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Effect of radio-frequency noise suppression on the coplanar transmission line using soft magnetic thin films

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We demonstrated the radio-frequency (rf) noise suppressor using soft magnetic films on a coplanar transmission line from 0.1 to 20 GHz. The coplanar transmission line is composed of magnetic film/polyimide/Cu transmission line/seed layer (Cu/Ti)/glass substrate with the dimension of 50 μm width of the signal line and 3 μm thickness (characteristic impedance: 50 Ω). The magnetic films (CoPdAlO, CoZrO, and CoNbZr) as a noise suppressor are prepared by rf sputtering. The saturation magnetization of each magnetic film is about 10 kG. The magnetic anisotropy field and the ferromagnetic resonance frequency are 230, 89, and 6 Oe and 4.2, 2.5, and 0.7 GHz, respectively. The power loss of the coplanar line with magnetic films is significantly larger than without magnetic and nonmagnetic films due to ferromagnetic resonance losses. © *2003 American Institute of Physics.* [DOI: 10.1063/1.1558084]

I. INTRODUCTION

According to the progress of radio-frequency (rf) semiconductor electronics and integration of electronic components, the interests for the electromagnetic interference (EMI) in the electronic devices and transmission lines have increased. In those rf devices, magnetic materials have important role as phase shifters, switches, variable attenuators, etc.,[1–3] whereas the application of magnetic materials in device structures has been limited except for a few types.[4]

Recently, a countermeasure for the electromagnetic noise emission on a rf integrated transmission line using the loss generation of ferromagnetic thin films is briefly suggested.[5,6]

We systematically studied the rf electromagnetic noise attenuation using various types of soft magnetic films on the transmission line. Actually, we demonstrated the noise suppressor using CoPdAlO, CoZrO, and CoNbZr magnetic films, whose performances are compared with that of nonmagnetic metal (Cu) and the coplanar line itself.

II. EXPERIMENTAL PROCEDURE

The coplanar transmission line with characteristic impedance of 50 Ω is designed with 50 μm width of signal line and 3 μm thickness on 7059 corning glass (permittivity, $\varepsilon_r = 5.84$) substrate, which is calculated using Muller and Hilberg equations.[7] As shown in Fig. 1, this structure is composed of magnetic film/polyimide/Cu transmission line/seed layer (Cu/Ti)/glass substrate, which is fabricated by the microfabrication process. The Cu/Ti seed layers are deposited by rf sputtering to the thicknesses of 1000 and 100 Å, respectively. The Cu transmission lines are deposited by electroplating. The amorphous $Co_{85}Nb_{12}Zr_3$, $Co_{67}Zr_8O_{25}$, and $Co_{53.4}Pd1_{9.4}Al_{8.1}O_{18.1}$ magnetic films and nonmagnetic Cu film are deposited by rf magnetron sputtering on the glass substrates, respectively, separating from transmission line. In order to align the direction of spins and increase the magnetic anisotropy field (H_k), magnetic films are annealed at about 300 °C during 1 h with an external magnetic field (~3 kG) after patterning with the size of 2 mm×15 mm using ion milling.

The magnetic properties of the CoNbZr, CoZrO, and CoPdAlO films with uniaxial magnetic anisotropy are shown in Table I. The saturation magnetization ($4\pi M_s$) of theses films are about 10 kG and the in-plane magnetic anisotropy fields (H_k) are 6.8, 89, and 230 Oe, respectively. The ferromagnetic resonance (FMR) frequency is given by $\gamma/2\pi [H_k(H_k+4\pi M_s)]^{1/2}$, where γ is the gyromagnetic ratio. These films exhibit about 0.7, 2.6, and 4.3 GHz, respectively. Figure 2 shows the relative permeability of these films with

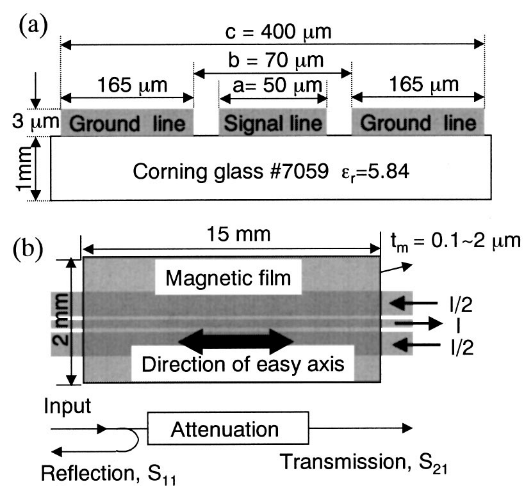

FIG. 1. Cross section (a) and top view with magnetic films (b) of the coplanar transmission line.

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TABLE I. Comparison of the magnetic properties for CoNbZr, CoZrO, and CoPdAlO magnetic films.

		CoNbZr	CoZrO	CoPdAlO
Thickness (μm)		~1	~1	~2
Resistivity ($\mu\Omega$cm)		120	470	220
4πMs (kG)		~8.5	~10	~10
Hc (Oe)	Easy	0.8	4.8	11.6
	Hard	0.8	1.5	4.0
H_k (Oe)		6.8	89	230
μ (1 GHz)	μ'	85	125	47
	μ''	350	31	4.8
FMR Freq. (GHz)		0.7	2.6	4.3

the increment of frequency from 0.1 to 3 GHz.

These magnetic films are placed on top of the coplanar line to suppress the noise signal. The electric performance is measured with two ground–signal–ground pin (GSG) type wafer probes mechanically touched at the left- and right-most ends of the transmission line using HP 8720D network analyzer from 0.1 to 20 GHz.

III. RESULTS AND DISCUSSION

In signal attenuation, the dielectric loss is smaller than the eddy current loss and the FMR in the coplanar transmission line. So, we focused on the FMR and eddy current loss. To observe the signal attenuation due to the FMR, the easy axis of the magnetic films should be in parallel to the wave

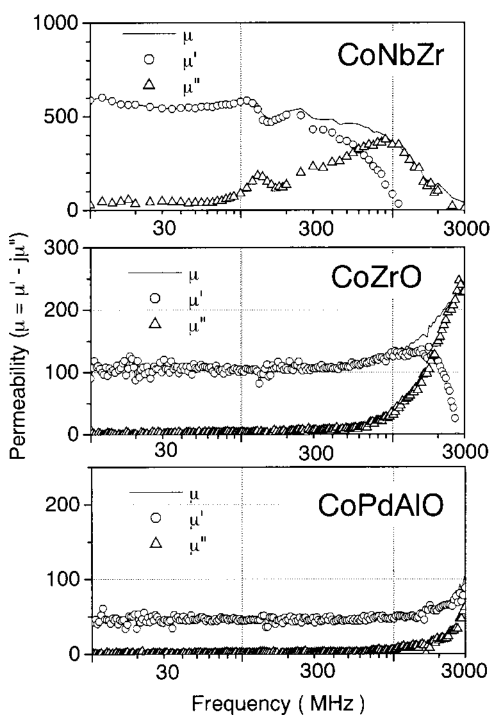

FIG. 2. Frequency dependence with permeabilities for the CoNbZr, CoZrO, and CoPdAlO magnetic films.

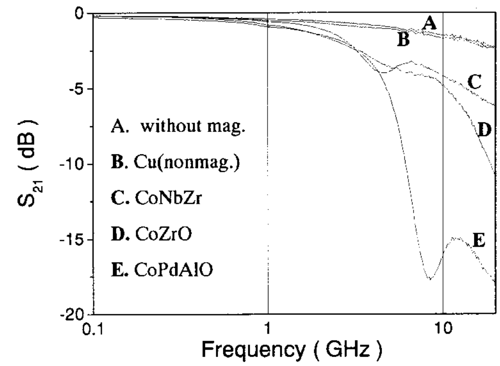

FIG. 3. Values of the transmission loss of the coplanar line with magnetic films in comparison with nonmagnetic metal and coplanar line itself (insulating layer is fixed with 7.5 μm).

propagation ($\mathbf{h}_{rf}$) of the coplanar line. Figure 3 shows the values of the transmission *s* parameter (S_{21}) on the coplanar line without the magnetic film in comparison with that of using the magnetic films and nonmagnetic metal. The transmission signal on the coplanar line with nonmagnetic metal (Cu) is a little attenuated and has nearly the same tendency as the coplanar line without the magnetic layer. In the case of the coplanar line with magnetic films, the attenuation is significant increased in comparison with the coplanar line using a nonmagnetic metallic film and without magnetic films. The tendency of the attenuation is changed at a specific frequency region, which is related to the loss generation of the FMR. The dip points in signal attenuation are determined by the FMR frequency, which is governed by the natural FMR frequency and the demagnetizing effects with the change of effective dimension of magnetic films.

Figure 4 is simulated by the commercial simulation package (HFSS Version 8.5) using the finite element method (FEM). It shows the behavior of the rf fields from the coplanar line with the signal linewidth of 50 μm, which has access to only small area of magnetic film (about 100 μm) among the total width of the magnetic film (2 mm). It means that the FMR frequency is increased due to the increasing of demagnetization as the narrow area of the magnetic field distribution. Figure 5 shows the values of transmission parameter (S_{21}) of the coplanar transmission line using the CoPdAlO

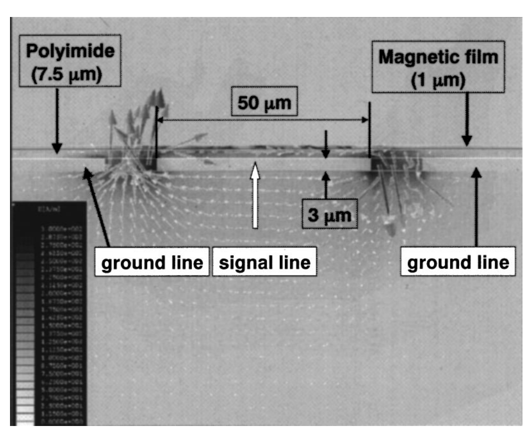

FIG. 4. Distribution and direction of the magnetic field ($\mathbf{h}_{rf}$) in cross-section view of the coplanar line with the magnetic films.

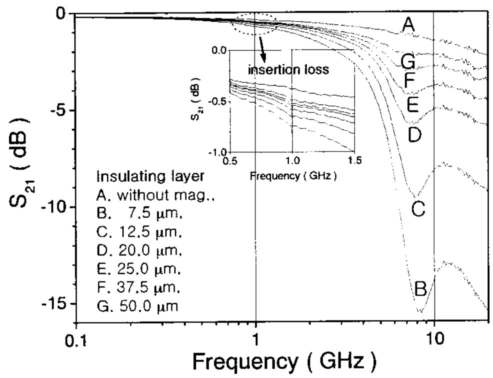

FIG. 5. Values of the transmission loss of the coplanar line with CoPdAlO magnetic films with the variation of insulating layer thickness.

magnetic film with the variations of the insulating layer (polyimide) thickness between the magnetic film and coplanar line. The attenuation is decreased with the increment of the thickness of insulating layer because magnetic field lowers with the distance from the transmission line surface.

Figure 6 shows the S_{21} and the generalized power loss with the increment of the CoNbZr magnetic film thickness, which is calculated using the reflection (S_{11}) and transmission (S_{21}) parameters as follows: ($P_{\mathrm{loss}}/P_{\mathrm{input}}=1-(|S_{21}|^2+|S_{11}|^2)$. The S_{21} is attenuated entirely due to eddy current loss as increasing thickness of the magnetic films. In Fig. 6(b), it is noted that the dip point due to the FMR is observed and shifted to high frequency as increasing thickness of the magnetic films. When the rf field ($\mathbf{h}_{\mathrm{rf}}$) accesses the magnetic film, the accessed effective area of the magnetic film narrows practically near the width of transmission signal line, as shown in Fig. 4. Therefore, the FMR frequency is increased as increasing the demagnetizing factor for thick of magnetic films.

IV. CONCLUSIONS

The noise suppression on the coplanar transmission line has been demonstrated using soft magnetic films. As a result, the insertion loss due to the resistivity of the magnetic films is extremely low (maximum ~0.5 dB at 1 GHz) in comparison with the main attenuation signal (maximum ~14 dB at 10 GHz) by the FMR loss. Therefore, the noise suppression can be tuned to the signal frequency and the magnitude of attenuation by controlling the dimension of the magnetic film with the relation to the demagnetizing factors as well as the eddy current loss and FMR loss generation.

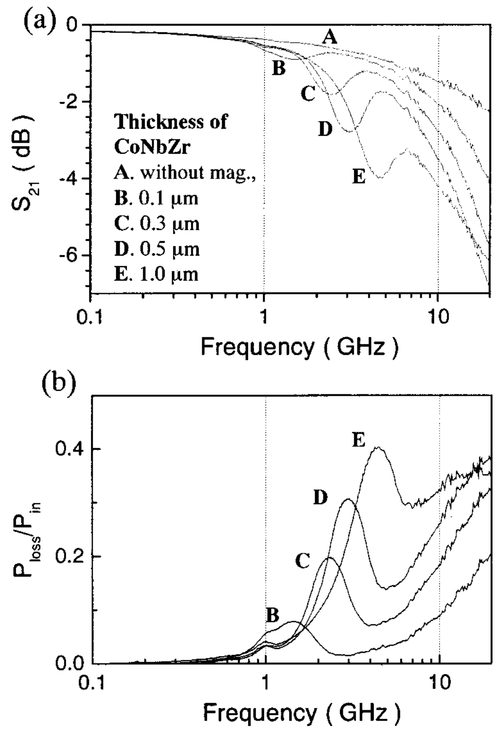

FIG. 6. Values of the transmission parameter S_{21}, (a) and power loss (b) of the coplanar line with CoNbZr magnetic film thickness (insulating layer is fixed with 7.5 μm).

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