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High-frequency Magnetic Shielding Technology for Electronic Devices

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1. Introduction

Development of miniaturized and fast-response electronic devices has been accelerated by the System-in-Package (SiP) technology. Advanced three dimensional packaging technology including the stacked multi-chip package and Package-on-Package (PoP) are also growing because of a further demand on the integration of new functions for example to the digital household appliances and cell phone systems.

On the other hand, these new technologies have raised up a need to suppress high-frequency noise in a LSI chip and on a printed circuit board. Ferromagnetic materials are used as a countermeasure to the noise problem. Among them is a classical magnetic shielding technique using thin but bulky magnetic materials.

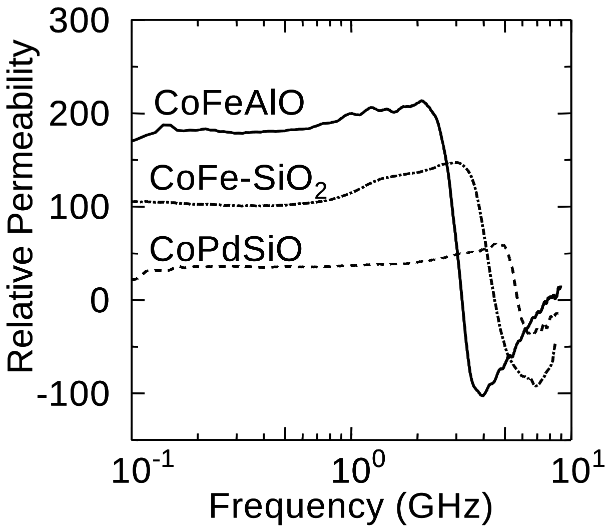
A new idea is to use the ferromagnetic resonance (FMR) losses that appear only in the GHz range for a soft magnetic sheets or thin films. In fact, much active research for development of magnetic films as noise suppressors is going on . This paper summarizes the materials for such applications, basic study over a transmission line, demonstration of magnetic near field suppression on a chip under operation, and a new idea of anti-shielding of RF current (or skin effect suppression) in a RF-current carrying conductor.

2. RF Soft Magnetic Materials

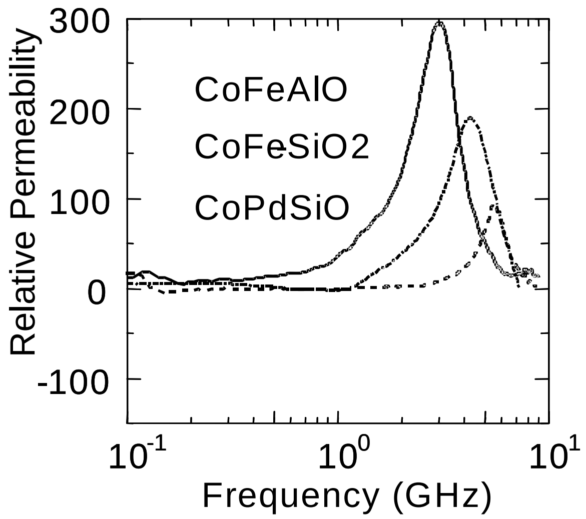
The L.L.G. equation reminds us the basic dynamics of magnetic moment as $\mu_i=M_s/H_k$, $f_{fmr}=(\gamma/2\pi)\ x(M_sH_k/\mu_0)^{1/2}$ and $\mu_i f_{fmr}$=const for uniaxial film, showing that a material with high M_s and high H_k is essential to realize higher f_{fmr}. A broad bandwidth complex permeability measurement was performed up to 9GHz for amorphous and granular thin films to discuss this idea. As shown in Fig. 1, Co-system granular films exhibit the FMR frequency above 1GHz.

3. Transmission Line Approach

Electromagnetic noise suppression in a near field of LSI and printed circuit board is an expected application target, which utilizes the FMR losses generated only at high frequencies. Sheet type has been industrialized already and its measurement standard has just been established in May 2006 by IEC (International Electrotechnical Commission.) Thin film type demonstrated signal attenuation of 54dB on coplanar transmission line at 10GHz, using either of CoNbZr or CoPdAlO film (15mm x 2mm x 2μm).



(a) Real part



(b) Imaginary part

Fig. 1 Frequency characteristics of complex permeability for granular type soft magnetic films [1] – [3].

4. Magnetic Film Integration on a Bare Chip

The test chip is a one-chip microprocessor with size of 10.8 x 10.4 mm2 and chip thickness of 725 um. The clock frequency is 40 MHz and the corresponding frequency spectrum reaches several hundred MHz and beyond. The close-up view of the chop is shown in Fig. 1. There are nominally 300 solder bump electrodes with diameter of 250-300 um. A 1.0 um-thick $Co_{85}Nb_{12}Zr_3$ amorphous soft

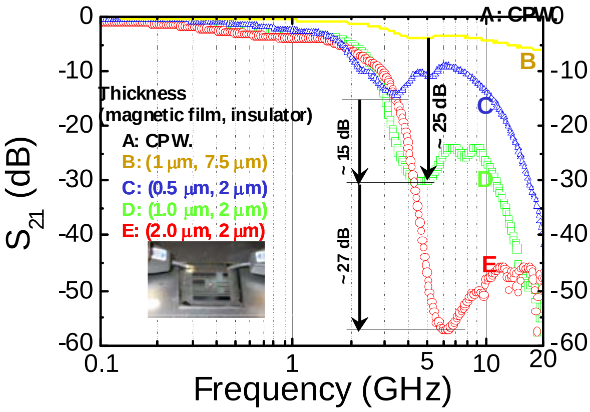


Fig. 2 RF attenuation by using ferromagnetic film.

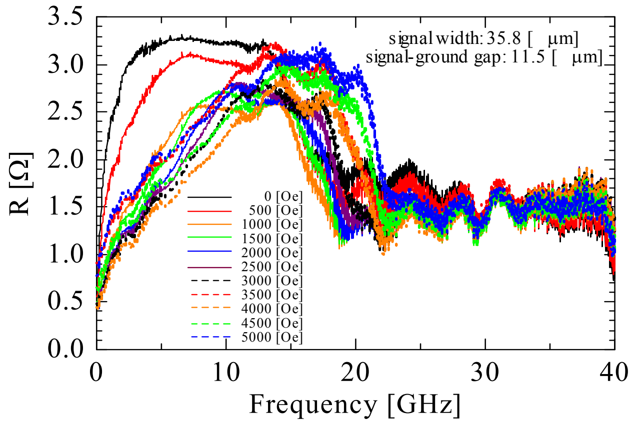


Fig. 3 RF resistance of ferromagnetic/conductive multi-layer.

magnetic film with saturation magnetization of 1.1 T, anisotropy field of 845 A/m, relative permeability of 1000 and ferromagnetic resonance frequency of 1.1 GHz was sputter-deposited on top of the polyimide passivation layer, followed by 0.5 um-thick SiO2 deposition to make sure the insulation. After electrode opening by a lift-off process, the chip was annealed at 340 degree-C for 2 hours in a dc 0.3T field. Then solder bumps were formed by a screen-mask method. We also processed copper film instead of magnetic film as a reference.

An electromagnetic near field measurement system (Type EMV-200, Hitachi display device, Inc.) with the probe size of 2.2 mm2 was used at a measurement distance of 3.85 mm in a frequency range of 10 MHz-1.44 GHz. The level of magnetic filed was successfully attenuated by the magnetic film, which was better than Cu film up to 360 MHz (9^{th} harmonic). Attenuation of 3-7 dB was also seen up to GHz range. Maximum attenuation achievd was 6.7 dB at 774 MHz. These demonstrate the usefulness of magnetic film.

5. Anti-Shielding: Skin Effect Suppression

It is popular that the real part permeability turns into negative beyond the FMR frequency. Material with negative permeability is useful to suppress skin effect in conductors [6]. Suppose an alternately multilayered structure of metal/magnetic thin film with thickness of each layer as t_N and t_F, respectively. Then the volume average of relative permeability, $\mu_{rav}= (1/t_N + \mu_r/t_F)/(t_N+t_F)$ ●●● (1), can be set zero if μ_r is negative.

We have reported that the 0.3 μm-thick Al film and the 0.1 μm-thick NiFe film were sputter-deposited in turn to the total thickness of 6 μm on a glass substrate, and the measured resistance exhibits decrease monotonically from the top level of 3.2 Ω at 13 GHz to the bottom level of 1.9 Ω at 17 GHz [7], as shown in Fig. 3. In detail, the signal line is 1000 μm long and 36 μm wide. The signal-to-ground gap is 11μm. For the NiFe layer, $4\pi Ms$= 10.0 kG, Hk=10 Oe (nominally, before microfabrication) and ρ=16.7 μΩcm. Easy axis direction is along the length direction of the co-planar line. The existence of a frequency range where resistance monotonically decreases is the first experimental verification of the skin effect suppression. This never happens in the case of normal metal. Such a frequency range linearly shifted toward higher frequency range with the applied external field.

Extensive discussion is on the actual thickness of each layer. Detailed electromagnetic field simulation by FEM (Ansort Co., HFSS Ver. 11) clarified the resistance monotonically decreases with thinning the layer, keeping the relation show in eq. (1) until the thickness equals to the half of the skin depth. Right now this is only phenomenological understanding and physical analysis should follow soon. Anyway this idea may open a new high-Q application of the permeability at just below the anti-resonance frequency.

6. Conclusions

Soft magntic films are innovatively useful for future potential for integrated electromagnetic shielding and RF power attenuation..

Acknowledgements

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