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Noise analysis of a 1 MHz–3 GHz magnetic thin film permeance meter

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We analyzed the permeability measurement error of a low permeance thin film. We clarified that the noise voltage was excited by a current loop which is composed of the coaxial cable and the ground plane. The current loop should be removed for high sensitivity of the permeameter. The permeability of a high electrical resistivity film (CoFeHfO) has been demonstrated 1 MHz–3.5 GHz. © *1999 American Institute of Physics.* [S0021-8979(99)78908-5]

I. INTRODUCTION

Recent high electrical resistivity thin films[1] demand both broad bandwidth and low permeability sensitivity for measurements of magnetic thin films. However, the low permeability of the thin film was difficult to measure accurately because of the signal to noise problem.

In our previous article, we have demonstrated a permeance meter using parallel plates and a shielded loop coil combination,[2] and CoNbZr thin film permeance was demonstrated for 1 MHz–3.5 GHz.[3] However, errors in permeability measurements were observed for low permeance thin films when using the permeameter.

In this article the errors have been analyzed and then removed. To provide high sensitivity permeability measurements, this clarification is available for the design of a permeameter formed by any kind of driving plates and pickup coil combination.

II. PERMEANCE MEASUREMENTS JIG

Figure 1 shows a cross sectional view of permeameter; the jig is composed of driving plates, a shielded loop pickup coil, and a 50 Ω coaxial cable which is connected to the pickup coil.[2] The film permeance can be measured over 1 MHz–3.5 GHz range.[3] Such a broad bandwidth measurement has been realized for the first time. The shielded loop coil is sensitive to the magnetic field, insensitive to electric field, and the structure provides balanced–unbalanced electromagnetic field conversion. The planar and multilayer PCB structure benefits fabrication simplicity, mass-production capability for any shape of planar coil, good reproducibility of electromagnetic properties, and easiness of coil array fabrication.

III. MEASUREMENTS ERROR

Figure 2 shows a measured relative permeability of CoFeHfO thin film.[1] Symbols show the real part of permeability, and the solid line shows the theoretical permeability taking into account the LLG equation and eddy current generation.[4] The measured permeability decreased as the frequency increased. This tendency is predominant under 10 MHz, although the calculated permeability is almost constant up to 1 GHz. Therefore the permeability was not measured accurately.

Figure 3 shows the output voltage of the shielded loop coil set in a permeameter. The circular symbols show the voltage which gave the permeability error in Fig. 2. The output voltage is not proportional to frequency under 10 MHz, which corresponds to the measurement error in Fig. 2. If the voltage is induced only by the shielded loop coil, the output voltage should be proportional to frequency. Therefore an error voltage is induced in addition to the voltage of the shielded loop coil, and the error voltage gives the permeability measurements error. In the following paragraphs we will clarify the mechanism by which the error voltage is generated in the permeameter.

IV. MECHANISM OF ERROR VOLTAGE GENERATION

A. Current paths and noise voltage

Figure 4 illustrates the frequency dependence of current paths excited in a shielded loop coil and coaxial cable in driving plates. The electrical connection between the shielded loop coil and driving plates at C and C′ (Ref. 5) provides two current paths; these are a current path in the outer conductor of coaxial cable (i_c) and a current path in the ground plane of driving plates (i_g). The total current in the center conductor is i_c+i_g. At higher frequencies i_c is much larger than i_g. However, i_g is larger than i_c at lower frequencies because the resistance of the driving plates was lower than the resistance of the outer conductor. Since the

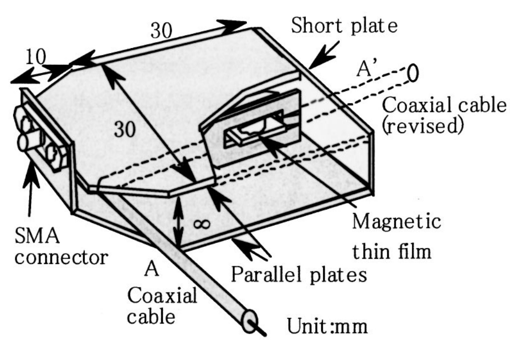

FIG. 1. Schematic view of permeameter.

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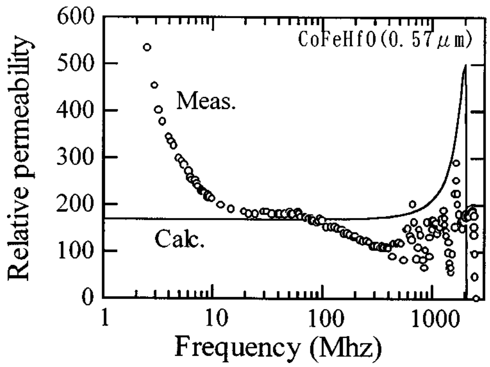

FIG. 2. Measured permeability of CoFeHfO.

radio frequency magnetic field is applied inside the driving plates, the voltage was induced by the sum of flux Φ_1 and Φ_2. The error voltage was induced by the flux Φ_2 which is across the secondary loop. In the article we call this loop secondary loop.

B. Calculation of noise voltage

Figure 5 shows the equivalent circuit model of Fig. 4. The model consists of three conductors, the inner conductor, the outer conductor of the coaxial cable, and the ground plane of driving plates. Each conductor has resistance, inductance, and capacitance. L_i, L_c, and L_g indicate the inductance of inner conductor, outer conductor, and ground plane of driving plates, respectively. R_i, R_c, and R_g indicate the resistances. M_{ic} shows the mutual inductance between the inner conductor and outer conductor, M_{ig} shows the mutual inductance between the inner conductor and ground plane. V_{in} shows the induced voltage, R_{out} shows the terminal resistance of the network analyzer. I_c is a current excited in an outer conductor of the semirigid cable, i_g is a current excited in the ground plane of driving plates. The circuit can be simplified as shown in Fig. 5(b). Capacitance can be removed up to 10 MHz, L_c can be ignored because L_c is almost equal to M_{ic}. R_g can be removed because the resistance of the ground plane was much smaller than the resistance of the outer conductor.

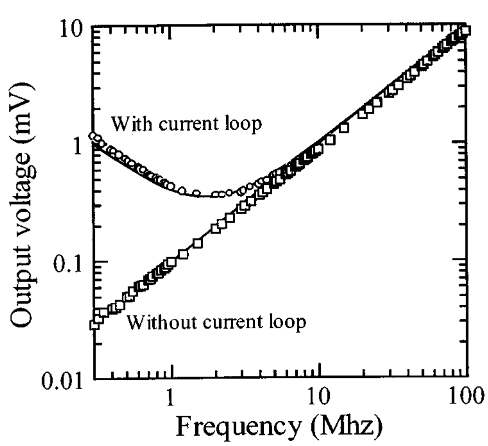

FIG. 3. Output voltage with and without current loop.

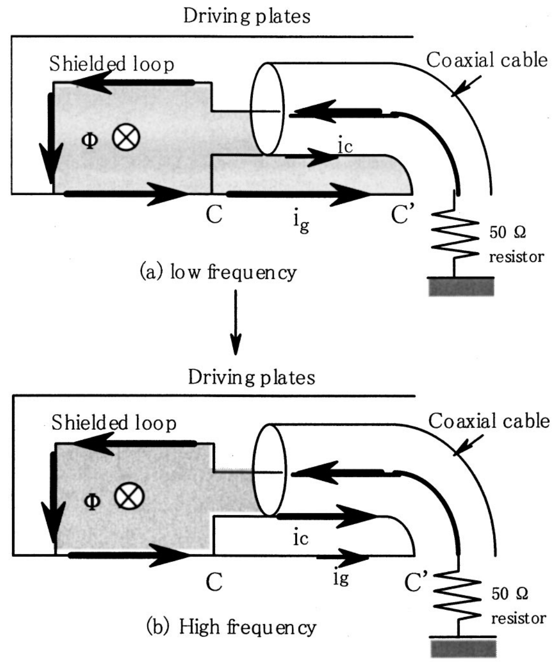

FIG. 4. Frequency dependence of current path and loop.

Figure 3 shows the measured and calculated voltages of the shielded loop coil. The calculated voltage V is given by Eq. (1)

$$V=\mu\omega HS_1+\mu\omega HS_2\frac{R_c}{R_c+j\omega(L_g-M_{ig})}, \quad (1)$$

where H shows magnetic field intensity, S_1 the area of shielded loop coil, S_2 the secondary loop area. R is 0.01 Ω, L is 17.2 nH taking into account the conductor structure.

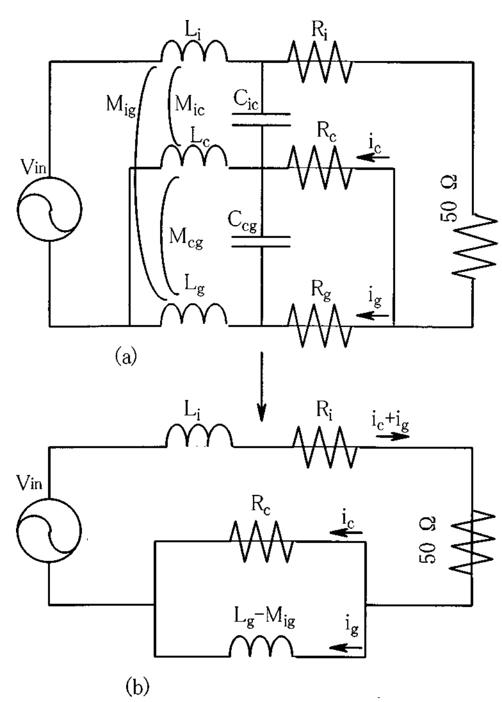

FIG. 5. Equivalent circuit.

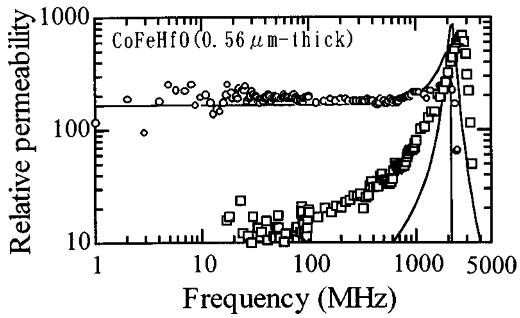

FIG. 6. Relative permeability of CoFeHfO.

In Fig. 3, circular symbols and rectangular symbols show the measured voltage with and without the secondary loop. Noise voltage suppression occurred when the secondary loop was removed. The data of Fig. 3 show that the calculated output voltage was in good agreement with measured voltage. In the investigation, the noise voltage is induced by the flux linkage through the secondary loop, therefore the secondary loop must be removed for high sensitivity permeability measurements. In this article the coaxial cable is set as A′ in Fig. 1 in order to remove the secondary loop.

V. MEASURED PERMEANCE OF CoFeHfO FILM

Figure 6 shows the measured relative permeability of a CoFeHfO film (0.56 μm thick)[1] which has high electrical resistivity. The film can be useful for gigahertz range magnetic components. Solid lines show calculated permeability.[4] The measured permeability and resonant frequency nearly agree with the calculated permeability. Accurate permeability measurement can be realized by the change of the jig setup in not only several megahertz but over 100 MHz. The removal of the secondary loop is effective to reduce magnetic coupling and capacitive coupling between driving plates and shielded loop coil over 100 MHz.

VI. CONCLUSIONS

We clarified the following factors for low permeance film measurements when using any kind of driving plates and pickup coil combination.

(1) Noise voltage causes low frequency permeance measurements error, and the noise voltage is induced by the loop which is composed of coaxial cable and ground plane.
(2) The current loop should be removed for noise voltage suppression.
(3) CoFeHfO film permeability has been demonstrated over the 1 MHz–3.5 GHz range.

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