Effect of Additions and Oxygen Partial Pressure on the Electromagnetic Properties of High Frequency MnZn Ferrites

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Abstract. The effect of dopant and low oxygen partial pressure during sintering on the magnetic properties of MnZn ferrites for use in high frequency power supplies was studied. A low partial pressure of oxygen in the sintering atmosphere and a proper temperature profile during sintering decrease the average grain size, while the dopant, which segregates to the outer grain region, increases the grain boundary resistivity resulting in a lowering of power loss.

1. INTRODUCTION

The miniaturisation of electronic devices demands a permanent increase of the driving frequency of switch mode power supplies. Therefore, reduction of the power loss of core materials at high frequency is an important challenge. The main motivation for using MnZn ferrites in transformer cores are their very low eddy current losses on account of the much higher electrical resistivity of ferrites in comparison to metals [2].

At higher operating frequencies, above 500 kHz, the contribution of the eddy current loss (P_E) to the total loss is dominant. Thus, when the power loss of MnZn ferrites is to be decreased the suppression of the eddy current loss is of essential importance. To decrease (P_E) successfully two key parameters must be modified; the average grain size (D) and the grain boundary resistivity $\rho_{gr.b.}$ [3,4]. Average grain size can be decreased by selecting a sintering profile which includes a low concentration of oxygen in the sintering atmosphere [5]. On the other hand, the grain boundary resistivity can be effectively improved by doping the MnZn ferrite with aliovalent ions which segregate to the outer grain region [6]. In this contribution the combined effect of a low oxygen partial pressure and additions of Ta_2O_5 during sintering was studied.

2. EXPERIMENTAL

A ferrite powder of composition $Mn_{0.66}Zn_{0.27}Fe_{2.07}O_4$ with additions of 0.2% Ta_2O_5 was prepared by the conventional ceramic processing method using chemical grade oxides. The average grain size of the ferrite powder after calcination and milling was about 1.5 µm. The powder was granulated and toroids were pressed to the dimensions OD = 22 mm, ID = 10 mm, and h = 5 mm. Samples were sintered in a computer-driven furnace at a temperature of 1280°C for 4 hours. The samples labelled as 1, 2, 3 and 4 were sintered at 20, 10, 5 and 1 vol.% of oxygen, respectively, and were doped with 0.2 wt.% Ta_2O_5. The samples labelled a, b, c and d were sintered at the same vol.% of oxygen but they were not doped. The sintered samples were characterised; the density was measured, average grain size determined, and grain boundary resistance measured by the use of impedance spectroscopy. The power loss of the samples was determined at frequencies of 100, 200, 300, 400, 500 and 700 kHz (50 mT) and 20°C, 60°C, 80°C and 100°C using a Clarke and Hass 258 W meter. P_H and P_E were obtained by extrapolating of the P/f-f plots to f= 0, where f is the frequency.

3. RESULTS AND DISCUSSION

The power loss of samples doped with 0.2 wt.% of Ta_2O_5 (A) and undoped samples (B) sintered at various oxygen concentrations is shown in Fig. 1. Samples 2, 3 and a, b, sintered at 10 and 5% of oxygen, respectively, exhibit the best magnetic properties, i.e. the lowest power loss.

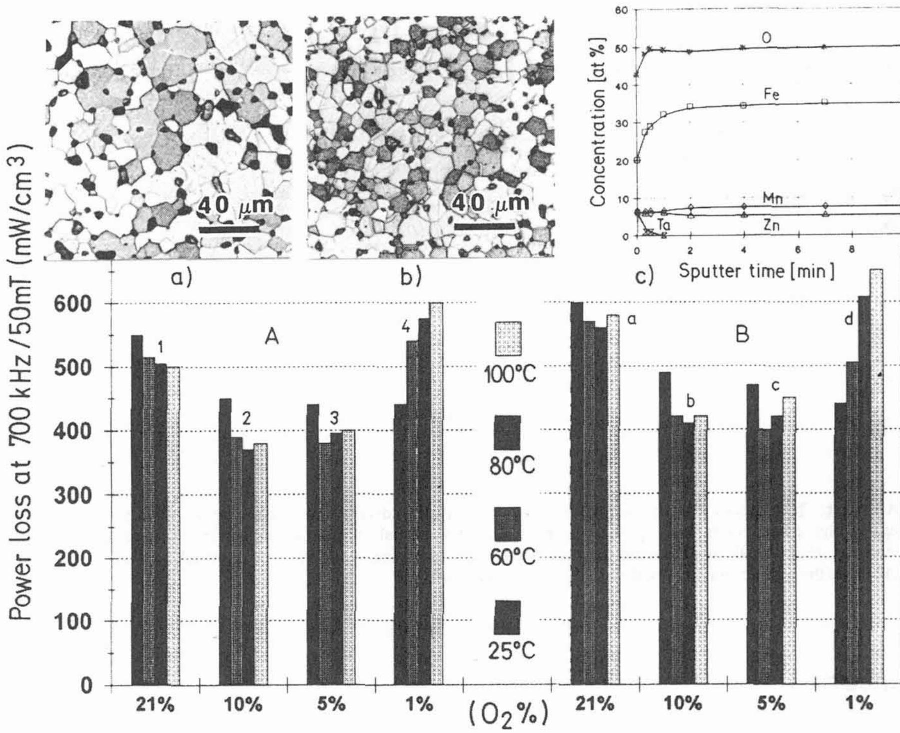

Figure 1a,b,c: Temperature dependence of power loss of samples sintered at various oxygen concentration (A) doped with Ta_2O_5 and (B) undoped, with typical microstructures of samples a) sintered at 21% of oxygen and b) sintered at 1% of oxygen. The insert c) show the concentration depth profile obtained by AES of a doped sample.

Table I: Density (ρ), thr. density (T.D.), average grain size($\overline{D}$), grain boundary resistivity ($\rho_{gr.b.}$), total loss (P_V) and eddy current loss (P_E).

ρ (g/cm^3)	T.D. (%)	$\overline{D}$ (μm)	$\rho_{g.b.}$ (Ω cm)	P_E80°C (mW/cm^3)	P_V80°C (mW/cm^3)	Sample Code	ρ (g/cm^3)	$\overline{D}$ (μm)	$\rho_{g.b.}$ (Ω cm)	P_E80°C (mW/cm^3)	P_V80°C (mW/cm^3)
4.73	92.7	12.3	164	499	541	1,a	4.73	11.2	95	553	581
4.75	93.1	10.4	153	352	387	2, b	4.73	10.6	87	406	427
4.77	93.5	9.1	145	362	390	3, c	4.78	9.9	63	401	422
4.82	94.5	8.1	151	534	576	4, d	4.85	8.2	52	583	632

The density of the samples increases on lowering the amount of oxygen in the sintering atmosphere, while the average grain size decreases. No significant differences in the average grain size were noted between doped and undoped samples; however, there is an essential difference in the grain boundary resistance. Samples doped with Ta_2O_5 exhibit an appreciably higher resisttivity (Table I). Typical microstructure of samples sintered at different partial pressures of oxygen is shown in Figs. 1a,b. From the results presented above, we can see that both a lowering ofthe oxygen concentration during sintering and doping of samples with Ta_2O_5, which segregates to the grain boundary (as can be seen from the conc. depth profile in Fig. 1c), lead to lower power loss. It can be shown that the eddy current loss depends on the ratio between the average grain size and the grain boundary resistivity [3,9]. At higher frequencies where the hysteresis loss can be ignored, the total loss P_V is therefore proportional to $\overline{D}/\rho_{g.b.}$. Thus, the beneficial influence of a low oxygen pressure during sintering and of the addition of Ta_2O_5 is mainly due to the formation of a fine microstructure and an increase of the grain boundary resistivity.

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