Effect of Grain Size on Residual Loss of Mn-Zn Ferrites

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Abstract — The effect of grain size on residual loss of Mn-Zn ferrites was investigated. Mn-Zn ferrites with grain size of 1.5 to 4.3 μm were prepared by sintering a hydrothermally precipitated powder. The residual loss of the Mn-Zn ferrites, which was computatively separated from the core loss, occupies the majority part of the core loss at 1MHz and is reduced with decreasing the grain size. The reduction of residual loss may be contributed to the decrease of a energy loss of damping for domain wall motion caused by subdivision of domain.

I. INTRODUCTION

Mn-Zn ferrites have been extensively used for transformers utilized for switching power supplies because of the low core loss at high frequency. However, if a high frequency driving up to the MHz range is needed, an increase of the core loss of Mn-Zn ferrites will be a serious problem. The increase of the core loss in MHz range may be caused by an increase of the residual loss, which occupies the majority of the core loss of Mn-Zn ferrites in MHz range[1]. Therefore the reduction of the residual loss is necessary for the applications of Mn-Zn ferrites in MHz range. We have reported that Mn-Zn ferrites with fine grain sizes under 3 μm showed the low core loss on comparing with a conventional Mn-Zn ferrite with grain size of 10 μm at a frequency from 0.5 to 2MHz[2, 3]. In this paper the effect of grain size on residual loss of Mn-Zn ferrites is investigated.

II. EXPERIMENTAL

$\text{Mn}_{0.72}\text{Zn}_{0.16}\text{Fe}_{2.12}\text{O}_4$ ferrites with the grain size of 1.5 to 4.3 μm were prepared by sintering a hydrothermally precipitated ferrite powder. The grain size was changed by the sintering temperature of 1323K to 1423K and the amount of additive, 0 to 0.4 wt% of Ta_2O_5 .

The core loss (P_{cv}) of the Mn-Zn ferrites was computatively separated into three loss components, which were the magnetic loss (P_{M}), eddy current loss (P_{e}) and equivalent dielectric loss (P_{d}) due to displacement current [1]. The analysis of P_{cv} was carried out by using the medium parameters; relative complex permeability at low frequency (μ_r' , μ_r''), dc conductivity (σ), relative permittivity (ϵ_r) and conductivity for displacement current (g) [1]. ϵ_r and g were determined by the frequency dependence of impedance of the ferrites. The hysteresis loss (P_{h}) was determined by P_{cv} at 1kHz because P_{cv} per cycle hardly varied under 10kHz. The residual loss (P_{r}) was calculated as $P_{\text{r}} = P_{\text{M}} - P_{\text{h}}$ assuming that P_{h} is

proportional to frequency.

The grain size was observed by SEM. Magnetic properties, which are P_{cv} and (μ_r' , μ_r''), and frequency dependence of impedance were measured with an ac B-H loop tracer and a LCR meter respectively. σ was measured by four-point probe method. All measurements were carried out at room temperature.

III. RESULTS AND DISCUSSION

A. Grain size and electric and magnetic properties

Figure 1 shows the change in the grain size as a function of Ta_2O_5 content. The grain size decreases from 4.3 μm to 1.5 μm with decrease of the sintering temperature and increase of the Ta_2O_5 content.

Fig.1 Change in the grain size as a function of Ta_2O_5 content. The samples of 0wt% Ta_2O_5 were sintered at different temperature of 1323 to 1423K. Other samples were sintered at 1323K.

The electric and magnetic properties are shown in table 1. These properties were used for the analysis of P_{cv} .

Table 1 Electric and magnetic Properties

Sintering temperature	Ta ₂ O ₅ (wt.%)	$\mu r' + j \mu r''$ at 1kHz	σ (S/m)	ϵr	g (S/m)
1323K	0	2100+j 157	13.9	35000	56
1323K	0.1	1680+j 73	1.91	30000	60
1323K	0.2	1410+j 63	1.36	27000	63
1323K	0.3	1180+j 51	1.77	24000	68
1323K	0.4	990+j 52	2.37	27000	60
1373K	0	2550+j 142	13.4	44000	70
1423K	0	2730+j 375	7.90	61000	68

B. Grain size dependence of residual loss

The analysis of P_{cv} was carried out to discuss the grain size dependence of the residual loss. P_{cv} was separated into four loss components described in section II. Figure 2 and figure 3 show the change in the loss components at 1MHz as a function of sintering temperature and the Ta₂O₅ content respectively. P_r occupies the majority of more than 50% of P_{cv} at 1MHz in both figures. P_r is reduced with decreasing the sintering temperature and increasing the Ta₂O₅ content. The Ta₂O₅ content dependence of P_r is similar to that of the grain sizes. Figure 4 shows the grain size dependence of P_{cv} and P_r . P_r is reduced with decreasing the grain size. The relationship between P_r and grain size indicates that fine grain size is effective in reducing P_r . P_{cv} varies discontinuously at a grain size of 2.5 μ m reflecting the decrease of P_h and P_e by an addition of 0.1wt% Ta₂O₅. And P_{cv} shows the minimum value at a grain size of 2 μ m. This is contributed to the increase of P_h with the increase of Ta₂O₅ content and the reduction of P_r with the decrease of the grain size.

The origin of P_r has been investigated from a domain

Fig.2 Change of each loss component at 1MHz as a function of sintering temperature in 0wt% Ta₂O₅ samples. Pd is included in Pe because Pd occupies at most 0.2% of P_{cv} at 1MHz.

Fig.3 Change of each loss component at 1MHz as a function of Ta₂O₅ content for the samples sintered at 1323K. Pd is included in Pe the same as Fig.2.

Fig.4 Grain size dependence of P_{cv} and P_r for the samples prepared on several conditions.

wall motion[1,4]. The reduction of P_r is associated with the change of domain structure depending on the grain size. It is known that the domain of ferrites is subdivided with decreasing the grain size[5]. With the decrease of domain size, the number of domain wall per volume increases; therefore the amplitude of vibration in domain wall motion is reduced in the same B_m and driving frequency. In other words, the switching frequency of spin inside the domain wall (f_s) is reduced. On the other hand, a energy loss of damping for damain wall motion is proportional to f_s^2 . Consequently the reduction of P_r may be related to the decrease of a energy loss of damping for damain wall motion caused by subdivision of domain.

IV. CONCLUSIONS

The effect of grain size on residual loss for the Mn-Zn ferrites was investigated. The following results were obtained:

1. The residual loss occupies more than 50% of the core loss of the Mn- Zn ferrites at 1MHz.
2. The residual loss is reduced with decreasing the grain size.
3. The reduction of residual loss may be contributed to subdivision of domain caused by decreasing the grain size.

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