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NiZn Ferrite Coating for Electrical Insulation of MnZn Ferrite Cores

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ABSTRACTS

The ferrite plating with applying power ultrasound waves of 19.5 kHz and 600 W enabled us to encapsulate entirely MnZn ferrite cores for transformers with $Ni_xZn_yFe_{3-x-y}O_4$ coating. Supplying a NH_4OH solution during the plating broke the limit of the solubility of Ni ions to ferrite-plated films. The electrical resistivity of the NiZn ferrite coating increased with increasing the Ni and Zn content, reaching 2.3×10^5 Ωcm at the composition of $Ni_{0.24}Zn_{0.30}Fe_{2.46}O_4$. The saturation magnetization was 540 emu/cm ^{3}. As a result, the MnZn ferrite cores were successfully encapsulated with the NiZn ferrite coatings for an insulation layer.

Key words : Ultrasound waves, Ferrite plating, NiZn ferrite, Electrical insulation, Ferrite core

1. Introduction

MnZn ferrite is used as cores of coils for transformers and inductors in electrical circuits. While it has good soft magnetic characteristics, its surface requires an insulation coating due to its low electrical resistivity. Though ferrite coatings with higher resistivity such as NiZn ferrite is the best way to insulate the MnZn ferrite cores, physical vapor deposition methods such as sputtering and vacuum evaporation cannot encapsulate the cores with complex shapes. The ferrite plating enables us to entirely coat substrates of various shapes, since it is a wet process.[1-3] The method with power ultrasound enhancement improved the microstructure and increased the Ni content in the NiZn ferrite films compared to other ferrite-plating methods by the sonochemical reaction.[4] However, the stoichiometric NiZn ferrite films were not synthesized by the ferrite plating because Ni ions were hard to include into the films compared with Zn ions. Since the Ni ions are easy to adsorb onto the substrate in a high pH range, a NH_4OH solution was supplied with a reaction solution. Magnetic and electrical properties of the $Ni_xZn_yFe_{3-x-y}O_4$ films on glass substrates were investigated, and the surface electrical resistance of MnZn ferrite cores coated with the NiZn ferrite films was also measured.

2. Experimental

Fig. 1 shows an apparatus for the ultrasound-enhanced ferrite plating. Ultrasound waves (19.5 kHz, 600 W) were applied by a horn (30 mm ϕ) to an aqueous reaction solution of 15 cm^3. The conditions of the solutions for NiZn ferrite are listed in Table 1. Both reaction and oxidizing solutions were supplied at the flow rate of 3.0 cm^3/min. The reaction temperature was 85°C. The reaction time was 20-30 min, and the film thickness was 0.25-0.35 μm. The substrates were glass and MnZn ferrite cores. The outer diameter, the inner diameter and the width of the MnZn ferrite core were 10, 5 and 4 mm, respectively. The composition of the films was determined by inductively coupled plasma spectroscopy.

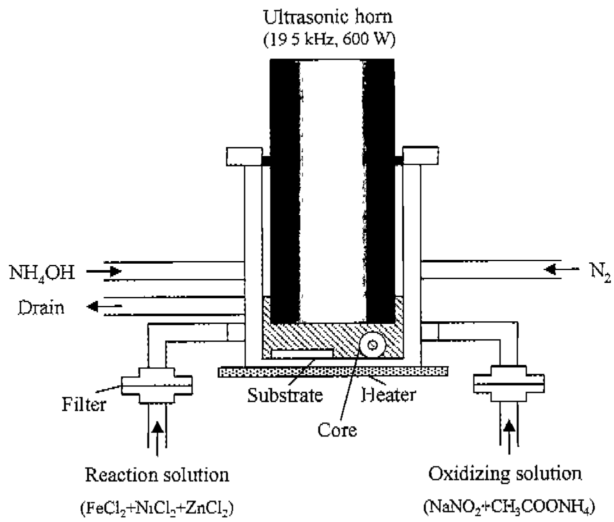

Fig. 1. Ultrasound-enhanced ferrite-plating apparatus.

Table 1. Conditions for NiZn Ferrite Thin Film

Reaction solution	$FeCl_2{\cdot}4H_2O$	0.05 mol/*l*
	$NiCl_2{\cdot}6H_2O$	0.0042-0.011 mol/*l*
	$ZnCl_2$	0.00073-0.0051 mol/*l*
Oxidizing solution	$NaNO_2$	0.0029-0.017 mol/*l*
	CH_3COONH_4	0.32 mol/*l*

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The thickness of the films was determined by a scanning electron microscope. The magnetic properties were analyzed by a vibrating sample magnetometer (VSM). The electrical resistance on glass substrates was measured by the four-probe method. The surface resistance of the core was measured by the two-probe method using the ultra-high resistance meter.

3. Results and Discussion

3.1. Film composition and magnetic properties

Fig. 2 shows the dependence of the content of (a) Ni and (b) Zn in the films on the ion ratio Ni^{2+}/Fe^{2+} and Zn^{2+}/Fe^{2+} in the reaction solution. In Fig. 2 (a), Ni^{2+}/Fe^{2+} in the reaction solution was varied, and Zn^{2+}/Fe^{2+} was kept constant. While the Zn content in the films was kept almost constant at y=0.57, the Ni content increased with increasing Ni^{2+}/Fe^{2+}. On the other hand, the Zn content increased with increasing Zn^{2+}/Fe^{2+} in Fig. 2 (b). These results suggest that Zn and Ni ions exist in the A and B site of the spinel structure in the $Ni_xZn_yFe_{3-x-y}O_4$ plated films, respectively, and Zn and Ni ions do not compete for their sites.

Fig. 3 shows the XRD diagrams for various Zn^{2+}/Fe^{2+}. It was observed that spinel ferrites were obtained in the range of Zn^{2+}/Fe^{2+} from 0.014 to 0.102.

Fig. 4 shows the dependence of the saturation magnetization M_s and the coercive force H_c on the Zn content in the film. M_s was almost constant 400 emu/cm^3 when the content in the films, y, was smaller than 0.5. Then, M_s drastically decreased with increasing the content of Zn. H_c decreased with increasing the content of Zn. From these results, when the ion ratio Ni^{2+}/Fe^{2+} and Zn^{2+}/Fe^{2+} in the reaction solution increased in order to obtain higher resistivity, only the Zn content in the films increased, therefore M_s decreased. Because there is a solubility limit of Ni ions into the ferrite-plated films.

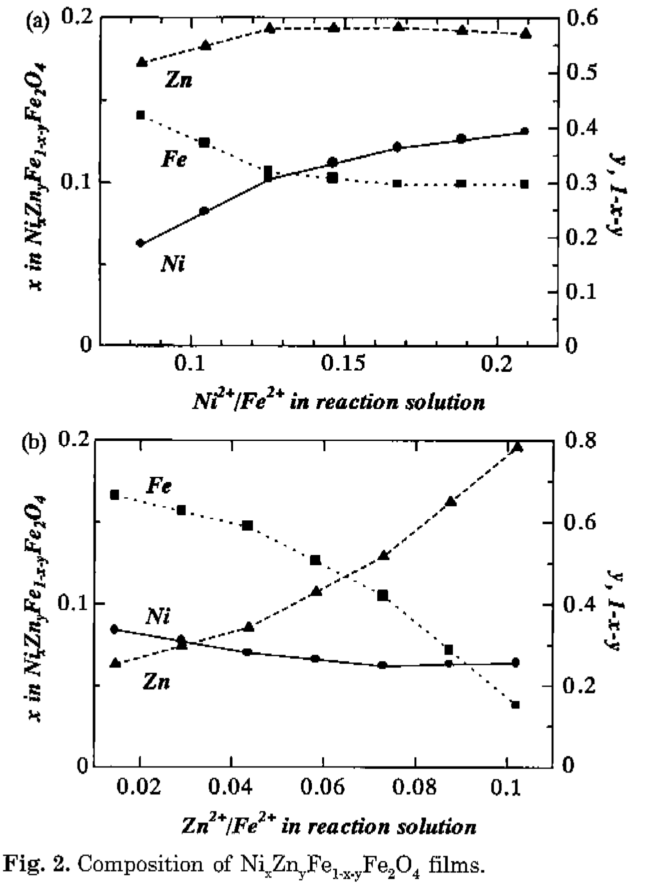

Fig. 2. Composition of $Ni_xZn_yFe_{1-x-y}Fe_2O_4$ films.

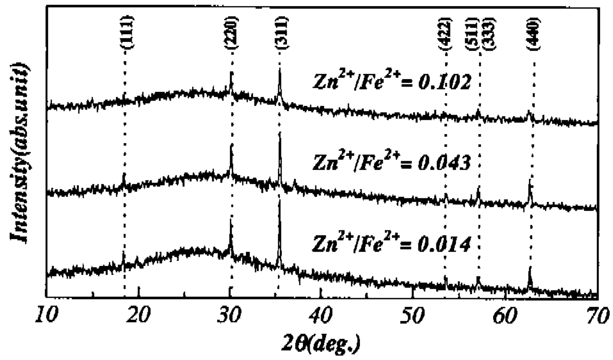

Fig. 3. XRD diagrams of the NiZn ferrite thin films for various Zn^{2+}/Fe^{2+}.

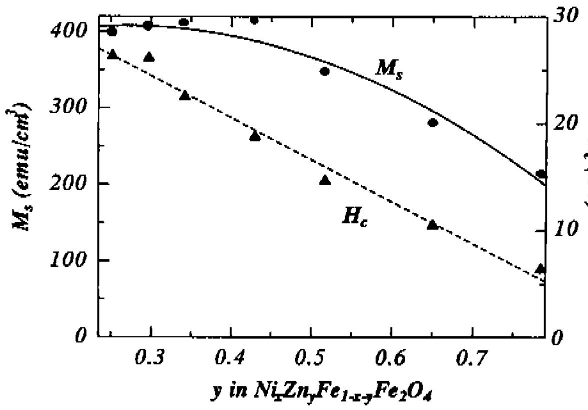

Fig. 4. Dependence of M_s and H_c on Zn^{2+}/Fe^{2+} ratio in the reaction solution.

3.2. Effect of NH_4OH addition on NiZn ferrite film preparation

In the ferrite plating, it is important to control the adsorption of metal ions onto OH groups on substrates. Ni^{2+} ions require higher pH in the solution for the adsorption than Fe^{2+} ions.[5] A NH_4OH solution of 0.0125 mol/l was supplied at the flow rate of 0.2 cm^3/min to increase the pH value in the solution. Fig. 5 shows the dependence of Ni content in the $Ni_xZn_yFe_{3-x-y}O_4$ films on the Ni^{2+}/Fe^{2+} ratio in the solution with and without supplying the NH_4OH solution. Supplying the NH_4OH increased the Ni content, and the maximum value of x was 0.26. Fig. 6 shows the dependence of M_s on the content of Ni and Zn, x+y, in the $Ni_xZn_yFe_{3-x-y}O_4$ films deposition with and without supplying the NH_4OH solution. M_s without NH_4OH decreased with increasing the Ni and Zn content, x+y, but M_s with NH_4OH was kept almost con-

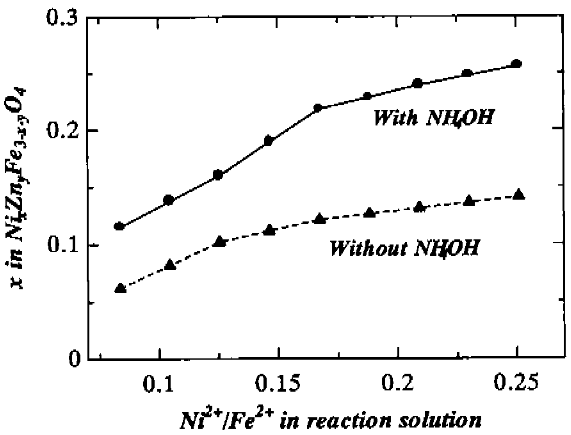

Fig. 5. Dependence of Ni content in the plated films with and without supplying NH_4OH solution.

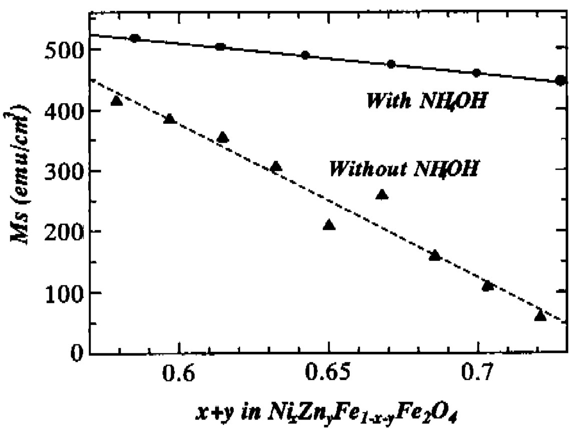

Fig. 6. Dependence of M_s on Ni and Zn content in the films, x+y, in the case with and without supplying NH_4OH solution.

stant. These results mean that supplying NH_4OH increased Ni content in the spinel structure, therefore M_s kept almost constant when the Ni and Zn content in the films increased from 0.582 to 0.727. In the case without NH_4OH, since Zn ions must be increased to increase x+y, M_s decreased as the same as seen in Fig. 4.

3.3. Electrical resistance of NiZn ferrite coatings

Fig. 7 shows the dependence of the electrical resistivity of $Ni_xZn_yFe_{3-x-y}O_4$ films on the content of Ni and Zn. The resistivity increased with increasing the Ni and Zn content, x+y, reaching 2.32×10^5 Ωcm, which is almost the same as the bulk value (10^6 Ωcm) even though x+y is much smaller than 1. These results suggest that the increase of the Ni and Zn

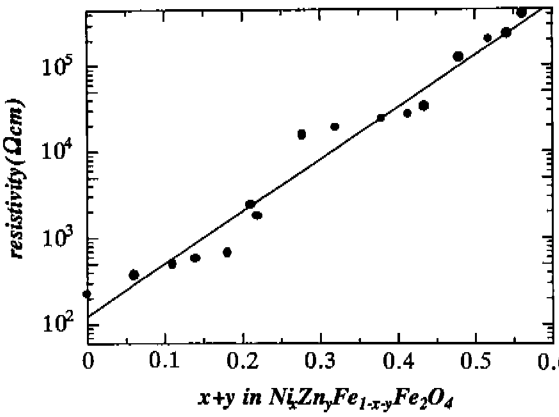

Fig. 7. Electric resistivity of NiZn ferrite films.

ions reduces Fe^{2+} ions that cause the hopping-conduction of electrons with Fe^{3+} ions in the films. The MnZn ferrite cores were successfully encapsulated with the NiZn ferrite coatings by the ultrasound-enhanced ferrite plating method. As a result, the surface resistance was increased from about 10 kΩ to over 100 kΩ.

4. Conclusion

MnZn ferrite cores with low electrical resistance were successfully encapsulated with NiZn ferrite coatings by the ultrasound-enhanced ferrite plating. The resistivity reached 2.32×10^5 Ωcm at the composition of $Ni_{0.24}Zn_{0.30}Fe_{2.46}O_4$ by supplying the NH_4OH solution with the reaction solution to increase the Ni content in the films. As a result, the surface resistance of the MnZn ferrite cores was increased from about 10 to over 100 kΩ.

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