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Noise Suppression Effect of Nano-granular Magnetic Thin Films at GHz Frequency

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The noise suppression effect of FeCo-Al-O nano-granular thin films, having high performance in GHz band, was investigated. Samples were prepared by reactive sputtering method using mixed gases both of oxygen and argon. A micro-strip line (MSL) with the granular films placed on its top was used to evaluate conduction noise suppression. The saturation magnetization, electrical resistivity, magnetic anisotropy field, permeability and ferromagnetic resonance frequency of the $Fe_{55}Co_{22}Al_8O_{15}$ film were about 15 kG, 190 μΩcm, 50 Oe, 300 and 3 GHz, respectively. The result of transmission and reflection measurements revealed that this film had high potential for noise suppressors in the GHz range, though the reflection parameter (S_{11}) was inconveniently large, because of its low conductivity. In order to reduce S_{11}, fabrication of film pattered with fine slits was found to be effective, i. e.; the patterned film with slits along the MSL reduced S_{11} remarkably below –10 dB. The patterned film with slits of 2.5 mm width demonstrates to exhibit the good noise suppression effect, S_{11}<-10 dB and P_{loss}/P_{in}=0.4 at around 3 GHz.

Key words: noise suppression, nano-granular, soft magnetic film, GHz frequency, high electrical resistivity

1. INTRODUCTION

There is an increasing problem for the electromagnetic interference (EMI) at high frequency range in the electronic devices and transmission lines. As the radio-frequency (rf) semiconductor electronics and integration of electronic components progress towards much higher frequencies and downsizing, this in turn requires the thin shape noise suppressor with appreciably high dynamic magnetic loss (μ'') at GHz range.

We have studied high permeability films with a nano-granular structure for use in these technologies [1], because the nano-granular soft magnetic films exhibit considerably high electrical resistivity (ρ) and saturation induction (B_s) [2]. In addition, Co based nano-granular soft magnetic films have a large magnetic anisotropy filed (H_k) up to 400 Oe [3]. The high ρ is expected to suppress eddy current loss appreciably, while both B_s and H_k lead to distinct and controllable magnetic resonance frequency (fr) in the GHz range[4]. Therefore Co based nano-granular soft magnetic films should be noteworthy as the strong candidates for noise suppressor at GHz range.

In this paper, we report our extended study to such nano-granular films, particular in $Fe_{55}Co_{22}Al_8O_{15}$, whose ρ, B_s and H_k are 15 kG, 50 Oe and 180 μΩcm, respectively. The size effect of the film on the magnetic and transmission properties will be clarified. The mechanism of noise suppression effect of the films will be discussed based on the control of magnetic anisotropy field.

2. EXPERIMENTAL

Films were prepared by rf reactive magnetron sputtering with $Ar+O_2$ gases in a background pressure lower than $2x10^{-7}$ Torr. FeCoAl alloy target was used to prepare FeCo-Al-O films with considerably large B_s and H_k [5]. The films were deposited on glass substrates (Corning 7059) in a magnetic filed of 100 Oe to induce an in-plane uniaxial magnetic anisotropy in the films. Compositions of the films were analyzed by an electron spectroscopy for chemical analysis (EPMA) and an energy dispersive X-ray spectrum (EDX) with a windowless detector. The microstructure of the films was observed by transmission electron microscopy (TEM) and X ray diffract meter. Magnetic measurements were conducted on a vibrating sample magnetometer (VSM), and the electrical resistivity was measured using the conventional four-point probe method. High frequency permeability was measured using the shielded loop coil method (6). A micro strip line (MSL, W=3 mm x L= 75 mm) of Zc=50 Ω connected at the both ends to the network analyzer (Agilent 8753ES) was used to evaluate noise suppression effects for signal transmission [1]. The 2 port transmission characteristics in the level of 5 dB were measured with samples of 20 mm square placed on the line. An automatic dicing saw did a patterning of slits for the film.

3. RESULTS AND DISCUSSION

3-1) Magnetic properties

In order to find excellent noise suppressive magnetic films useful at high frequencies, a wide compositional range of FeCo-Al-O films have been investigated. Fig. 1 shows the typical TEM micrograph of $Fe_{55}Co_{22}Al_8O_{15}$ film, of which the detailed properties were mentioned above. The Film composed of granules (darkly imaging regions) and intergranules (brightly imaging region). The granules consisted of pure bcc-FeCo, and the intergranules are in the amorphous Al-O state. The average granule size was approximately a few nm. The intergranule width was so narrow that some of the granules were directly contacted, thus one would expect

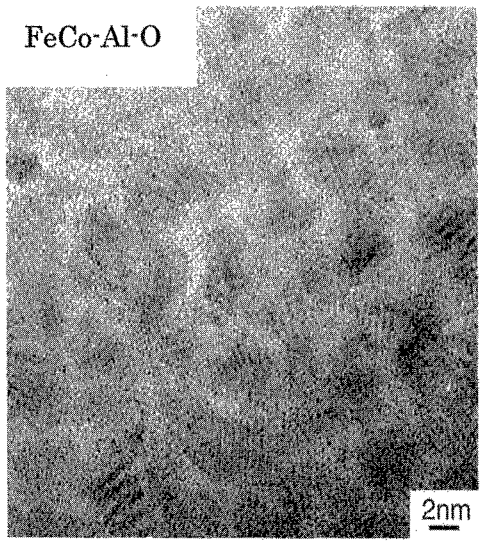

Fig.1 High resolution TEM micrograph of a nano-granular $Fe_{55}Co_{22}Al_8O_{15}$ film

that the granules were magnetically coupled. In fact, nano-granular $Fe_{55}Co_{22}Al_8O_{15}$ film exhibits soft magnetic feature.

Though nano-granular $Fe_{55}Co_{22}Al_8O_{15}$ soft magnetic film has larger ρ than those of conventional soft magnetic metals, the magnitude of ρ is not enough to reduce the reflection parameter less than –10dB in GHz region [1]. And the reflection becomes conspicuous compared to the background level without samples [1]. This suggests the samples work as a stub to the strip line due to the low ρ of the granular films. To remove such an influence of the stub effect, it is considered to be effective either making of the thin film with slits whose each width is smaller than the wavelength or reducing the width of sample to the similar size to the strip line width [1].

In order to increase ρ for removing the stub effect, nano-granular Co-Fe-Al-O thin films were cut into several variety of width with air gaps of a few micrometers in width, as shown in Fig.2. Effective uniaxial magnetic anisotropy is known to be given as the sum of induced magnetic anisotropy and shape anisotropy determined by the ratio of length (L) to

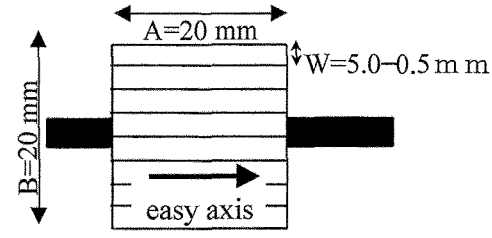

Fig.2 Schematic illustration of the micro strip line and a nano-granular $Fe_{55}Co_{22}Al_8O_{15}$ thin film which was pattered with slits parallel to the MSL

cross-sectional area (S) of strip [7]. Therefore, it is expected that the narrower the patterned film, its H_k increase.

Fig.3 shows magnetization curves of the nano-granular $Fe_{55}Co_{22}Al_8O_{15}$ film. Film(a) is without patterning and

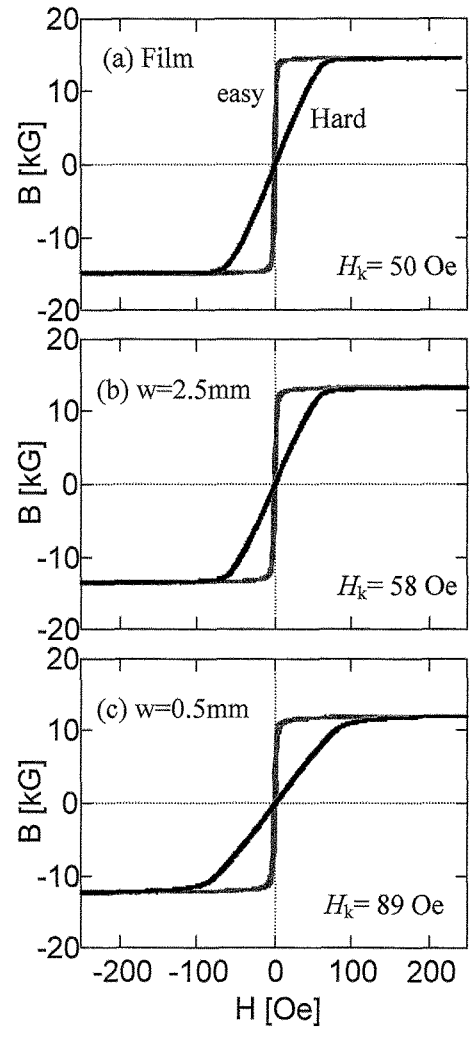

Fig. 3 Magnetization curves for nano-granular $Fe_{55}Co_{22}Al_8O_{15}$ thin films; (a) film without slits, (b) and (c) films with slits along easy axis.

films (b) and (c) are patterned with slits of 2.5 mm and 0.5 mm parallel to the MSL, respectively. The film(a) shows excellent soft magnetic properties of B_s=15 kG, H_c=1.2 Oe, and H_k=50 Oe. As can be seen in (b) and (c), the anisotropy field increases with decrease of films width, owing to the shape anisotropy (L/S, L:length, S:cross-sectional area).

Fig. 4 demonstrates frequency dependence of permeabilities, μ' and μ'', for the films shown in Fig. 3. The magnitude of μ' for the film without slits is about 300 up to 2 GHz. The resonance frequency (fr) is around 3 GHz, and the μ'' is 600 near fr(Fig.4a). This value is one order greater than those of the composite magnetic material sheets and the ferrites which are employed as conventional noise suppressors. As can be seen in Figs. 4(b) and 4(c), μ' decreases with increasing H_k ($\mu'=B_s/H_k$), on the other hand, fr increases. Even though the width of patterned film(c) is around 0.5 mm, μ' and μ'' is 150 and 400, respectively, at 3 GHz. Note that the limmitation frequency of our apparatus is about 3 GHz. The above results suggest that nano-granular $Fe_{55}Co_{22}Al_8O_{15}$ pattered film with slits has a high potentiality as a noise suppresor in the GHz band.

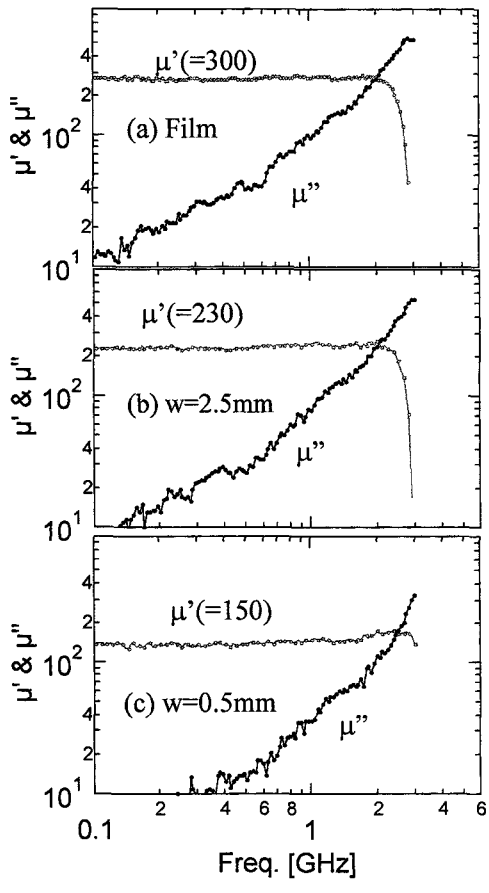

Fig.4 Permeability μ' and μ'' as a function of frequency for FeCo-Al-O nano granular thin films. (a) films, (b) and (c) films, which were patterned with, slit along the easy axis.

3-2) Transmission characteristics

Next, samples, used in Figs. 3 and 4, of 20 mm square were placed on the micro strip line, and the transmission parameters S_{11} and S_{21} were measured. The results are shown in Figs. 5(a) and 5(b) respectively. In Fig.5(c), the result of the power loss P_{loss}/P_{in}, which is calculated from S_{11} and S_{21} according to the equation (1) of

$$P_{loss}/P_{in}=1-(S_{11}^2+S_{21}^2), \quad (1)$$

is shown.

It is noteworthy that the decrement of S_{11} is obseved in the patterened films. This tendency can be enhanced with decreasing the width of patterned film. It seems that the stub effect is supressed by the increment of film resisitvity and by patterning the film with slits. When the width is 2.5 mm, S_{11} becomes under –10dB, which is near to our desired value, and 0.4 of P_{loss}/P_{in} is obtained in this film. In the case of the width of 0.5 mm, S_{11} is less than –20 dB, which seems no refrection from the film, however P_{loss}/P_{in} becomes considerably small. It is very

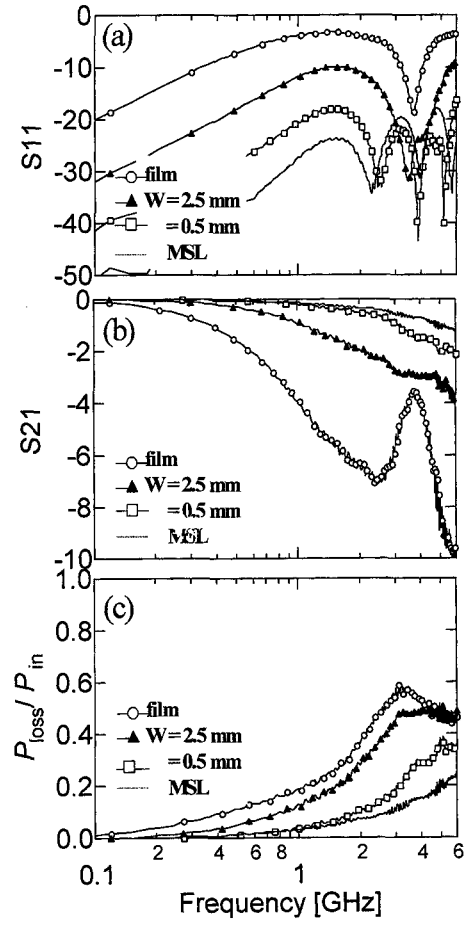

Fig.5 Transmission characteristics for FeCo-Al-O films, (a) reflection parameter (S_{11}), (b) transmission parameter (S_{21}) and (c) power loss (P_{loss}/P_{in}).

important for us to choose the width of patterned films, as a consequence of the measurment of transmission characteristics, in order to supress the stub effect and to obtain the large P_{loss}/P_{in}. When the width of the patterned films is almost the same as that of MSL, we can obtain the excellent properties of both refrection and power loss in the case of the nano-granular FeCo-Al-O soft magnetic film.

We also investigated on the film patterned with slits perpendicular to the MSL. Although a large P_{loss}/P_{in} is also observed in the film patterned perpendicular to the MSL, any decrement of S_{11} although could not be observed. The stub effect can be improved only in the case of film patterned by slits parallel to the MSL. The same tendency is observed in other nano-granular soft magnetic films.

The P_{loss}/P_{in} of nano-granular soft magnetic film (thickness, t=1 μm), which is patterned into the width of 2.5 mm and shows an excellent tranmission properties, is compared with the conventional composite magnetic

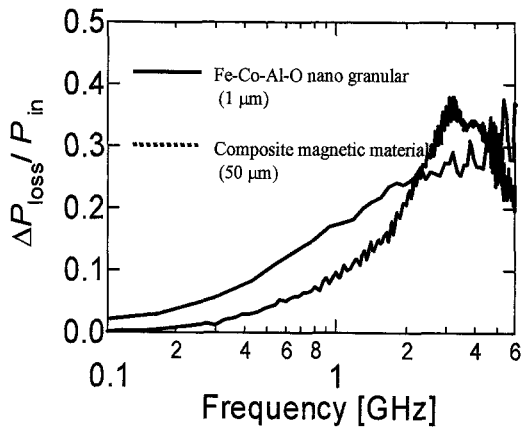

Fig.6 Comparison of power loss for the FeCo-Al-O nano-granular thin film (1μm) and composite magnetic material sheet (50 μm).

material sheet (t=50 μm) well-known as a noise suppressor (Fig.6). No matter how the film thickness of nano-granular soft magnetic films is 1/50 of the composite sheet, the suppression effect of nano-granular films is similar to that of composite magnetic sheet or larger.

4 SUMMARY

Magnetic and transmission properties of soft magnetic FeCoAl-O films with nano-granular structure have been investigated to evaluate the possibility as a noise suppressor at GHz range. Nano-granular magnetic films exhibit higher *fr* at GHz and large magnetic loss near *fr*. Both values of fr and the loss are controllable by changing the magnitude of magnetic anisotropy H_k of the films. A large S_{11} based on the stub effect is obseved in $Fe_{55}Co_{22}Al_8O_{15}$ film, and the decrement of S_{11} is favorble for improving the noise suppression of fims. The patterning of the film with slits parallel to the MSL is effective for reducing the stub effect and decreasing S_{11} less than −10 dB. The smaller width of pattern leads to the smaller P_{loss}/P_{in} of films. It is consequently required to find the optimum width of patterned films for obtaining both the improvement of S_{11} and the greater P_{loss}/P_{in}. In the case that the width of MSL is 3 mm, the best width of patterned film is 2.5 mm, and the film shows the S_{11} under −10 dB and the P_{loss}/P_{in} of 0.4 at 3 GHz. The suppression effect of patterned nano-granular $Fe_{55}Co_{22}Al_8O_{15}$ film is 50 times greater than that of conventional composite magnetic sheets or more in the GHz range.

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