Study of Loss Mechanisms of Mn-Zn Ferrites in the Frequency from 1 MHz to 10 MHz

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Abstract-The core loss mechanism of low loss grade Mn-Zn ferrite in the frequency from 1MHz to 10MHz was investigated in order to find out the possibility of developing Mn-Zn ferrites to be used at such high frequency region. under the condition of f.B=25KHz.T, it was found that dielectric loss dominated the core loss at the frequency between 1.1 and 3MHz, while eddy current loss dominated the core loss at the frequency higher than 3MHz. It is suggested that decrease of grain boundary capacitance and increase of grain resistivity of the core may be the suitable ways for the Mn-Zn ferrites to be used at such frequency region.

I. Introduction

Recently,the operating frequency of switching mode power supplies is increased from 25kHz to several MHz to increase their power density and make them more compact. Therefore, it is urgently need to reduce the power loss of core material in order to use it at higher frequencyl. Mn-Zn ferrites are suitable core material in the frequency range under 1MHz[2,3]. For the frequency higher than 1MHz, Ni-Zn ferrites seem to be the best candidate for applications[4],but nowadays,it was reported that Mn-Zn ferrites can also be used at 1MHz[5]. On the other hand, only a few papers have discussed possibility of using Mn-Zn ferrites in the frequency higher than 1MHz. This paper will mainly investigate the core loss phenomenon of Mn-Zn ferrites in the frequency range between 1MHz and 10MHz in order to find out the possible ways which can be approached for the Mn-Zn ferrite cores to be used in the frequency higher than 1MHz.

II.Experimental

Low loss grade Mn-Zn ferrite samples are prepared by conventional ceramic process. The powders containing Fe_2O_3, MnO and ZnO in molar ratio of 52.9:37.6:9.5 with the addition of 0.2wt% of CaO and 0.02wt% of SiO2 where prepared, and the powders were pressed into toroids with 20mm(O.D.) x 10mm(I.D.) x 5mm(t) and disk shape with 11mm (ϕ)x2.5mm(t). The green compacts were sintered at 1200℃ for 2hrs in air and then annealed at 1100℃ for 2hrs in the oxygen partial pressure of 0.5%, 1% and 3%, and they are represented by sample A, B and C, respectively. The samples sintered in 1% oxygen partial pressure were chosen to be cooled with different times (4hrs and 8hrs) from 1100℃ to 800℃ for comparison, in order to study the effect of cooling rate on the resistivity and power loss of the final cores. The impedance and permeability were measured in the frequency range from 5Hz to 13MHz with HP 4192A impedance analyzer. Power loss was measured with Ryowa MMS-0375 Iron loss measuring system at constant B_{meas} x f_{meas}(=25kHz.Tesla) value.

III.Results and discussion

Figure 1 shows the permeability of the sample A,B and C at the frequency from 1KHz to 10 MHz. From the figure, it is found that the permeability is almost the same among them at such frequency range. This suggest that the permeability of the studied Mn-Zn Ferrites is independent of the sintering condition.

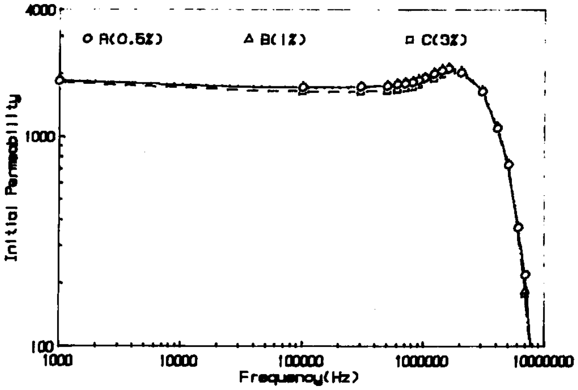

Fig.1.Frequency dependence of permeability of the sample A ,B and C

Figure 2 shows the variation of core loss with frequency of the samples sintered in various oxygen atmosphere. It is apparent that the core loss of the samples measured at f.B=25KHz.T can be divided into three parts.The first part is the loss in the frequency lower than 1.1MHz, which is proportional to 1/f.Second part is the loss from 1.1MHz to around 3MHz,which is proportional to f. Third part is the loss from 3MHz to 10MHz which is independent of f.

The core loss of power ferrite is reported consisting of three parts, there are hysteresis loss (Ph)[6,7],eddy current loss (Pe)[6,7] and dielectric loss (Pde)[8]. There are usually defined as follows:

$$Ph=Kh\ f\ B^2 \quad .... \quad (1)$$

$$Pe=Ke\ f^2\ B^2/\rho \quad .... \quad (2)$$

$$Pde=Kde\ f^3\ B^2 \quad .... \quad (3)$$

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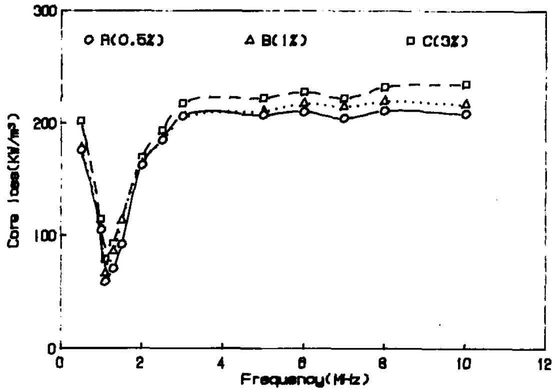

Fig.2.Frequency dependence of core loss of Mn-Zn ferrites sintered at different oxygen partial pressure

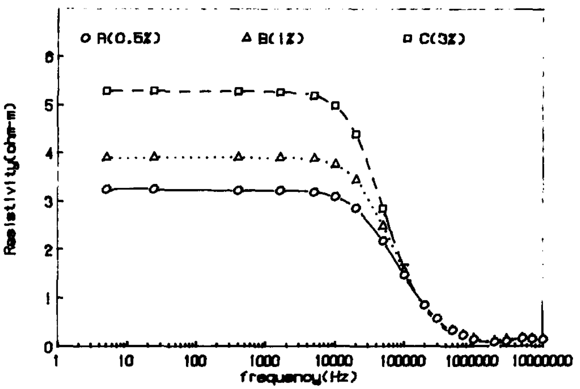

Fig.3.Frequency dependence of resistivity of Mn-Zn ferrites sintered at different oxygen partial pressure

where Kh, Ke and Kde 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. If we keep the measuring condition at constant f B, then the equations of above can be changed to the following:

$$Ph=Kh(f\ B)^2/f \quad .... \ (4)$$
$$Pe=Ke(f\ B)^2/\rho \quad .... \ (5)$$
$$Pde=Kde(f\ B)^2\ f \quad .... \ (6)$$

From equation(4)to(6), it is clear that Ph is proportional to 1/f, Pe has no relationship with f, while Pde is proportional to f, if f B is kept constant. That is to say the core loss of the studied samples is dominated by hysteresis loss in the frequency lower than 1.1 MHz, dominated by dielectric loss in the frequency from 1.1MHz to 3MHz and dominated by eddy current loss in the range from 3MHz to 10MHz.

Figure 3 shows the variation of the resistivity with frequency for the samples sintered in various atmospheres. It demostrates that bulk resistivity of the samples was increased with increasing the oxygen partial pressure at the frequency lower than 1MHz. However, it became identical among them at frequency higher than 1MHz. From the complex impedance plot of the sample A,B and C, see figure 4, it was found that the variation of impedance follows the Kroops' model[9]. According to figure 4, 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 Xcb(=1/ωC_b). From equation (5), it is known that eddy current loss will be decreased with increasing the bulk resistivity. It is presumed that increase of grain boundary resistivity may decrease of eddy current loss , i.e. core loss. In reality , at the frequency higher than 3MHz, the grain boundary impedance decreases very rapidly, therefore, the apparent impedance of the core approaches the value of grain resistivity. This was proved by the result of small difference in R_g for the samples sintered in different oxygen partial pressure at the frequency higher than 3MHz, as shown in figure 5. High resistivity grain boundary phase (CaO-SiO_2)has no direct relationship with impedance of the core and also the core loss at such high frequency. In view of the result as above, one can conclude that increase of grain resistivity instead of grain boundary resistivity is necessary for improving the loss at the frequency higher than 3MHz.At the frequency between 1.1 MHz and 3 MHz, it is suggested that decrease of the grain boundary capacitance (C_b) would decrease its core loss, that is the dielectric loss.

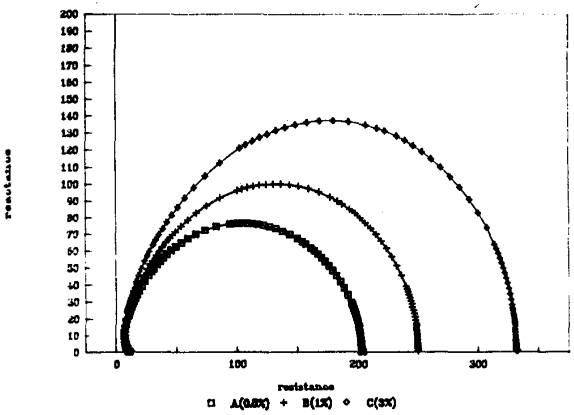

Fig.4.Complex impedence plot of sample A,B and C

Table 1
Physical properties of samples A to D

sample	A	B	C	D
μ_i	1841	1857	1810	1822
R_g(ohm)	6.9	8	6.6	5.3
R_b(ohm)	197	242	326	250
C_b(nF)	9.5	9.4	9.7	7.9

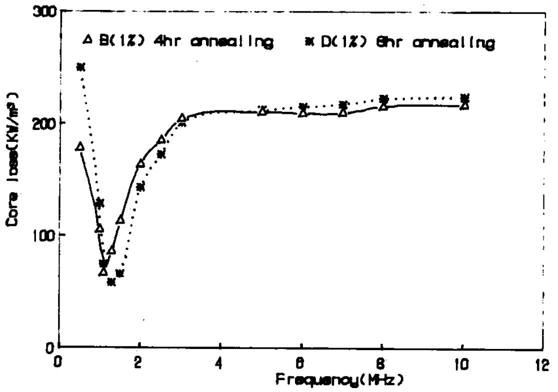

Fig.6.Frequency dependence of core loss of Mn-Zn ferrites sintered at different annealing condition

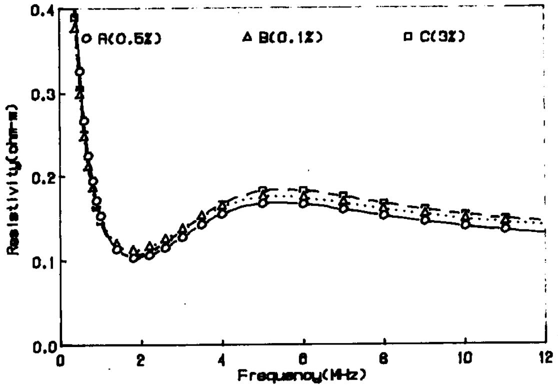

Fig.5.Frequency dependence of resistivity of Mn-Zn ferrites sintered at different oxygen partial pressure in higher frequency(>1MHz) range

In order to prove the importance of grain boundary capacitance on the core loss in the frequency from 1.1MHz to 3MHz, samples with different cooling condition was applied in order to alter the thinckness of the grain boundary phase, or the capacitance of the grain boundary. Table 1 lists some physical properties of the samples studied in this experiment. It is apparent that Cb of the sample (sample D) with longer cooling time (8 hrs) between 1100℃ and 800℃ is larger than that of sample (sample B) with shorter cooling time(4 hrs). Figure 6 shows the core loss of sample B and D at various frequency. It is found that the core loss of sample D is lower than that of smaple B at the frequency between 1.1MHz and 3 MHz. Whereas, it did not hold true when the frequency is higher than 3MHz. This result supports the direct prove of the importance of grain boundary capacitance at the middle high frequency , i.e.1.1~3MHz in this study.

IV.Conclusions

The core loss of low loss grade Mn-Zn ferrites is strongly dependant upon the frequency under the condition of f.B= 25KHz.T. At low frequency region(<1.1MHz), hysteresis loss will mainly dominate the core loss. At middle high frequency region (1.1MHz~3MHz), dielectric loss dominates the core loss. At high frequency region (3MHz~10MHz), eddy current loss will dominate the core loss. It is suggested that by decreasing the grain boundary capacitance at middle high frequency or increasing the grain resistivity at high frequency region are the appropriate ways for the Mn-Zn ferrites to be used at the frequency between 1MHz and 10 MHz.

Acknowledgment

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References

[1] A.F.Goldberg, J.G.Kassakian and M.F. Schlecht, "Issues Related to 1-10MHz Transformer Design", IEEE Trans on Power Electronics, Vol.4, No.1, p.113-123. Jan. 1989
[2] T.Ochiai and K. Okutani, "Ferrite for High Frequency Switching Power Supplies", 4th Int. Conf. on Ferrite, Vol. 16,1985
[3] E. Otsuki, S. Yamada, T. Otsuka, K. Shoji and T. Sato, "Microstructure and Physical Properties of Mn-Zn Ferrites for High-Frequency Power Supplies",J.Appl.Phys., 69(8),15,p.5942-5944, 1991.
[4] K.D.Ngo, M.H.Kuo, "Effects of Air Gaps On Winding Loss in High Frequency Planar Magnetics", IEEE PESC, Record p 1112-1119, 1988.
[5] W.A.Tabisz and M.M. Jovanovic,"Practical Design Considerations for High Frequency Transformers and Resonant Inductors", VPEC Seminar, Sept. 1990.
[6] E.C.Snelling and A.D.Giles, "Ferrite for Inductors and Transformers", Philips Research Laboratories, Redhill, Surry, England. p.54-62,1983.
[7] J. Smit and H.P.J. Wijn,"Ferrites", Philips Technical Library, Eindhoven, p.134, 1959.
[8] S. Yamada, E.Otsuki and T.Otsuka,Ac Resistivity of Mn-Zn Ferrites", Tokin Technical Review, Vol.18, p.16-23, 1991.
[9] C. G.Koops. "On the Dispersion of resistivity and Di electric Constant of Some Semiconductors at Audio frequencies",Phys. Rev., Vol. 83-1, p.121-124, 1951.