The Electromagnetic and Thermal Properties of the Mn-Zn Ferrite for the Power Line Communication

Hae-Yon Lee, Hyun-Sik Kim, Jeoung-Sub Huh and Young-Woo Oh

Abstract - The electromagnetic properties and thermal behavior of Mn-Zn ferrite cores for the blocking filter of PLC application were investigated as the function of additives. The highest density and permeability were 4.98 g/㎤ and 8,221, respectively and were obtained to the specimen with composition of MnO 24 mol%, ZnO 25 mol% and Fe_2O_3 51 mol%, added MoO_3 of 400 ppm, SiO_2 of 100 ppm, and CaO of 200 ppm. The uniform grains were organized, and the microstructures were compacted due to reduction of pores in the specimen. The permeability was increased up to 13,904 as the temperature of specimen increased to 110℃. However, it was decreased precipitously under 100 over 110℃. The exothermic behavior was observed in the frequency range from 1 kHz to 1 MHz, and the maximum temperature of specimen was 102℃ at 1 MHz. In the consequence, the Mn-Zn ferrite core developed in this research will maintain the stable electromagnetic properties since the temperature of ferrite core rose to 93℃ in the range of 100 kHz to 450 kHz bandwidth qualified for PLC. The blocking filters were designed for single phase and three phases using the in-line and non-contact core. The best attenuation ratios of -46.46 dB and -73.9 dB were measured in the range of 100 kHz to 450 kHz bandwidth, respectively.
Keywords - PLC(Power Line Communication), Mn-Zn ferrite, high permeability, blocking filter, exothermic behavior

1. Introduction

The power line communication (PLC) is a potential communication technology with very high possibility of utilization. However, there is little investigation on the magnetic core materials which have been used as a kernel device in a filter and transformer applications, so that the insufficient development of basic PLC technology causes lots problems in various applications. Magnetic core materials developed and produced up to now, which have magnetic characteristics at the low frequency bandwidth, are not suitable for high frequency of ultra high speed power line home networking. The conventional type of magnetic core which has been used in the range of high frequency is concomitant with heat generation as the power losses. The soft ferrite core is an essential material for the reduction of power losses since it is higher electrical resistivity than metallic core.

The electromagnetic properties of the Mn-Zn ferrite which is commonly used in the range of hundreds kHz are strongly dependent on additives to promote sintering and high d.c. electrical resistivity layer as well as proper composition and heat treatment. In order to produce the Mn-Zn ferrite with high permeability and good frequency dependence using variable additives, Bando *et al.* reported that the addition of CaO and SiO_2 created liquid phase to promote the grain growth at the eutectic point 1100℃ ± 10℃ with ferrite. Stijntjes *et al.* analyzed the effect of additives such as SiO_2, ZrO_2, and Bi_2O_3 on the electromagnetic characteristics, and they reported that the decrease of power loss resulted from forming high electrical resistivity layer on the grain boundaries [1, 2].

In the current research, our purpose is to develop the magnetic core material having predominant electromagnetic properties which are high permeability and low losses in the range of high frequency. Therefore, the electromagnetic properties and thermal behavior of Mn-Zn ferrite cores used for the blocking filter in the PLC application were investigated as functions of additives such as CaO, SiO_2 and MoO_3.

2. Experimental procedures

Mn-Zn ferrite has high permeability at nominal composition of MnO : ZnO : Fe_2O_3 in a molar ratio of 24 : 25 : 51 mol% and is selected at the 3-component system and successively prepared by the conventional ceramic process using chemical grade oxides. The mixture was then homogenized during milling and calcined at 900℃ for 3 hours. The calcined Mn-Zn ferrite was granular using spray drier, and then added from 100 ppm to 200 ppm of SiO_2, from 100 ppm to 500 ppm of CaO, from 0 ppm to 1000 ppm of MoO_3. The resultant mixture was pressed at 1.5 ton/cm^3 into pressure with toroidal shaped specimens, which were sintered at 1350℃ for 3 hours. Sintering was carried out in the air. When the specimens were cooled the

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Hae-Yon Lee, Hyun-Sik Kim, Jeoung-Sub Huh are with Mattron Co., Ltd., 449 Wolyoung-Dong, Masan, 631-701, Korea.

Young-Woo Oh and Jong-Ryung Kim are with Division of Advanced Materials Engineering, Kyungnam University, Masan, Korea.

precisely controlled atmosphere of partial oxygen pressure was employed according to following equation [3].

$$\text{Log } Po_2 = A - 14540 / T(K)$$

Where, Po_2 is the partial pressure of the oxygen, A is the atmosphere parameter, and T is the temperature. Blocking filter manufactured by Mn-Zn ferrite cores with the highest permeability of 8221 as functions of power types which are single phase and three phases.

Thermal gravity of Mn-Zn ferrite was analyzed by TA and phases were identified using an X-ray diffractometer. Microstructure analysis was carried out by SEM and permeability was measured by an impedance analyzer.

3. Result and discussion

The thermal gravity characteristic of Mn-Zn ferrite as a function of heat treatment temperature is shown in Fig. 1. A remarkable weight loss is observed between 800℃ and 1200℃, since raw materials such as MnO, ZnO, and Fe_2O_3 formed Mn-Zn spinel ferrite by oxidation and deoxidation reaction.

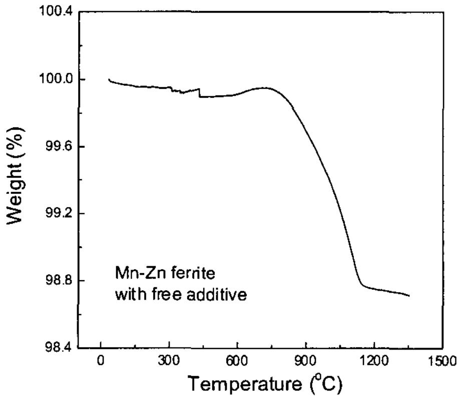

Fig. 1 Weight change of the Mn-Zn ferrite

This weight loss is consistent with spinel reaction of Mn-Zn ferrite, which forms in three component system with $MnO\text{-}ZnO\text{-}Fe_2O_3$ based on the two component system such as MnO-ZnO, $ZnO\text{-}Fe_2O_3$ and $MnO\text{-}Fe_2O_3$ according to following reaction scheme, analyzed up to now by other investigators [4,5].

$$2MnO + ZnO \rightarrow ZnMn_2O_4 \quad (580℃\sim 650℃)$$
$$ZnO + Fe_2O_3 \rightarrow ZnFe_2O_4 \quad (650℃\sim 710℃)$$
$$MnO + 2Fe_2O_3 \rightarrow MnFe_2O_4 + Fe_2O_3 \quad (800℃\sim 900℃)$$

The development of spinel phase for Mn-Zn ferrite as functions of calcination and sintering temperatures is shown in Fig. 2. Clearly, the spinel ferrite existed after calcination at 900℃ but hematite phase(α- Fe_2O_3) also presented. Generally, it is known that hematite existing after calcination promotes sintering as a catalyser. However, only single spinel phase existed in the Mn-Zn ferrite sintered at 1350℃, and any other second phase was not founded. Therefore, it is believed that sintering temperature of 1350℃ is appropriate to achieve a single spinel ferrite. The x-ray diffraction analyses in this investigation agree well with the thermal gravity analyses and spinel reaction scheme as the above mentioned.

Fig. 3. shows the microstructures of Mn-Zn ferrites added CaO 400 ppm and SiO_2 200 ppm and sintered at 1350℃ in relation to the amount MoO_3. Lots of pores existed in the specimens with the added MoO_3 free and 100 ppm, since the abnormal grain growth was originated by the rich liquid phase due to basic additives of CaO and SiO_2.

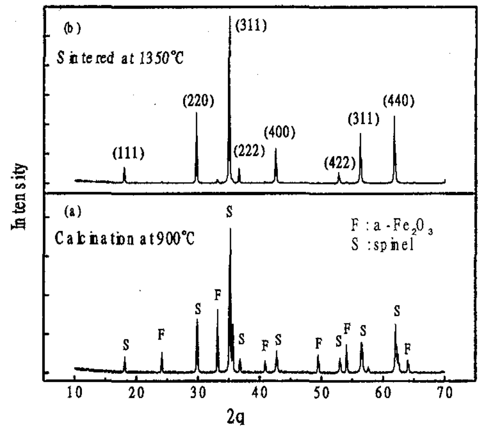

Fig. 2 X-ray diffraction patterns

However, the pores reduced considerably in the specimens added MoO_3 of above 400 ppm as shown in Fig. 3 (c), (d), and (e). MoO_3 has been used as an additive which promotes grain growth and compaction in the sintering process due to diffusion resulted from MoO_3 liquid phase. But this sintering mechanism could be applied to only MoO_3 addition and MoO_3 rich region in $ZnO\text{-}MoO_3$ and $CaO\text{-}MoO_3$ system. In this study, the amount of MoO_3 addition could not create liquid phase with CaO and ZnO through eutectic reaction, and also, the reaction with ZnO

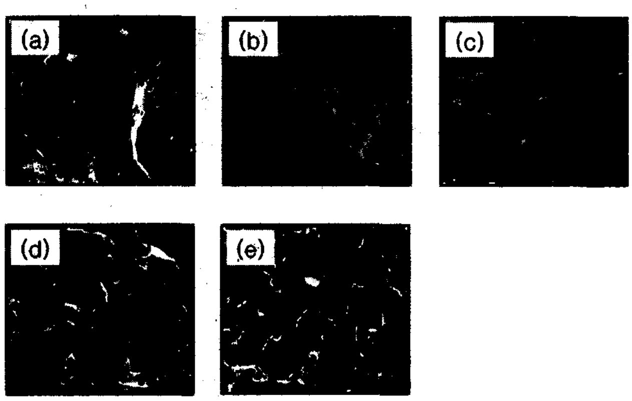

Fig. 3 Microstructures of the Mn-Zn ferrite as a function of MoO_3 additive (a) MoO_3 free additive, (b) 100 ppm, (c) 400 ppm, (d) 700 ppm, (e) 1000 ppm

has been excluded since MoO_3 addition was carried out after calcination. Therefore, the reaction in the CaO-MoO_3 system forms the second phase such as Ca_3MoO_6 which exists in the grain boundaries up to sintering temperature and exhibits grain growth [6-8].

The sintering density and permeability as functions of MoO_3 additive contents are exhibited in Fig. 4. The sintering density increased with MoO_3 contents and the highest density was obtained to the specimen added MoO_3 of 400 ppm. On the other hand, there was no difference over 400 ppm addition. This result is corresponding to the microstructures, as shown in Fig. 3, which have fine and uniform grains and remarkably reduced pores. Also, the permeability increased with MoO_3 contents, and the highest density was obtained at MoO_3 of 400 ppm due to the increasing density, However, it decreased at the addition over 400 ppm since the rich amount of non-magnetic element MoO_3 was added.

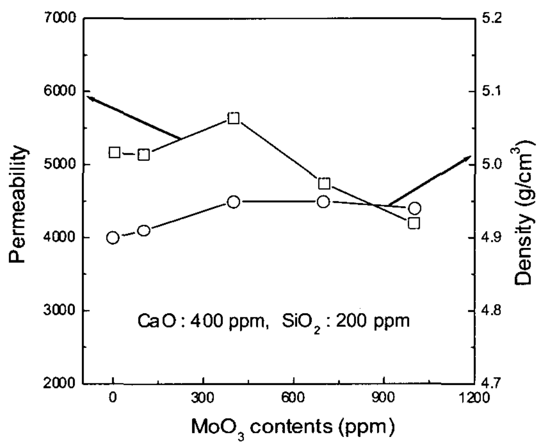

Fig. 4 Density and permeability as functions of MoO_3 contents

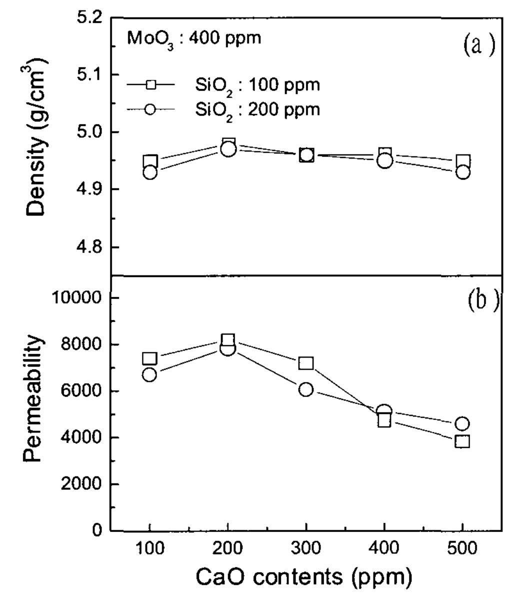

Fig. 5 Density and permeability as a function of CaO contents

Fig. 5 represents the sintering density and permeability of Mn-Zn ferrites added MoO_3 of 400 ppm with the highest permeability as functions of CaO and SiO_2 additive contents. The density was little changed and the maximum value of 4.98 g/cm^3 was obtained at CaO of 200 ppm and independently on the SiO_2 additive contents. The highest permeability of 8221 was attained by CaO addition of 200 ppm due to high density, but it considerably decreased CaO over 200 ppm addition because of the rich amount of non-magnetic element such as MoO_3, CaO, and SiO_2.

The thermal behavior of Mn-Zn ferrite core added MoO_3 of 400 ppm, SiO_2 of 100 ppm and CaO of 200 ppm is shown in Fig. 6. The surface temperature of specimens increased up to 102℃ at 1 MHz in proportion to frequency due to high eddy current loss. The maximum temperature of 93℃ was measured in the range of 100 kHz to 450 kHz qualified for PLC. It is generally important for the ferrite cores that the stable electromagnetic characteristics must be maintained under the thermal behavior in relation to frequency, because electromagnetic properties are destroyed by the temperature originated from eddy current loss as the application frequency moves to higher region.

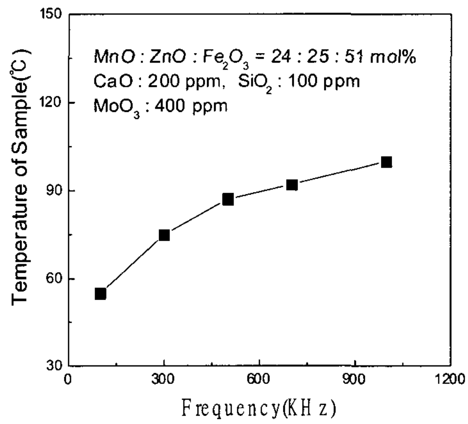

Fig. 6 Exothermic behavior as a function of frequency

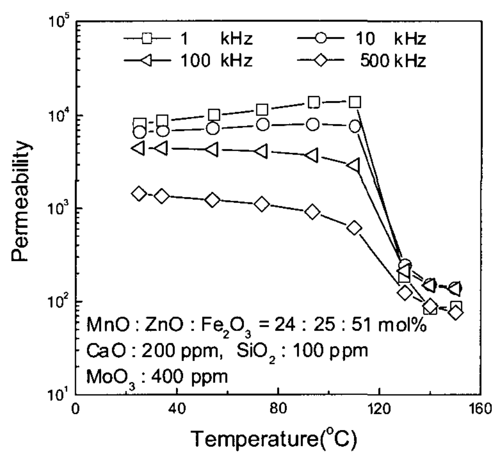

Fig. 7 Permeability as a function of temperature

Fig. 7 shows permeability of Mn-Zn ferrite added MoO_3 of 400 ppm, SiO_2 of 100 ppm and CaO of 200 ppm as a function of temperature. The permeability, which was 8221 at room temperature(25℃), increased up to 13094 at 110℃ with the increasing temperature of specimen. However, the permeability was decreased precipitously to under 100 over 110℃. In the consequence, the ferrite core developed by this research will maintain its stable electromagnetic properties since the temperature of ferrite core rose to 93℃ in the range of 100 kHz to 450 kHz for PLC application.

Fig. 8 represents circuit diagram of blocking filter manufactured by Mn-Zn ferrite cores with the highest permeability of 8221 as functions of power types which are single phase and three phases. The blocking filter, which blocks the communication signal between in and out door, was designed in order to attenuate frequency of 100 kHz to 450 kHz for PLC application. L and L1 in the Fig. 8 (a) and (b) were organized by in-line cores with toroidal shape. L2 was constituted by the cut cores in the plastic cases because it is difficult to cut the established power line. Also, the capacitors were connected between each phase. The dimension and number of core used in each blocking filter are shown in Table. 1.

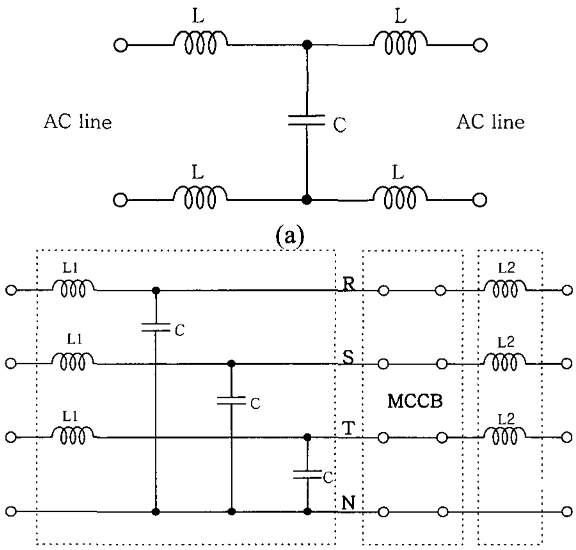

Fig. 8 Circuit diagrams of Blocking filter as functions of power types (a) single phase, and (b) three phases

Table 1 Dimension and number of core used in each blocking filter

Dimension (mm)	Mn-Zn Ferrite core		
	L	L1	L2
O. D	21.5	27.7	21.5
I. D	13.8	16	13.8
Thickness	12.3	12.7	12.3
Number	2	4	2

Attenuation ratio of blocking filter as a function of frequency is plotted in the Fig. 9. The best attenuation ratios of -46.46 dB and -73.9 dB in the range of 100 kHz to 450 kHz were attained to the blocking filter for single and three phases, respectively. It is believed that the attenuation ratio for three phases was better than that of single phase independently on frequency due to higher inductance values resulted from bigger dimension and larger number of Mn-Zn ferrite cores in the blocking filter. The predominant characteristics of attenuation ratio over -40 dB required to blocking filter for power line with the variable loads was attained in both of single and three phases by Mn-Zn ferrite cores developed in this research.

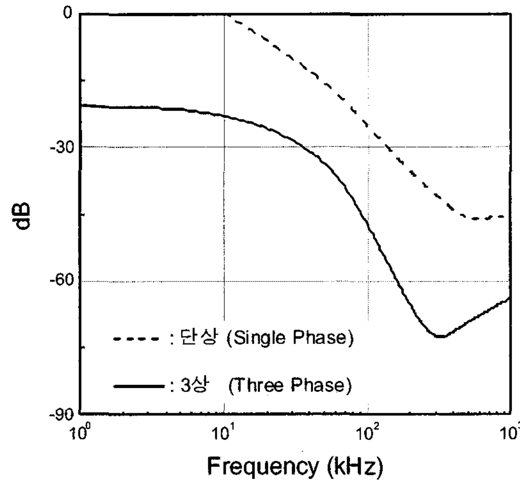

Fig. 9 Attenuation ratio of Blocking filter as functions of power types

4. Conclusion

We investigated the electromagnetic properties and thermal behavior of Mn-Zn ferrite used for blocking filter in PLC application. The nominal composition of MnO : ZnO : Fe_2O_3 has a molar ratio of 24 : 25 : 51 mole% as functions of the additive contents.

1. The highest density and permeability of 4.98 g/cm^3 and 8221 at room temperature were obtained in specimen added MoO_3 of 400 ppm, SiO_2 of 100 ppm, and CaO 200 ppm because of achievement of uniform microstructures and high density.

2. The permeability, which was 8221 at room temperature, increased up to 13904 at 110℃ with increasing temperature of specimen. But the maximum surface temperature of specimens increased up to 93℃ was measured in the range of 100 kHz to 450 kHz, qualified for PLC application.

3. The blocking filter was designed for single phase and the three phases using the in-line and non-contact core. The magnitude responses of single phase and three phases

blocking filter were measured the best values of -46.46 dB and -73.9 dB at the bandwidth range of 100 kHz to 450 kHz, respectively.

Acknowledgement

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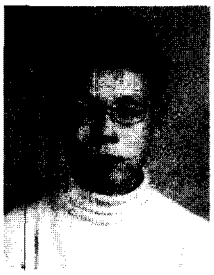
Reference

[1] T. G. W. Stijntjes, Proc. Int. Conf. Ferrites, p. 194, 1970.
[2] A. Goldman, "Modern Ferrite Technology", Kluwer Academic, p.119, 1990.
[3] J. M. Blank, "Equilibrium Atmosphere Schedules for Cooling of Ferrite," J. Appl. Phys., 32, 376, 1961
[4] S. O. Yun, H. J. Lee, G. H. Yun and H. J. Jung, "Magnetic materials", Bando, p.20, 1996.
[5] Y. W. Oh, H. S. Kim, J. Advanced Material Institute of Kyungnam Uni., Vol. 7, p.5, 1996.
[6] H. Inaba and T. Abe, J. Solid State Chem., Vol. 121, p.117, 1996.
[7] T. M. Yanushkevich and V. M. Zhukovskii, Russ. J. Inorg. Chem., Vol. 18, No. 8, p.1182, 1973.
[8] C. Hendricks, V. Amarakoon and D. Sullivan, Am. Ceram. Bull.,Vol. 70, p.817, 1992.



Hae-Yon Lee received the M.S in inorganic materials engineering from Kyungnam University in 2001. Since 2000, he has been with MATTRON Co.,Ltd. as a research engineer in the R&D center. His research interests include fabrication and characterization of magnetic core materials.

Jeoung-Sub Kim received the M. S in inorganic materials engineering from Kyungnam University in 2000. Since 2000, he has been with MATTRON Co.,Ltd. as a research engineer in the R&D center. His research interests include fabrication and characterization of magnetic thin film.

Hyun-Sik Kim received the Ph.D degree in inorganic materials engineering from Kyungnam University in 1998. He was a research engineer in electrical & magnetic devices group of KERI from 1993 to 2000. He is currently a president of MATTRON Co.,Ltd. His research interests include fabrication and characterization of electro-magnetic devices.

Young-Woo Oh received the Ph.D degree in materials engineering from Pusan National University in 1988. He was a research engineer in RIST from 1982 to 1985. Since 1985 he has been with Kyungnam University as a professor in division of advanced materials engineering. His research interests include fabrication and characterization of magnetic materials.