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A Study of Making Ferrimagnetic Sheet Materials for RFID Applications

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Magnetic sheets comprising ferrimagnetic materials were developed and verified to be suitable for alleviating metal interference problems in radio frequency identification (RFID) systems. To fabricate the magnetic sheets, ferrite powders and polyurethane solution were blended and used to form composite sheets with the desired thickness. An apparatus which is capable of evaluating the resonance frequency and return loss of tags was established, and was used to investigate the relationship between ferrite composition and the performance of the magnetic sheets. It was demonstrated that using ferrite powders with higher permeability could reduce the thickness of the magnetic sheets and enhance the energy harvested by RFID tags. In addition, employing magnetic sheets with correctly tuned resonance frequency and with a greater harvested energy could recover a larger reading range. Based on the investigation, a practical magnetic sheet material, capable of recovering 60% of reading range, was developed and its performance was proved comparable to commercial products.

1. INTRODUCTION

As telecommunication is moving up to high frequency ranges, the applications of ferrite oxides in the microwave frequency region have drawn a lot of attention(1,2). Ferrites are promising materials for high frequency artifacts due to their high permeability, broad bandwidth, mild conduction, and low cost. One of the products in demand is magnetic composite materials which comprise magnetic powders embedded in resin. Magnetic composites are widely used as electromagnetic wave absorbers which can suppress electromagnetic interference or act as magnetic sheets which can enhance communication signals(3).

Radio frequency identification (RFID) is a successful technology of communication employing electromagnetic coupling between tags and readers. However, when the tag is directly mounted on metal objects, the tag and the reader are not able to communicate with each other. This is because the conductive surface reduces the magnetic field in the surface and results in a failure of communication. For a high frequency (HF) RFID system, the metal interference problem can be alleviated by the insertion of a magnetic sheet between the tag and the metal surface. The magnetic sheet concentrates the magnetic flux emitted from the reader and thus enhances the coupling effect.

In the present work, an advanced method for evaluating the performance of magnetic sheets and the process of approaching ultimate products were reported. A magnetic sheet of ferrite powders suitable to remedy metal interference problems for HF RFID systems has thus been developed.

2. EXPERIMENTAL METHODS

2.1 Sample Preparation

The spray dried Mn-Zn ferrite oxides, graded MZ43, M15, and M71, were supplied by HiMag Company, Taiwan. The powders were compacted and then sintered at 1350°C to evaporate binders and to enlarge the magnetic grains. The sintered samples were crushed and then sieved to 325 mesh. The collected fine powders are known as sintered ferrite powders.

To fabricate magnetic sheets, polyurethane was first dissolved in methyl ethyl ketone and a certain amount of the sintered ferrite powders were added to the polymer solutions. The weight ratio between the polyurethane and the ferrites was kept at 5:95 and the solution was vigorously agitated. After thorough mixing, the solution was coated onto a piece of release paper to form a sheet with the desired thickness. After being dried at 95°C for 20 minutes and released from the paper substrate, a magnetic sheet was obtained. The magnetic sheets containing sintered MZ43, M15 and

M71 powders were denoted as MZ43-PU, M15-PU and M71-PU, respectively.

2.2 Characterization

The performance of the magnetic sheets was analyzed by a measurement system as illustrated in Fig. 1. Instead of obtaining the reading range using an RFID reader directly, measuring by the system offers the designer much more valuable information such as matching and the coupling condition of the RFID tag. In such a system, the power emitted from a network analyzer (E5071B, Agilent Technology) is coupled to the RFID tag using a magnetic sheet as its substrate. The matching condition of the tag can be monitored by the magnitude of the reflected power. The tag performs best if the reflected power has its minimum value at the communication frequency of 13.56 MHz. The measurement system is a very useful tool for tuning the ingredients and the thickness of the magnetic sheet. More details about the measurement technique have been documented elsewhere[4].

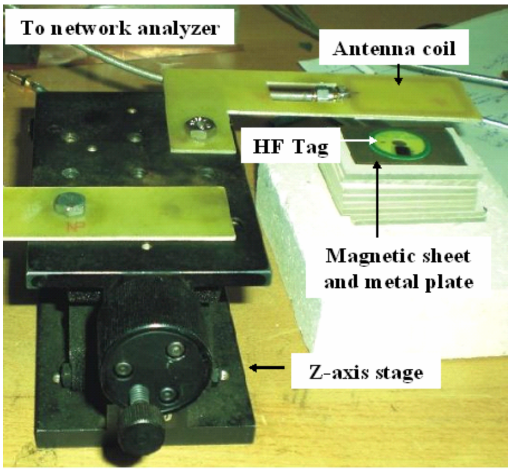

Fig. 1. Apparatus used to measure the performance of HF RFID tags on magnetic sheets and metal.

Since the magnetic sheet is formed by mixing magnetic particles and the polymer at different volume ratios, measuring the effective material property is another way to understand how the material constants affect the performance of the magnetic sheet. To this end, an impedance analyzer, Agilent E4991A, was used to measure the permeability and permittivity values at 13.56MHz.

3. RESULTS AND DISCUSSION

3.1 Effect of Ferrite Composition

Intensive efforts have been dedicated to adjust the performance of magnetic sheets. It has been suggested that the composition, particle size, and content of ferrite, and the sheet thickness crucially affect the electromag

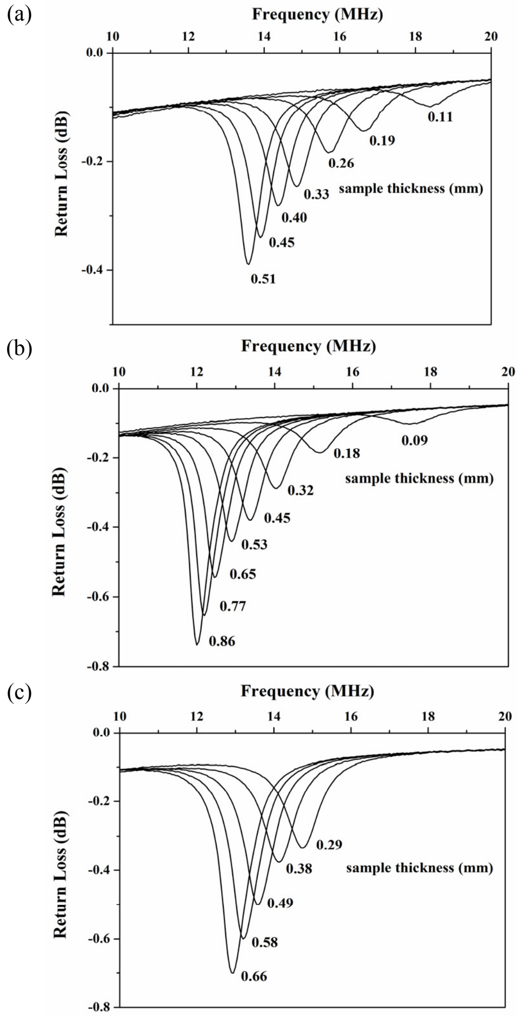

Fig. 2. Plots showing resonance spectrum of HF RFID tags on (a) MZ43-PU; (b)M15-PU; and (c)M71-PU and metal with a function of sample thickness.

netic performance[5,7]. In the present study, three kinds of Mn-Zn ferrites were used to realize the effect of ferrite composition. Figure 2 presents the resonance spectra of the tags on MZ43-PU, M15-PU, and M71-PU materials with various sheet thicknesses. The data were collected by the method described in Section 2.2. Besides, the electromagnetic properties of the sheets at 13.56 MHz (in HF region) were measured by impedance analyzer and are listed in Table 1. The results evidently reveal that as the sample thickness increased, the system resonated at a lower frequency and the return loss was enhanced. Varying the sample thickness altered the coupling coefficient and impedance of tags; consequently, the resonance spectrum changed. A thicker magnetic sheet concentrated more magnetic flux and thus more energy was emitted from the analyzer and harvested by the tag, which resulted in more decay in return loss. Moreover, a complex change of the tag's impedance induced a shift of resonance toward low frequency as the sample thickness increased.

Table 1 Electromagnetic properties of magnetic sheets at the frequency of 13.56MHz

	Permeability		Permittivity	
	μ’	μ”	ε’	ε”
MZ43-PU	8.5	-0.4	28.7	4.6
M15-PU	9.8	0.6	25.9	10.1
M71-PU	8.9	0.3	6.9	2.7

For HF RFID application, the resonance frequency between readers and tags should be around 13.56 MHz. According to the results depicted in Fig. 2, there was an appropriate sheet thickness such that the resonance frequency was tuned to 13.56 MHz. The appropriate thickness strongly depended on the sort of fillers. The thickness was 0.42 mm for M15-PU and approximately 0.50 mm for MZ43-PU and M71-PU. M15-PU had the highest real part of permeability constant (μ’ in Table 1), and hence a relatively thinner sample was needed to acquire enough magnetic flux[8]. This also implied that the permeability constant of ferrite powders is the most important parameter in determining the thickness of the magnetic sheets.

The conduction of the magnetic sheets, on the other hand, would induce an eddy current and reduce the power harvested by the tag. The imaginary parts of permittivity constants (ε”) of the magnetic sheets, as shown in Table 1, indicated that the conduction of the samples was nearly the same. Measured with a resistance meter, the magnetic sheets were found to be sufficiently insulating, so that the permeability constant was evidently the dominating factor in determining the performance in the present study.

3.2 The Reading Range

A useful magnetic sheet should be able to recover the reading range once it is inserted between a tag and the metal surface. It was verified that the reading range is governed by the energy harvested by the tag, which could be expressed by[4]

$$Power = \int P_t(f) G_r(f)\, df$$

where P_t is reader power measured by analyzer spectrum, and $G_r(f) = |1-S_{11}(f)|$ is the power transmission coefficient, with $S_{11}(f)$ being the measured return loss. Since the spectrum of the reader power in this case is a sharp peak at 13.56 MHz with a bandwidth of 1.5 MHz, a significant drop in return loss at around 13.56 MHz was necessary to guarantee an acceptable reading range.

Figure 3 shows the measured resonance spectra of the tags employing MZ43-PU, M15-PU and M71-PU with a sheet thickness of 0.42 mm. The energy harvested by the tags could thus be calculated according to the formula above. The reading range for each case was also measured and listed in Table 2 along with the consumed energy. Apparently, the tags placed onto the M15-PU sheet consumed the most energy and possessed the widest reading range. As the consumed energy decreased, the reading range declined. The performance of the tag on the M15-PU sheet exhibiting the largest reading range was promoted by the facts of resonance frequency matching with the reader power and a significant drop in return loss.

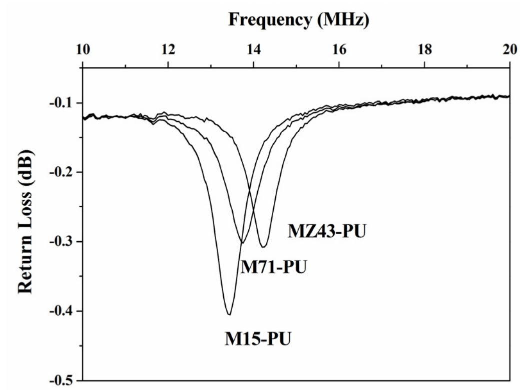

Fig. 3. Plot showing resonance spectra of HF RFID tags on 0.42mm-thick magnetic sheets.

The results reveal that to fabricate practical magnetic sheets, not only should the resonance frequency be correctly tuned, but also the return loss should be as large as possible. A prominent decay in return loss suggested a large portion of the energy emitted from the readers was consumed by the tag, and hence mutual communication was activated.

Table 2 Energy harvested by HF RFID tags employing 0.42mm-thick magnetic sheets and corresponding reading range

Magnetic sheet employed	Power (dBm)	Reading range (cm)
MZ43-PU	0.5	1.5
M15-PU	1.5	1.8
M71-PU	1.0	1.8

3.3 The Developed Products

Based on the relationship between the electromagnetic properties and the performance of the magnetic sheet, a HiMag magnetic sheet product of 0.40 mm thickness was developed and proved suitable for RFID application. The manufactured HiMag magnetic sheet is shown in Fig. 4. It took an advantage over commercial products of low cost. The performance was compared with commercially available magnetic sheets A and B from Japanese companies. The corresponding reading range was measured by using a commercial tag and the results are illustrated in Fig. 5. The reading range of the tag on a free surface was 3.7 cm while failure of communication broke out when the tag was placed on metal. By inserting A, B, and HiMag magnetic sheets between the tag and the metal, the reading ranges recovered to 1.7, 2.1 and 2.2 cm, respectively. The application of HiMag magnetic sheets recovered about 60% reading range, indicating that the developed magnetic sheets were practically functional and the performance was comparable to commercial products.

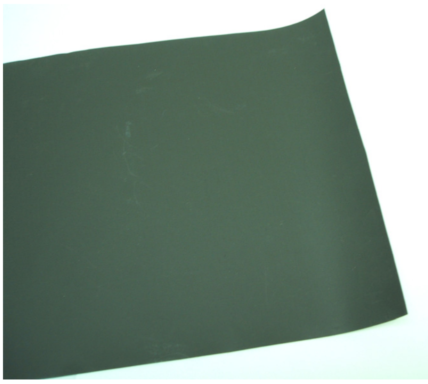

Fig. 4. A piece of HiMag magnetic sheet.

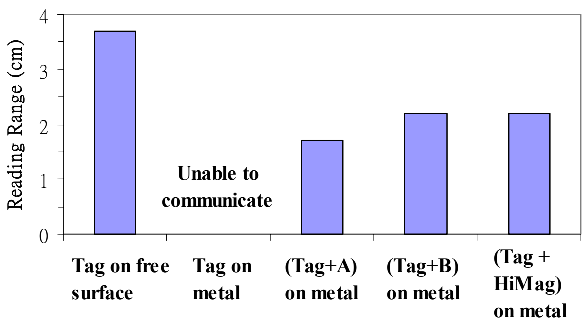

Fig. 5. Reading ranges of HF RFID tags in different conditions.

4. CONCLUSIONS

Magnetic sheets comprising ferrimagnetic materials were fabricated to suppress metal interference problems in RFID systems. Ferrite powders with a higher permeability constant could reduce the thickness of the magnetic sheets and enhance the energy harvested by the tags. It was also demonstrated that a greater harvested energy resulted in a larger reading range. Based on the investigation, a practical magnetic sheet, capable of recovering 60% of the reading range, was developed and the performance proved comparable to commercial products.

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