MILLIMETER WAVE MATERIAL CHARACTERIZATION OF STRONTIUM FERRITES USING MAGNETO-OPTICAL APPROACH

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ABSTRACT

Complex dielectric permittivity and magnetic permeability measurements of solid strontium ferrites have been performed in the broad band millimeter wave frequency range employing free space technique based on transverse magneto-optical approach. The experimental set-up consisting of a quasi-optical millimeter wave spectrometer with a backward wave oscillator as a high power tunable source of coherent radiation provides the transmittance spectra, in a magnetic field up to 7.5 kOe. Dielectric and magnetic parameters of strontium-ferrites have been calculated by matching theoretical curves to the experimental transmittance spectra. Shift of the ferromagnetic resonance to higher frequencies, as well as broadening of the zone of strong absorption with the increase of magnetic field, have been observed.

I. INTRODUCTION

Complex magnetic permeability and dielectric permittivity are two fundamental parameters that describe the response of matter to the external electric and magnetic fields. The development of new methods that provide accurate determination of both parameters from a single set of measurements is important for practical application of ferrite materials.

In the millimeter wave range, a technique based on the concepts of quasi-optical Gaussian beams and free-space propagation is an alternative to the resonance techniques. High accuracy of this method was proven by numerous dielectric measurements carried out using the channel, as well as the Fourier transform technique [1] – [4]. The conventional approach applied in the millimeter-wave range uses well known Fresnel equations for calculation of dielectric and magnetic properties from a set of free-space measurements. At least four independent free-space measurements are necessary for the complete characterization of the demagnetized isotropic ferrites. This method turns out to be indirect and less convenient for the characterization of magnetic materials. The technique based on magneto-optical approach overcomes the shortcomings of the conventional method and its significant advantage being that the millimeter-wave dielectric and magnetic parameters are determined from a single set of broad-band transmission measurements thus enabling the complete and accurate characterization of ferrites in the entire frequency range.

II. MEASUREMENT TECHNIQUE

There are essential differences in the origin of magneto-optical activity in various parts of the electromagnetic spectrum. While in optics such effects are initiated mainly by dielectric permittivity [5], the magneto-optical activity in the microwave and millimeter wave range is entirely due to the magnetic permeability [6] – [8]. The study of magneto-optical effects in the ferrites paves way for the determination of millimeter wave magnetic permeability. In contrast to optics, the magneto-optical measurements in the millimeter wave range are rather sophisticated by essential effect of diffraction. Combined the effects of diffraction and displacement of the focal plane introduced by a sample can be significantly reduced by imposing and following restrictions on the sample dimensions: $D \geq 8\ \lambda$ and $d \leq 3\lambda$. Here, D and d are respectively the cross section and thickness of a plane parallel sample.

The block diagram of the millimeter-wave quasi-optical spectrometer (QOM) is shown in Fig. 1. The planar sample is seated between the poles of an electromagnet. The electromagnet with an adjustable gap provides a transverse magnetic field up to 7.5 kOe. The millimeter wave measurements were realized with a frequency sweep mode. The output signal seems to be a complicated function of the backward wave oscillator (BWO) power, transmission characteristics of the quasi-optical channel and the properties of the sample. The transmittance spectra were obtained by relating the data from a set of two measurements: with and without a sample in the quasi-optical channel. The high stability of the BWO power supply assured the repeatability and high accuracy of spectral measurements.

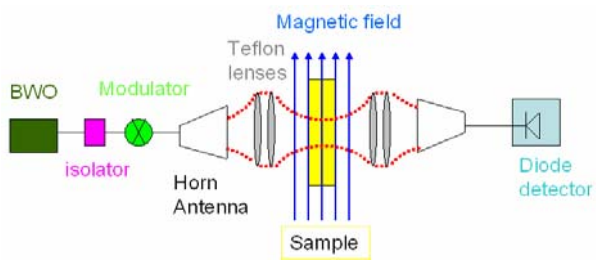

Fig.1. Block-diagram of QOM spectrometer with the electromagnet set-up

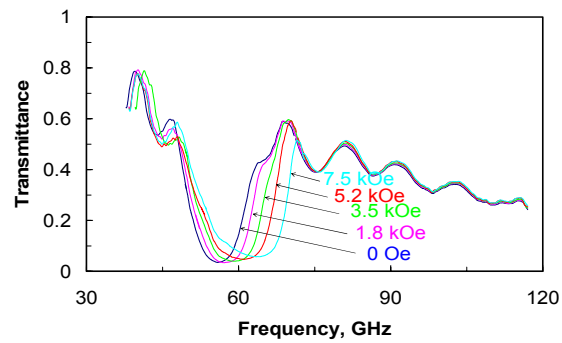

Fig.2. Transmittance spectra of sample SRL

III. RESULTS AND DISCUSSION

Three disc-shaped samples of strontium ferrite ceramics of different specific gravities were prepared by mixing strontium ferrite powder with different ratios of fiber glass resin (epoxy) and very small amount of peroxide hardener. After that, the samples have been warmed in the oven and than polished to obtain well plane parallel and smooth surfaces. Each of the three samples, namely, 1s (ρ = 1.9 g/cm^3, d = 4.3 mm), SRL (ρ = 1.75 g/cm^3, d = 3.2mm), and SRH (ρ = 1.9 g/cm^3, d = 6.7 mm) were subjected in transverse magnetic fields. Shown in Fig. 2, the transmittance spectrum exhibits oscillating patterns that are due to the multiple reflections of an electromagnetic wave within a planar sample. The development of sharp oscillations in the transmission spectra of the low-loss materials like microwave ferrite enables the accurate determination of both real and imaginary parts of permittivity. Indeed, the period of oscillation that inversely depends on the optical thickness of a sample gives the refractive index. The absorption coefficient given by the amplitude of oscillation can be obtained numerically from the experimental spectrum.

The average real part of permittivity for samples 1s, SRL and SRH in the 35 – 120 GHz range are 3.86, 16.93 and 4.08 respectively. The imaginary part of permittivity at 35 GHz for samples 1s, SRL and SRH are 0.117, 0.246 and 0.088 respectively and that at 120 GHz are 0.11, 0.395 and 0.12 respectively. The absolute accuracy of measurement of the refractive index with the free space method is 0.2 % and that of absorption index varies from 5 % for samples with moderate absorption to 20 % for the low loss materials.

The magneto-optical activity in the millimeter-wave range is determined by the phenomenon of magnetic resonance. Magnetic resonance signifies a region where there is complete absorption. However, the samples being discussed in this paper are not pure strontium ferrites. The presence of epoxy resin alters the absorption rate at and near the resonance frequency. From Fig. 2, it can be seen that the resonance shifts towards the higher frequencies with increase in the magnetic field strength. The shift of the center of gravity of the absorption zone is caused by the random orientation of the axes in the grains of the non-oriented strontium ferrite ceramics and the broadening of the resonance line with increase in the field strength is due to the contribution of a variety of non-intrinsic dissipation processes developing in the close vicinity of the magnetic resonance [9].

Using least square fit, the theoretical best fit curve for the samples corresponds to a high magnetic anisotropy H_a, a low saturation of magnetization $4\pi M_S$, and dissipation factor G higher than that of pure strontium ferrites [10]. The values of these parameters for the three different samples of strontium ferrite are listed below in Table I.

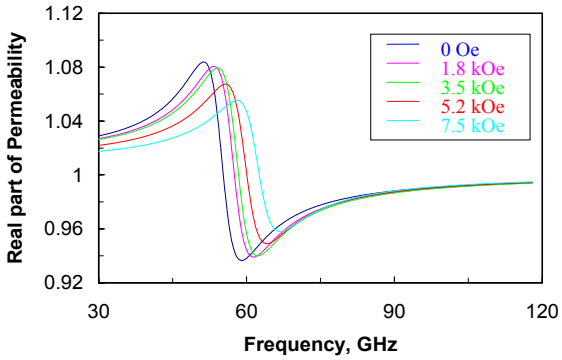

Fig.3. Real part of Permeability for sample SRL SRL of thickness 3.2mm

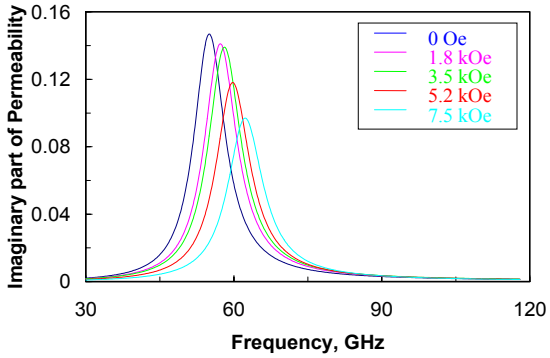

Fig.4. Imaginary part of permeability of sample SRL of thickness 3.2 mm

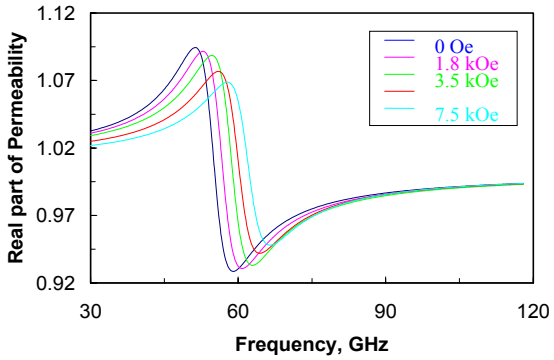

Fig.5. Real part of permeability of sample SRH of thickness 6.7 mm

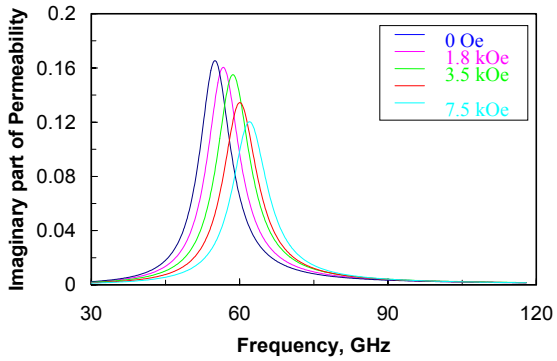

Fig.6. Imaginary part of permeability of sample SRH of thickness 6.7 mm

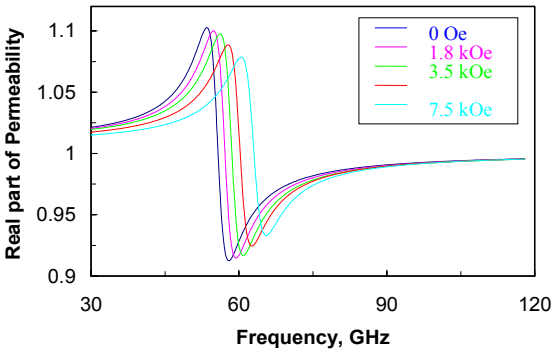

Fig.7. Real part of permeability of sample 1s of thickness 4.3 mm

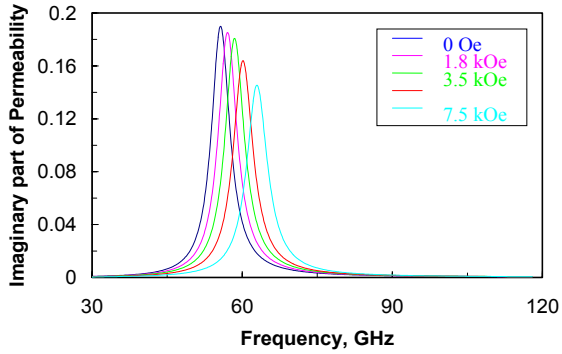

Fig.8. Imaginary part of permeability of sample 1s of thickness 4.3 mm

IV. CONCLUSIONS

Complex dielectric and magnetic properties of randomly oriented strontium ferrite samples in transverse magnetic field have been studied. Ferromagnetic resonance frequency has been calculated from the transmittance spectra. Shift of the resonance to higher frequencies, as well as broadening of the zone of strong absorption with the increase of magnetic field, have been observed. It has been shown that due to the presence of considerable amounts of epoxy resin, the strontium ferrite samples are weakly ferromagnetic.

All samples manifest rather high magnetic anisotropy and low saturation of magnetization. The dissipation parameter *G* is different from that of the commercially available pure strontium ferrite and this difference can be attributed to the non-zero absorption zone observed in the transmittance spectra.

Table I. Magnetic parameters for the strontium ferrite samples

Sample	Magnetic field (kOe)	$4\pi M_S$ (kOe)	H_a (kOe)	G
1s	0	0.3	19.9	0.04
	1.8	0.3	20.4	0.04
	3.5	0.3	20.9	0.04
	5.2	0.28	21.5	0.04
	7.5	0.26	22.5	0.04
SRL	0	0.4	19.7	0.07
	1.8	0.4	20.5	0.07
	3.5	0.4	20.8	0.07
	5.2	0.35	21.4	0.07
	7.5	0.3	22.3	0.07
SRH	0	0.45	19.7	0.07
	1.8	0.45	20.3	0.07
	3.5	0.45	21	0.07
	5.2	0.4	21.5	0.07
	7.5	0.37	22.2	0.07

V. ACKNOWLEDGEMENT

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