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EMI Suppression Properties of Fe-ferrite Film Prepared by Aerosol Deposition Method

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The Aerosol Deposition Method (ADM) is effective for the preparation of thick films with high deposition rate. We studied EMI (Electromagnetic Interference) suppression properties of Fe-ferrite film prepared by ADM on a polyimide film. The deposition rates of Fe-ferrite composite films increased with in proportion to the Fe ratio of Fe-ferrite powder before deposition. The Fe-ferrite composite film with Fe: ferrite = 8: 2 (weight ratio) showed a remarkable EMI mitigation characteristic for microstrip line structures in the range of 2.5-10 GHz. We also applied Fe-ferrite composite films by ADM on FPC (Flexible Printed Circuit) for practical use. The FPC was connected to a transmitter board and a receiver board. Compared with a FPC without Fe-ferrite composite films, the FPC with one could suppress electric field intensity by about 10dB around 1.2 GHz in the far field, which was resonance frequency of the FPC.
Key words: Aerosol Deposition method, thin film, magnetic property, EMI, EMC

1. INTRODUCTION

Recently the importance of the countermeasures in Electromagnetic Compatibility (EMC) related issues are significantly increasing according to the advance in the electronics industry, such as consumer electronics, wireless communications and so on. Some researchers report the attempt of application of magnetic materials to reduce the electromagnetic interferences (EMI) in high frequency range [1]. For example, Yoshida showed the effectiveness of the flexible magnetic sheet and explained the relationship between the magnetic properties and transmission attenuation [2]. The flexible magnetic sheets are often placed on FPC (Flexible Printed Circuit) in products when they are needed since the FPC often acts as a transmission line and an antenna for noise signals in products.

Even though these flexible sheets have certain characteristics and exhibit noise reduction, there are still certain points that are expected to be improved from the practical point of view, thickness, for instance. As the volume of the electronics gadget decreases day by day, the space to be filled with those sheets is diminishing accordingly. To solve this problem, thin magnetic material with high permeability in high frequency range is expected to be developed.

In order to achieve a good balance between less thickness and high performance, nano-granular magnetic thin films prepared by sputter method are extensively studied by Ohnuma et al. [3]. Magnetic films, that has the thickness of between 1μm and 50μm, prepared by "ferrite panting" method are studied by Abe et al. [4].

Authors started to study the Aerosol Deposition Method (ADM) to prepare magnetic films [5]-[8]. The principle of the ADM is based on shock loading solidification due to the impact of ultra fine particles, which are accelerated by carrier gas. The ADM is effective for the preparation of thick films with high deposition rate.

Aiming to add the function of noise suppression to FPC, in this study, we describe EMI suppression properties of Fe-ferrite film prepared by ADM on a polyimide film that is surface material of FPC.

2. EXPERIMENTAL PROCEDURE

The primary powders for the ADM were Fe and Ni-Zn ferrite powders. The Fe powder exhibited average size of around 1.0μm. The Ni-Zn ferrite powder was $Ni_{0.7}Zn_{0.3}Fe_2O_4$ and average size of around 0.7μm. The 150g of the powder was put in an aerosol chamber and shook vertically by 350rpm. Helium gas was used as carrier gas, led to the aerosol chamber, mixed with the powder and formed into aerosol. The aerosol was transferred to a deposition chamber, which was evacuated to 10-100 Pa in advance, and finally injected through the nozzle.

The carriage rate of the aerosol was controlled 3.0litters/min. The distance between substrate and nozzle was kept constant at 20 mm. The material of the substrate was SiO2, and a polyimide. Deposition time was chosen between 7 min and 10 min, to clarify the relationship between the thickness and the deposition time. The process diagram was shown in Fig. 1.

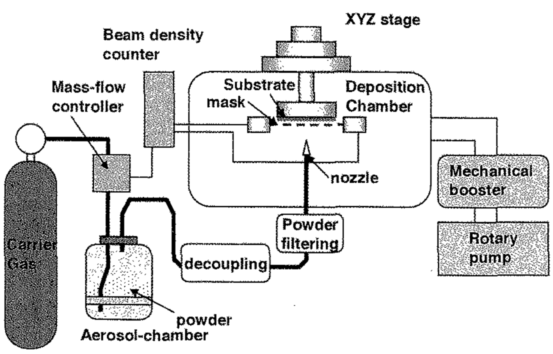

Fig. 1 Process diagram of AD method

The magnetic properties of the obtained film were measured using VSM (Vibrating Sample Magnetometer). The maximum applied magnetic field was set at 5.0kOe. The microstructure was observed by scanning electron microscopy (SEM). High frequency permeability was measured using the shielded loop coil method. To evaluate the noise suppression properties of the film, authors measured transmission attenuation of the micro strip line of Zc ≒ 50Ω. The testing circuit boards made of glass-epoxy resin (FR4) were prepared and connected to a two-port network analyzer via SMA connectors. Frequency was swept from 50MHz to 20GHz. An overview of experimental apparatus is shown in Fig. 2. S11 and S21 parameters were used to estimate the transmission attenuation of the film. In addition, to evaluate the noise suppression properties of the FPC with magnetic film, authors measured electric field intensity in far field. Two substrates of the transmitter board and the receiver board were connected with FPC of 100mm. The signal clock of the the transmitter board is 33MHz. Frequency was swept from 400MHz to 2GHz.

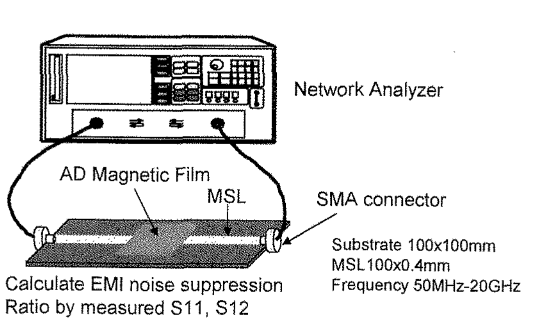

Fig. 2 An overview of experimental apparatus

3. RESULTS

3.1 Relation between "Characteristic of film" and "Mixture ratio of Fe powder and Ni-Zn Powder"

First the relationship between characteristic of film and mixture ratio of Fe powder and Ni-Zn Powder were investigated. Deposition time was fixed at 7 min.

Fig. 3 shows the relationship between the maximum thickness of magnetic films and the amount of Fe. When the amount of Fe is assumed to be x wt%, the amount of Ni-Zn ferrite is 100-x wt%. The material of the substrate was SiO2, and polyimide. The maximum thickness of the film increased according to amount of Fe. And the maximum thickness of the polyimide substrate was thinner than that of the SiO2. When the amount of Fe was 100 wt%, the maximum thickness was about 10μm and about 6μm in the SiO2 substrate and the polyimide substrate respectively.

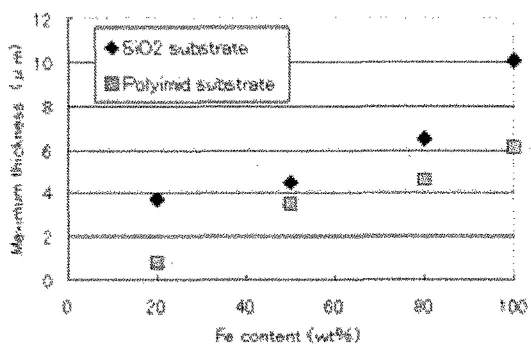

Fig. 3 The relationship between the maximum thickness of magnetic films and the amount of Fe

Fig. 4 shows magnetic hysteresis loops of Fe-ferrite films. The mixture ratios of Fe powder and Ni-Zn ferrite powder were 10:0, 8:2, 5:5, 2:8 (weight ratio) respectively. The material of the substrate was SiO2. The saturation magnetization of the film increased with an increase in the amount of Fe. On the other hand, the coercive force of the film decreased with an increase in the amount of Fe. In fig. 4, the saturation magnetization of Fe: Ferrite= 10:0 film was a big value of 800 emu/cm3 or more.

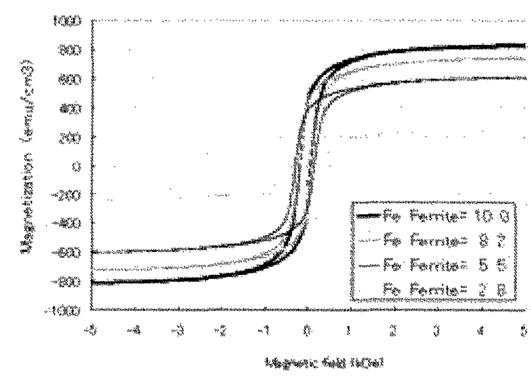

Fig. 4 Magnetic hysteresis loops of Fe-ferrite films

Fig. 5 shows the frequency dependence of relative real part (μ_r') and imaginary part (μ_r'') of permeability in Fe-ferrite films. The mixture ratios of Fe powder and Ni-Zn ferrite powder were 10:0, 8:2, 5:5, 2:8 (weight ratio) respectively. The material of the substrate was SiO2. The maximum permeability of the film increased with an increase in the amount of Fe. In fig. 5, the maximum permeability of Fe: Ferrite= 10:0 film was μ_{rmax}' ≒ 21 and μ_{rmax}'' ≒ 15. And the maximum permeability of Fe: Ferrite= 8:2 film was μ_{rmax}' ≒17 and μ_{rmax}'' ≒12.

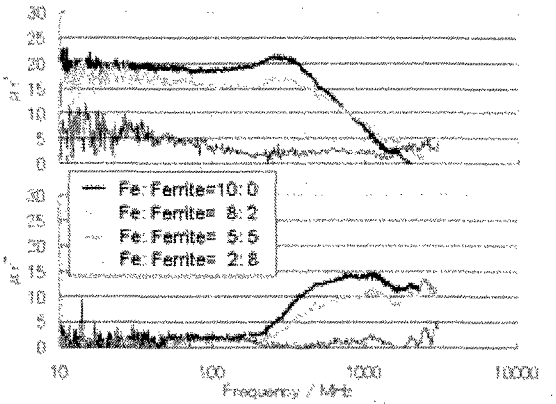

Fig. 5 The frequency dependence of relative real part (μ_r') and imaginary part (μ_r'') of permeability in Fe-ferrite films

3.2 Observation of Fe-Ferrite films

Next, the surface and the cross section of Fe-Ferrite films were observed. Deposition time was fixed at 10 min. The material of the substrate was polyimide.

Fig. 6 shows the surface image of Fe: Ferrite= 8:2 (weight ratio) film. White and gray parts were Fe and black parts were Ferrite from EDX analysis in fig. 6. The molar concentration of Fe and Ni in the area that had been enclosed with the white line was about 20:1 (%). The molar concentration of Fe: Ni-Zn ferrite was about 6:1 in Fe: Ferrite= 8:2 (weight ratio) film, considering the Ni-Zn ferrite powder was $Ni_{0.7}Zn_{0.3}Fe_2O_4$.

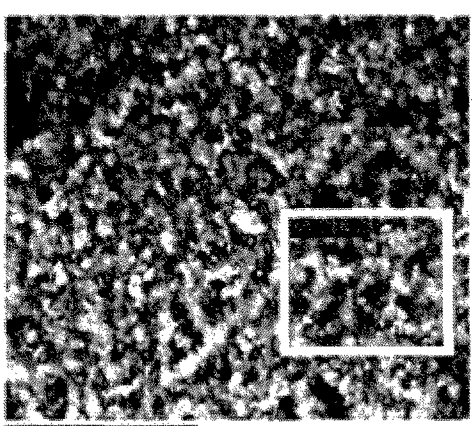

Fig. 6 The surface image of Fe: Ferrite= 8:2 film

Fig. 7 shows the cross section image of Fe: Ferrite= 8:2film. The film thickness was about 7.0μm. In fig. 7, the particle size was small in a layer near the polyimide, and large in the surface. The particle sizes in a layer near the polyimide ((A) area in fig.7) and in the surface ((B) area) were about 100-200nm and 300-600nm respectively. It was understood that the particle had been fined by ADM, considering that the average sizes of Fe powder and Ni-Zn powder were around 1.0μm and 0.7μm before deposition respectively.

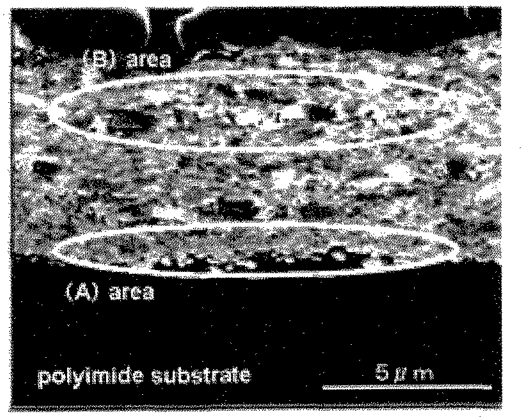

Fig. 7 The cross section image of Fe: Ferrite= 8:2 film

3.3 Evaluation of the EMI suppression properties of Fe-Ferrite films

To evaluate the transmission properties of the Fe-Ferrite films, 10x25mm films of Fe: Ferrite= 8:2 and 2:8 (weight ratio) were deposited on the polyimide substrate. Deposition time was fixed at 10 min. The transmission properties of the Fe-Ferrite films were evaluated with the polyimide substrate with magnetic films had been set up on microstrip line.

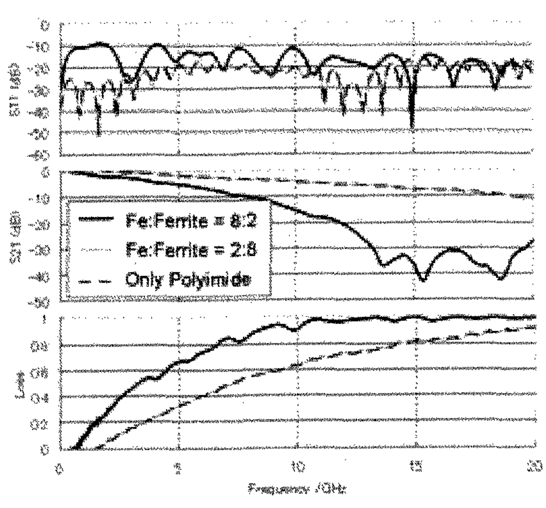

Fig. 8 The frequency dependence of S11, S21 and transmission loss (LOSS) in the polyimide substrate with Fe-Ferrite films

Fig. 8 shows the frequency dependence of S11, S21 and transmission loss (LOSS) in the polyimide substrate with Fe: Ferrite= 8:2 film, with Fe: Ferrite= 2:8 film and without magnetic films, respectively. The polyimide substrate with Fe: Ferrite= 2:8 film and without magnetic films (only the polyimide substrate) were almost the same characteristics. Therefore, there was little EMI suppression effect of the polyimide substrate with Fe: Ferrite= 2:8film. On the other hand, Compared with the polyimide substrate without magnetic films, the polyimide substrate with Fe: Ferrite= 8:2film had the Loss characteristic that was 30% or larger in the range of 2.5-10 GHz.

To evaluate the electric field intensity of the Fe-ferrite films in the far field, the Fe: Ferrite= 8:2 (weight ratio) film of 10mm in width was deposited with the surface of FPC on the reverse. And the film was deposited to the vicinity of FPC of both connectors. Deposition time was fixed at 10 min. The distances between two substrates connected with FPC of 100mm length and the receiving antenna was about 2m.

Fig. 9 shows the measurement results of the electric field intensity in the far field. Fig. 9 has two graphs of a parallel element and a vertical element of the electric field intensity. A black line was a measurement result of a FPC without the Fe-ferrite films (normal FPC), and a gray line was a measurement result of a FPC with the Fe-ferrite film. In fig. 9, compared with a FPC without Fe-ferrite films, a FPC with one could suppress electric field intensity by about 10dB around 1.2 GHz in the far field. 1.2 GHz was resonance frequency of a FPC without Fe-ferrite films from the measurement result of magnetic field intensity above FPC. Magnetic field intensity at both ends of a FPC without the Fe-ferrite films was large around 1.2 GHz. Therefore, Fe-ferrite film prepared by ADM on FPC suppressed magnetic element of noise signals around 1.2 GHz.

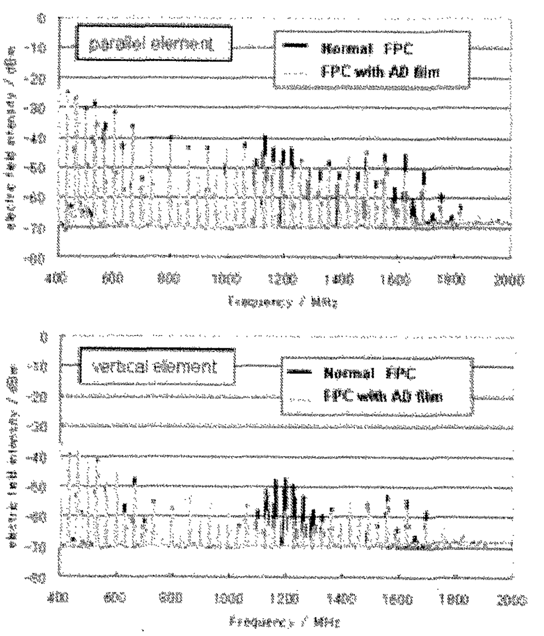

Fig. 9 The measurement result of the electric field intensity in the far field

4. SUMMARY

Fe-ferrite films were prepared on a SiO2 substrate, a polyimide substrate or FPC by using ADM. Magnetic properties and EMI suppression properties of the films were investigated and the following results were obtained.

(1) The maximum thickness of the Fe-ferrite film increased according to amount of Fe on a SiO2 substrate or a polyimide substrate.
(2) The saturation magnetization of Fe: Ferrite= 10:0 film was a big value of 800 emu/cm3 or more.
(3) The maximum permeability of Fe: Ferrite= 10:0, 8:2 film was μ_{rmax}' ≒21, 17 and μ_{rmax}'' ≒15, 12 respectively.
(4) Compared with a polyimide substrate without Fe-ferrite films, a polyimide substrate with Fe: Ferrite= 8:2film had the Loss characteristic that was 30% or larger in the range of 2.5-10 GHz.
(5) Compared with a FPC without Fe-ferrite films, a FPC with one could suppress electric field intensity by about 10dB around 1.2 GHz in the far field.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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