Journal of Magnetism and Magnetic Materials 349 (2014) 259–263

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

Ultrathin broadband microwave absorbers using ferromagnetic films

Ping Chen*, Ren-kai Li, Yan Gu, Yue Shi, Rui-xin Wu

School of Electronic Science and Engineering, Nanjing University, Nanjing 210093, People's Republic of China

ARTICLE INFO

Article history:
Received 24 January 2013
Received in revised form
19 August 2013
Available online 12 September 2013

Keywords:
Electromagnetic wave absorption
Magnetic film
Magnetic multilayer

ABSTRACT

We have theoretically studied the absorption performances of microwave absorbers made of ferromagnetic films. For films with different frequency dispersive types of permeability, we have found that only the films with relaxation type of permeability can be used to realize broadband microwave absorbers with thin thickness. The condition for optimal absorption has also been derived. As the demonstrations, we have designed the magnetic film absorbers using Ni–Zn–Co ferrite film and iron nanofilm, respectively. Deploying periodic multilayer structure, the absorbers work at the optimal absorption condition. The numerical results show our absorbers have good absorption performances in broadband microwave frequency range.

1. Introduction

In the past decades, the problem of electromagnetic (EM) interferences in electronic equipment is getting serious due to the increasing complexity of equipment [1]. To suppress the EM interferences, EM wave absorbers are often used [1–3]. Since the available space inside equipment is usually restricted, the absorber should be as thin as possible [3]. On the other hand, the frequency bands of electromagnetic signals are becoming much wider in many types of modern electronic equipment. For instance, the working frequencies of wireless communication devices and clock frequency of CPU in current computers are from hundreds of MHz to several GHz. The broadband absorbers will be preferable to suppress the EM interferences between such signals with different frequencies. Apparently, the broadband absorber together with thin thickness is in demand. In order to improve the performances of absorber, numerous new designs have been proposed, including the metamaterial absorbers, the resistive frequency selective surface (RFSS) absorbers, the ferromagnetic absorbers and so on [4–11]. The metamaterial absorber made of planar metallic resonators can achieve perfect absorption near the resonance frequency of resonators. The thickness of metamaterial absorber is much thinner than that of traditional absorber. However, the metamaterial absorber is difficult to obtain a broad absorption bandwidth due to its resonance absorption mechanism [4]. The RFSS absorber is similar to the Salisbury screen absorber except that the resistive sheet in Salisbury screen is replaced by the resistive patches with designed shapes [5]. By optimizing the shape of resistive patch, broadband RFSS absorbers can be obtained [5–7]. The main disadvantage of RFSS is that its thickness is not thin enough, typically in millimeter dimension [5–7]. The ferromagnetic materials or their composite structures also can be used to absorb microwave radiation [8–11]. In fact, the ferromagnetic films have large magnetic permeability and characteristic frequencies due to their huge shape anisotropy [12]. This feature suggests that the ferromagnetic films can be used to realize broadband absorbers together with thin thickness [13].

In this work, the EM responses of multilayer structures made of alternant ferromagnetic and dielectric films were studied in the framework of equivalent transmission network theory. It was demonstrated that the structure made of ferromagnetic films with relaxation type of permeability could be a broadband microwave absorber with thin thickness. In order to achieve the optimal absorption, a periodic multilayer structure was proposed. Based on the theoretical model, two microwave absorbers were designed using the ferromagnetic films reported in literatures. The reflectivity was lower than -10 dB (0.5 ~ 18 GHz) for the Ni–Zn–Co ferrite film absorber and -4 dB (2 ~ 18 GHz) for the iron film absorber, respectively. Meanwhile, the thicknesses of absorbers were only in sub-millimeter dimension.

2. Model and theory

The basic magnetic absorber is a sandwich structure as shown in Fig. 1(a). It is composed of a ferromagnetic layer, a spacer layer and a cover layer, respectively. The cover layer is usually a dielectric layer to protect the ferromagnetic film from oxidation. For the convenience of discussion, the spacer layer and cover layer are supposed to be the same. Generally, the absorber is placed against a metallic ground. If the structure is normally illuminated by the EM wave, its EM responses can be modeled by the equivalent transmission network shown in Fig. 1(b) [14], where V_1, I_1 are the equivalent

---

* Corresponding author. Tel./fax: +86 2583592595.
E-mail address: chenping@nju.edu.cn (P. Chen).

0304-8853/$ - see front matter
http://dx.doi.org/10.1016/j.jmmm.2013.09.010

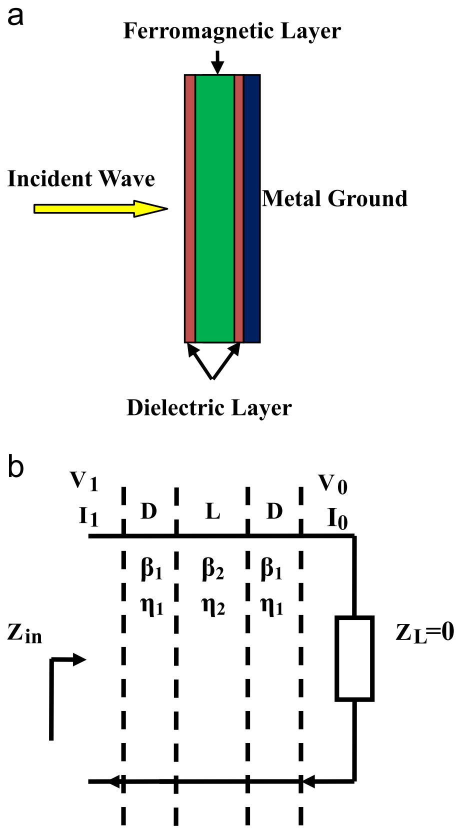

Fig. 1. (a) Sketch of magnetic film absorber and (b) its equivalent transmission network model.

voltage and current at the interface between free-space and absorber, V_0, I_0 are the equivalent voltage and current at the interface between absorber and metallic ground, β_1 and β_2 are the propagation constant, and η_1, η_2 are the wave impedance in dielectric and ferromagnetic layers, respectively. According to the transmission network theory [15], the relationship between V_1, I_1, V_0, I_0 can be described by transmission matrix A:

$$\begin{pmatrix} V_1 \\ I_1 \end{pmatrix} = A \begin{pmatrix} V_0 \\ I_0 \end{pmatrix} \tag{1}$$

Here, matrix A is the product of transmission matrix of the ferromagnetic layer and two dielectric layers: $A = A_1 A_2 A_1$ where

$$A_1 = \begin{pmatrix} \cos(\beta_1 D) & -j\eta_1 \sin(\beta_1 D) \\ -j\frac{\sin(\beta_1 D)}{\eta_1} & \cos(\beta_1 D) \end{pmatrix} \tag{2}$$

$$A_2 = \begin{pmatrix} \cos(\beta_2 L) & -j\eta_2 \sin(\beta_2 L) \\ -j\frac{\sin(\beta_2 L)}{\eta_2} & \cos(\beta_2 L) \end{pmatrix} \tag{3}$$

D, L are the thickness of dielectric layer and ferromagnetic layer, respectively. The input impedance Z_{in} of whole structure can be obtained from Eq. (1):

$$Z_{in} = -\frac{V_1}{I_1} = -\frac{a_{11}V_0 + a_{12}I_0}{a_{21}V_0 + a_{22}I_0} = -\frac{a_{11}V_0/I_0 + a_{12}}{a_{21}V_0/I_0 + a_{22}} \tag{4}$$

where a_{ij} (i, $j=1$, 2) is the element of transmission matrix A. Since magnetic absorber is placed on a metallic background, its load impedance $Z_L = V_0/I_0$ is zero. If the absorber is made of thin films, so that $\beta_1 D \ll 1$ and $\beta_2 L \ll 1$, then Z_{in} can be simplified as:

$$Z_{in} = -\frac{a_{12}}{a_{22}} \approx j\omega\mu_0(2D + \mu_r L) \tag{5}$$

where ω is the frequency of EM wave, μ_0 is the magnetic permeability of free-space, μ_r is the relative magnetic permeability of ferromagnetic film. The absorption performance of absorber loaded with a metallic background usually can be described by its reflectivity R at the interface between absorber and free-space, which is defined as [14]:

$$R = \left| \frac{Z_{in} - \eta_0}{Z_{in} + \eta_0} \right| \tag{6}$$

where $\eta_0 = 120\pi$ is the wave impedance of free-space.

It is well known that the magnetic permeability of ferromagnetic material is frequency dependent. The dispersion type of permeability will result in quite different absorption performances. The basic dispersion types of magnetic permeability are the resonant type and the relaxation type [16]. For the resonant type, the frequency dependence of permeability is [16]:

$$\mu_r = 1 + \frac{\chi_s}{1 + i\beta\varpi_r - \varpi_r^2} \tag{7}$$

where $\varpi_r = \omega/\omega_r$ is the normalized frequency versus the resonant frequency ω_r, χ_s, β are the static susceptibility and damping coefficient of ferromagnetic material, respectively. Substituting Eq. (7) for the μ_r in Eq. (5), we have the Z_{in} of resonant type of magnetic absorber

$$Z_{in} = R_c^r \frac{(\beta\varpi_r)^2}{(1-\varpi_r^2)^2 + (\beta\varpi_r)^2} + jR_c^r \left[\frac{(2D_n+1)\beta\varpi_r}{\chi_s} + \frac{\beta\varpi_r(1-\varpi_r^2)}{(1-\varpi_r^2)^2 + (\beta\varpi_r)^2} \right] \tag{8}$$

where $R_c^r = \chi_s\mu_0 L\omega_r/\beta$ is the characteristic resistance for resonant type of ferromagnetic film, $D_n = D/L$ is the thickness ratio of dielectric layer to magnetic film. Using Eqs. (6) and (8), the reflectivity of magnetic absorber can be calculated. Fig. 2 plots the numerical results of the absorbers with different characteristic resistances, R_c^r. In the calculation, we take values $\chi_s = 100$, $\beta = 0.1$ and $D_n = 0.1$. As shown, the reflectivity of absorber with $R_c^r = \eta_0$ is lower than -50 dB at $\varpi_r = \omega/\omega_r = 1$, which is an excellent absorption performance. However, the results also show that the absorption band is very narrow, indicating that the ferromagnetic films with resonant type of permeability are unsuitable to construct broadband absorbers.

On the contrary, the ferromagnetic films with relaxation type of permeability can realize broadband absorbers. The permeability of relaxation type of magnetic material is [16]:

$$\mu_\tau = 1 + \frac{\chi_s}{1 + i\varpi_\tau} \tag{9}$$

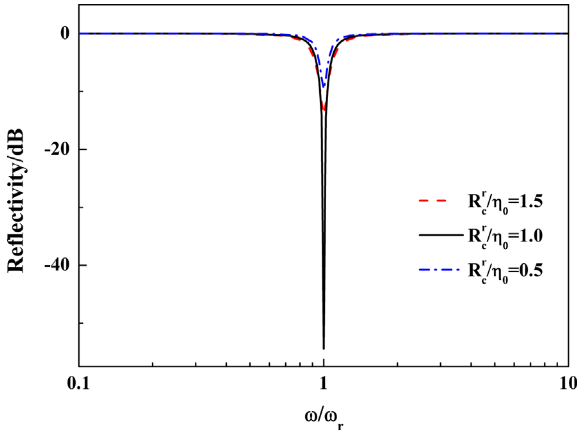

Fig. 2. Reflectivity spectrums of resonant type of magnetic film absorber with different characteristic resistance R_c^r.