A BANDPASS FILTER USING YIG FILM GROWN BY LPE

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ABSTRACT

A 1.575 GHz bandpass filter using YIG film grown by liquid phase epitaxy (LPE) has been developed. Low insertion loss, high spurious suppression and small temperature drift have been achieved, and the performance of this filter satisfies the requirements for use in a microwave receiver.

INTRODUCTION

Microwave devices based on the ferrimagnetic resonance in a YIG film have advantages over devices using conventional YIG sphere technology in batch production, lower cost and compatibility with microwave integrated circuits. The problems of spurious responses (due to higher order magnetostatic modes) and temperature drift (due to changes in the internal dc magnetic field) inherent to thin film YIG resonators, however, have prevented them from being used in actual systems [1].

This paper describes the fabrication and testing of a 1.575 GHz bandpass filter using YIG film grown by LPE. Our approach to suppression of spurious modes and temperature compensation is also described.

DEVICE FABRICATION

The configuration of the two-pole filter is shown in Fig.1. Two YIG disk resonators were fabricated from lanthanum-substituted yttrium iron garnet (La:YIG) film epitaxially grown on a gadolinium gallium garnet (GGG) substrate. The YIG disks were 2.5 mm in diameter and 25 to 30 μm thick. The distance between the centers of the disks was 9 mm. Input and output microstrip lines were formed photolithographically on a 1.27-mm-thick alumina substrate and grounded at their extremities. The two disks were placed over the input and output microstrip lines. The microstrip line for inter-resonator couplings was formed on the GGG substrate and grounded at both ends. A biasing magnetic field of about 2,300 Oe was applied perpendicularly by a permanent magnet.

Q_u, Q_{e1} and Q_{e2} were estimated from the bandstop filter configurations of a single YIG resonator positioned over the microstrip line on the alumina substrate at the point where the microstrip line on the GGG substrate passes over [2]. Here, Q_u is the unloaded Q of the resonator, Q_{e1} is the external Q corresponding to the coupling

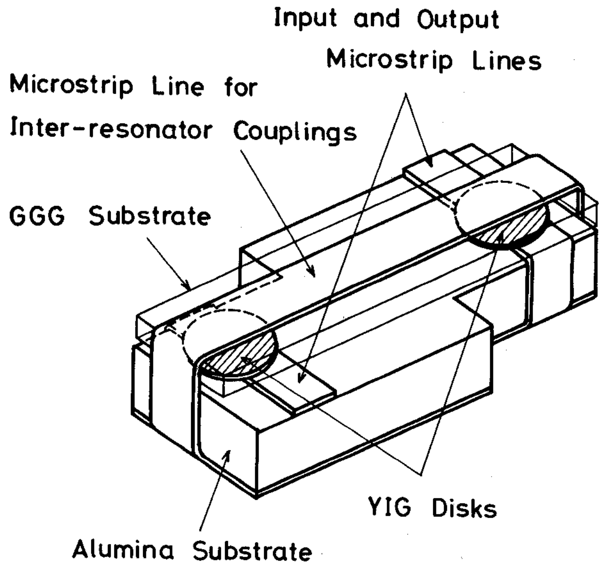

Fig. 1 Configuration of the two-pole filter

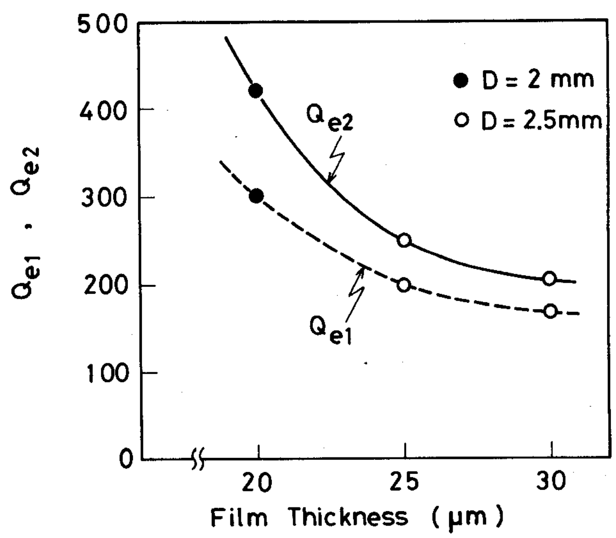

Fig. 2 Q_{e1} and Q_{e2} plotted against various sizes of YIG resonators

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of the resonator to the microstrip line on the alumina substrate, and Q_{e2} is the external Q corresponding to the coupling of the resonator to the microstrip on the GGG substrate. The measured values of Q_{e1} and Q_{e2} for different sizes of YIG resonators are shown in Fig. 2, while Q_u was about 800 independent of the dimensions of the resonator.

SUPPRESSION OF SPURIOUS MODES

A grooved circle concentric with the center of the disk was formed photolithographically on the surface of the disk, as is shown in Fig. 3. The groove was 10 μm wide and its depth was 10 to 20% of the film thickness. The ratio of the diameter of the grooved circle to that of the disk was 0.8. In a disk whose aspect ratio (thickness/diameter) is about 1×10^{-2}, the uniform precession mode of perpendicular resonance has its node at the groove, where the rf magnetization of the higher magnetostatic modes of perpendicular resonance is not zero. The magnetization is pinned at the groove, hence the groove suppresses the non-uniform magnetostatic modes.

Figure 4 (a) is the spectrum of perpendicular resonance with a grooveless YIG disk observed in a TE_{011} cylindrical cavity at 9 GHz. Many absorption peaks corresponding to a series of modes $(1,N)_1$ with N=1,2,3,... appear in the spectrum [3]. The lowest mode $(1,1)_1$ is a uniform mode appearing as the peak with the largest amplitude in the spectrum. Figure 4 (b) is the spectrum of perpendicular resonance with a grooved YIG disk. Note that the modes $(1,N)_1$ with N=2,3,4,... are effectively suppressed without sacrificing the $(1,1)_1$ mode.

This spurious-suppression technique has the following advantages:

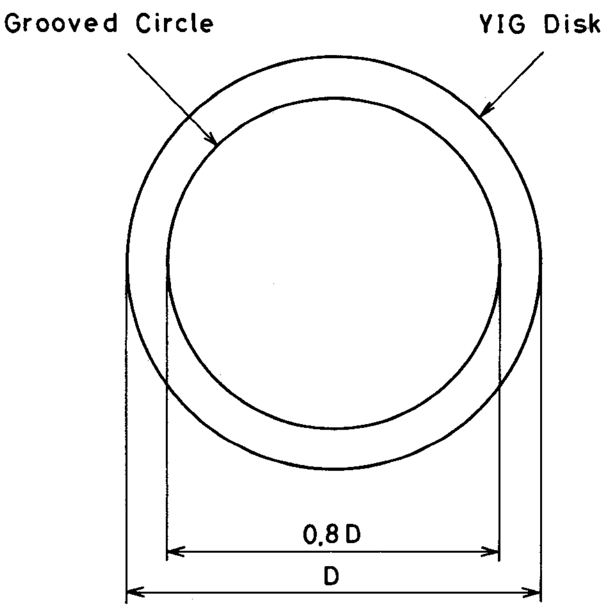

Fig. 3 Grooved circle formed on the surface of YIG disk

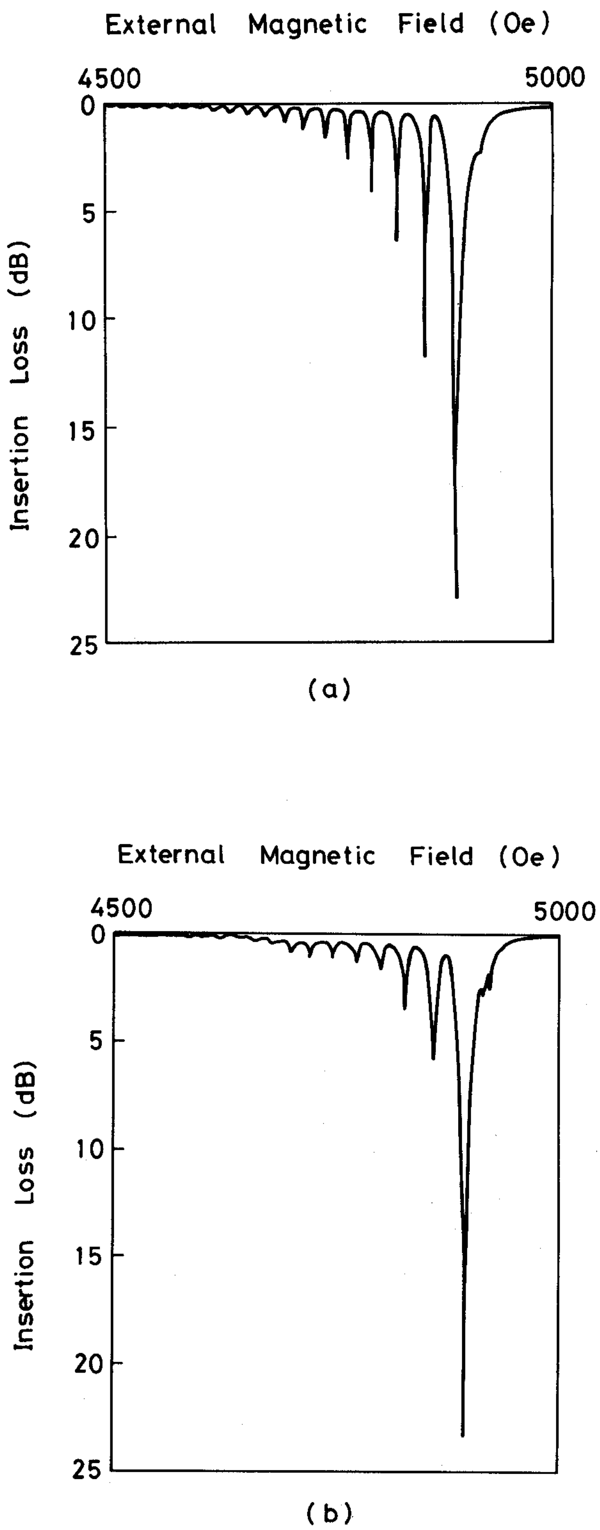

Fig. 4 Spectra of perpendicular resonance in the TE_{011} cylindrical cavity at 9 GHz
(a) grooveless YIG disk
(b) YIG disk with grooved circle

1) As the configurations of transverse rf magnetization for each magnetostatic mode do not depend on the saturation magnetization of the resonator, the position of the groove need not be changed as the film composition changes.
2) As the position of the nodes for each magnetostatic mode is a slowly varying function of the resonator's aspect ratio, the position of the groove need not be changed with small changes in the thickness of the film between the wafers.
3) As the position of the groove is calculated using magnetostatic mode theory and is therefore independent of the resonance frequency, this technique is equally applicable to the tunable filters.

TEMPERATURE COMPENSATION

The remaining problem to be overcome is the variation of the filter's center frequency with changes in temperature. The variation with temperature is caused by the changes in the internal dc magnetic field in the disk which is in turn caused by changes in the saturation magnetization of YIG. A compact magnet which supplies the biasing magnetic field was designed to compensate for temperature changes. The magnet has been constructed of permanent magnets and soft ferrite plates. The structure of the magnet is shown in Fig. 5. In the following analysis, the magnet depicted in Fig. 5 was assumed to be an idealized magnetic circuit. That is, the permeability of the yoke is infinite, all the magnetic flux goes through the gap, and the magnetic field is spatially constant in the gap. The magnetization of the each ferrite plate is assumed to be saturated. It is further assumed that the permanent magnet is hard enough to have a linear demagnetization curve of constant recoil permeability μ_r. Then, the magnetic field strength, $H_g(T)$, in the gap can be obtained as

$$H_g(T) = \frac{L_m \cdot B_r(T)/\mu_r + L_x \cdot N_z^X \cdot 4\pi M_s^X(T)}{L_g + L_m/\mu_r + L_x}, \quad (1)$$

where $B_r(T)$ is the remanence, N_z^X is the demagnetization factor of the ferrite plates in the perpendicular direction, and $4\pi M_s^X(T)$ is the saturation magnetization of the ferrite plates.

The resonance frequency of the YIG disk resonator in the magnet can be predicted from magnetostatic mode theory and expressed, if the anistropy field is ignored, in the form of Kittel's equation:

$$f(T) = \gamma\{H_g(T) + (N_t^Y - N_z^Y) \cdot 4\pi M_s^Y(T)\}, \quad (2)$$

where $f(T)$ is the resonance frequency, γ is the gyromagnetic ratio, and $4\pi M_s^Y(T)$ is the saturation magnetization of the YIG resonator. N_t^Y and N_z^Y are the demagnetization factors of the YIG disk in the transverse and perpendicular directions, respectively, and $(N_t^Y - N_z^Y)$ is calculated from magnetostatic mode theory. In equations (1) and (2), $f(T)$, $H_g(T)$, $B_r(T)$, $4\pi M_s^X(T)$ and $4\pi M_s^Y(T)$ are all functions of temperature T.

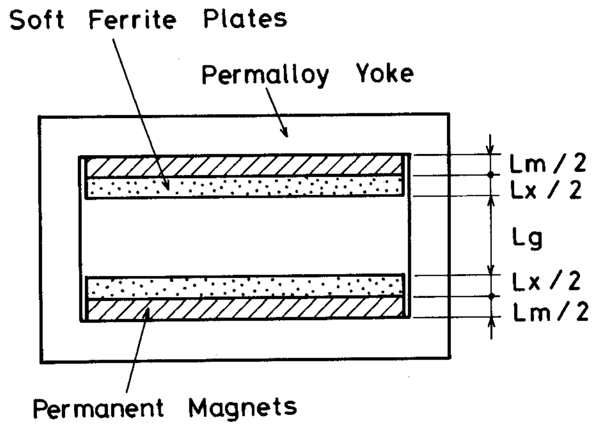

Fig. 5 Cross section of the magnet structure

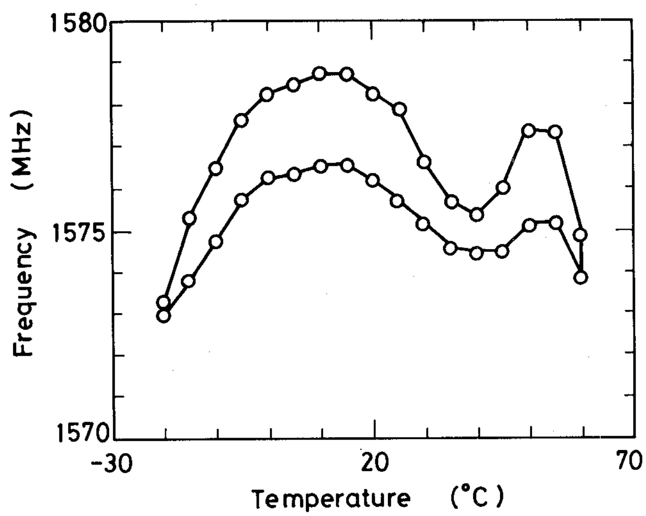

Fig. 6 Temperature dependence of the resonance frequency of the YIG disk in the magnet

Table I Comparison of the results of the simulation and the experiment

	simulation	experiment
Total thickness of permanent magnets Lm (mm)	1.57	1.50
Total thickness of ferrite plates Lx (mm)	1.60	1.70
Gap distance Lg (mm)	4.0	3.3
Variation of resonance frequency in temperature range from - 20°C to + 60°C (MHz)	±3.0	±2.9

The optimum dimensions of the magnet were determined using equations (1) and (2) in computer simulation. Figure 6 shows the experimental result of the temperature dependence of the resonance frequency of the YIG disk in the magnet. The variation of resonance frequency was ± 2.9 MHz over the temperature range from $-20^{\circ}C$ to $+60^{\circ}C$. The results of the simulation and the experiment are compared in Table I.

PERFORMANCE

Figure 7 shows a typical response of the filter packaged in the magnet. A low insertion loss of 3 dB and a high spurious suppression of more than 35 dB have been achieved. When a YIG disk 2.5 mm in diameter is used, the 3 dB bandwidth of this filter can be changed from 10 MHz for a 25-μm-thick film to 14 MHz for a 30-μm-thick film. The characteristics of the filter are summarized in Table II. The variation of the filter's center frequency was ± 8 MHz over the temperature range from $-20^{\circ}C$ to $+60^{\circ}C$, compared to ± 2.9 MHz variation in Fig. 6. This is because we used permanent magnets from a different lot than the lot of the magnets used in Fig. 6. The filter is of a drop-in type with overall dimensions of 20x10x9 mm. A photograph of the filter is shown in Fig. 8.

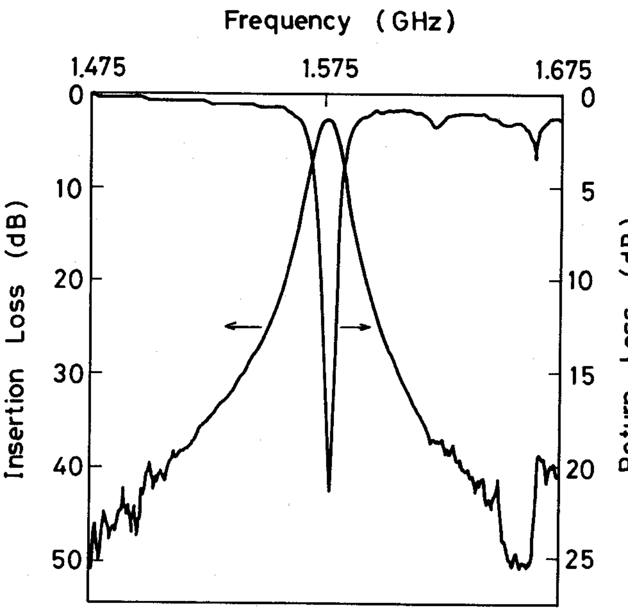

Fig.7 Transmission and reflection response of the filter

Table II Characteristics of the bandpass filter

Center frequency (GHz)	1.575
Insertion loss (dB)	3.0
Return loss (dB)	>15
3 dB bandwith (MHz)	10 – 14
Isolation (dB)	>45
Spurious suppression (dB)	>35
Variation of center frequency in temperature renge from -20°C to +60°C ΔF (MHz)	±8.0

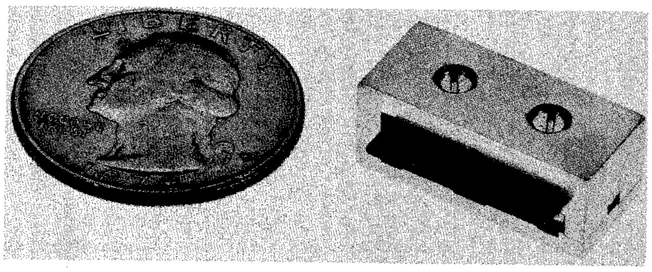

Fig. 8 A drop-in type bandpass filter

CONCLUSIONS

A 1.575 GHz bandpass filter using YIG film grown by LPE has been developed. A new spurious-suppression technique and the method of designing a magnet to compensate for temperature changes have been developed and applied to the filter. Low insertion loss, high spurious suppression and small temperature drift have been achieved. A compact drop-in type filter with these performance characteristics has wide potential applications in microwave communication equipment.

ACKNOWLEDGEMENTS

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