The following article appeared in J. Appl. Phys. 99, 08M309 (2006) and may be found at http://dx.doi.org/10.1063/1.2177208.

Mn-Ir/Fe-Si exchange-coupled multilayer film with plural ferromagnetic resonance absorptions for wideband noise filter

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(Presented on 2 November 2005 ; published online 3 May 2006))

Mn-Ir/Fe-Si exchange-coupled multilayer films for a wideband and GHz band noise filter are fabricated and evaluated. The Fe-Si film has characteristics of high saturation magnetization of 19 kG, low magnetostriction of the order of 10^{-6} and high resistivity of 73 $\mu\Omega\cdot$cm. When the exchange bias magnetic field is introduced to the Fe-Si layers by the effect of Mn-Ir/Fe-Si exchange-coupling, the ferromagnetic resonance (FMR) frequency of the multilayer film is higher than the natural frequency of the single Fe-Si film. In addition, the multilayer film which has different thickness in each Fe-Si layer has plural FMR frequencies. The multiple FMR frequency gives the films characteristic of wideband energy absorption. The FMR absorption bandwidth of the multilayer film which has three FMR frequencies is about three times wider than that of single FMR film. Therefore, the multilayer film with plural FMR frequencies has an advantage in wideband noise absorption and will be useful material for the wideband and GHz frequency range noise filterings.

I. INTRODUCTION

The electromagnetic interference (EMI) has become extremely important in a variety of electronic equipment such as personal computers (a few GHz), cellular phones (0.8-2 GHz) and others. For instance, a gigahertz logic signal has many harmonic components, so their harmonic noise radiation must be suppressed to comply with electromagnetic compatibility (EMC). In order to solve this problem, it is necessary to develop a wideband noise absorption filter in the gigahertz band.

In this study, a Mn-Ir/Fe-Si exchange- coupled multilayer film has been proposed as a ferromagnetic resonance (FMR) absorption material for the wideband noise filter [1, 2]. Since the exchange bias magnetic field H_{ex} is introduced to the ferromagnetic Fe-Si layers by the effect of Mn-Ir/Fe-Si exchange coupling, the FMR frequency of the Fe-Si layer can be written using the following equation,

$$f_r=(\gamma/2\pi)\{(H_k+H_{ex})(H_k+H_{ex}+M_s)\}^{1/2} \tag{1}$$

where γ is the gyromagnetic constant, H_k is the uniaxial anisotropy magnetic field, and M_s is the saturation magnetization Therefore a higher FMR frequency can be obtained.

In addition, the Mn-Ir/Fe-Si exchange-coupled multilayer film which has different thickness in each Fe-Si layer is introduced to obtain the wideband energy absorption. As it is well known, the exchange bias field H_{ex} in the ferro/antiferro exchange-coupled film can be written using the following equation [3],

$$H_{ex} = J_{ex} / M_s t_F \tag{2}$$

where J_{ex} is the exchange energy and t_F is the ferromagnetic layer thickness. Therefore, to change the exchange bias field H_{ex} of each Fe-Si layer in the exchange-coupled multilayer film, each Fe-Si layer thickness t_F must be changed, as in Eq. (1). So the exchange-coupled multilayer film with different exchange bias fields has plural FMR absorptions frequency [4].

As already reported previously [5], it was found that the one directional anisotropy dispersion of Fe-Si become smaller when a 1 nm Ru layer is used below the Fe-Si layer, so that sharp FMR absorption is observed. In this study, a Mn-Ir/Fe-Si/Ru exchange-coupled multilayer film with varied thickness for each Fe-Si layer is fabricated and evaluated.

II. FABRICATION OF THE FILMS

The Ru, Fe-Si and Mn-Ir film are fabricated by using a conventional r.f. magnetron sputtering machine (ANELVA; SPF-313). The substrate used here was (100)Si with a thermally oxidized SiO_2 surface.

The films were deposited under dc magnetic field of 140 Oe in parallel with the film plane. The sputtering conditions for Ru, Fe-Si and Mn-Ir are shown in Table 1.

The magnetization curves of the films are evaluated using a vibrating sample magnetometer (VSM, Riken Denshi; BHV-55). The complex permeabilities of the films are evaluated using a thin film permeameter (Ryowa Denshi; PMM-9G1).

TABLE 1. Sputtering conditions for the Ru, Fe-Si and Mn-Ir multilayer films (substrate: (100)Si with surface SiO_2).

	Ru	Fe-Si	Mn-Ir
3" Target	Ru	$Fe_{89}Si_{11}$(at.%)	$Mn_{80}Ir_{20}$(at.%)
Base pressure		< 9 x10^{-5} Pa	
Ar pressure	0.7 Pa	0.7 Pa	0.7 Pa
r.f. power	100 W	200 W	300 W
Deposition rate	0.1 nm/s	0.1 nm/s	0.8 nm/s
Remarks	----------	Substrate rotation	----------

TABLE 2. Three kinds of the Mn-Ir/Fe-Si/Ru exchange-coupled multilayer films fabricated [values in parentheses: measured H_{ex}, H_s, and predicted f_r in each Fe-Si, that is (H_{ex}, H_s , f_r)].

	#1 film	#2 film	#3 film
Mn-Ir layer thickness	10 nm		
Fe-Si layer thickness	(i) 100 nm × 1 layer (12 Oe, 24 Oe, 1.9 GHz)	(i) 100 nm × 1 layer (12 Oe, 24 Oe, 1.9 GHz) (ii) 25 nm × 4 layer (39 Oe, 65 Oe, 3.1 GHz)	(i) 100 nm × 1 layer (12 Oe, 24 Oe, 1.9 GHz) (ii) 25 nm × 4 layer (39 Oe, 65 Oe, 3.1 GHz) (iii) 10 nm × 10 layer (75 Oe, 115 Oe, 4.1 GHz)
Ru layer thickness	1 nm		
Total thickness	111 nm	255 nm	465 nm

III. RESULTS AND DISCUSSION

Three kinds of Mn-Ir/Fe-Si exchange-coupled multilayer films are fabricated. The structure of the #1 film is Mn-Ir/Fe-Si (100 nm)/Ru/SiO_2/Si, so #1 film has one kind of Fe-Si layer thickness. The structure of #2 film is Mn-Ir/Fe-Si (100 nm)/Ru/[Mn-Ir/Fe-Si (25 nm) /Ru]$_4$/SiO_2/Si, so #2 film has two different kind of the Fe-Si layer thickness. The structure of #3 film is Mn-Ir/Fe-Si (100 nm)/Ru/[Mn-Ir/Fe-Si (25 nm)/Ru]$_4$/[Mn-Ir/ Fe-Si (10 nm)/Ru]$_{10}$ /SiO_2/Si, so #3 film has three different kind of the Fe-Si layer thickness. All Mn-Ir layer thicknesses are 10 nm and all Ru layer thicknesses are 1 nm.

Table 2 shows the thickness of the three types of fabricated multilayer films. In Table 2, the values in the parentheses show the measured H_{ex} and H_s and predicted f_r for each Fe-Si layer, where H_s is the saturation magnetic field in the hard axis magnetization curve, as shown in Fig. 1 (a).

Figure 1(a) shows the magnetization curves measured for #1 film. Figure 1(b) shows the measured complex permeability of #1 film. In Fig. 1(a), the exchange bias field H_{ex} and the saturation magnetic field H_s in the hard axis direction are estimated to be about 12 and 24 Oe. The saturation magnetization M_s is estimated to be about 19 kG. The predicted FMR frequency f_r is about 1.9 GHz, and the observed peak absorption is around 1.8 GHz. The measured FMR frequency is nearly the same as the predicted one shown in table 2.

Figure 2(a) shows the measured magnetization curves of #2 film. Figure 2(b) shows the measured complex permeability of #2 film. In the figure, the symbols (i) and (ii) corresponds to the contributions due to each Fe-Si layer with two different thicknesses. In Fig. 2(a), a two-step magnetization jump is observed in the easy axis. The measured H_{ex} of each Fe-Si layer is nearly same as the predicted value shown in Table 2. In Fig. 2(b), two peak absorptions frequencies are observed. The first peak is observed at around 1.9 GHz, and this frequency is equal to the predicted one for a 100 nm Fe-Si X 1 layer. The second peak is observed at around 3.2 GHz, and this frequency is nearly equal to the predicted one for a 25 nm Fe-Si X 4 layer. The FMR absorption band width of #2 film is wider than that of #1 film.

Figure 3(a) shows the measured magnetization of #3 film. Figure 3(b) shows the complex permeability of #3 film. The symbols (i) - (iii) indicate the contributions due to each Fe-Si layer with three different thicknesses. In Fig. 3(a), a three-step magnetization jump is observed in the easy axis. The measured H_{ex} for each Fe-Si layer is nearly the same as the predicted one shown in Table 2. In Fig. 3(b), three peak absorption frequencies are observed.

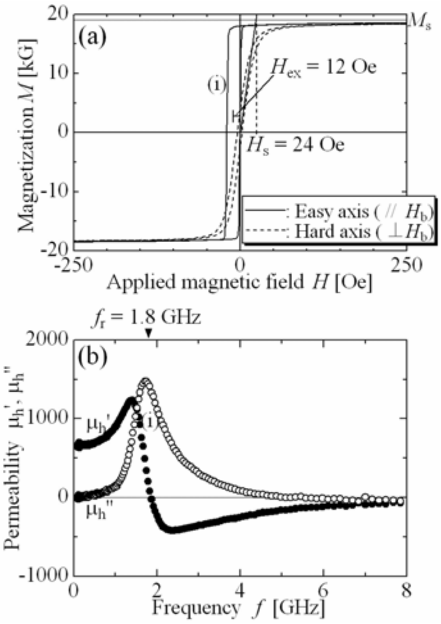

FIG. 1. (a) Static magnetization curves and (b) frequency dependence of the complex permeability measured for the Mn-Ir(10 nm)/Fe-Si (100 nm)/Ru (1 nm)/SiO_2/Si film with one resonance peak.

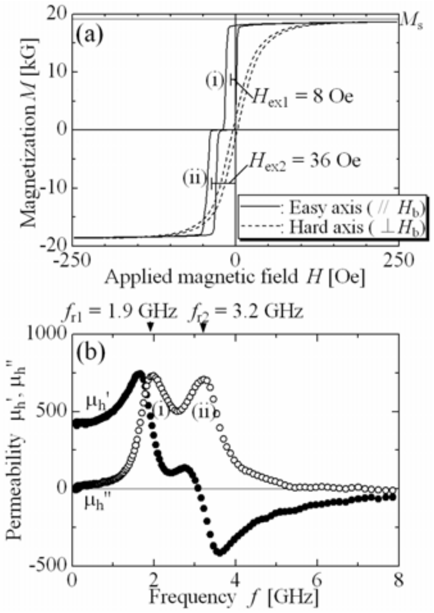

FIG. 2. (a) Static magnetization curves and (b) frequency dependence of the complex permeability measured for the Mn-Ir (10 nm)/(i) Fe-Si (100 nm)/Ru (1 nm)/[Mn-Ir (10 nm)/(ii) Fe-Si (25 nm) /Ru (1 nm)]$_4$/SiO_2/Si film with two resonance peaks.

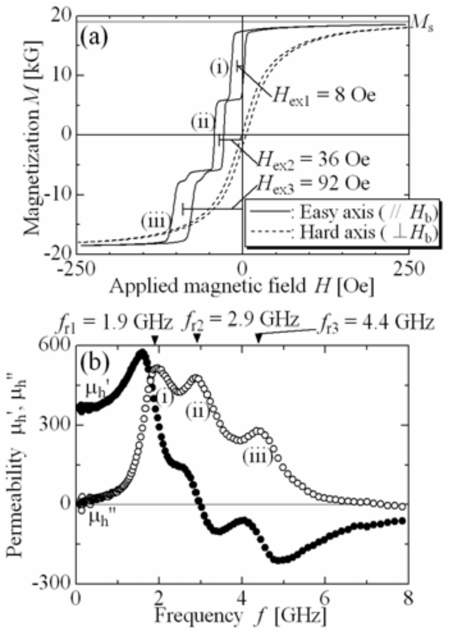

FIG. 3. (a) Static magnetization curves and (b) frequency dependence of the complex permeability measured for the Mn-Ir (10 nm)/(i) Fe-Si (100 nm)/Ru (1 nm)/[Mn-Ir (10 nm)/(ii) Fe-Si (25 nm)/Ru (1 nm)]$_4$/[Mn-Ir (10 nm)/(iii) Fe-Si (10 nm)/Ru (1 nm)]$_{10}$/SiO_2/Si film with three resonance peaks.

The first peak is observed at around 1.9 GHz, and this frequency is equal to the predicted one for the 100 nm Fe-Si X 1 layer. The second peak is observed at around 2.9 GHz, and this frequency is nearly equal to the predicted one for 25 nm Fe-Si X 4 layer. The third peak is observed at around 4.4 GHz, and this frequency is nearly equal to the predicted one for 10 nm Fe-Si X 10 layer. #3 film exhibited wideband FMR absorption characteristics, and the absorption frequency bandwidth was about three times wider than that of #1 film with single FMR.

IV. CONCLUSIONS

The Mn-Ir/Fe-Si exchange-coupled multilayer films for use as a wideband noise absorption material are fabricated and evaluated. The multilayer films with multiple thickness of Fe-Si layers exhibited the plural exchange biasing and plural FMR absorptions. As a result, the bandwidth of energy absorption became wider in accordance with the number of the FMR absorption peaks. Therefore, it is considered that the Mn-Ir/Fe-Si exchange-coupled multilayer film with different thicknesses of each Fe-Si layer will be useful for as a wideband electromagnetic absorption material.

Acknowledgement

This work is supported by the Grant-in-Aid for Scientific Research (C)(2) (No.16560271) of the Japanese Ministry of Education, Culture, Sports, Science and Technology.

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