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 4.3μm were prepared by sintering a hydrothermally precipitated powder. The residual loss of the Mn-Zn ferrites, which was computationally separated from the core loss, occupies the majority part of the core loss at IMHz and is reduced with decreasing the grain size. The reduction of residual loss may be contributed to the decrease of an 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 3μm 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

Mn0.7Zn0.16Fe2.12O4 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 Ta2O5.

The core loss (Pcv) of the Mn-Zn ferrites was computationally separated into three loss components, which were the magnetic loss (PM), eddy current loss (Pe) and equivalent dielectric loss (Pd) due to displacement current [1]. The analysis of Pcv was carried out by using the medium parameters; relative complex permeability at low frequency (μr, μr'), dc conductivity (α), relative permittivity (εr) and conductivity for displacement current (g) [1]. εr and g were determined by the frequency dependence of impedance of the ferrites. The hysteresis loss (Ph) was determined by Pcv at 1kHz because Pcv per cycle hardly varied under 10kHz. The residual loss (Pr) was calculated as Pr = PM − Ph assuming that Ph is proportional to frequency.

The grain size was observed by SEM. Magnetic properties, which are Pcv and (μr, μr'), and frequency dependence of impedance were measured with an ac B-H loop tracer and a LCR meter respectively. α 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 Ta2O5 content. The grain size decreases from 4.3μm to 1.5μm with decrease of the sintering temperature and increase of the Ta2O5 content.

![Fig.1 Change in the grain size as a function of Ta2O5 content. The samples of 0wt% Ta2O5 were sintered at different temperature of 1323 to 1423K. Other samples were sintered at 1323K.](image-url)

The electric and magnetic properties are shown in table1. These properties were used for the analysis of Pcv.
Table 1  Electric and magnetic Properties

<table>
<thead>
<tr>
<th>Sintering temperature (K)</th>
<th>Ta2Os (wt.%)</th>
<th>µr+ j µi</th>
<th>σ (S/m)</th>
<th>εr</th>
<th>g (S/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1323</td>
<td>0</td>
<td>2100+j 157</td>
<td>13.9</td>
<td>35000</td>
<td>56</td>
</tr>
<tr>
<td>1323</td>
<td>0.1</td>
<td>1680+j 73</td>
<td>1.91</td>
<td>30000</td>
<td>60</td>
</tr>
<tr>
<td>1323</td>
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<td>1410+j 63</td>
<td>1.36</td>
<td>27000</td>
<td>63</td>
</tr>
<tr>
<td>1323</td>
<td>0.3</td>
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<td>1.77</td>
<td>24000</td>
<td>68</td>
</tr>
<tr>
<td>1323</td>
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<td>990+j 52</td>
<td>2.37</td>
<td>27000</td>
<td>60</td>
</tr>
<tr>
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<td>2550+j 142</td>
<td>13.4</td>
<td>44000</td>
<td>70</td>
</tr>
<tr>
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<td>0</td>
<td>2730+j 375</td>
<td>7.90</td>
<td>61000</td>
<td>68</td>
</tr>
</tbody>
</table>

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 Ta2Os 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 Ta2Os content. The Ta2Os 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 2.5μm reflecting the decrease of $P_h$ and $P_e$ by an addition of 0.1wt% Ta2Os. And $P_{cv}$ shows the minimum value at a grain size of 2μm. This is contributed to the increase of $P_h$ with the increase of Ta2Os 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 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 domain wall motion is proportional to $f_s^2$. Consequently the reduction of $P_r$ may be related to the decrease of an energy loss of damping for domain 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 1 MHz.
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.

REFERENCES