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MICROWAVE PROPERTIES AND ABSORPTION CHARACTERISTICS OF YIG - TPNR COMPOSITES

M. ABDUL AZIZ[1], H. A. MUSTAFFA[2], H. A. SAHRIM[2], A.H. SITI ATKAH[1]
[1] Faculty of Applied Science, Universiti Teknologi Mara 26400 Jengka, Pahang, Malaysia.
[2] Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43000 Bangi, Selangor, Malaysia.

ABSTRACT

Yttrium iron garnet (YIG) - thermoplastic natural rubber (TPNR) magnetic composites with 10 - 30 weight percent of YIG filler were prepared via a Brabender plasticorder internal mixer. Their microwave electromagnetic properties and absorption characteristics at room temperature (299 K) were studied in the range of 0.3 to 13.5 GHz using a microwave vector network analyzer (MVNA) . The real and imaginary components of the relative complex dielectric permittivity ($\varepsilon_r^* = \varepsilon_r' - j\varepsilon_r''$) and magnetic permeability ($\mu_r^* = \mu_r' - j\mu_r''$) were computed from the reflection and transmission complex scattering parameters (S_{11}^* and S_{21}^*) using the Nicolson-Ross and Precision models. The result shows that the reflection coefficient (Γ) strongly depends on the thickness and the electromagnetic properties of the samples.

Keywords: ***Microwave properties; absorption characteristics; permittivity; permeability; scattering parameters; reflection coefficient.***

INTRODUCTION

Extensive study has been carried out to develop microwave-absorption materials with high efficiency (Yin and Liao 1993). One of criterion for selecting the microwave absorbing material is the location of its natural resonance region. Thus, a study of the frequency dependence of the complex permeability of the ferrite has been a field of interest.

An ideal absorber is a reflection-free one port where the incident power is completely absorbed and dissipated as a heat. Ferrites are one of the best absorbing material that have been extensively used for that purpose (Kim et al. 1991; Shin and Oh 1993; Kwon et al. 1994). However, ferrites have some constrains in producing the microwave absorbers.

Polymeric composites are useful as effective microwave absorber materials due to their advantages with respect to stronger, lighter, low cost, design flexibility, corrosion-resistant, economical and easily processed material systems over intrinsic ferrites (Kishan et al. 1985; Kim et al. 1996; Wang et al. 1999).

The absorbing characteristics of the materials depend on the wavelength, layer thickness, complex permittivity (ε_r'- $j\varepsilon_r''$) and complex permeability (μ_r' - $j\mu_r''$). By controlling the filler volume fraction, one can vary the complex permeability and permittivity of the composites; hence the absorbing properties can be changed (Musal and Smith 1990).

The objectives of this study are to examine the microwave electromagnetic properties and absorption characteristics of yttrium iron garnet - thermoplastic natural rubber composites with YIG filler content in the range of 0 – 30 wt %.

MATERIALS AND METHODS

The YIG used as a magnetic filler was obtained from Cerac Incorporated, USA. It was supplied in a powder form of about ~ 200 mesh (75μm) with purity of 99.9%.

The materials used as a matrix were polypropylene (PP) and natural rubber (NR) with liquid natural rubber (LNR) as a compatibilizer in the ratio of 70:20:10 (Ahmad et al. 1994; 1995). The LNR was prepared by photosensitized degradation of NR in visible light. The matrix was prepared by melt-blending of the materials in a laboratory cam mixer (Brabender Plasticorder Model PL 200 and Mixer Model W 50E/2) at about 170 °C and rotor speed of 50 r.p.m. The LNR was added into the mixer 1 min after introducing NR, then allowed to mix for about 2 min before PP was charged into the mixer. Once homogeneous mixing was assumed after about 12 min, the blend was removed from the mixer. The TPNR matrix was ground by a granulator (Granulator Model Ph 400 SS).

TPNR – YIG composites were prepared by melt-blending of the materials in a laboratory cam mixer at 170 °C and rotor speed of 50 r.p.m. The garnet content was varied from 0 to 30 weight percent. The powder was added into the mixer 2 min after introducing TPNR. The materials were allowed to mix for about 12 min. Once homogeneous mixing was assumed, the blend was removed and subsequently compressed at about 175 °C and 7 kN pressure for about 2 min using a hot press (Carver Laboratory Press) into a thin sheet of about 5 mm thickness from which test specimens were cut.

Samples of toroidally - shaped were prepared to fit closely into a coaxial measurement cell with outer diameter of 3.5 mm and inner diameter of 1.6 mm. A toroid of YIG was also prepared by sintering at 1050 °C for 6 hours. The complex scattering parameter (S_{11}* and S_{21}*) were measured using a Hewlett Packard HP 8719D network analyzer in the frequency range of 0.3 - 13.5 GHz. The complex permittivity and permeability were evaluated using the Nicolson - Ross model for magnetic materials and Precision model for non - magnetic materials.

For a microwave absorbing material, the input impedance (Z_{in}) at the air-material interface is given by $Z_{in} = Z_o(\mu_r^*/\varepsilon_r^*)^{1/2}\tanh(\gamma t)$, where $\mu_r^* = \mu_r' - j\mu_r''$, $\varepsilon_r^* = \varepsilon_r' - j\varepsilon_r''$, Z_o is the intrinsic impedance of free space, $\gamma = [j\omega(\mu_r^*/\varepsilon_r^*)^{1/2}]/c$ is propagation factor in the material and t is the thickness of the sample. The reflection coefficient (Γ) is defined as $\Gamma = (Z_{in}/Z_o - 1)/(Z_{in}/Z_o + 1) = [(\mu_r^*/\varepsilon_r^*)^{1/2}\tanh(\gamma t) - 1]/[(\mu_r^*/\varepsilon_r^*)^{1/2}\tanh(\gamma t) + 1]$. This relation is based on normal incidence of an electromagnetic wave at the surface of a single layer material backed by a perfect conductor. The power reflectivity or the reflection loss (R_L), in decibel (dB) can be written as $R_L = 20\log_{10}|\Gamma|$ (Kim et al. 1991; Wallace 1993; Nalwa 1997; Truong et al. 1998).

RESULTS AND DISCUSSION

Figure 1 a) and b) show the variations of the real and imaginary parts of the magnetic permeability (μ_r' and μ_r'') as a function of frequency. μ_r' for YIG and the composites increase with increasing frequency up to about 1 GHz and then decrease to constant values at about 3 GHz for the composites and at about 6 GHz for YIG. The magnetic loss (μ_r'') for YIG and the composites decrease sharply on increasing frequency up to about 5 GHz and then decrease very slightly when the frequency increases up to 13.5 GHz. For TPNR, both μ_r' and μ_r'' are constant at 1 and 0 respectively throughout the whole range of frequency.

Figure 2 a) and b) show the real and imaginary components of the dielectric permittivity of the pure ferrite, pure TPNR and the composites as a function of frequency. ε_r' for YIG increases slowly with increasing frequency ($\varepsilon_r' \approx 3.5 - 4.5$), while for TPNR and composites, ε_r' are about constant throughout the whole frequency range. At a fixed frequency, ε_r' for the composites increases with increasing ferrite content, but the values are smaller than those for TPNR. ε_r'' for YIG, TPNR and their composite decrease sharply with increasing frequency up to about 4 GHz. For the frequency higher than 4 GHz, ε_r'' of the samples are almost constant, except a slight increase at frequencies above 10 GHz for the composites and YIG. A strong variation in ε_r'' at the low frequency end indicates that the lowest frequency bordering the regime of dipolar relaxation. It seems that the dielectric properties at frequency above 1 GHz is predominantly due to atomic polarization.

Complex permittivity, $|\varepsilon_r^*|$, and permeability, $|\mu_r^*|$, as a function of frequency are depicted in Figure 3 a) and b). $|\varepsilon_r^*|$ for all samples shows a sharply decreasing value up to about 2 GHz and become almost constant at higher frequencies. For a fixed frequency above 2 GHz, $|\varepsilon_r^*|$ for the composite increases with increasing filler content, but the values are lower than those for pure YIG and TPNR. YIG has the highest value of $|\varepsilon_r^*|$ followed by TPNR and the composites.

Complex permeability for all composites decrease with increasing frequency up to about 4 GHz. For a fixed frequency above 4 GHz, $|\mu_r^*|$ decreases with increasing YIG content. Pure YIG has the lowest value of $|\mu_r^*|$ of about 0.85, while it is constant at 1 for pure TPNR throughout the whole range of frequency. The values for 10 wt % and 15 wt % YIG are higher, while those for 20, 25, 30 wt % YIG are lower than that for the pure TPNR at frequencies above 3 GHz.

Both $|\varepsilon_r^*|$ and $|\mu_r^*|$ strongly influence the microwave absorption characteristics of the materials. Reflection coefficient (Γ) is calculated from these quantities for different thicknesses of the samples. Minimum Γ indicates the maximum power absorption. Reflection coefficient (Γ) as a function of frequency for different compositions is shown in Figure 4. All compositions show two matching conditions at low and high frequencies. The first matching condition at low frequency is associated with a quarter wavelength, $\lambda/4$, (Truong et al. 1998); while the one at high frequency is associated with a three quarter wavelength, $3\lambda/4$ where λ is the propagation wavelength in the materials. The matching conditions for the composites occur near those for both pure materials. It can be seen that the minimum reflection coefficient increases with increasing filler content.

Table 1 shows the calculated matching frequencies, f_1 and f_2 corresponding to ($\lambda/4$) and ($3\lambda/4$) in comparison to those frequencies obtained experimentally.

CONCLUSIONS

Dielectric permittivity (ε_r'), dielectric loss (ε_r''), magnetic permeability (μ_r'), magnetic loss (μ_r'') and reflection coefficient (Γ) of the composites depend on the concentration of filler content. Two matching conditions were found at low and high frequencies at the same thickness for all composites. These matching conditions are associated with $\lambda/4$ and $3\lambda/4$ thickness of the materials

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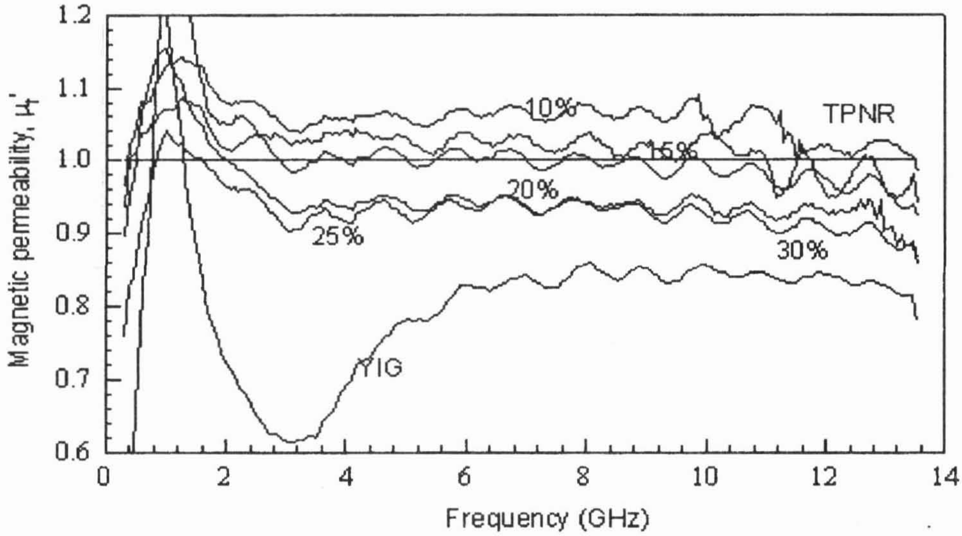

Figure 1 a) Magnetic permeability as a function of frequency

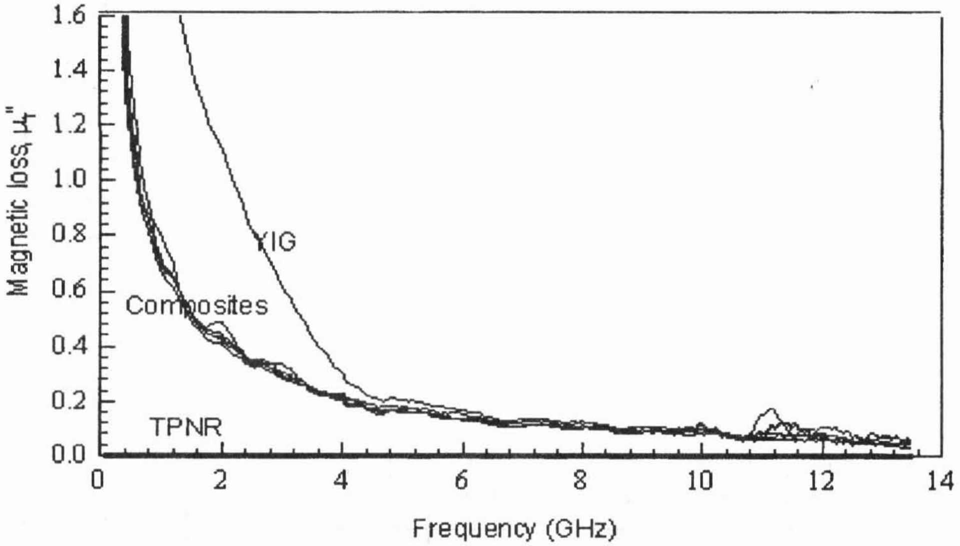

Figure 1 b) Magnetic loss as a function of frequency.

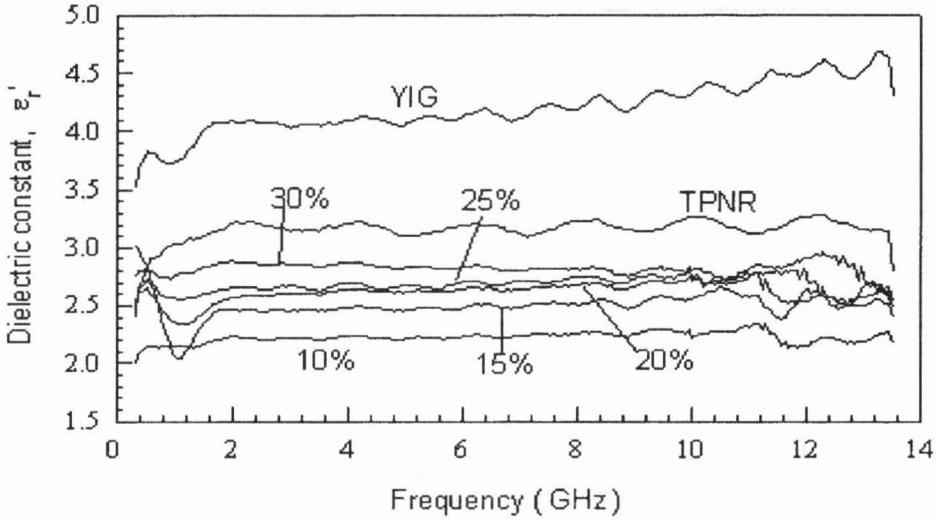

Figure 2 a) Dielectric constant as a function of frequency.

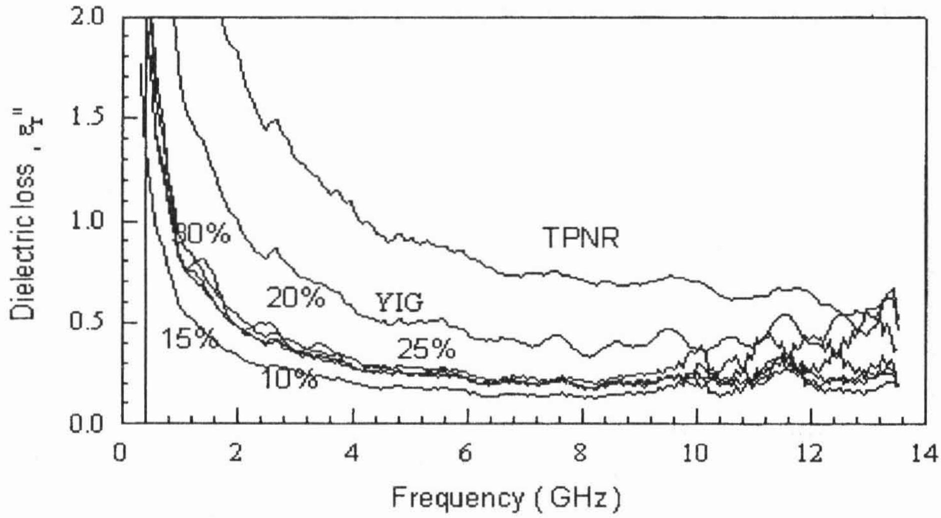

Figure 2 b) Dielectric loss as a function of frequency.

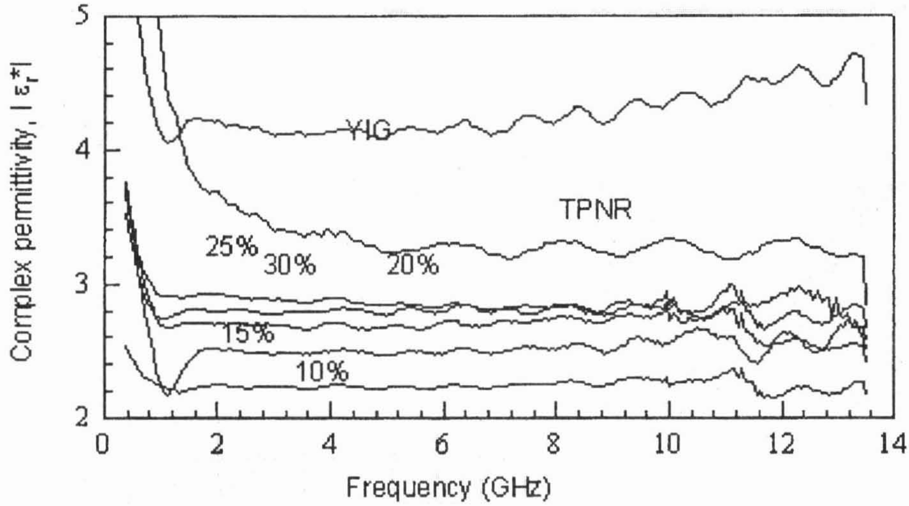

Figure 3 a) Complex permittivity as a function of frequency.

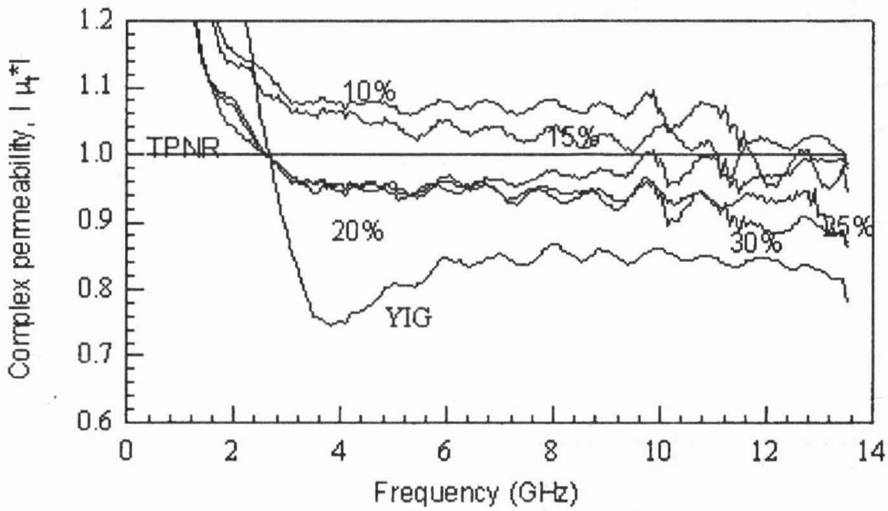

Figure 3 b) Complex permeability as a function of frequency.

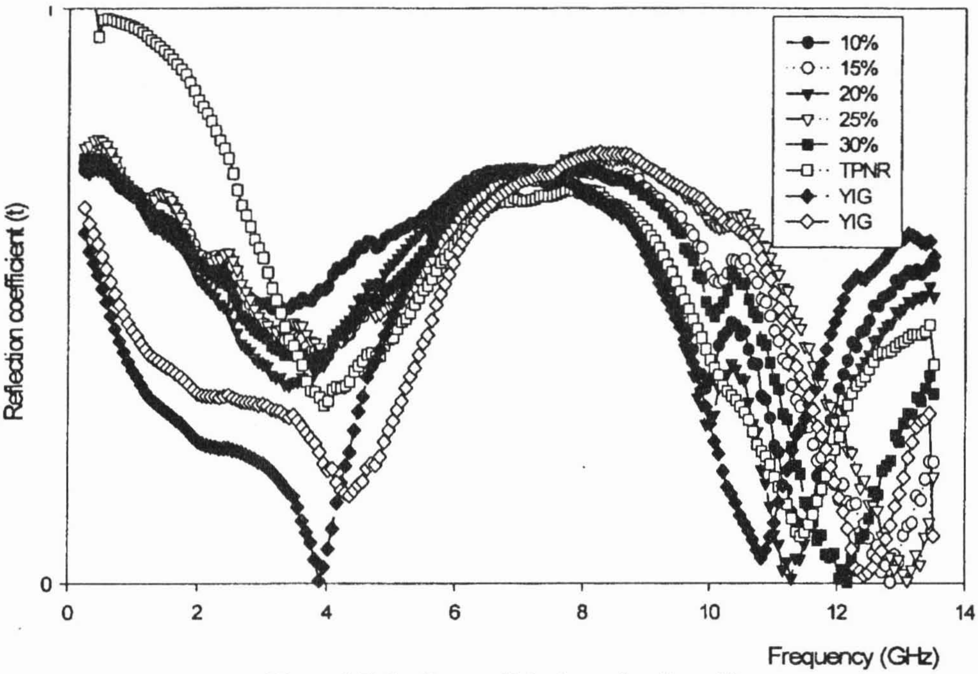

Figure 4 Reflection coefficient as a function of frequeny.

Figure 4 Reflection coefficient (Γ) as a function of frequency.

Table 1: Calculated and experimental matching frequencies for different samples.

Samples	(f_1 ±0.05)GHz (exp)	(f_1 ±0.05)GHz (calculated)	(f_2 ±0.05)GHz (exp)	(f_2 ±0.05)GHz (calculated)
TPNR	**4.02**	**3.63**	**11.49**	**11.14**
10%	**3.21**	**3.67**	**11.49**	**11.30**
15%	**4.02**	**4.05**	**12.84**	**12.70**
20%	**3.68**	**3.58**	**11.29**	**11.10**
25%	**4.02**	**4.23**	**13.11**	**13.05**
30%	**3.75**	**3.80**	**12.16**	**11.96**
YIG(10.9 mm)	**3.89**	**3.92**	**10.82**	**10.75**
YIG(9.3 mm)	4.36	4.59	12.43	12.61