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Relationship between Magnetic Properties of YIG Ferrites and Intermodulation Characteristic of Microwave Isolators

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The generation of the intermodulation noises in microwave isolators has been studied in relation to the characteristics of YIG ferrites designed for this application. We have investigated the influences of porosity and crystalline anisotropy related to the magnetic loss, which causes the generation of intermodulation signals. The power dependence of the intermodulation power level is stressed as the crystalline anisotropy decreases. These results are consistent with the nonlinear effects of a single normal mode before the excitation of the spin-waves. It also appears that this power level is proportional to the magnitude of dc bias magnetic field.

Key words: YIG, Isolator, Intermodulation, Ferrimagnetic resonance(FMR), Nonlinear effect

I. Introduction

Recently microwave ferrite isolators and circulators are widely used in mobile wireless communication systems. Especially for isolators used in the base station systems, nonlinear intermodulation characteristics are very important because of operation under the high-power fields. The intermodulation signals generate clicking noises and interference in the telephone lines. It is necessary to reduce this phenomena in ferrite isolators in order to improve the quality of the transmission signals.

How *et al.*[1] have reported the theoretical analysis of the third-order intermodulation problem for a ferrite junction circulator. They have approximated the equation of motion of magnetization vector up to the third order in the rf-excited fields and analytically solved the coupled Maxwell equations. Finally, they have concluded that the static demagnetization field can effectively increase the intermodulation output power.

However, their equation of motion omitted the influence of crystalline anisotropy and actual factors such as porosity and the strength of dc bias field, which are expected to contribute to the generation of the intermodulation signals. From the standpoint of designing ferrite characteristics, the crystal anisotropy and the porosity play significant roles in decreasing magnetic losses and controlling the temperature stability of isolators. The standard technique to study microwave losses in ferrites is to measure ferrimagnetic resonance(FMR) linewidth. FMR linewidth in polycrystalline ferrites can be separated in different contributions :

$$\Delta H = \Delta Hi + \Delta Ha + \Delta Hp \qquad (1)$$

where ΔHi is the linewidth of the corresponding single crystal sample, its value is usually much smaller than those of the corresponding polycrystalline materials. Therefore, this contribution can be neglected. ΔHa and ΔHp are the line broadening induced by anisotropy and porosity contribution, respectively. Much effort has been devoted to decrease the porosity and the anisotropy in order to reduce the magnetic loss in microwave applications.

The purpose of this work is to experimentally demonstrate the effects of the porosity and the anisotropy on the intermodulation signals. In addition, the influence of dc magnetic field strength has been studied.

II. Experimental Procedure

Garnet ferrite is of prime importance today for many microwave applications. Polycrystalline garnet samples used in this study were prepared by the usual ceramic technique. X-ray analysis and the optical microscope observation were used to confirm if the single phase was obtained. Magnetic characteristics were measured by a Vibrating sample magnetometer.

The porosity was controlled by a variation in compacting pressure. Since the fabricated samples for ΔH measurement and attaching to isolators are quite small, the porosity was inferred from the density measurements on large blocks of the fired materials. The porosity, p, was estimated by comparing the bulk density with the theoretical density, which was determined from the lattice constants measured by XRD. The bulk density was determined by weighing a known volume of the material.

For the ferrimagnetic resonance(FMR) linewidth measurements, spherical samples of about 1.0 mm diameter were used. A basic FMR spectrometer equipped with a fre-

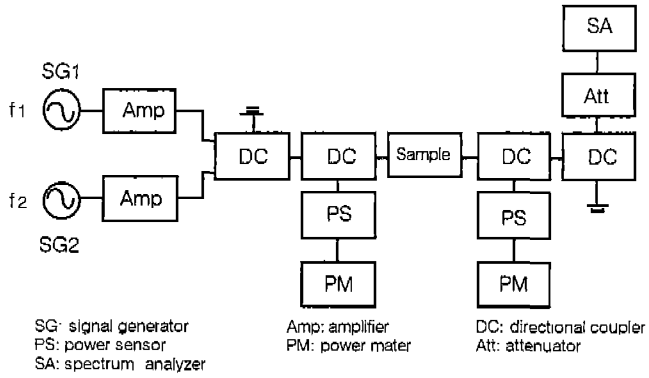

Fig. 1. IMD measurement system.

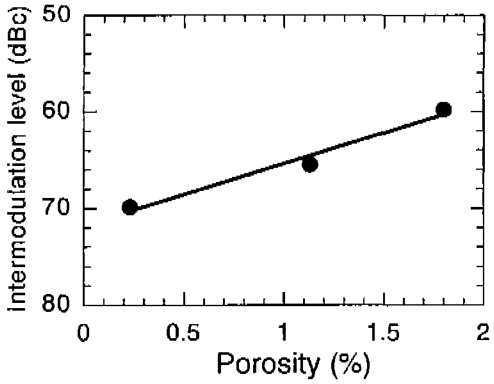

Fig. 2. Relationship between porosity and intermodulation level. (Input power=39 dBm).

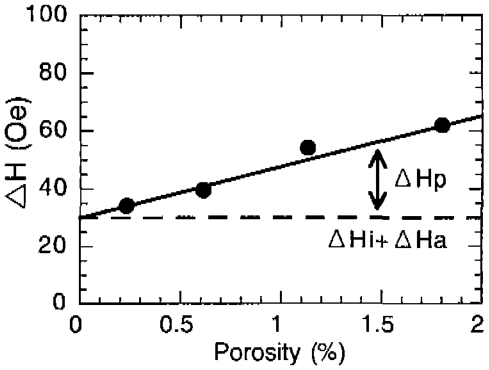

Fig. 3. Relationship between ΔH and porosity.

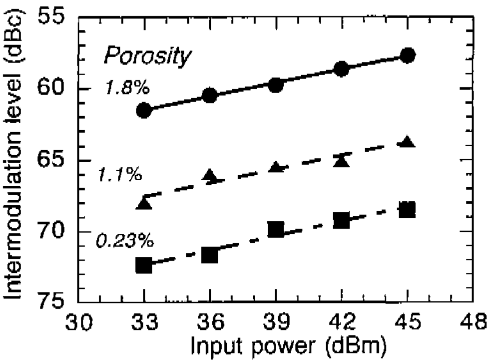

Fig. 4. Input power dependence of intermodulation level for various porosity levels.

quency sweep generator, a transmission cavity, and an electromagnet. The detected cavity-resonance line was observed on a spectrum analyzer.

Ferrite disks attached to isolators were cut from the bulk into the fixed size. For the intermodulation characteristics measurement, we prepared the distributed (A) and the lumped-element (B) isolators with the following characteristics.

1) saturation magnetization of ferrites, 4 πMs=1230 Gauss

2) ferrite disk size (A) ϕ3.5×0.4 mm (B) ϕ13.0×1.0 mm

3) center transmission frequency (A) 1960 MHz (B) 948 MHz

4) voltage standing wave ration (vswr) less than 1.5

5) isolation loss higher than 20 dB

Fig. 1 shows the system used for detecting the intermodulation characteristics of isolators. Two fundamental signals, f_1 and f_2 were generated by separate signal generators at (A) f_1=1960 MHz, f_2=1960.1 MHz, (B) f_1=948 MHz, f_2=948.1 MHz. These signals were amplified with arbitrarily the same magnitude and coupled at the directional coupler. The synthesized signal was applied to the isolator sample, and output signals which contained intermodulation signals with the frequency of $2f_1$-f_2, $2f_2$-f_1 were detected by the spectrum analyzer. The input and output power levels were observed by power meters. Throughout this paper, the input power means total power of two main signals. The intermodulation signal level is expressed as the average power of two generated signals, $2f_1$-f_2, $2f_2$-f_1.

III. Results and Discussion

(1) The influence of ferrite characteristics

Fig. 2 shows the intermodulation level as a function of the porosity of ferrite disks in a distributed-type isolator with input power of 39 dBm(8W). The ferrite material used in this study is Al-substituted YIG with 4 πMs of 1230 Gauss. Intermodulation level increases as the porosity increases. Around a pore, demagnetization fields may occur, and this effect is also reflected on FMR linewidth of the corresponding spherical sample as shown in Fig. 3. From Eq. (1), the porosity broadening, ΔHp is the difference between total ΔH and the intercept which ascribes to ΔHi+ΔHa. ΔHp is given by [2)]

$$\Delta Hp=1.47(4\,\pi Ms)p \qquad (2)$$

where p is the effective porosity.

Fig. 4 shows the input power dependence of intermodulation levels for various porosity materials. The slopes d(IM)/d(power) of all samples are almost the same, i.e. 0.3. This result implies the power dependence is a function of the fer-

Table 1. Composition and Magnetic Properties of YIG Ferrites

Composition	4 πMs (Gauss)	Tc (°C)	Porosity (%)	ΔH (Oe)
$Y_{2.42}Ca_{0.6}Fe_{4.68}V_{0.3}O_{12}$	1243	0.3	34	
$Y_{2.3}Ca_{0.72}Fe_{4.59}V_{0.33}Zr_{0.06}O_{12}$	1252	264	03	30
$Y_{2.22}Ca_{0.8}Fe_{4.53}V_{0.35}Zr_{0.1}O_{12}$	1214	259	0.3	20
$Y_{2.06}Ca_{0.96}Fe_{4.4}V_{0.38}Zr_{0.2}O_{12}$	1215	233	0.3	<10

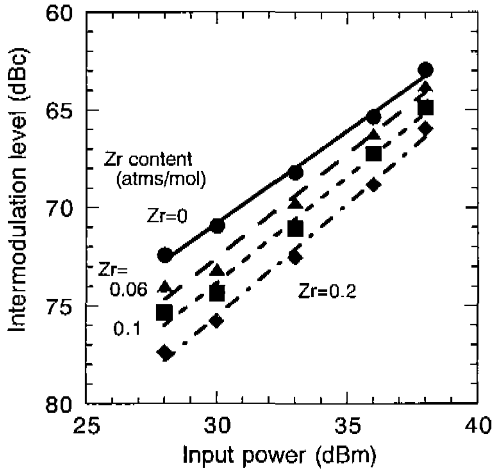

Fig. 5. Input power dependence of intermodulation level in Zr-substituted Ca-V garnet.

rite composition.

The anisotropy broadening, ΔHa, is due to the random orientation of the anisotropy energy axes of the different grains. This contribution was calculated by schlöann[3]

$$\Delta Ha \propto K_1^2/Ms^3 \qquad (3)$$

where K_1 is the first order anisotropy constant and Ms is the saturation magnetization. It is well known that the Zr-substitution in garnet shows a remarkable effect on the reduction of the crystalline anisotropy.[4] For the study of the influence of anisotropy on intermodulation coupling, we prepared the four Zr-substituted Ca-V garnet samples with the saturation magnetization about 1230 Gauss. The characteristics of these samples are listed in Table 1. From Eq. (1) to (3), since porosity and saturation magnetization of these samples are almost the same, the reduction of total ΔH is attributed to the increase in Zr-content, which in turn decreases the anisotropy field. Needless to say, this evaluation is fairly rough, ΔHi and spin-wave contribution should be exactly taken into account.[5]

Fig. 5 shows the intermodulation levels plotted against the input power for various Zr-substituted Ca-V garnet in the lumped-element isolators. While intermodulation levels decrease with the increase in Zr-substitution over the whole input power range measured, the differences of its levels dwindle as input power increases. The slope of intermodulation levels against input power increases with increasing Zr-substitution as show in Fig. 6.

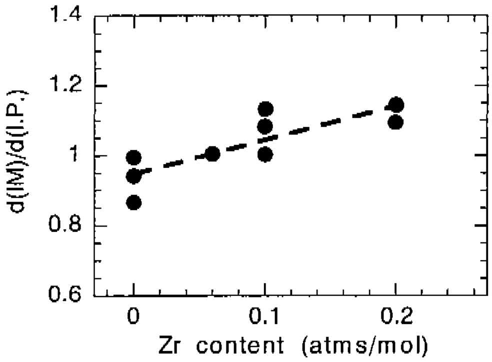

Fig. 6. Slope of intermodulation level against the input power as a function of Zr-content.

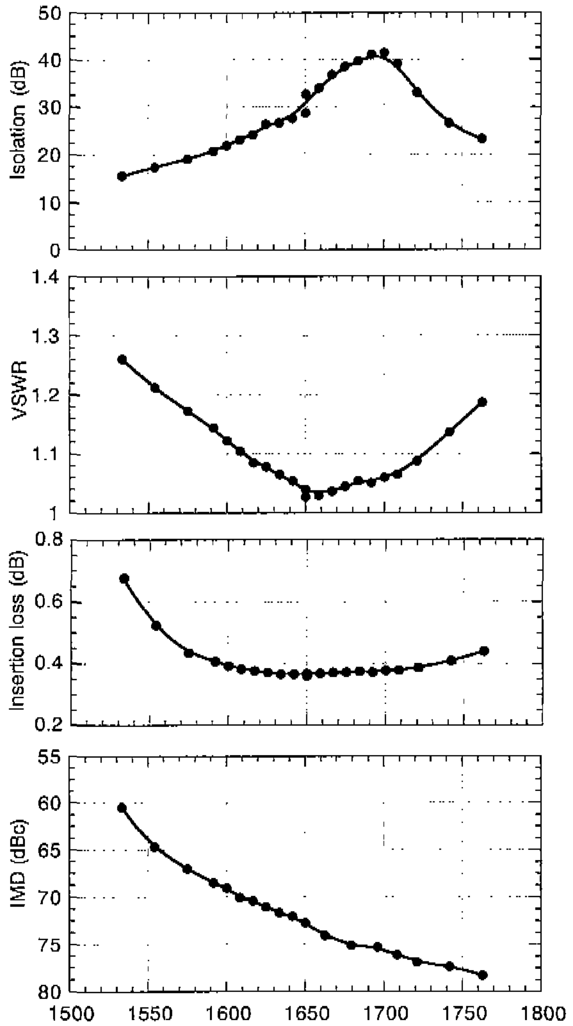

Fig. 7. Typical isolator characteristics and intermodulation levels as function of dc field.

There have been various investigations on the nonlinear phenomenon of ferrites. Enormous research about this problem was first summarized by Dammon.[6] It was focused on the relation between the transverse magnetization due to spin precession amplitude and rf field strength. Two types of nonlinearities occur due to increase in the input power.

At low power level, the nonlinear nature arises under uniform precessions of the rigid magnetization. The effective field contains contributions from the demagnetizing effects, crystal anisotropy, and other phenomenological terms. Thus, the restoring torque of the system changes and the precession rate varies with rf field strength. The results of the influence of porosity and anisotropy in this study corresponds to the above described model.

Further more, at high power level, since the precession amplitude is rapidly lager, dipole-dipole interaction between neighboring spins cannot be neglected. Beyond this critical rf field, the energy begins to couple into the propagation of spin-waves rather than into maintaining the uniform precession mode. Decreases in crystalline anisotropy is always accompanied by a decline in the critical rf field strength. Therefore, the input power dependence of intermodulation signals can be regarded as the essential non-linear effect due to the spin-wave instability occurring at the subsidiary absorption at ferrimagnetic resonance.

(2) The influence of dc magnetic field strength

Fig. 7 shows the isolation loss, vswr, insertion loss and the intermodulation level at 948 MHz as a function of applied dc magnetic field in a lumped-element isolators. Generally, vswr. and isolation loss of isolators should be higher than 1.2 and 20 dB, respectively, in order to perform as a passive non-reciprocal device. This isolator satisfied the above conditions from 1600 Gauss to 1700 Gauss with the stable insertion loss below 0.4 dB. In this range, vswr changed between 1.02 and 1.1, effective transmitted power through the isolator is almost fixed. Therefore, the input power dependence of intermodulation level can be neglected.

From Fig. 7 intermodulation level decreases as dc magnetic field increases with no relation to other characteristics of the isolator. Decrease in the magnitude of the biasing field directly corresponds to the vanishing of the spin orientation ability. Therefore, it is required to design an isolator which runs under strong magnetic field in order to avoid non-orientated spin motion. However, since the bandwidth of isolators become narrow, the enhancement of dc magnetic field can not be carried out easily.

IV. Summary

The nonlinear intermodulation problem for microwave isolators have been investigated from the stand point of designing ferrite characteristics. The intermodulation signals arise from the crystal anisotropy and the demagnetization around the pores. These properties of ferrites are also very effective on narrowing of ΔH, which is related to the magnetic loss. Therefore, a low-intermodulation isolator can be achieved by selecting highly dense and low-anisotropy ferrites. However, the power dependence of intermodulation levels is stressed as the crystalline anisotropy decreases, and hence this essential nonlinearity relating to the spin-wave generation in low-anisotropy materials should be considered to design high power systems.

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