GHz conducted noise suppressors using NiZn ferrite films plated at 90 °C directly onto printed circuit boards

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Abstract: A NiZn ferrite film (3µm thick) was deposited at 90 °C by the spin-spray ferrite plating from an aqueous solution onto 50 Ω microstrip line formed on an epoxy printed circuit board (PCB). The NiZn ferrite film exhibited a natural resonance frequency of f0=850 MHz and initial real permeability of µr=40 at low frequencies. The ferrite film exhibited strong noise suppression effects in the GHz range, the transmission loss ∆P_{trans} reaching 70 % attenuation at 5 GHz. This was twice as strong as a commercialized sheet-type noise suppressor (50 µm thick) in which ferromagnetic metal flakes are embedded in a polymer matrix. Furthermore, the reflection parameter was very weak, S11 being less than 10 % below 10 GHz. Thus plated NiZn ferrite films hold strong promise to be actually applied to a novel type of thin film electromagnetic noise suppressors; the films can be directly deposited onto noise sources (semiconductor elements or electronic circuits) to attenuate conducted-electromagnetic noises up to ~10 GHz.

Key words: ferrite plating, Ni-Zn ferrite film, electromagnetic noise, complex permeability.

1. Introduction

To ensure stable operation of the most advanced, downsized personal computers and cellular phones, which are currently driven at frequencies higher than several GHz, EMC (electromagnetic compatibility) has become indispensable at present. Conventional lumped constant type noise suppressors (i.e. those composed of capacitors and coils) cannot attenuate the GHz electromagnetic noise radiation. The GHz noises can be suppressed only by the distributed constant type suppressors composed of highly permeable magnetic bodies placed in close vicinity to the electronic circuits.

A distributed constant type noise suppressor was commercialized with the trade name Flex Suppressor. They are composite sheets (25 µm - 1 mm in thickness) in which ferromagnetic metal flakes are embedded in a polymer matrix [1]. The composite sheet noise suppressors are, however, limited to a few GHz in operation frequency, because the anisotropy field of the metal flake is not very high. Also the composite type noise suppressors cannot be made thinner than 10 µm, because the amount of imaginary permeance becomes insufficient below this thickness.

In order to improve the problem, we are developing another type of noise suppressor [2], using NiZn ferrite films which are synthesized by spin-spray ferrite plating, a wet chemical process. We showed that the spin-sprayed NiZn ferrite films are highly permeable in the GHz range, exceeding so-called Snoek's limit for bulk ferrite samples [3]. Since the films are synthesized directly from an aqueous solution at low temperatures (< 100 °C) without annealing for crystallization, we can deposit the films directly onto the noise sources (circuits and semiconductor elements), covering their surfaces completely. This will attenuate noises more efficiently than composite-sheet noise suppressors which are glued to the vicinity of the noise sources.

In this paper we report that the spin-sprayed NiZn films are very promising for being actually utilized as noise suppressors for several GHz frequencies. We concluded this based on the transmission and reflection losses observed up to 10 GHz for a NiZn ferrite film which was deposited onto microstrip lines formed on an epoxy printed circuit board (PCB).

2. Experiments

The ferrite films of 3 µm thickness were deposited onto a PCB (having a 50 Ω microstrip line 75 mm in length formed on its surface) made of epoxy resin, 160x100x1.6 mm² in dimension. The substrate was mounted on a spinning table, onto which a reaction solution of FeCl₃ + NiCl₂ + ZnCl₂

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and an oxidizing solution of NaNO₂ + CH₃COONH₄ were simultaneously sprayed at 90 °C, as Fig. 1 shows.

The ferrite film was subjected to the following characterization at room temperature: the crystallographic, microstructural, and chemico-compositional properties were analyzed by Cu-Kα X-ray diffractometry (XRD), scanning electron microscopy (SEM), and inductively coupled plasma spectroscopy (ICPS), respectively. We measured static M-H loops using a vibrating sample magnetometer (VSM), and complex permeability up to 3 GHz using a shielded-loop-coil permeance meter [4]. We measured in-plane electric resistivity by a four-probe method. Using a network analyzer as Fig. 2 shows, we evaluated the conducted noise suppression effect by the ferrite films ∆Ploss (pure increase in Ploss, the microstrip line (MSL) loss being subtracted) calculated from the reflection parameter S11 and the transmission parameter S21 by the following equations:

\[ P_{\text{loss}} = 1 - (\Gamma^2 + T^2) \]  
\[ \Delta P_{\text{loss}} = P_{\text{loss}} \text{ (MSL+Ferrite)} - P_{\text{loss}} \text{ (MSL)} \]

where \( \Gamma \) and \( T \) are expressed as \[ S_{11} = 20 \log |\Gamma| \] and \[ S_{21} = 20 \log |T| \]. We also evaluated the conducted noise suppression effect by a commercialized composite sheet-type noise suppressor having a thickness of 50 µm for comparison, by mounting it on the microstrip line.

3. Results and discussion

Fig. 3 shows that the ferrite film is of single phase with a spinel structure. No preferential orientation appeared in the film when deposited on the PCB substrate, while (111) texture was observed for the film plated onto glass substrates [3]. The film had a composition Ni₀.3Zn₀.7Fe₂.6O₄.

As Fig. 4 shows, the ferrite film had a twisted columnar structure and an undulated surface with average roughness of ~1 µm, inheriting the roughness in the surface of the PCB. The film had the thickness of ~3 µm.

![Fig. 3 XRD diagram for ferrite film plated onto printed circuit board. Indices show those for spinel structure.](image)

![Fig. 4 Cross-sectional SEM image for ferrite film plated onto printed circuit board.](image)
The ferrite film had in-plane electric resistivity of \(\sim 2 \times 10^5\ \Omega\cdot\text{cm}\). The value is much smaller than that \((\sim 10^7\ \Omega\cdot\text{cm})\) reported for the NiZn ferrite bulk samples. This is because the spin-sprayed NiZn ferrite film had a considerable amount of Fe\(^{3+}\) ions, expressed as \(\text{Ni}_{0.5}^{2+}\text{Zn}_{0.5}^{2+}\text{Fe}_{0.5}^{3+}\text{Fe}_{0.5}^{3+}\text{O}_4\).

Fig. 5 shows the \(M-H\) loops for the ferrite film. The solid and dotted lines represent the radial (\(r\)-) and circumferential (\(\theta\)-) direction of spinning table, respectively. The film was magnetically isotropic; no discernible change was observed in the \(M-H\) loops when measured along various directions in the film plane.

Fig. 6 shows the frequency dependence of the complex permeability for the ferrite film. In the low frequency range (20-200 MHz) the film had a real permeability of \(\mu'\sim 40\), which decreased to half the value at 850 MHz, which we call the natural resonance frequency \(f_r\). This is about six times higher than those reported for bulk samples with \(\mu'\sim 40\), which are limited by Snoek's limit.

Fig. 7(a) and Fig. 7(b) show the reflection parameter \(S_{11}\) and the transmission parameter \(S_{21}\) for the microstrip line itself, ferrite-plated microstrip line and the commercialized composite sheet of 50 \(\mu\)m thickness, respectively. The reflection by the ferrite film was satisfactorily weak, less than 10 \(\%\) (< -10 dB) in the measured frequency range. This is almost the same as that by the commercialized composite sheet. As shown in Fig. 7(b), the attenuation by the ferrite film was stronger than that by the commercialized composite sheet in the GHz range.

Fig. 7 shows the transmission loss \(\Delta P_{\text{loss}}\) by the NiZn ferrite film and the composite sheet. \(\Delta P_{\text{loss}}\) by the NiZn ferrite film steeply increased in the GHz range, from 35 \(\%\) attenuation at 1 GHz to 70 \(\%\) at 5 GHz. This is much stronger than the composite sheet-type noise suppressor of 50 \(\mu\)m thickness.

Fig. 8 Transmission loss \(\Delta P_{\text{loss}}\) for the ferrite film and composite sheet-type noise suppressor.

Fig. 5 \(M-H\) loops for the ferrite film. Solid and dotted lines represent radial (\(r\)-) and circumferential (\(\theta\)-) direction of spinning table, respectively.

Fig. 6 Frequency dependence of permeability for the ferrite films plated onto printed circuit board.

Fig. 7 Reflection and transmission parameters, (a) \(S_{11}\) and (b) \(S_{21}\) for microstrip line, ferrite film and composite sheet-type noise suppressor.
Fig. 9 shows the frequency dependence of the value $\mu'$ multiplied by frequency $f (\mu' \times f)$. Here, the magnetic loss in the ferrite film is supposed to be proportional to $\mu' \times f$. It seems that the magnetic loss is the predominant factor in $\Delta P_{loss}$ since the $\Delta P_{loss}$ profile shown in Fig. 7 is similar to that of $\mu' \times f$ below 3 GHz, the upper limit of our measurement range. However, we have to measure the permeability in the higher frequency range (~9 GHz) to evaluate the magnetic loss contribution to $\Delta P_{loss}$.

Thus the NiZn ferrite films will be actually utilized to the noise suppressors operating up to ~10 GHz. Because the films are magnetically isotropic in the film plane (as shown by the $M-H$ loop measurements), we will be able to fabricate noise suppressors of isotropic type which attenuate noise electromagnetic waves radiated in any direction.

4. Conclusions

Our experimental results revealed that the spin sprayed NiZn ferrite film exhibited the noise suppression effect strong enough and also the reflection weak enough to be practically applied to noise suppressors operated up to ~10 GHz. The spin spray ferrite plating is a low-temperature, wet process requiring no vacuum, thus being advantageous for mass production. Therefore, the novel GHz noise suppressors made by the ferrite plating will give new impetus to the EMC technology.

References