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Initial Permeability Dependence on the Microstructural and Compositional Changes in Ni-Zn-Sc Ferrites

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Abstract. Observed variations in density, grain size and initial permeability ($\mu_\text{dc}$) in two series of Ni-Zn-Sc ferrites with varying concentrations of zinc and scandium have been discussed in terms of their microstructural and compositional changes. Initial amounts of scandium enhanced densification and sintering in both the series. Subsequent concentrations of only scandium caused reduction in $\mu_\text{dc}$ in Series-I, whereas simultaneous substitutions of zinc and scandium together resulted in an increase in $\mu_\text{dc}$ in Series-II. Conclusions have been drawn towards the domination of the microstructural changes in series-I and compositional changes in series-II in the study of initial permeability.

1. INTRODUCTION

Ni-Zn ferrites with their ease in preparation and versatility for use in wide ranging applications are very attractive materials from the commercial point of view. Microstructural and magnetic properties of these ferrites are highly sensitive to the preparation methodology, sintering conditions and to the amount of constituent metal oxides and impurities present in them. There have been number of reports in this regard indicating the influence of chemical composition [1,2] and microstructure [3,4] on the initial permeability of ferrites. The present work is aimed at elucidating such aspects as whether are the microstructural or the compositional changes played dominantly in determining the permeability in certain Ni-Zn-Sc ferrites.

2. EXPERIMENTAL DETAILS

Polycrystalline Ni-Zn-Sc ferrites with the following structural formulae $\text{Ni}_0.65\text{Zn}_{0.35}\text{Fe}_{2x}\text{Sc}_x\text{O}_4$ with $x$ values ranging from 0.00 to 0.25 in steps of 0.05 (Series-I) and $\text{Ni}_{0.65+x}\text{Zn}_{0.35+x}\text{Fe}_{2x}\text{Sc}_x\text{O}_4$ with $x$ values ranging from 0.000 to 0.125 in steps of 0.025 (Series-II) have been sintered at 1300°C for 4 hours in air atmosphere. X-ray studies confirm single phase spinel structure in all the samples. Permeability measurements were made at 10 KHz by using HP4192A Impedance Analyzer under the magnetic field of less than 0.1 mT. Saturation magnetization studies were made by the Ponderometer method. Microstructures have been taken by using JEOL T330A SEM.

3. RESULTS

Table-I gives the values of % bulk density, grain size and saturation magnetization (Ms) of various Ni-Zn-Sc ferrites in both the series. For lower concentrations of scandium, density and grain size are found to increase in both the series and at higher concentrations they remained almost unaltered. Simultaneous substitutions of zinc and scandium at higher concentrations improved Ms values in Series-II. Typical microstructures for some samples are shown in Fig.1.

![Typical microstructures of Ni-Zn-Sc ferrites](http://dx.doi.org/10.1051/jp4:1997191)
The microstructures of all the substituted samples are characterized by large grains with number of small pores trapped inside the crystallites, while the microstructure of the undoped sample shows no intragranular pores. The initial permeabilities were corrected for density following the procedure adopted by Globus [3]. The variations in corrected initial permeability ($\mu_{oc}$) with 'x' at room temperature for the two series are given in Figs. 2a and 2b. The $\mu_{oc}$ has been observed to decrease with the increase in $x$ in Series-I whereas it increased with 'x' in Series-II.

<table>
<thead>
<tr>
<th>$N_{0.65}$ Zn$_{0.35}$ Fe$_2$O$_4$ Sc$_2$O$_3$</th>
<th>$N_{0.65}$ Zn$_{0.35}$ Fe$_2$O$_4$ Sc$_2$O$_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$</td>
<td>Grain size, $\mu$m</td>
</tr>
<tr>
<td>0.00</td>
<td>7.5</td>
</tr>
<tr>
<td>0.05</td>
<td>12.3</td>
</tr>
<tr>
<td>0.10</td>
<td>12.0</td>
</tr>
<tr>
<td>0.15</td>
<td>12.0</td>
</tr>
<tr>
<td>0.20</td>
<td>10.3</td>
</tr>
<tr>
<td>0.25</td>
<td>10.0</td>
</tr>
</tbody>
</table>

4. DISCUSSION

Observed higher values of density and grain size in first doped samples of each series indicate that Sc$_2$O$_3$ enhances sinterability and thereby promoting densification as well as grain growth processes. This has been attributed to the increase in bulk diffusivity. For subsequent concentrations of Sc, though the variations in grain size are not significant in any of the series, slightly lower values of grain size are observed in both the series compared to those of first doped samples. The observed changes in grain size have been correlated to insolubility of Sc in Series-I and the presence of increasing Zn content in Series-II. Dispersed second phase inhibit the grain boundary mobility thus decreasing the sintering and grain growth rates [5], while Zn substitution on the other hand is known to decrease crystalline anisotropy and exchange energy which in turn decrease the domain wall spacing, as a result smaller crystallites are to be expected with increasing Zn content [6].

The decrease of $\mu_{oc}$ in Series-I is interpreted on the basis of observed microstructures. Since the grain sizes do not differ much for various samples in a given series, this is not expected to bring about a significant change in $\mu_{oc}$. However, the microstructures with number of small pores inside the crystallites hinder the domain wall motion thereby decreasing its contribution to $\mu_{oc}$ [6]. Further, at higher concentrations of scandium, there appears a discontinuous grain growth which may be due to the increased insolubility of scandium in the matrix. When these insoluble nonmagnetic impurities (i) if lie between the grains, they introduce wall discontinuity across the grain boundaries [2], and (ii) if present inside the grains, they hinder the reversible motion of the domain walls [7]; both invariably decrease the $\mu_{oc}$.

In the microstructures of Series-II, except for the sample with $x=0.025$, a fewer number of pores are taken place inside grains. Besides, the slightly higher values of Ms in this series as compared to those in Series-I, which are a consequence of the changes in composition have resulted an increase in the $\mu_{oc}$. For the sample at $x=0.025$, eventhough there is an increase in Ms, the $\mu_{oc}$ has not shown a corresponding increase because of the defective microstructure of that particular sample.

In conclusion, the microstructural changes marked by more number of intragranular pores and insoluble nonmagnetic impurities played dominantly in decreasing the $\mu_{oc}$ with 'x' in Series-I, while the compositional changes of simultaneous substitutions in Series-II have contributed to improve the Ms primarily and thereby the $\mu_{oc}$ in that series.

References