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The Effect of Grain Boundary Impedance on the Power Loss of Mn-Zn Ferrites over 1 MHz

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Abstract: Recently, the operating frequency of switching mode power supplies has been increased from 25 kHz to several MHz to enhance their efficiency in a smaller size. Although, it was reported that Mn-Zn ferrites can also be used at 1 MHz, only few papers have discussed the possibility of using Mn-Zn ferrites at the frequency higher than 1 MHz. Our early paper reported that the core loss of low loss grade Mn-Zn ferrites is strongly dependent upon the capacitance of grain boundaries of sintered cores. In frequency region between 1 MHz to 3 MHz, the dielectric loss dominates the core loss, while eddy current loss is the major factor of the core loss in 3 MHz to 10 MHz. It is suggested that decreasing the grain boundary capacitance at middle high frequency or increasing the grain resistivity at high frequency region are the appropriate ways for Mn-Zn ferrites to be used at the frequency between 1MHz and 10 MHz. This paper investigated the core loss of Mn-Zn ferrites in the frequency range between 1 MHz and 10 MHz in order to improve the properties of the Mn-Zn ferrite cores for their potential applications in this frequency region.

The powders containing Fe_2O_3 , MnO and ZnO in a molar ratio of 54.2:37.3:8.5 with the addition of CaO and SiO_2 from 150 ppm to 450 ppm were prepared by a conventional ceramic process. Samples were sintered at 1150°C to 1250°C for 2 hrs then annealed at various condition. The results show that the sintering temperature and annealing condition altered the grain boundary impedance. For example, the grain boundary capacitance changes from 13 pF to 7 pF, meanwhile, the dielectric loss factor is lowered from 0.28×10^{-9} to 0.17×10^{-9} , and consequently the power loss decreases from 253 KW/m³ to 145 KW/m³ at 2.5 MHz.

Introduction: Mn-Zn ferrites are widely used as core material in electronic devices, especially for the switching mode power supply (SMPS). Nowadays the working frequency of SMPS is increased to several MHz to meet the requirement of higher efficiency and low profile. Our previous study shows that the power loss at the frequency higher than 1MHz is influenced not only by the hysteresis and eddy current loss but also by the dielectric loss. The dielectric loss is affected by grain boundary capacitance in the range from 1 MHz to 3 MHz. In this study, we reduced the dielectric loss by increasing the grain boundary impedance.

Experimental: Low loss grade Mn-Zn ferrite samples were prepared by a conventional ceramic process. The powders containing Fe_2O_3 , MnO and ZnO in a molar ratio of 54.2:37.3:8.5 were prepared with the addition of 450 ppm of CaO and 150 ppm or 250 ppm of SiO_2 . The powders were pressed into toroids of 20 mm (O.D.) $\times$ 10 mm (I.D.) $\times$ 5 mm (t) and disks of 11 mm (ϕ) $\times$ 2.5 mm (t). The green compacts were sintered at 1150 °C or 1250°C for 2 hrs in air and then annealed at 1100°C for 2 hrs in a controlled atmosphere of 1% oxygen partial pressure. The samples were then cooled from 1100°C to 800°C at different rates (2 hrs, 4 hrs 6 hrs and 8 hrs) respectively, in order to study the effect of cooling rate on the resistivity and power loss of the sintered cores. The impedance and permeability were measured in the frequency range from 5 Hz to 13 MHz with HP 4192A impedance analyzer. Power loss was measured with Ryowa MMS-0375 Iron loss measuring system at constant $B_{\text{meas}} \times f_{\text{meas}} (=25\text{kHz} \cdot \text{Tesla})$ value.

Results and Discussion: Table 1 shows the permeability and core loss of the samples sintered at 1150 °C (sample A, B, C) and 1250°C (Sample D, E, F). This table shows that the higher sintering temperatures resulted in good permeability and core loss. Figure 1 shows the variation of core loss with frequency of the samples sintered in various annealing conditions. It is apparent that the core loss of the samples measured at $f \times B = 25\text{kHz} \cdot \text{Tesla}$ can be divided into three regions. The first part is the loss in the frequency lower than 1.2 MHz, where the core loss is in proportion to $1/f$. The second portion is from 1.2 MHz to around 3 MHz, where the core loss is proportional to f . The third region is from 3 MHz to 5 MHz, in which the loss is independent of the measured frequencies.

Table 1. The effect of sintering temperature and annealing time on permeability and core loss

Annealing time	2 hrs	4 hrs	6 hrs
Sample identification	A	B	C
Initial permeability	1262	1204	1181
core loss(KW/m ³)*	222.4	223.1	222.7
Sample identification	D	E	F
Initial permeability	1844	1851	1822
core loss(KW/m ³)*	184.9	189.6	172.9

*: at 2.5MHz/10mT

Table 2: Physical properties of the samples F and G

Sample identification	F	G
Annealing time	6 hrs	10 hrs
CaO-SiO ₂ (ppm)	450/150	450/250
grain boundary capacitance (Cb:pF)	13	6.6
X _{cb} (ohm/2.5MHz)	4.9	9.6
grain boundary resistance(ohm)	254	401
grain boundary impedance	4.8	9.4
Initial permeability	1822	1912
core loss(KW/m ³)(2.5MHz/10mT)	172.9	145.1

The core loss of power ferrite is reported consisting of three factors, namely, hysteresis loss(P_h)^{1,2}, eddy current loss (P_e)^{1,2} and dielectric loss (P_{de})³. These factors are all heavily dependent upon the frequency and flux density. If the measuring condition is kept at a constant $f \times B$, the three factors of the core loss can be defined as follows:

$$P_h = K_h (f \times B)^2 / f \quad \dots(1)$$

$$P_e = K_e (f \times B)^2 / \rho \quad \dots(2)$$

$$P_{de} = K_{de} (f \times B)^2 \times f \quad \dots(3)$$

where K_h , K_e and K_{de} represent the coefficient of hysteresis loss, eddy current loss and dielectric loss, respectively. B represents the magnetic induction, f represents the frequency and ρ represents the resistivity of the core.

From equation (1) to (3), it clearly shows that P_h is proportional to $1/f$, P_e has no relationship with f , while P_{de} is proportional to f , if $f \times B$ is kept constant. That means the core loss of the studied samples is dominated by dielectric loss in the frequency from 1 MHz to 3MHz. Follows the Kroops' model⁴, the impedance of the sample will be dominated by the grain boundary resistivity (R_b) at low frequency, while it will be dominated by the grain resistivity (R_g) at high frequency due to rapid decrease of $X_{cb}(=1/\omega C_b)$. It is presumed that the increase of grain boundary impedance may cause the decrease of eddy current loss, i.e., the core loss. Therefore, at the frequency between 1 MHz and 3 MHz, it is suggested that the decrease of the grain boundary capacitance (C_b) would cause the decrease of its core loss, i.e., the dielectric loss.

In order to prove the grain boundary capacitance on the core loss in the frequency from 1 MHz to 3 MHz, the samples with higher CaO-SiO₂ additive and longer cooling condition was applied in order to alter the thickness of the grain boundary phase, or the capacitance of the grain boundary. Table 2 lists the properties of the studied samples in this experiment.

It is apparent that C_b of the sample G is smaller than that of the sample F, and the grain boundary impedance are dominated by impedance of C_b . It is found that the core loss of sample G is lower than that of the sample F at the frequency of 2.5MHz. This result reveals the importance of grain boundary capacitance at the middle high frequency, i.e., 1~3MHz in this study.

Conclusions: The core loss of low loss grade Mn-Zn ferrites is strongly dependent upon the frequency under the condition of $f \times B = 25\text{KHz} \cdot \text{T}$. At the middle high frequency region (1.2 MHz ~ 3 MHz), the dielectric loss dominates the core loss. It is suggested that by decreasing the grain boundary capacitance at middle high frequency is the appropriate way to improve the properties of the Mn-Zn ferrites and permits its application in this frequency range.

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References:

- [1] E.C. Snelling and A.D. Giles, "Ferrite for Inductors and Transformers", Philips Research Laboratories, Redhill, Surry, England. p.54-62,1983.
- [2] J. Smit and H.P.J. Wijn, "Ferrites", Philips Technical Library, Eindhoven, p.134, 1959.
- [3] S.Yamada, E.Otsuki and T.Otsuka, "Ac Resistivity of Mn-Zn Ferrites", Tokin Technical Review, Vol.18, p.16-23, 1991.
- [4] C.G.Koops. "On the Dispersion of resistivity and Dielectric Constant of Some Semiconductors at Audio frequencies", Phys. Rev., Vol. 83-1, p.121-124, 1951.

Figure 1: Core loss of sample A to F. ($f \times B = 25\text{KHz} \cdot \text{Tesla}$)