Soft Magnetic Properties of Iron based Aerosol Deposition film

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Soft magnetic properties of iron based film prepared by Aerosol Deposition (AD) method were investigated. Deposition rate of 1.4 μm/min was obtained. Saturation magnetization and coercive force of the film was 200 emu/g and 80 Oe, respectively. Saturation magnetization of the AD film slightly decreased when the thickness of the film increased. This seems to be related to the defects of the film, which were observed at the surface of the film. The transmission attenuation of the micro strip line showed -4dB in the 15-20 GHz range. This suggests the iron film has the potential to reduce high frequency electromagnetic noise.
Key words: Aerosol Deposition method, thin film, iron, magnetic property, transmission attenuation, 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. Besides certain conventional EMC countermeasures using circuit simulation, EMC countermeasure parts and electronic shielding, some researchers report the attempt of application of magnetic materials to reduce the electromagnetic interferences 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].

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. In terms of solving this problem, thin magnetic material with high permeability in high frequency range is expected to develop.

In order to compatible less thickness and high performance, nano-granular magnetic thin film is extensively studied by Ohnuma et al. [3]. The imaginary part of permeability (μ") over 1000 and thickness of 1μm was obtained, although this nano-granular thin film is still in a feasibility stage. Magnetic film that has the thickness of between 1μm and 50μm was studied by Abe et al. [4] and μ" of around 100 was reported. However, this film was deposited through galvanization method and also in a feasibility phase.

Authors started to study Aerosol Deposition method [5], which has practical advantages, for instance, high deposition rate, inexpensive equipments, and potential to accomplish the nano-structured composite. Spinel ferrites were tried to apply for EMC usage, however, they showed low saturation magnetization of 0.28 T [6]. To develop the high performance magnetic materials to reduce the electromagnetic interference in the GHz range, we investigated the soft magnetic properties of iron AD film. In this study we also describe the transmission attenuation properties of micro strip line to evaluate the EMC property of the film.

2. EXPERIMENTAL PROCEDURE

Iron powder was prepared by deoxidization process. The particle size was arranged between 400 and 600nm. Fig. 1 shows the SEM image of this starting material. The 150g of the powder was put in an aerosol chamber and shook vertically by 300Hz. Helium gas was used as carrier gas, lead to the aerosol chamber, mixed with the powder and formed into aerosol. The aerosol was transferred to deposition chamber, which was evacuated to 10-100 Pa in advance, and finally injected through the nozzle.

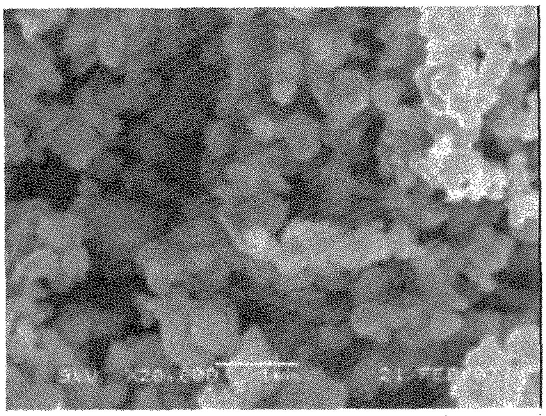

Fig. 1 SEM image of the iron powder

The carriage rate of the aerosol was controlled between 3 litters/min and 7 litters/min. The distance between silica substrate and nozzle was kept constant at 20 mm. The iron aerosol was deposited in a circular shape, the diameter of 8 mm. Deposition time was chosen between 3 min and 12 min, to clarify the relationship between the thickness and the deposition time. The process diagram was shown in Fig. 2.

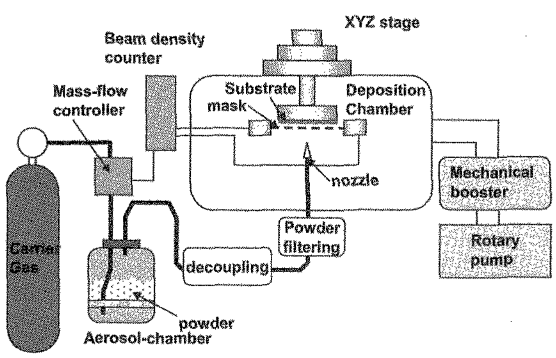

Fig. 2 Process diagram of AD method

The magnetic properties of the obtained film were measured using VSM (Vibrating Sample Magnetometer). The maximum applied magnetic field was set at 10 kOe. X ray diffraction method was used to decide the phase. To evaluate the noise attenuation effectiveness of the film, authors measured transmission attenuation of the microstrip line. The testing circuit boards made of glass-epoxy resin (FR4) were prepared and connected to the two ports network analyzer via SMA connectors. Frequency was swept from 50MHz to 20GHz. An overview of experimental apparatus is shown in Fig. 3. S21 parameter was used to estimate the transmission attenuation of the film.

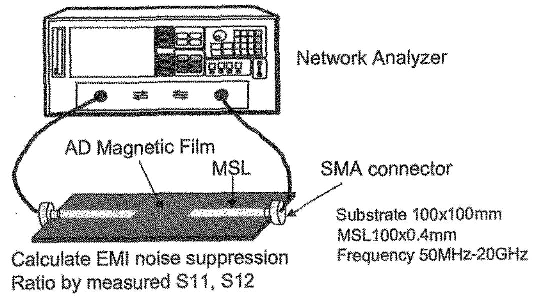

Fig. 3 An overview of experimental apparatus

3. RESULTS

3.1 Characteristics of the starting powder

Firstly the magnetic properties of the starting powder were investigated. Fig. 4 shows magnetic hysteresis loop of the iron powder. Saturation magnetization was 203 emu/g and coercive force was 136 Oe, respectively. This iron powder was used as the starting material.

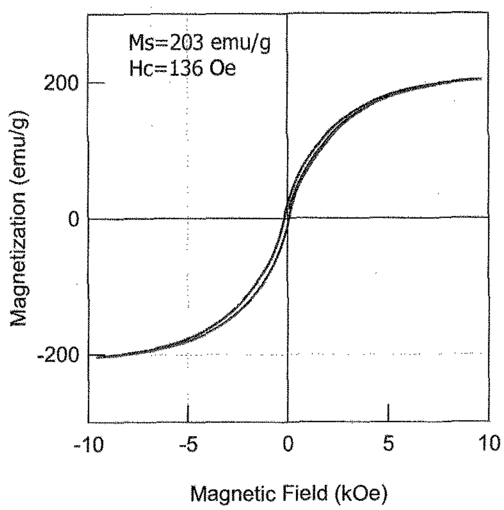

Fig. 4 Magnetic hysteresis loop of iron powder

3.2 Depositing condition and the properties of the film

Then the relationship between deposition conditions and characteristics of the film were investigated. To begin with, deposition time was fixed at 3 min and Helium gas flow rate was varied from 3 litters/min to 7 litters/min.

In Fig. 5 the thickness dependence on the gas flow rate is shown. Clear linear dependence exists between two parameters, thickness and flow rate. The surface roughness of the AD film was increased corresponding to the increasing carrier gas flow rate. As shown in the small pictures in Fig. 5, fairly large voids and cracks were observed on the film deposited under the flow rate of 5 litters/min and 7 litters/min. Thus the helium gas flow rate was determined to 3 litters/min in this experiment.

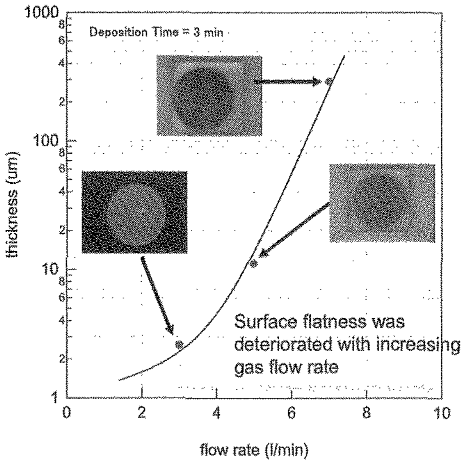

Fig. 5 Thickness dependence on the gas flow rate

Next the thickness dependence on the deposition time was measured. From Fig. 6, which shows the relationship between the deposition time and the thickness, linear relationship was observed. In this experiment, 17μm thickness can be obtained by 12 minutes deposition time under 3 litters/min gas flow rate. This corresponds to approximately 1.4 μm /min deposition rate. So this AD method proved to be able to exhibit practical deposition rate compared to the other thin film process.

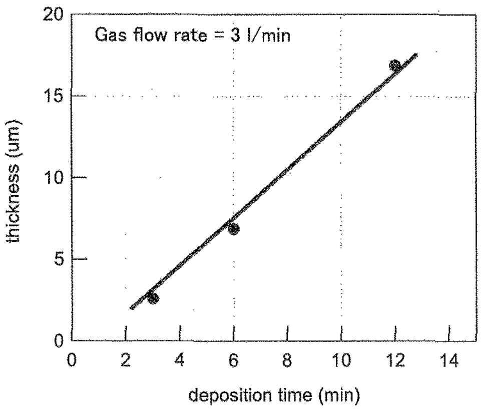

Fig. 6 Relationship between thickness and deposition time

3.3 Observation on the surface of the film

Fig. 7 shows the surface image of the as deposited iron film. Unevenness of the surface is due to the deposition mechanism and each pinnacle is estimated to be 0.1-0.5 μm, approximately. Akedo[5] referred three steps of the deposition; (1) starting powder impacts to the substrates, (2) chemically activated surface comes out from the crack, and (3) adhere to the substrate. According to this theory, iron powder used in this study was fractured to the small particle. Smaller size of the particle implies even the iron powder undergoes this process.

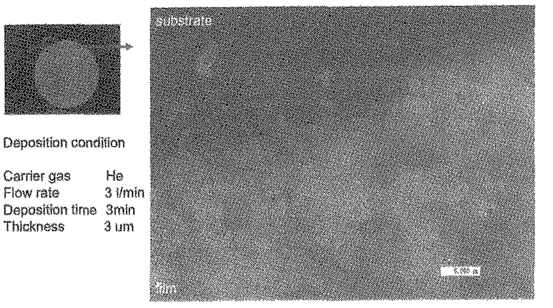

Fig. 7 Surface laser-microscope image of the as deposited AD film

3.4 X ray diffraction pattern of the film

The existing phase was identified using X ray diffraction method. Fig. 8 shows the XRD pattern of the as deposited iron film, comparing with that of powder's. XRD pattern showed neither the hallo pattern nor amorphous pattern. The previous study about dielectric ceramics [5] revealed that as deposited AD film does not show the clear crystalline structure by XRD pattern, though in this study the crystalline iron single phase was obtained. This difference seems due to the difference between ceramics powder and iron metal powder. Akedo mentioned that the ceramics powder impacts and breaks on the surface at its deposition, while the metal powder seems to spread at the impact at its deposition, keeping its crystalline structure.

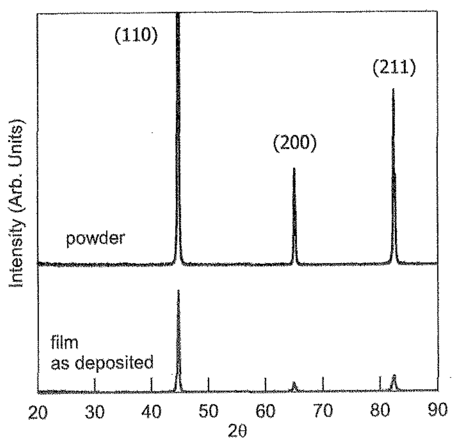

Fig. 8 X ray diffraction pattern of the film

3.6 Magnetic properties of the film

Magnetic properties of the deposited AD film, which turned out to be single iron phase, were measured by VSM. Fig. 9 shows thickness dependence on the saturation magnetization on the left hand axis, and coercive force on the right hand axis, respectively. Fig. 10 shows its magnetic hysteresis loops.

Saturation magnetization decreased from 200 emu/g at 11μm to 170 emu/g at 290μm, while the coercive force did not show remarkable dependence and ranged between 80 and 90 Oe. As shown in Fig. 5, voids and cracks were introduced in the film as the thickness increases, which may caused the slight decrease in the saturation magnetization.

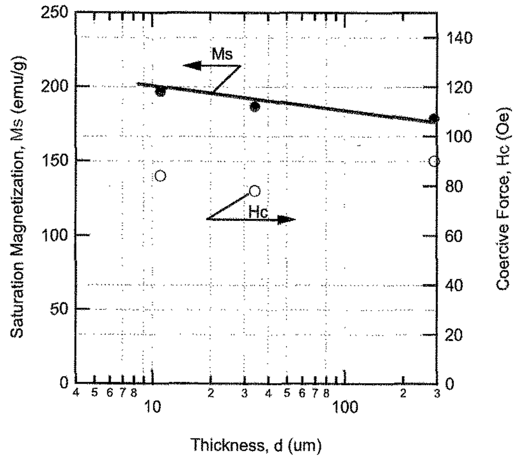

Fig. 9 Thickness dependence on the magnetic properties of the as deposited iron film

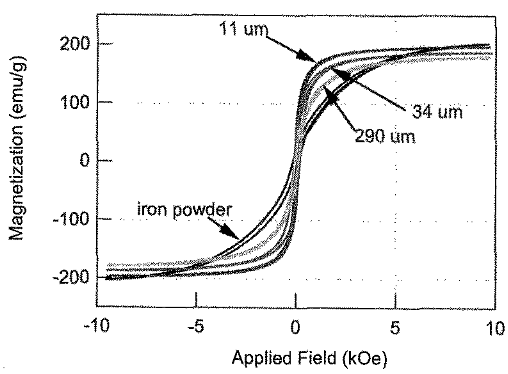

Fig. 10 Magnetic hysteresis loops of the as deposited iron film

3.7 Evaluation of the EMC properties of the film

To evaluate the EMC effectiveness of the AD film, 10x20mm iron film was deposited on the micro strip line. The thickness was 0.5μm, which was much less than that on the glass substrate. Fig. 11 and Fig. 12 show frequency dependence of the S21 and attenuation, respectively. This iron film exhibited attenuation of 4dB in 15-20 GHz range, while the thickness of the film was less than 1μm. This implies that the iron film have the potential to reduce noise coupling among the circuits or between the two devices.

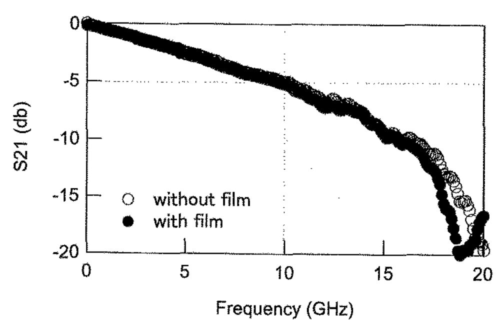

Fig. 11 Transmission properties of the micro strip line, S21.

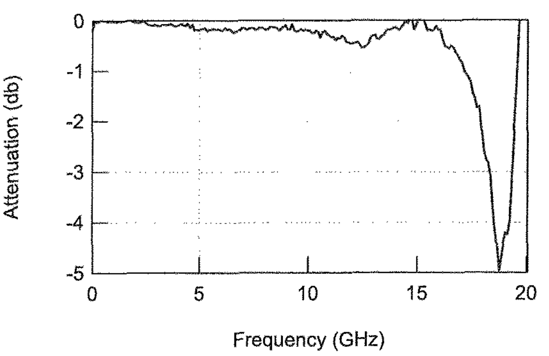

Fig. 12 Transmission attenuation of the micro strip line

4. SUMMARY

Iron films were prepared by using AD method. Magnetic properties and transmission attenuation properties of the films were investigated.

(1) Saturation Magnetization of 195 emu/g was obtained. Under the gas flow rate of 3 litters/min, the deposition rate of 1.4 μm/min was obtained.
(2) Voids, clack and defects were observed under the gas flow rate of over 3 litters/min.
(3) Using micro strip line, transmission attenuation of 4dB was observed in the 15-20 GHz range.

In the future study, we aim to

(1) Optimize the deposition condition
(2) Apply to the practical circuit boards
(3) Measure high frequency permeability of the film

5. ACKNOWLEDGEMENT

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6. REFERENCES

[1] M. Sato, S. Yoshida, E. Sugawara, H. Shimada, *J. Magn. Soc. Jpn.*, Vol. 20, 421-424, (1996).
[2] S. Yoshida, *J. Magn. Soc. Jpn.*, Vol. 22[10], 1353-1356, (1998).
[3] S. Ohnuma, *J. Appl. Phys.*, 79, 5130, (1996).
[4] M. Abe, N. Matsushita, *J. Magn. Soc. Jpn.*, Vol. 27[6], 721-729, (2003).
[5] J. Akedo, *Ceramics*, 38[5], 363-368, (2003).
[6] R. Kobayashi, S. Sugimoto, K. Inomata, M. Lebedev, J. Akedo, K. Okayama, K. Kimura, *Spring Conference of Jpn. Inst. Metal*, No. 236, (2003).

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