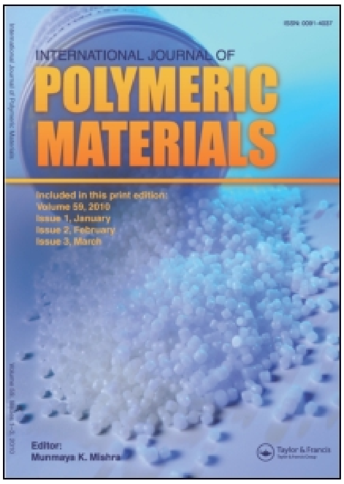

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Magnetic and Dielectric Properties of YIG/HDPE Composites for High-Frequency Applications

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A low loss high-frequency magnetic composite with $Y_3Fe_5O_{12}$ (YIG) ultrafine particles embedded in a high-density polyethylene (HDPE) matrix was fabricated by using a simple low-temperature hot-pressing technique. The magnetic and dielectric properties of the as-prepared composites were investigated in detail. The results indicate that as the volume of the ceramic fillers increases, the permittivity, permeability, dielectric and magnetic loss of the composite all increase. The cut-off frequencies of the composites are all above 700 MHz. Since the low resistivity of YIG, the dielectric losses of the composites are high and decrease with frequency in the lower frequency range. Good frequency stability of the permittivities and permeabilities, and low dielectric and magnetic losses within the measurement range have been observed.

Keywords composites, dielectric properties, magnetic properties, $Y_3Fe_5O_{12}$

INTRODUCTION

Ferrites find extensive applications in making useful devices like inductor cores, circulators, isolators, refrigerator door seals, EMI shields, and storage

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media [1,2]. Polycrystalline ceramic ferrite powders can be incorporated into various elastomer matrices to produce polymer-based ferrite composites [3,4]. Polymer-based composites with high permeability [5–7] have been proposed due to their flexibility, compatibility with printed wiring board (PWB), and the advantage of moldability into complex shapes, which is not easily possible by conventional ceramic magnets.

$Y_3Fe_5O_{12}$ (YIG), a ferromagnetic material known as microwave ferrite, has been widely applied in passive microwave devices, such as circulators, oscillators, and phase shifters, because it possesses controllable saturation magnetization, low dielectric loss tangent ($\tan\delta$) in the microwave region, and small linewidth (ΔH) in ferromagnetic resonance [8,9]. Compared to the dielectric loss, the cut-off frequency of YIG is low and the magnetic loss is high in the microwave range. Incorporating YIG powder into a polymer matrix can increase the cut-off frequency and lower the magnetic loss of YIG in the microwave range.

In this paper, novel low loss high-frequency magnetic composites were achieved by introducing YIG fillers into a high density polyethylene (HDPE) matrix. The magnetic and dielectric properties of the composites were investigated in detail. Such magnetic composites, possessing very low loss, could be used in high-frequency communications for the inductor integrating devices such as electromagnetic interference filters and antennas.

EXPERIMENTAL

The HDPE (density: 0.95 g/cm^3, M_w: 100000) powders were used as a matrix. The YIG filler was fabricated by conventional oxide mixing method and ground into powders, with the grain size of about 500 nm. To make the powders possess an active surface, they were fully mixed with 2% oleic acid solution. Then the surface-modified ceramic powders and the HDPE powders were mixed together, followed by a low-temperature hot-pressing at 180°C for 5 min under the pressure of 10 MPa. The magnetic and dielectric measurements were carried out by a HP4291B impedance analyzer with a HP16454 L magnetic material test fixture and a HP16453A dielectric material test fixture, respectively. The frequency ranges were 10 MHz$\sim$1 GHz and 1 MHz$\sim$1 GHz, respectively. The magnetic hysteresis loop of the composites were measured with a LDJ9600 type of VSM.

RESULTS AND DISCUSSION

Figure 1 shows the magnetic hysteresis loops of the composites with the same matrix volume but different volume fractions of YIG. The saturated

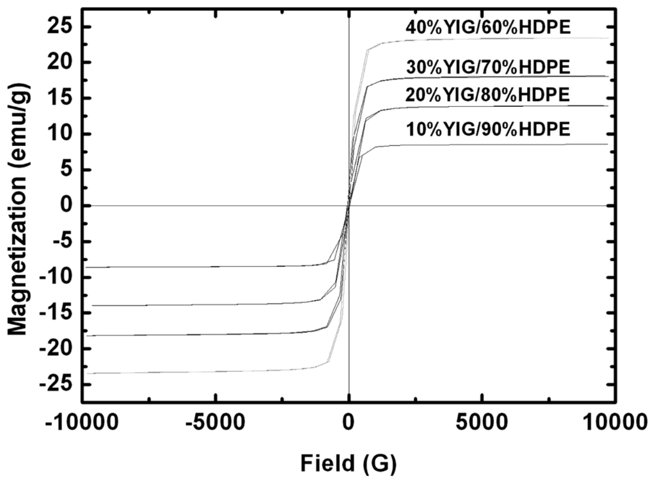

Figure 1: Magnetic hysteresis loops of the composites with different volume fractions of YIG.

magnetization (Ms), remnant magnetization (Mr) and coercivity (H_C) were determined from the hysteresis loops, as shown in Table 1. As it can be seen in Table 1, the magnetic properties of the composites clearly depend on the ferrite loading. It can be found that the saturation magnetization (Ms) and remnant magnetization (Mr) increase with the increasing of YIG content, as expected, since these parameters depend on the total mass of the magnetic material. The reduction of the values may be caused by noncolinearity of the magnetic moments at the surface of the YIG particles, resulting in a decrease of the saturation magnetization for a lower YIG content [10]. The coercivity (H_C) nearly keeps constant as the variation of YIG content, which shows all the samples have very similar microstructure.

Figure 2 shows the frequency dependence of the magnetic properties of the composites with different volume fractions of YIG. It can be seen that with the increasing of YIG, the permeability and magnetic loss increase. According to Rikukawa [11], for either domain wall movement or spin rotation, the initial permeability is proportional to M_s^2. It is known that with increasing the YIG content of the composites, M_s increases. With the increasing of frequency,

Table 1: Magnetic parameters of YIG/HDPE composites with different volume of YIG.

Sample	M_S	M_r	H_C
10% YIG/90% HDPE	8.5	0.2	40.5
20% YIG/80% HDPE	13.9	1.4	41.8
30% YIG/70% HDPE	18.1	1.9	42.2
40% YIG/60% HDPE	23.5	2.5	43.5

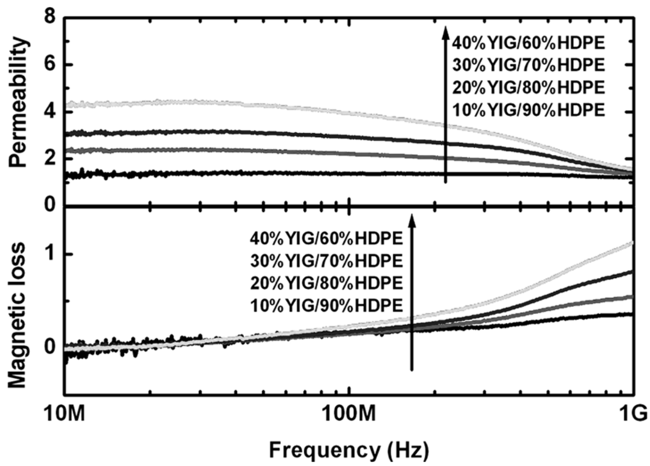

Figure 2: Frequency dependence of the magnetic properties of the composite with different volume fractions of YIG.

the permeabilities of all the composites nearly keep constant and the magnetic losses show dispersion and increase slightly only in the high frequency range. It is also found that the cut-off frequencies (i.e., the frequency where the μ' value reaches half of the starting value) of the composites are all above 700 MHz. And it can be assumed that with the decreasing of YIG content, the cut-off frequency increases. According to Snoek's law [12], the product of the initial susceptibility and cut-off frequency is a constant for a ferromagnetic material, i.e.,

$$(\mu_i - 1)f_r = \gamma/(2\pi M_s) \tag{1}$$

where f_r is the cut-off frequency, γ is the gyromagnetic ratio, M_s is the saturation magnetization and μ_i is the initial permeability. The decreasing of YIG content may cause the decrease of M_s. Accordingly, the increase of cut-off frequency can be expected. Additionally, the magnetic losses of the composites are all very low. This is probably due to the fact that the insulating matrix wraps the YIG particles, which drastically increases the resistance and reduces the eddy-current loss of the composites.

Figure 3 shows the comparison of magnetic properties for the bulk YIG ceramic and the 20% YIG/80% HDPE composite. It can be seen that the bulk YIG ceramic shows a resonance at about 20 MHz, whereas the resonance frequency of the two-phase composite shifts to a much higher frequency beyond the HP4291B measurement range, which indicates that the two-phase composite possesses an advantage of a much wider working frequency range.

Figure 4 shows the dielectric properties of the composites with different volume fractions of YIG. It can be easily found that the permittivities and

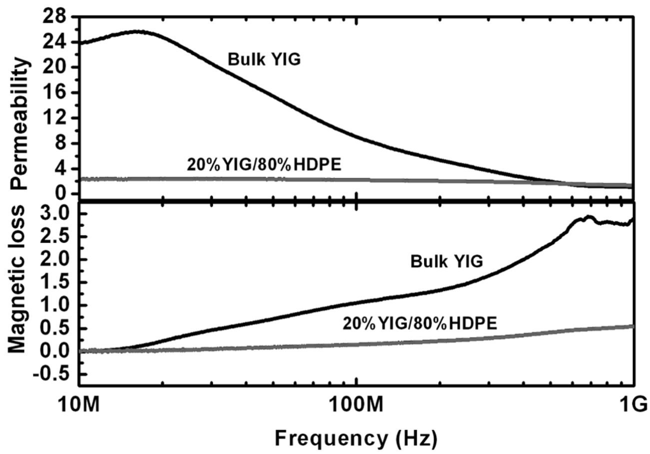

Figure 3: Frequency dependence of the magnetic properties of the 0.4 YIG/0.6 HDPE composite and the bulk YIG.

the dielectric losses increase with the increasing of YIG content, since the permittivity and dielectric loss of YIG are both higher than those of HDPE matrix. The dielectric losses of all the composites are very low in the high frequency range. The permittivities of all the composites nearly keep constant within the measurement frequency range. It also can be found that the dielectric losses of the composites are relatively high in the low frequency range. The dielectric losses decrease first and then increase with the increasing of frequency. This is attributed to the low resistivity of YIG and can be explained by the following formula [13]. When an alternating electric field is applied, not

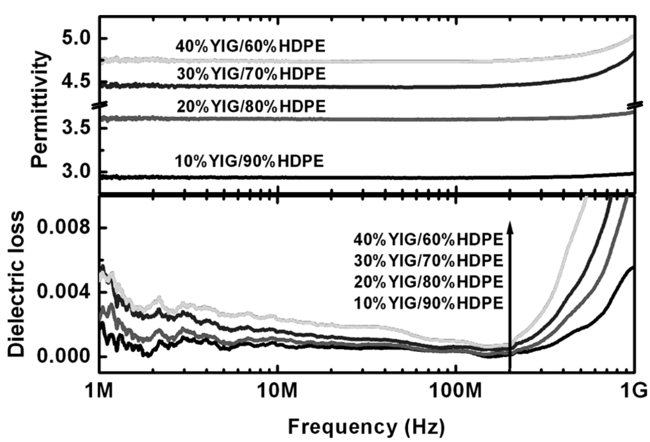

Figure 4: Frequency dependence of the dielectric properties of the composite with different volume fractions of YIG.

only polarization loss but also leakage loss generates. The dielectric loss is divided into two parts.

$$D = D_P + D_G = \frac{(\varepsilon_S - \varepsilon_\infty)\omega\tau}{\varepsilon_S + \varepsilon_\infty \omega^2 \tau^2} + \frac{\gamma}{\omega \varepsilon_0}\left(\frac{1}{\varepsilon_\infty + \frac{\varepsilon_S - \varepsilon_\infty}{1+\omega^2\tau^2}}\right) \tag{2}$$

where D is the total dielectric loss tangent, D_P is the polarization loss tangent, D_G is the leakage loss tangent, γ is conductivity and τ is relaxation time. It can be deduced that at a certain temperature when frequency (ω) goes to 0, i.e., static electric field, D_P goes to 0. In such a case, the dielectric loss is almost attributed to the leakage loss. Thus when the frequency is very low, $\omega \cdot \tau << 1$, the dielectric loss can be described approximately as below.

$$D \cong \frac{\gamma}{\omega \varepsilon_0 \varepsilon_S} \tag{3}$$

Hence the dielectric loss is inversely proportional to frequency in the low frequency range. As the frequency increases, the D_P gradually increases and becomes predominant while the D_G decreases. In the higher frequency range towards the end of the measurement range of HP 4291B, a resonant peak would occur due to the LC resonance in the measurement circuit which caused the increasing of the measured dielectric loss.

CONCLUSIONS

YIG/HDPE magnetic composites with various volume fractions of ceramic fillers were prepared by using a simple low-temperature hot-pressing technique. With the increase of the volume of YIG, the permittivity, permeability, dielectric and magnetic loss of the composite all increase. The cut-off frequencies of the composites are all above 700 MHz. The permittivities and permeabilities of all the composites have shown good frequency stability and low dielectric and magnetic losses within the measurement range. Such magnetic composites are candidates for the capacitor-inductor integrating devices such as electromagnetic interference filters in RF communications.

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