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journal or publication title	Journal of Applied Physics
volume	93
page range	8588-8590
year	2003
URL	http://hdl.handle.net/10097/51994

doi: 10.1063/1.1557766

FEM analysis on the effects of soft magnetic film as a noise suppressor at GHz range

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(Presented on 15 November 2002)

To investigate the rf electromagnetic noise attenuation properties by soft magnetic films, the finite element method is applied to analyze electromagnetic field and loss generation in a coplanar transmission line with soft magnetic thin film at GHz range. The coplanar transmission line is with the total width of 400 μm and 50 μm width of signal line, 3 μm thickness, respectively, and has 50 Ω characteristic impedance. The change of the magnetic field distribution, the induced surface current density on the coplanar transmission line and hence the rf noise suppression by magnetic films are significant as a function of the magnetic film width/slit width (10/3, 20/3, and 50/3 μm) and magnetic film thickness (0.1, 0.3, 0.5, and 1 μm). © *2003 American Institute of Physics.*
[DOI: 10.1063/1.1557766]

I. INTRODUCTION

In GHz frequency devices, magnetic materials have important role of the improvements of signal and noise control devices such as phase shifter, switches and variable attenuators, whereas the applications of the magnetic materials and the types of their device structure in high frequency devices are limited.[1]

A new application of magnetic properties at radio frequency (rf) fields is suggested by us as a countermeasure material for the electromagnetic noise emission on rf integrated transmission line.[2,3] Utilization of ferromagnetic resonance (FMR) losses is essential to get the effective noise attenuation.

The degree of noise attenuation, however, was only less than 1 dB in our previous demonstration.[2] Therefore, we simulated this device using a finite element method commercial simulation package (HFSS ver.8.5). This method is proved to be powerful in the modeling of radiation problems in free space. Experimental verification is separately discussed.[4]

II. DESIGN OF THE COPLANAR TRANSMISSION LINE

A model of the coplanar line was designed to examine the rf noise suppression which is composed of magnetic film/polyimide/Cu transmission line/glass substrate. The magnetic film is employed the conventional CoNbZr film. In order to intensify the ferromagnetic resonance effect, the easy axis of magnetic film is placed to the perpendicular with the microwave magnetic field h_{rf} as shown in Fig. 1.

The characteristic impedance, Z_0, and effective permittivity of the coplanar line, ε_{eff}, are given as follows:[5]

$$Z_0=\frac{\eta_0}{4.0\sqrt{\varepsilon_{eff}}}\frac{1}{[K(k_1')/K(k_1)]+(t/b-a)}(\Omega), \quad (1)$$

$$\varepsilon_{eff}=1+\frac{\varepsilon_r-1}{2}\frac{K(k_2')/K(k_2)}{[K(k_1')/K(k_1)]+(t/b-a)}, \quad (2)$$

where a, b and t are the cross sectional dimensions of the coplanar line, as shown in Fig. 1(a). The k_1, k_1', k_2 and k_2' are the functions of cross sectional dimensions of a, b, c and h. The $Z_0=50\Omega$ line was designed with $a=50\ \mu$m, $b=74.3\ \mu$m, $c=400\ \mu$m and $h=3\ \mu$m on the glass substrate.

III. CONSIDERATIONS OF THE MAGNETIC THIN FILMS

The primary concern with the magnetic thin film is to have a large loss generation in a high frequency range, especially in the GHz frequency range where most of the bulk and the composite ferrite materials have only a small loss generation. FMR losses of uniaxial anisotropy films are useful for this purpose rather than eddy current losses in this frequency range. Controllability of the frequency range of the FMR loss generation is significantly required to match the system design of pass-band and stop-band. To estimate

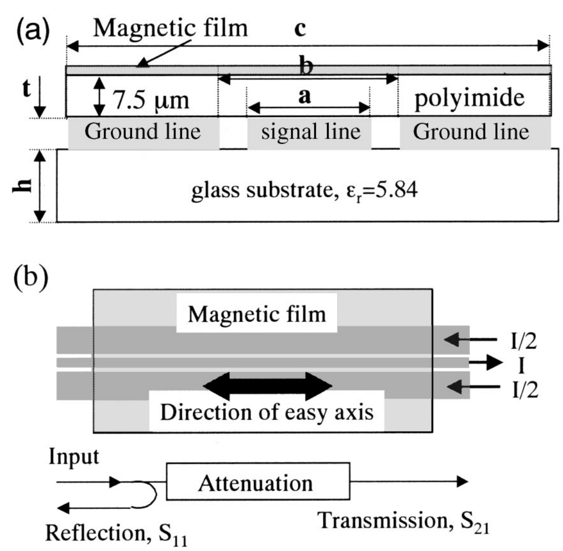

FIG. 1. The schematic of the cross sectional view (a) and top view with magnetic films (b) of coplanar transmission line.

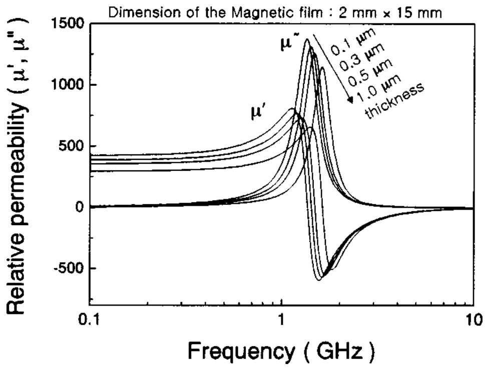

FIG. 2. Theoretical values of the frequency dependent relative permeability with the increment of magnetic film thickness from 0.1 μm to 1 μm.

the noise suppression, an amorphous CoNbZr soft magnetic film is employed whose saturation magnetization (M_s) is 1 *T*, uniaxial magnetic anisotropy (H_k) of 800 A/m (10 Oe), resistivity and damping constant(α) are 120 $\mu\Omega$ cm and 0.015, respectively.

In order to observe the effect of FMR loss, the hard axis of the magnetic films should be in transverse to the wave propagation ($\mathbf{h}_{\rm rf}$) from the coplanar transmission line. The FMR frequency (ω_0) and the effective permeability ($\mu_{\rm eff}$) that are governed by the demagnetizing field due to the change of patterned magnetic films shape as follows:

$$\omega_0/\gamma=\sqrt{[(M_sH_k+N_dM_s^2)/\mu_0]}, \tag{3}$$

$$\mu_{\rm eff}=M_s/(H_k+N_dM_s). \tag{4}$$

N_d, H_k is the demagnetizing factor and magnetic anisotropy field. M_s is saturation magnetization, ω_0 is ferromagnetic resonance frequency, γ is gyromagnetic ratio. When the magnetic film size is supposed infinite, relative permeability ($\mu_r=\mu_r'-j\mu_r''$) can be obtained by the Landau–Lifshitz–Gilbert (LLG) equation, which is written as[6]

$$\mu_r'=\frac{M_s}{H_k\mu_0}\cdot\frac{\omega_0^2(\omega_0^2-\omega^2)}{(\omega_0^2-\omega^2)^2+(4\pi\lambda\omega)^2}+1, \tag{5}$$

$$\mu_r''=\frac{M_s}{H_k\mu_0}\cdot\frac{\omega_0^2(4\pi\lambda\omega)}{(\omega_0^2-\omega^2)^2+(4\pi\lambda\omega)^2}, \tag{6}$$

where $\lambda(=\alpha\gamma M_s/4\pi\mu_0)$ is the relaxation frequency. When a dimension of the magnetic film is fixed with 2 mm ×15 mm, Fig. 2 shows the calculated frequency profile of the relative permeability. The FMR frequency is shifted from 1.3 GHz to 1.6 GHz with the increment of thickness, which results from the change of demagnetizing factors.

In order to improve the characteristic of high frequency, we use the patterned magnetic film with different slit width (w_s) and magnetic film width (w_m). With the decrease of the width of magnetic film, the FMR frequency is shifted to higher frequency than that of without magnetic slit pattern as shown in Fig. 3.

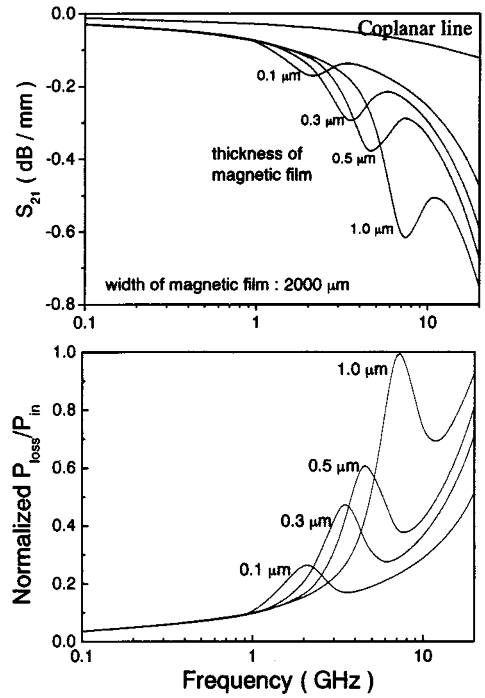

FIG. 4. The values of transmission parameter S_{21}, and the power loss of the coplanar line with magnetic films.

IV. SIMULATION FOR THE NOISE SUPPRESSION

Figure 4 shows the transmission parameter (S_{21}) and the normalized power loss ($P_{\rm loss}/P_{\rm in}=1-(|S_{21}|^2+|S_{11}|^2)$, after extracting the ohmic loss of the coplanar line conductor, the magnetic film is without slits. The S_{21} is attenuated entirely due to eddy current loss as increasing thickness of the mag-

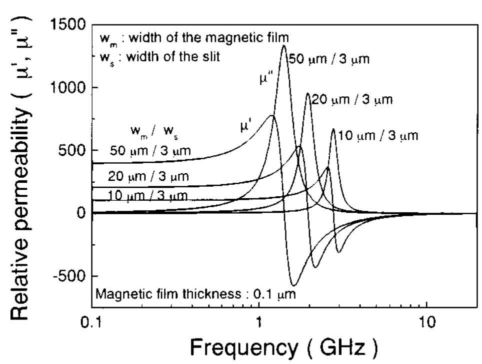

FIG. 3. Theoretical values of the frequency dependent relative permeability with the change of the patterned magnetic film slit size.

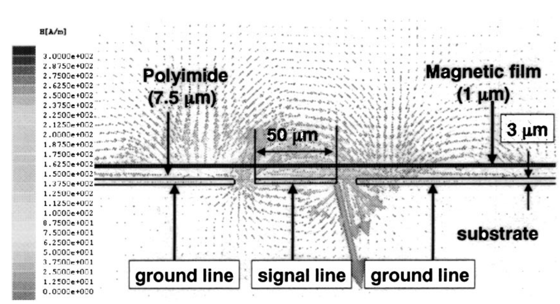

FIG. 5. The distribution and direction of the magnetic filed ($\mathbf{h}_{\rm rf}$) in cross section view of the coplanar line with the magnetic films.

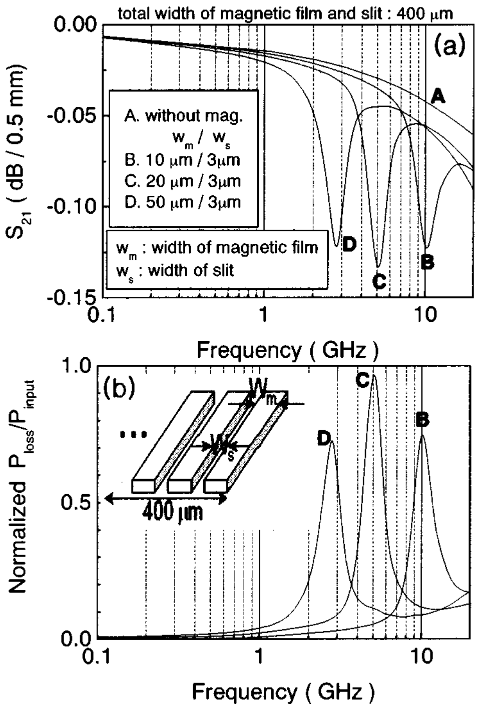

FIG. 6. The values of transmission parameter S_{21}, and the power loss of the coplanar line with the slit pattern of the magnetic films.

netic films. It is noted that the dip point due to the FMR is observed and shifted to higher frequency as increasing thickness of the magnetic films.

This shift of FMR frequency is because of demagnetization associated with the structure of magnetic flux path. In Fig. 5, the direction of inplane flux flow in the magnetic film and above the signal line is oppositely to that above the ground plane. Therefore magnetic film on the signal line feels demagnetization as if the film has a limited width that nominally equals the width of signal line. Therefore, FMR frequency is increased as increasing the demagnetizing factor with the increment of magnetic film thickness.

Figure 6 shows the transmission parameter (S_{21}) and the normalized power loss with the change of the magnetic film slit pattern (10/3, 20/3, and 50/3 μm: magnetic film width /slit width). In the case of magnetic film slit pattern, the magnitude of eddy current loss are less than that of without slit pattern and the signal attenuation due to the FMR loss is more significant.

V. CONCLUSIONS

The effect of rf noise suppression by magnetic films shows dominant results with the variation of magnetic film slit size and the thickness of magnetic film. The rf noise suppression using soft magnetic films is significant related to the eddy current and ferromagnetic resonance losses as well as layout of the model. As a result, the slit patterned magnetic film is well applicable to the rf noise suppression in comparison with the unite magnetic film.

ACKNOWLEDGMENTS

This work was supported in part by Telecommucations Advancement Organization of Japan (development of high performance electromagnetic wave absorber by nanostructure-controlled thin film material) and Ministry of Education, Culture, Sports, Science and Technology (development of micromagnetic technology using room-temperature fabricated highly insulative ferrite films).

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