Journal of the Korean Ceramic Society
Vol. 43, No. 11, pp. 700~702, 2006.

# Preparation and Characteristics of the Ni-Ferrite Encapsulated Mo-Permalloy Powder

**Hyun-Kyu Park, In-Geol Ji, Jae-Hee Oh,† and Taegyung Ko**

*School of Materials Science and Engineering, Inha University, Inchon 402-751, Korea*
(Received October 19, 2006; Accepted October 27, 2006)

**ABSTRACT**

We prepared a Ni-ferrite encapsulated Mo-permalloy powder through simple electroless plating and heat treatment. It was observed that Ni-ferrite particles formed in a spherical form on each Mo-permalloy grain. The microstructure and the magnetic characteristics of the encapsulated powders depended strongly on oxidation time in the heat-treatment. When the powder was oxidized for 60 min, a dense Ni-ferrite layer covered the Mo-permalloy grain, which in turn exhibited high saturation magnetization of 85.8 emu/g. The magnetic core prepared additionally with the encapsulated powder exhibited a resonant frequency of 12 kHz.

***Key words*** **: *Magnetic core, Ferrite, Permalloy, Ni-ferrite encapsulated, Mo-permalloy***

## 1. Introduction

Permalloy has been used in electronic components, such as transformers, magnetic cores, switching power supplies, and electromagnetic shields, owing to low hysteresis loss, high DC permeability and stability.[1-3] However, the permalloy has low resistivity, which may restrict its application to magnetic cores used for high frequency ranges.

To solve this problem, Fu *et al.*[4] suggested the use of a ferrite thin film coated on permalloy powder. Kim *et al.*[5] reported that a permalloy encapsulated with NiZn-ferrite using ultrasound enhanced ferrite plating[6-11] exhibited well-enhanced high frequency characteristics. Their result demonstrated a technique to produce a permalloy composite for application at high frequency ranges. However, their permalloy composite exhibited low permeability and may not be suitable for the magnetic core of a kHz device. The above-mentioned plating method needs to be modified so that the ferrite layer covers each permalloy grain to improve the permeability of the resultant permalloy composite.

In this study, a Ni-ferrite encapsulated Mo-permalloy powder was prepared through electroless plating and subsequent heat treatment. We investigated magnetic properties of the magnetic core prepared from the powder.

## 2. Experimental Procedure

Mo-permalloy powder (3%Mo16%Fe81%Ni) was obtained from the CS Cooperation (Korea). NiFe encapsulation was performed on the Mo-permalloy powder by reducing the Ni- and Fe-containing salts using $NaPH_2O_2 \cdot xH_2O$ (0.06~0.15 M). The conditions of the plating solution for the NiFe encapsulation are listed in Table 1. To be converted to a Ni-ferrite phase, the NiFe deposited layer was oxidized at 600°C in air for 30~90 min, then purged with nitrogen for 30 min, and finally heat-treated at 800°C under nitrogen for 1 h. The prepared powders were examined using ICP, SEM, and XRD.

Two types of magnetic cores were prepared each from the Mo-permalloy and the Ni-ferrite encapsulated Mo-permalloy powders. Their magnetic properties were measured using a vibrating sampling magnetometer and an impedance analyzer.

## 3. Results and Discussion

The deposition rate of the NiFe film coated on the Mo-permalloy powder and the concentration of phosphorous in the film are shown in Fig. 1. By increasing the amount of $NaPH_2O_2 \cdot xH_2O$ (0.06~0.15 M) as a reducing agent, the deposition rate and the phosphorous concentration increased

**Table 1.** NiFe Alloy Electroless Plating Chemicals and Their Concentrations

| | Chemical | Concentration |
|---|---|---|
| Complexing agent | $KNaC_4H_4O_6 \cdot 4H_2O$ | 0.3 M |
| Reducing agent | $NaPH_2O_2 \cdot H_2O$ | 0.06~0.15 M |
| Metal salts | $NiCl_2 \cdot 6H_2O$ | 0.05 M |
| | $FeSO_4(NH_4)_2SO_4 \cdot 6H_2O$ | 0.1 M |

†Corresponding author : Jae-Hee Oh
E-mail : jaeheeoh@inha.ac.kr
Tel : +82-32-860-7524 Fax : +82-32-862-5546

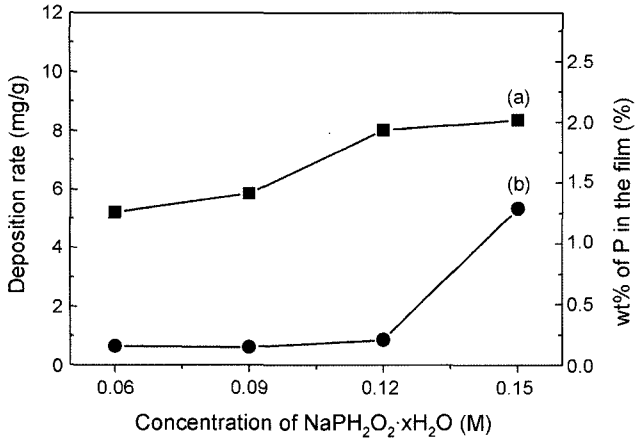


**Fig. 1.** (a) Deposition rates of the NiFe film and (b) weight percentages of phosphorous contained in the coated film depending on the concentration of $NaPH_2O_2 \cdot xH_2O$.

from 5.2 mg/g to 8.4 mg/g and from 0.2 wt% to 1.3 wt%, respectively. Especially, at 0.15 M of the reducing agent, the phosphorous concentration increased rapidly. With heat-treatment, the phosphorous contained in the deposited layer appeared to be converted to a $P_2O_5$ phase.[13,14] This phase is a nonmagnetic material that may reduce both saturation magnetization and initial permeability.[13,14] Therefore, we considered the optimal concentration of the reducing agent to be 0.12 M.

Fig. 2 shows the XRD patterns of the NiFe encapsulated Mo-permalloy and Ni-ferrite encapsulated Mo-permalloy. Two peaks, at 35.65° and 62.94°, belonging to a ferrite phase were present in all the heat-treated specimens. The NiFe deposited layer was converted to the Ni-ferrite layer through the following heat treatment: the NiFe encapsulated Mo-permalloy was oxidized at 600°C in air for 30 min, then under nitrogen for 30 min, and finally heat-treated at 800°C under nitrogen for 1 h.

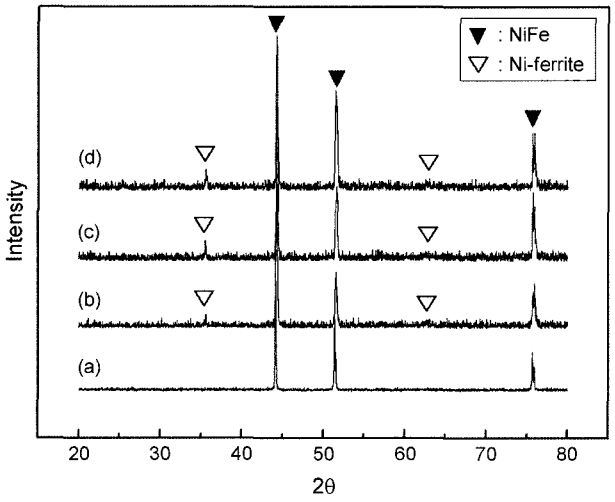


**Fig. 2.** XRD patterns of the Ni-ferrite encapsulated Mo-permalloy powders heat-treated at 800°C for 1 h under $N_2$, after being oxidized for various times at 600°C: (a) as-prepared (NiFe encapsulated Mo-permalloy), (b) 30 min, (c) 60 min, and (d) 90 min.

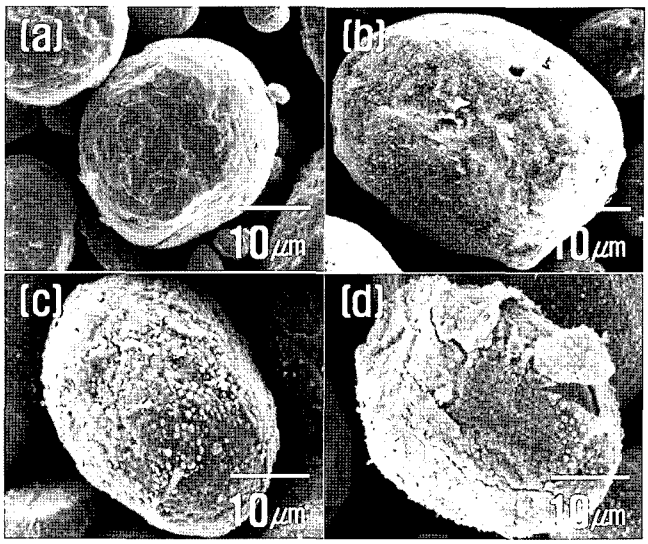


**Fig. 3.** SEM images of the Ni-ferrite encapsulated Mo-permalloy powders heat-treated at 800°C for 1 h under $N_2$, after being oxidized for various times at 600°C: (a) as-prepared, (b) 30 min, (c) 60 min, and (d) 90 min.

Fig. 3 presents the SEM images of the as-prepared (NiFe encapsulated Mo-permalloy) and the heat-treated NiFe encapsulated powders. A Ni-ferrite layer formed on the surface of each Mo-permalloy grain and showed good encapsulation when the as-prepared powder was oxidized for 30 and 60 min. However, we observed that the Ni-ferrite layer was partly exfoliated from Mo-permalloy grains, when it was oxidized for 90 min.

The hysteresis loops of the Ni-ferrite encapsulated Mo-permalloy powders are presented Fig. 4. Their saturation magnetization ($M_s$) decreased from 86.9 emu/g to 81.8 emu/g by increasing the oxidation time up to 60 min, indicating that the Ni-ferrite layer might not change $M_s$ significantly.

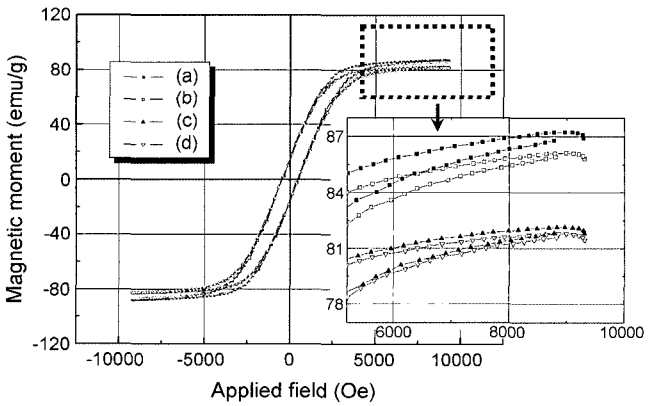


**Fig. 4.** Hysteresis loops of the Ni-ferrite encapsulated Mo-permalloy powders heat-treated at 800°C for 1 h under $N_2$, after being oxidized for various times at 600°C: (a) as-prepared, (b) 30 min, (c) 60 min, and (d) 90 min.

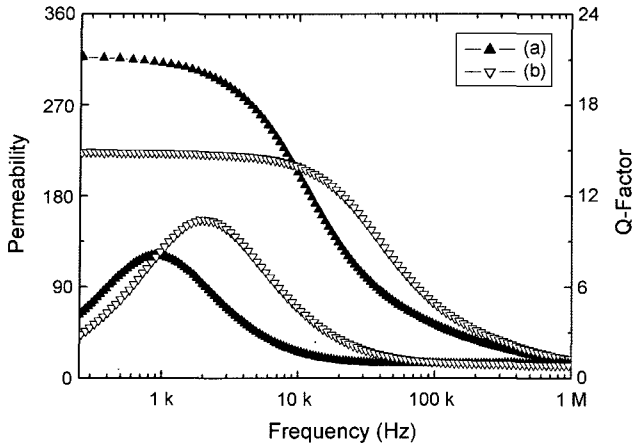


**Fig. 5.** Permeabilities and Q-factors of the magnetic cores prepared from (a) the NiFe encapsulated Mo-permalloy and (b) the Ni-ferrite encapsulated Mo-permalloy powders.

The permeabilities and the Q-factors of the two magnetic cores are plotted against frequency in Fig. 5. The NiFe encapsulated Mo-permalloy was prepared with the reducing agent of 0.12 M and the Ni-ferrite encapsulated Mo-Permalloy was heat-trated at 800°C under nitrogen for 1 h, after being oxidized at 600°C in air for 30 min. The magnetic cores prepared from the NiFe encapsulated Mo-permalloy powder exhibited the resonant frequency of 1 kHz and the Q-factor of 8. With Ni-ferrite encapsulation, these values increased to 12 kHz and 10.5, respectively. The permeability of the magnetic core was low for the Ni-ferrite encapsulated Mo-permalloy powder, compared to the Mo-permalloy. However, the former could be better than the latter for applications at high frequency ranges. This indicates that the Ni-ferrite layer could provide effective electric insulation among the alloy grains, resulting in a higher resonant frequency as well as a greater Q-factor.

## 4. Conclusion

A Ni-ferrite encapsulated powder was prepared through electroless plating and heat treatment. We observed that spherical Ni-ferrite grains formed densely on the surface of each Mo-permalloy grain. The magnetic core prepared from the encapsulated powder exhibited high saturation magnetization and well-enhanced frequency characteristics. This indicates that our magnetic core is suitable for a kHz device under a high DC magnetic field.

## Acknowledgment

This work was supported by Inha University Research Grant.

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