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Effect of Co_2Y additive on power loss of $Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrites

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Abstract

$Ba_2Co_2Fe_{12}O_{22}$ (Co_2Y, 0 wt%, 2 wt%)-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ polycrystalline ferrites are prepared by solid-state reaction method, and the magnetic properties of ferrites are investigated. Magnetic measurements show that the magnetic loss is obviously decreased with Co_2Y addition. Loss separation reveals that both hysteresis loss and eddy current loss reduce significantly after Co_2Y addition. The mechanism of magnetic loss decreasing due to Co_2Y additive is discussed, and the decrease of magnetic hysteresis loss and eddy current loss caused by Co^{2+} cation doping was regarded as the main reason for the observed power loss decrease in ferrites and insulating grain boundary composed by barium compound which plays a role in decreasing eddy current loss. The Q value of Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrite was much higher than that of $Ni_{0.8}Zn_{0.2}Fe_2O_4$ sample which can be used as inductors for high-frequency applications.

1 Introduction

Ni–Zn ferrites are important soft magnetic materials with numerous applications in electronics and communication technologies. High electrical resistivity, high cutoff frequency, broadband and low magnetic losses make Ni–Zn ferrite an obvious choice as a magnetic core material for high-frequency applications. In comparison, M-type ferrites with hexagonal structure are suitable as higher-frequency soft magnet ferrites [1–6], but they have a relatively large hysteresis loss, so Ni–Zn ferrites are suitable for application in the 1–200 MHz band. Different applications need different characteristics of ferrites, which can be achieved by doping of suitable cations in materials [5–16]. For example, manganese dioxide doped in nickel–zinc ferrites can decrease the magnetic loss in materials [17–19]. The nickel–zinc ferrites applied as inductance cores in radio frequency band-pass filters need high-temperature stability of permeability and low magnetic loss, and the temperature stability of common nickel zinc ferrites cannot meet this requirement. It was reported that Co_2Y added to nickel–zinc ferrites can obviously improve the temperature stability of permeability [20–24] and improve DC-bias superposition characteristics [25]. However, only a few works have been done on the effect of Co_2Y addition on magnetic power loss in Ni–Zn ferrites [25, 26], so the influence of Co_2Y additive on magnetic loss in Ni–Zn ferrites is investigated in this paper.

2 Experiment

The ferrite samples are prepared by solid-state reaction method. Reagent-grade Ni_2O_3, ZnO, and Fe_2O_3 are used in the required proportion in the chemical formula $Ni_{0.8}Zn_{0.2}Fe_2O_4$, the mixtures are milled thoroughly in agate mortar to ensure the raw materials are mixed evenly and then calcined at 1050 °C for 3 h in air. The resulting mixtures are reground to reduce them into micron-sized particles. The obtained powder is divided into two parts, and 2% weight ratio Co_2Y powder is added in one part. Every part is mixed thoroughly and then pressed in a toroidal shape in 200 MPa pressure using 5% PVA solution as the binder. The toroidal green samples are sintered for 3 h at 1220 °C in air followed by natural cooling to room temperature. The crystal structure of obtained ferrite samples is investigated by X-ray diffractometer (XRD, Mac Science MPX18AHF, Cu Kα radiation), and the power losses of ferrite are measured by BH analyzer (Iwatsu SY-8258) and the measurement error is controlled at 1%.

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3 Results and discussion

As shown in Fig. 1a, b, the XRD patterns of $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrite powders match well with the standard XRD data for spinel phase; no other phases can be found in the patterns. Initial permeability measurement shows that Co_2Y addition caused decrease in permeability (from 28 to 20). Power loss data at different magnetic flux densities and frequencies are measured for ferrite samples. The magnetic flux density (B_m) dependence of power loss of $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrites at 200 kHz is shown in Fig. 2. It is found that the power loss of Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrite is about half of $Ni_{0.8}Zn_{0.2}Fe_2O_4$ sample, which indicated that moderate addition of Co_2Y in Ni–Zn ferrites could dramatically decrease the power loss of sample [26].

The measured magnetic loss dependence on the frequency of two samples at $B_m = 6$ mT is shown in Fig. 3 and it is found that the measured power loss increases with increase of frequency. Compared with Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$, the power loss of $Ni_{0.8}Zn_{0.2}Fe_2O_4$ sample is about twice of the former, which also shows that the power loss of $Ni_{0.8}Zn_{0.2}Fe_2O_4$ obviously decreased with Co_2Y additive.

The measured power loss includes hysteresis loss, eddy current loss and residual loss. It is regarded that the power loss can be separated using the empirical Legg formula at low frequency and low magnetic flux density range [27]. To investigate the Co_2Y additive influence on hysteresis loss, the relative loss factor ($\tan\delta/\mu'$) versus magnetic flux density at 500 kHz is measured for Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ and $Ni_{0.8}Zn_{0.2}Fe_2O_4$ samples. The measured data are shown in Fig. 4. Theoretically, $\tan\delta/\mu'$ vs B_m obeys a simple linearity, as predicted by the Legg formula:

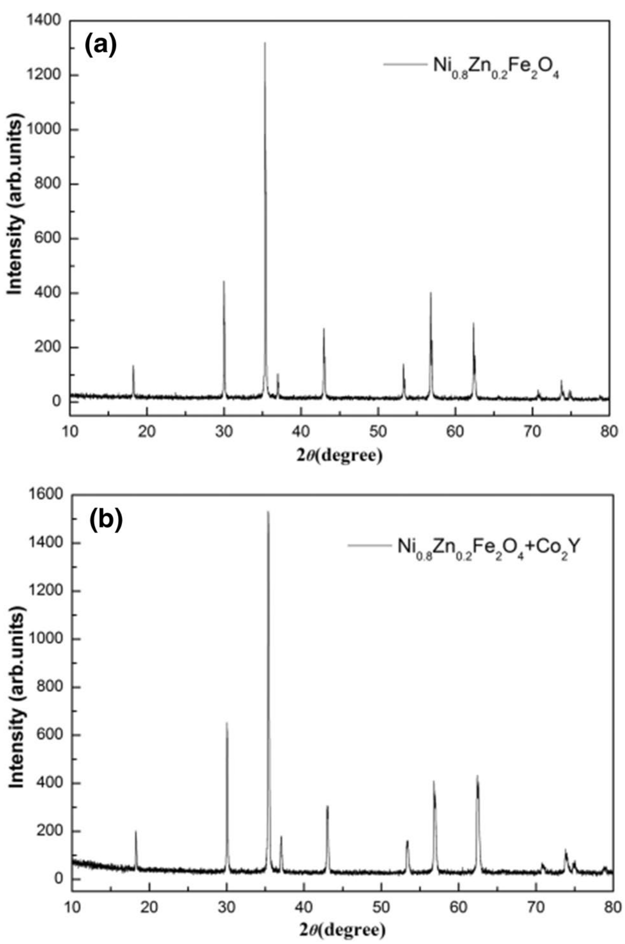

Fig. 1 Powder XRD patterns of $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrites

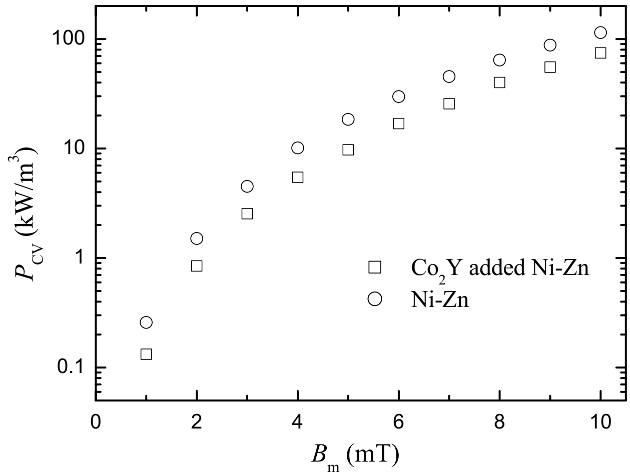

Fig. 2 Variation of power loss versus magnetic flux density of $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrites at 200 kHz

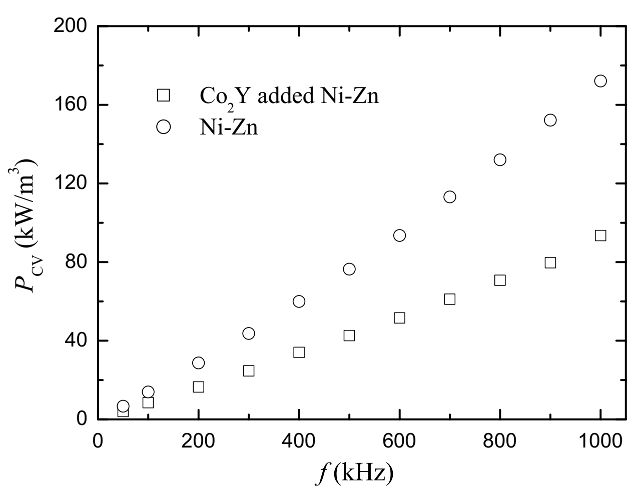

Fig. 3 Variation of power loss versus frequency of $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ferrites at $B_m = 6$ mT

$$\frac{\tan\delta}{\mu'} = \frac{1}{2\pi}(aB_m + ef + c) \quad (1)$$

where f is frequency, a, e and c are hysteresis loss coefficient, eddy current loss coefficient and residual loss coefficient, respectively. The Legg formula tells that the slope represents hysteresis loss coefficient. Compared to the experimental results in Fig. 4, it can be found that the linear slope of $Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrites is bigger than that of Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ sample. The hysteresis loss coefficient obtained from the linear fitting of measured data in Fig. 4 is 3.4×10^{-5}/mT and 2.3×10^{-5}/mT for $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ samples, respectively, which indicates that the hysteresis loss of Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ is about two-thirds of $Ni_{0.8}Zn_{0.2}Fe_2O_4$ under the same test condition.

The hysteresis loss performance of ferrite can be observed by measuring its hysteresis loop. The amount of energy lost in the material in one cycle of the applied field is proportionate to the area inside the hysteresis loop. Figure 5 gives the room temperature magnetic hysteresis loop for $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ samples measured at 10 mT and 1 MHz. It can be found in Fig. 5 that the Co_2Y addition obviously reduced the area of hysteresis loop, in spite of the decrease in permeability. The hysteresis loops in Fig. 5 also indicate that hysteresis loss decreases with Co_2Y addition in Ni–Zn ferrites.

The influence of Co_2Y addition in $Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrite on the eddy current loss can also be investigated using the Legg formula. The measured $\tan\delta/\mu'$ as a function of frequency for $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ samples at $B_m=6$ mT is shown in Fig. 6. It was noted that the measured $\tan\delta/\mu'$ linearly increased with increasing f, which was consistent with Formula (1). The

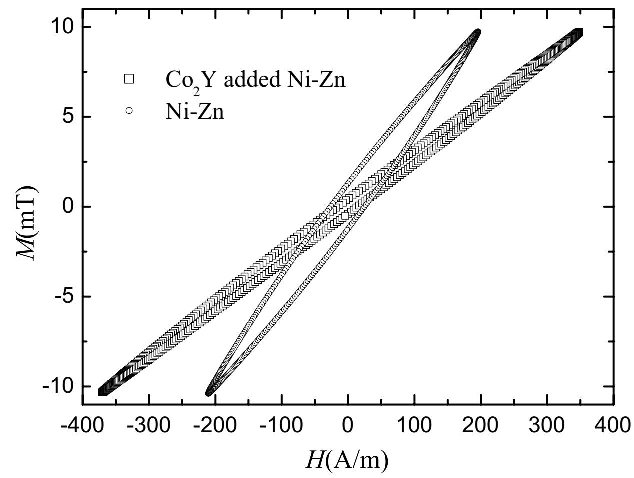

Fig. 5 Room temperature magnetic loops of $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrites measured at 1 MHz and 10 mT

eddy current loss coefficient obtained from the linear fitting of measured data in Fig. 6 is 6.9×10^{-11} s and 2.3×10^{-11} s for $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ samples, respectively, which indicates that the eddy current loss of Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ is about one-third of $Ni_{0.8}Zn_{0.2}Fe_2O_4$ under the same measurement conditions. Experimental data indicate that Co_2Y added in $Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrite can obviously reduce the eddy current loss. Considering that the eddy current loss would play a dominant role at high frequency, Co_2Y-added Ni–Zn ferrites are more suitable for high-frequency applications [25].

The above experimental results show that the addition of Co_2Y reduced the power loss of ferrite to about half of the $Ni_{0.8}Zn_{0.2}Fe_2O_4$ sample at the same frequency

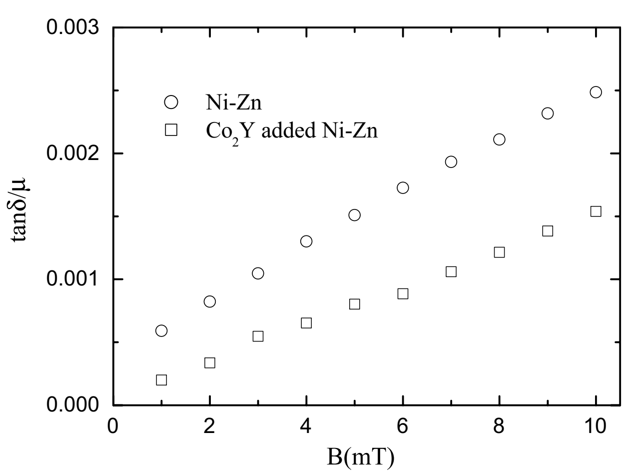

Fig. 4 Variation of relative loss factor versus magnetic flux density of $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ samples at 500 kHz

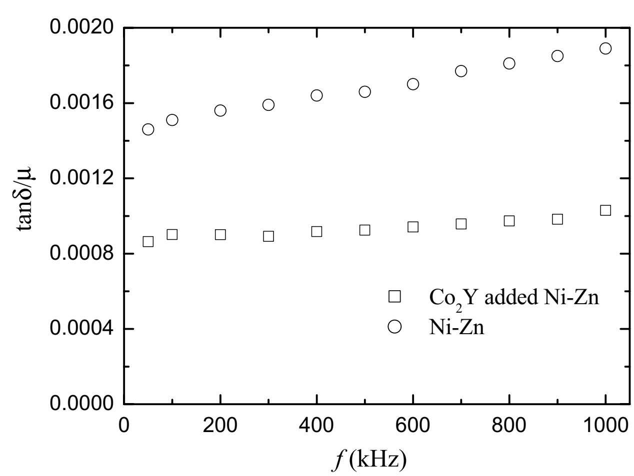

Fig. 6 Variation of relative magnetic loss factor $\tan\delta/\mu'$ versus frequency of $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ samples at 6 mT

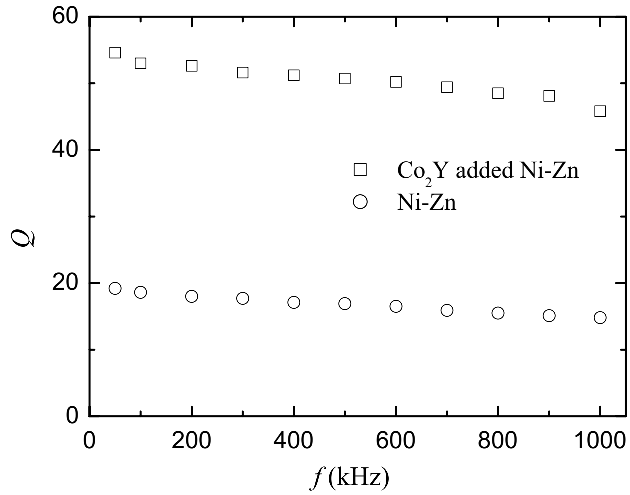

Fig. 7 Variation of relative magnetic quality factor (Q) versus magnetic flux density of $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ samples at 6 mT

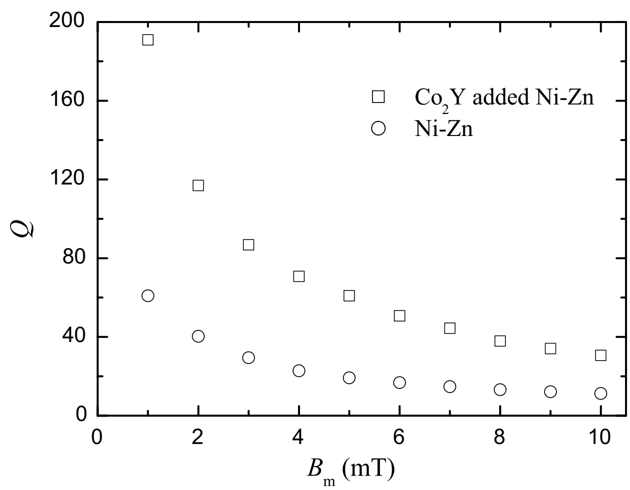

Fig. 8 Variation of relative magnetic quality factor (Q) versus frequency of $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ samples at 200 kHz

and magnetic flux density. Considering that the permeability of Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ is less than that of $Ni_{0.8}Zn_{0.2}Fe_2O_4$, the field energy stored in the Co_2Y-added Ni–Zn is more than that in Ni–Zn ferrite with the same magnetic flux density. The reduction of power loss due to the addition of Co_2Y is underestimated, in case of the same magnetic flux density. The Q factor of two samples is measured to compare the ratio of stored field energy to power loss in one cycle, and the variation of Q factor with magnetic flux density and frequency is shown in Figs. 7 and 8. It could be found that the Q value of Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrite is about three times higher than that of $Ni_{0.8}Zn_{0.2}Fe_2O_4$ sample in Figs. 7 and 8, which shows that the difference in Q value between the two samples is more obvious than that of power loss.

The reason for power loss reduction caused by Co_2Y addition in Ni–Zn ferrites can be analyzed as follows. Co_2Y cannot form a single phase, which reveals that Y-type ferrite is unstable at a high temperature [28]. It is considered that Co_2Y added to Ni–Zn ferrites decomposes at a high temperature, and Co^{2+} ion enters the spinel lattice. The addition of Co^{2+} in spinel improves the performance, as validated by the reduction of power loss, however at the expense of μ_i [29]. It is regarded that Co^{2+} doping is the main reason for hysteresis loss reduction in Ni–Zn ferrites. Ba^{2+} ion cannot enter lattice due to its big radius, so it concentrates on the grain boundary to form a high-resistance layer, which leads to a reduction in eddy current loss. On the other hand, the presence of Co^{2+} stabilizes Fe^{3+}, as its third ionization energy is higher than that of Fe^{2+}, which also reduces eddy current loss [29].

4 Conclusions

In summary, $Ni_{0.8}Zn_{0.2}Fe_2O_4$- and Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrite samples are prepared by solid-state reaction method and their magnetic properties are investigated. Magnetic measurements show that the magnetic loss obviously decreased after Co_2Y addition. Magnetic loss separation indicates that the hysteresis loss coefficient and eddy current loss coefficient both decreased due to the addition of Co_2Y to Ni–Zn ferrites. The Q value of Co_2Y-added $Ni_{0.8}Zn_{0.2}Fe_2O_4$ ferrite is about three times higher than that of $Ni_{0.8}Zn_{0.2}Fe_2O_4$ sample. The reduction of hysteresis loss caused by Co^{2+} cation doping in Ni–Zn ferrite and decrease in eddy current loss are considered to be the formation of high-resistance insulating grain boundary containing the barium compound. The obvious reduction of eddy current loss reveals that Co_2Y-added Ni–Zn ferrites are more suitable for high-frequency applications.

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