High permeability MnZn ferrite for wide-temperature applications

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High-TC high-permeability MnZn ferrite with excellent temperature stability was developed by addition of SnO2 and optimizing of sintering conditions. With increasing the SnO2 content, the temperature of the second permeability peak Tsp decreases while the Curie temperature TC maintains as high as 160 ℃, guaranteeing the high initial permeability μi in a wide temperature range. Permeability of the sample with 6000 ppm SnO2, μi at 25 ℃ is 7244 and exhibits excellent temperature stability with the low specific temperature coefficient of 0.35×10-6 ℃-1 between 25 and 130 ℃. The addition of SnO2 generates Fe2+ and adjusts the magneto-crystalline anisotropy constant K1 = 0 point, which is responsible for the wide-temperature high permeability.

Keywords: MnZn ferrites, high permeability, additives, soft magnetic materials.

1. Introduction

MnZn ferrites have been widely applied in the fields of electronic communications, new energy vehicles, consumer electronics, smart grid and military products. Due to the variable temperature of working environments such as new energy vehicles and 5G communications, MnZn ferrites are required to maintain high permeability over a wide temperature range up to over 150 °C. Thus, it is vital to develop the high-T_C high-permeability MnZn ferrite with excellent temperature stability.

In this work, we developed high-T_C and high-permeability MnZn ferrites by the SnO_2 additive. The best sample shows an excellent temperature stability of permeability in a wide temperature range.

2. Results and discussion

XRD patterns of MnZn ferrites with different SnO_2 addition show that all sintered samples present a single-phase spinel structure. The cross-section SEM images and the corresponding grain size distributions for the samples with different SnO_2 addition show that the addition of SnO_2 results in an increase of average grain size (D_{ave}) and D_{ave} reaches a maximum of 32.8 μm.

High-angle annular dark-field transmission electron microscopy (TEM) images and the corresponding element distributions of the sample with 6000 ppm SnO_2 additive (Fig. 1) shows that Si and Ca are aggregated at the grain boundaries, while Sn is uniformly distributed with no obvious aggregation, indicating that Sn^{4+} ions dissolve in the lattice.

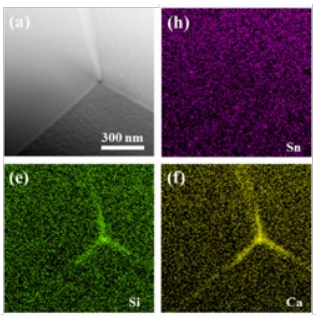

Fig. 1. TEM images and the distributions of Sn, Si and Ca.

Figure 2 shows the temperature dependence of initial permeability [$\mu_i(T)$] for samples with different SnO_2 additions. μ_i of all samples maintains high values above 6000 between the first and second peaks, and decreases below the secondary peak temperature (T_{sp}), while the Curie temperature (T_C) maintains as high as 160 °C and concurrently T_{sp} moves to the lower temperature with increasing SnO_2 addition. The T_Cs in this series of samples are higher than the T_Cs of 120~130 °C in general high-permeability MnZn ferrites. The T_{sp} decreases to 25 °C when SnO_2 addition increases to 6000 ppm (Fig. 2). Hence μ_i maintains high values above 6000 in a wide temperature range from room temperature to 150 °C, makes them suitable to work at higher temperatures compared to general high-permeability MnZn ferrites.

The position of T_{sp} is related to the temperature corresponding to the magneto-crystalline anisotropy constant $K_1 = 0$. The K_1 value of MnZn ferrites is negative whereas that of Fe^{2+} is positive. In this series of samples, the Sn^{4+} replacement of Fe^{3+} produces Fe^{2+} due to $2Fe^{3+} \rightarrow Sn^{4+} + Fe^{2+}$. The Fe^{2+} content increases with the addition of SnO_2. As K_1 of Fe^{2+} is positive and that of MnZn ferrite is negative, which leads to $K_1 = 0$ at a certain temperature. There is an inverse association between μ_i with the absolute value of K_1, so the temperature of $K_1 = 0$ corresponds to the second peak temperature T_{sp} in the $\mu_i(T)$ curve. The generation of more Fe^{2+} ions results in the $K_1 = 0$ point shifting to the lower temperature. Therefore, T_{sp} also shifts to lower temperature.

The addition of SnO_2 reduces T_{sp} and μ_i at high temperatures, consequently enhances μ_i at T_1 = 25 °C, improving the temperature stability of μ_i. The sample with 6000 ppm SnO_2 shows an excellent temperature stability with α_μ/μ of 0.35×10^{-6} °C^{-1}, which makes it suitable to apply in scenarios of wide working temperature, such as 5G tele-communication base station and new energy vehicle.

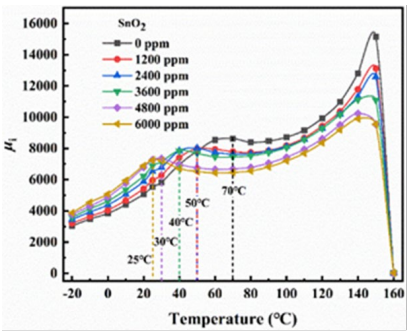

Fig. 2. μ_i versus temperature for samples with different SnO_2 additions.