The Effect of V2O5 Addition on the Microstructure and Magnetic Properties of Mn-Zn Ferrites

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Abstract. In response to the need for the improvement of low-loss core materials used for high-frequency power transformers, microstructures and magnetic properties of Mn-Zn ferrite have been investigated with the addition of CaO, SiO$_2$ and V$_2$O$_5$. The specimens of (Mn$_{0.8}$Zn$_{0.2}$)O$_{0.67}$Fe$_{2}$O$_{4.5}$ composition are prepared from the powders synthesized by SHS (Self-propagation High-temperature Synthesis) process. The presence of V$_2$O$_5$ in the addition to the CaO and SiO$_2$ results in a fine grain structure and suppress the abnormal grain growth. The electrical resistivity increases with the addition of V$_2$O$_5$, which is believed to be attributed to the melting of V$_2$O$_5$ and formation of liquid phase at grain boundaries. The eddy-current loss is reduced, therefore, lowered with addition of V$_2$O$_5$. However, if V$_2$O$_5$ is over-weighted above an optimum value, the hysteresis loss becomes dominant and, therefore, the total core-loss increases.

1. INTRODUCTION

The growing demand for miniaturization of electrical devices requires the low-core-loss materials of Mn-Zn ferrites at high frequencies. The loss in power ferrites consists of hysteresis loss and eddy current loss. The hysteresis loss can be reduced by attainment of uniformity in both chemistry and microstructure. The eddy current loss is reduced by increasing the electrical resistivity of ferrite material. The general approach for reduction of eddy current loss is to obtain a highly resistive grain boundary by the addition of small amount of resistive compound [1,2,3].

In the present study, the microstructures and magnetic properties are investigated in Mn-Zn ferrites containing CaO, SiO$_2$, and V$_2$O$_5$. The selection of V$_2$O$_5$ as the third additive compound is based on its low melting point (675°C). It is therefore expected that the grain boundary structure and grain growth kinetics are highly influenced by this compound as suggested in other studies [4,5]. The core loss is discussed on the base of the observed microstructure and electrical resistivity of Mn-Zn ferrites containing V$_2$O$_5$ in addition to the CaO and SiO$_2$.

2. EXPERIMENTALS

Mn-Zn ferrite samples, having the composition (Mn$_{0.8}$Zn$_{0.2}$)O$_{0.67}$Fe$_{2}$O$_{4.5}$ are prepared from the powders synthesized by SHS (Self-propagation High-Temperature Synthesis) process. Atomized Fe powder (about 15 wt%) was used as an exothermic source. The mixture of powders was reacted in SPS reaction chamber under controlled oxygen partial pressure. The reacted powders with additives (CaO, SiO$_2$, V$_2$O$_5$) were milled in an attritor. Powder compacts were sintered under controlled heating schedule and atmosphere. The sintering condition is the same irrespective of V$_2$O$_5$ contents. DC electrical resistivity, initial permeability, maximum flux density and core loss were measured by the conventional techniques.

3. RESULTS AND DISCUSSION

The previous study has shown that the binary additives of CaO and SiO$_2$ has considerable effect in reducing the core loss [6]. The optimum content of CaO and SiO$_2$ was found to be 0.05 and 0.02 wt%, respectively. For further reduction of core loss, the third compound V$_2$O$_5$ was added in the range from 0.01 to 0.04 wt%.

Fig.1 shows the microstructural change developed in the cores with the addition of V$_2$O$_5$. In the sample containing only CaO and SiO$_2$ (without V$_2$O$_5$), some large abnormal grains are observed (Fig.1(a)). In the case of more CaO- and SiO$_2$-doped specimen, a typical duplex grain structure (huge grains are imbedded in surrounding small grain matrix) was developed. However, the presence of V$_2$O$_5$ in addition to the CaO and SiO$_2$ results in a microstructure of grain refinement and suppress the abnormal grain growth as shown in Fig.1(b) and Fig.1(c). It is believed that the added V$_2$O$_5$ because of its low melting point, may melt at grain boundary and act as a grain growth inhibitor. The deep etched grain boundary in the heavily doped sample (Fig.1(c)) provides an indirect evidence for the grain boundary melting.

Fig.2(a) shows the variation of initial permeability with the addition of V$_2$O$_5$. A slight increase in initial permeability is observed in the lightly doped sample (0.01 wt% V$_2$O$_5$). If V$_2$O$_5$ exceeds 0.02 wt%, the initial permeability decreases drastically. The similar tendency is observed in maximum flux density as shown in Fig. 2(b).

Fig.2(c) shows the variation of electrical resistivity and core loss with the addition of V$_2$O$_5$. The electrical resistivity increases with the amount of V$_2$O$_5$, especially in lightly doped cores. The results are considered to be attributed to the non-magnetic liquid film, which are arising from V$_2$O$_5$ melting at grain boundaries. However, the most reduced core loss was found to be at 0.02 wt% V$_2$O$_5$. If V$_2$O$_5$ is over-weighted above this content, the core loss increases again in spite of the higher resistivity.
The core loss of ferrite materials is, in general, given by the summation of eddy-current loss and hysteresis loss. The residual loss can be neglected at high power level. Eddy-current loss is inversely proportional to the electrical resistivity. The slight reduction in core loss in the sample with a small amount of V₂O₅ (about 0.02 wt%) can be explained by the increase of electrical resistivity. However, the increase of core loss in highly-doped sample (V₂O₅ > 0.02 wt%) deviates from the reciprocal relationship between eddy-current loss and resistivity. It is, therefore, understood that in those samples the hysteresis loss is more dominant than eddy-current loss. The hysteresis loss, which comes from irreversible motion of domain walls, can be increased by the liquid film at grain boundaries.

Fig.1. Microstructures of Mn-Zn ferrite containing SiO₂ (0.02 wt%) and CaO (0.06 wt%) : (a) V₂O₅=0.00 wt%, (b) V₂O₅=0.02 wt%, (c)=0.04 wt%.

Fig.2. Variation of magnetic properties with addition of V₂O₅ at a fixed amount of SiO₂ (0.02 wt%) and CaO (0.06 wt%) : (a) initial permeability, (b) maximum flux density, (c) electrical resistivity and core loss.

4. CONCLUSION

The addition of a small amount of V₂O₅ in combination of CaO and SiO₂ is effective to obtain the fine grain structure and to improve the magnetic properties (especially, core loss) in Mn-Zn ferrite materials. The added V₂O₅, due to its low melting point, may form the liquid film at grain boundary and thereby, inhibit the grain growth and reduce the eddy-current loss. However, if V₂O₅ is over-added above an optimum value, the hysteresis loss becomes dominant and, therefore, the total core loss can be increased.

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