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The Effect of V_2O_5 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_2O_5 . The specimens of $(Mn_{0.7}Zn_{0.2}O)_{0.94}(Fe_2O_3)_{1.06}$ composition are prepared from the powders synthesized by SHS (Self-propagation High-temperature Synthesis) process. The presence of V_2O_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_2O_5 , which is believed to be attributed to the melting of V_2O_5 and formation of liquid phase at grain boundaries. The eddy-current loss is, therefore, lowered with addition of V_2O_5 . However, if V_2O_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_2O_5 . The selection of V_2O_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_2O_5 in addition to the CaO and SiO_2 .

2. EXPERIMENTALS

Mn-Zn ferrite samples, having the composition $(Mn_{0.7}Zn_{0.2}O)_{0.94}(Fe_2O_3)_{1.06}$, 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 SHS reaction chamber under controlled oxygen partial pressure. The reacted powders with additives (CaO, SiO_2 , V_2O_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_2O_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 0.06 and 0.002 wt%, respectively. For further reduction of core loss, the third compound V_2O_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_2O_5 . In the sample containing only CaO and SiO_2 (without V_2O_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_2O_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_2O_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_2O_5 . A slight increase in initial permeability is observed in the lightly doped sample (0.01 wt% V_2O_5). If V_2O_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_2O_5 . The electrical resistivity increases with the amount of V_2O_5 , especially in lightly doped cores. The results are considered to be attributed to the non-magnetic liquid film, which are arising from V_2O_5 melting at grain boundaries. However, the most reduced core loss was found to be at 0.02 wt% V_2O_5 . If V_2O_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, is 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 V_2O_5 (about 0.02 wt%) can be explained by the increase of electrical resistivity. However, the increase of core loss in highly-doped sample ($V_2O_5 > 0.02$ 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 ferrites containing SiO_2 (0.002 wt%) and CaO (0.06 wt%) : (a) V_2O_5 -0.00 wt%, (b) V_2O_5 -0.02 wt%, (c)-0.04 wt%.

Fig.2. Variation of magnetic properties with addition of V_2O_5 at a fixed amount of SiO_2 (0.002 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 V_2O_5 in combination of CaO and SiO_2 is effective to obtain the fine grain structure and to improve the magnetic properties (especially, core loss) in Mn-Zn ferrite materials. The added V_2O_5 , 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 V_2O_5 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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