ℓ was 340 and the maximum off-resonance rejection was 25 dB.

Adjusting a width of microstrip transducer b at X band, a better resonance performance was observed with Q_ℓ = 2000 and insertin loss 20 dB.

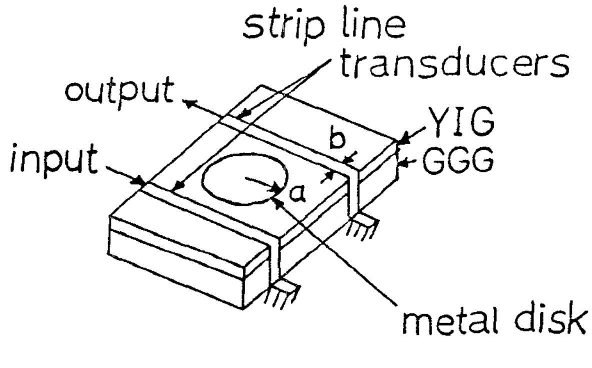


Fig.5 experimental set-up of the magnetostatic wave resonator

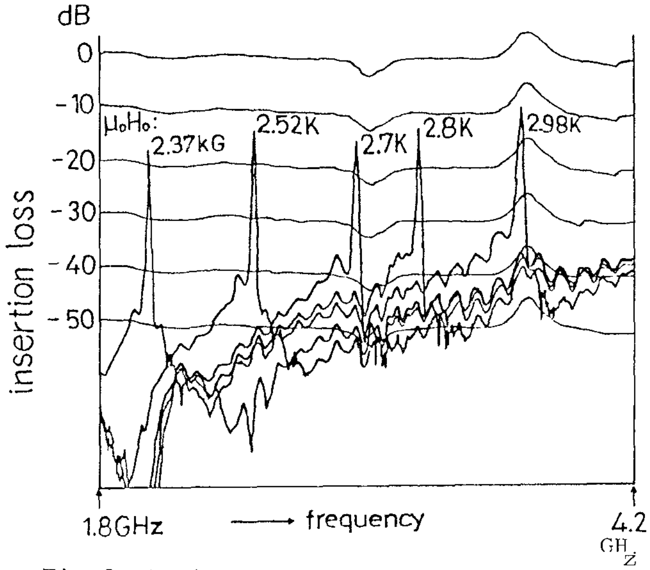


Fig.6 typical frequency response of the resonator

CONCLUSIONS

Characteristics of the magnetostatic wave resonators of microstrip type have been analyzed by making use of the mode matching technique. Magnetic potential distribution outside of the microstrip disk have been evaluated numerically with high concentration of the magnetostatic wave energy, and mode chart with various resonator dimensions have been given.

Experiments were carried out using 20 μm thick YIG film with 6 mm diameter microstrip disk. Typical resonance characteristic reveals loaded Q_ℓ =340, average insertion loss 15 dB and dynamic range =25 dB. If we use thicker YIG film than 40 μm, further improvement of resonant characteristic will be possible with low sprious level.

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