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Plating of Permalloy Using Flow Cell

S. H. Jeon, J. H. Ahn and T. Kang

*School of Materials Science and Engineering,
Seoul National University, Seoul 151-742, Korea*

Abstract

Electroplating of 80%Ni permalloy thin plate for magnetic core materials. was studied The convected flow of electrolyte was used for stirring methode. The current density could be increased up to 250mA/cm^2 by flow cell. The composition of electroplated layer with vespect to current density and flow rate was investigated and experimental equation to predict the composition was made. How cell yielded more uniform thickness distribution than paddle cell did. The composition distribution was also studied. The thickness was the most important factor to the permeability. The permeability of 5μm plated permalloy was over 2000 at 1 MHz.

Key words : *flow cell, permalloy, electroplating, soft magnetic material, permeability*

1. Introduction

Permalloy is a Ni-Fe alloy which has been used widely for soft magnetic material. It has highly effective permeability at high frequency and low coercivity. It has been used for cores of magnetic devices like recording heads or transformers[1].

Permalloy plating has been studied mostly for magnetic head materials[2,3].

In these studies, the current density was relatively small, so the deposition rate was not high. Rolled permalloy plates have been used as core materials of various electric devices. Rolled permalloy is usually thicker than 10 micrometers and needs heat treatment at high temperature. Electroplating has some advantages for making thin permalloy plate. In electroplating thickness control is very easy and much thinner plate can be made. The grain size of electroplated plate can be very small, so that it has high electric resistance, which reduces eddy current loss. Heat treatment can be omitted or carried out at low temperature.

For high speed electroplating, flow cell has been studied[4,5]. In flow cell, the flow of electrolyte gives stirring and circulating effect. Flow cell is suitable for making thin permalloy plate with high speed because it has good adaptability to continuous electroplating and strong stirring effect compared with paddle cell. Due to the small gap between anode and cathode, more uniform current distribution can be obtained in flow cell, and thickness and composition become more uniform.

The purpose of this study is to make pemalloy thin plate with higher speed by using flow cell than by paddle cell, to control the amount and the uniformity of Fe contents in flow cell and to improve magnetic properties.

2. Experiment

Fig. 1 shows the flow cell used in this study. Concentrations of the components in the solution and some electroplating conditions are listed in Table 1. Stainless steel was used for the cathode because the electroplated layer can be easily detached from that metal which has passivity film in the surface. Ni plate was used as the anode. The current density was 100~250 mA/cm^2. Above 250 mA/cm^2, the electroplating was not possible because the hydroxides was deposited on the cathode. The thickness was 5~20 ㎛(mostly 10㎛). The flow rate was 42~126 cm/sec^2.

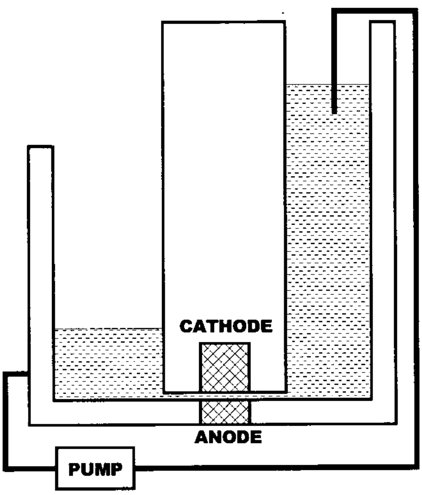

Fig. 1 Schematic diagram of the flow cell

Table 1. The composition of the electrolyte and conditions of electroplating

	Component	Concentration
Solution	Nickel Chloride	109 g/L
	Iron Sulfate	Variable (5~10 g/L)
	Boric Acid	25 g/L
	Sodium Saccharine	2.4 g/L
	Sodium Lauryl Sulfate	0.2 g/L
	Sodium Chloride	30 g/L
Temperature		45℃
pH		2.5

The thickness was measured by coulometric Method and Fe composition was examined by SEM-EDS. Permeability meter with 8-figure coil was used for testing magnetic property.

3. Result and Discussion

3. 1 Composition of electroplated permalloy

Fig. 2 shows that the Fe contents decreases as current density increases. Fig. 3 explains this result. The deposition rates of Ni and Fe were plotted in Fig. 3. Fe deposition rate was independent

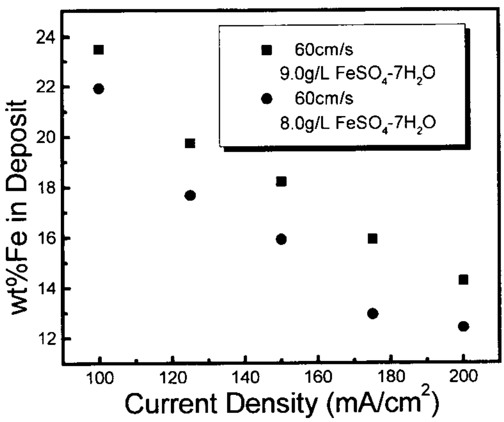

Fig. 2 Effect of current density on Fe content

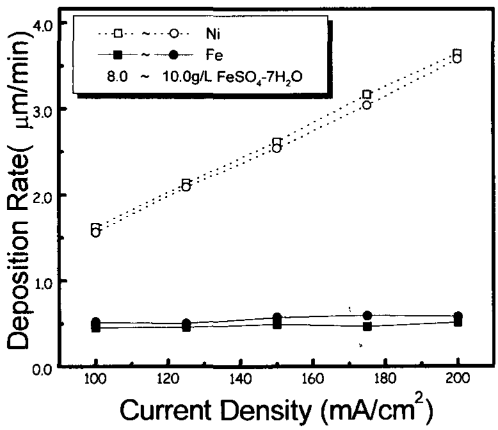

Fig. 3 Effect of current density on the deposition rate of Ni and Fe

of current density, which means reduction of ferrous ion is under mass transfer control. The current efficiency calculated by the weight was over 98%.

As reduction of Fe ion is under diffusion control and that of Ni is under charge transfer control in the current range of this study, the deposition rates of Fe and Ni follow equation (1).

$$I_{Fe} = 2FD\frac{dC}{dx} = 2FD\frac{C_0}{\delta}$$

$$I_{Ni} = I - I_{Fe} \quad (1)$$

where,

I_{Fe} : current density of Fe reduction

D : diffusion coefficient

C : concentration of ferrous ion

C_O : concentration of ferrous ion in bulk solution

δ : diffusion layer thickness

The relationship between concentration of Fe ion in the solution and Fe contents in deposited layer was shown in Fig. 4. This Experimental result agrees with the value of theoretical equation. Fig.5 shows the effect of flow rate. As the diffusion layer thickness is inversely proportional to the flow rate and deposition rate is inversely proportional to the diffusion layer thickness, the Fe content is proportional to the flow rate. From above discussions, the amount of Fe in electrodeposited layer follows equation 2.

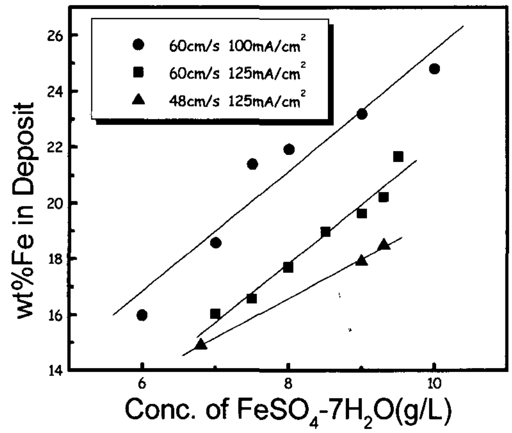

Fig. 4 The relationship between the concentration of ferrous ion in the solution and Fe content in electrodeposited layer

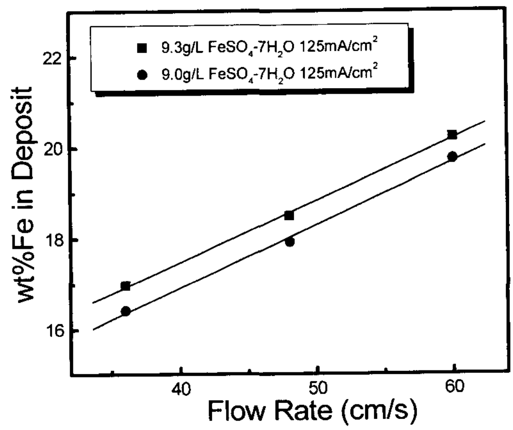

Fig. 5 The effect of flow rate on the Fe content

$$at\%Fe = \frac{I_{Fe}}{I} = 2FD\frac{C_0}{I\delta} \propto \frac{VC_o}{I} \qquad (2)$$

Fig. 6 shows best fitting curve from data at various electroplating conditions. Though the equation have some constants different from theoretical equation, these data satisfy above theory.

3. 2 Thickness distribution

Thickness distributions of the permalloy plates deposited in flow cell and paddle cell are compared in Fig. 7. Even without dummy electrode, thickness of plate deposited in flow cell was much more uniform than that of plate deposited in paddle cell. In electrodeposition, as the gap between anode and cathode become small, more uniform current distribution can be obtained. In paddle cell this gap can not be small, because some space is needed for paddle movement. On the contrary, in flow cell, it can be pretty small.

3. 3 Distribution of the composition

Variation of Fe contents along the flow direction at different flow rate conditions is displayed

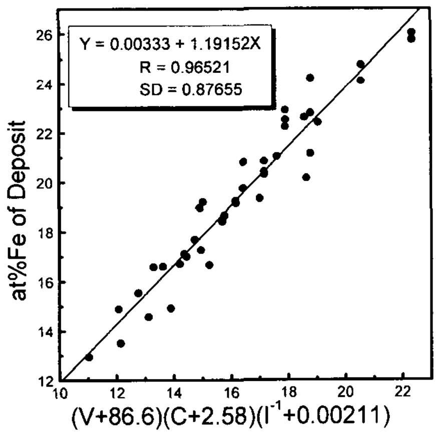

Fig. 6 Fe contents with current density, flow rate and ferrous sulfate concentration

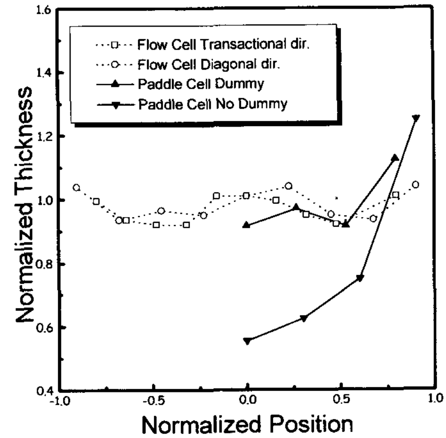

Fig. 7 Thickness distribution of the layers electroplated in paddle cell and flow cell

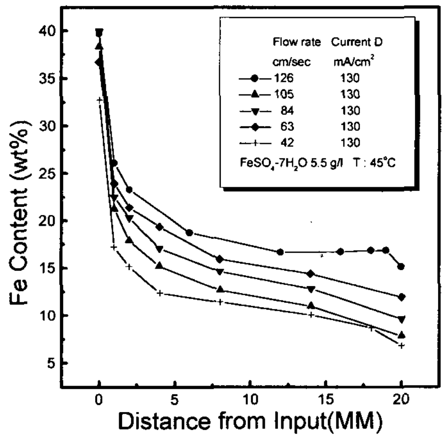

Fig. 8 Distribution of composition with variation of flow rate

in Fig. 8. As laminar flow of electrolyte passes between two flat plates, the reaction rate decreases because the diffusion layer grows as the metal ion depleted. This can be expressed equation 3[6].

$$i = kC_\infty\left(\frac{<v>}{x}\right)^{\frac{1}{3}} \qquad (3)$$

In the region near input, Fe contents decrease rapidly as indicated in equation 3. In the middle region, the Fe content is nearly constant, because the flow is not exactly laminar. Near the end of electrode, Fe contents is slightly smaller than in adjacent area, because much amount of Ni was deposited at that region as the current is concentrated to the edge of cathode.

3. 4 Magnetic property

Fig. 9 shows the permeabilities of layers electroplated to different thickness at 1 MHz. Permeability was nearly inversely proportional to the thickness. It reveals that eddy current loss proportional to the square of thickness[7] is a key factor for magnetic property. Little change was observed in accordance with the variation of flow rate or current density.

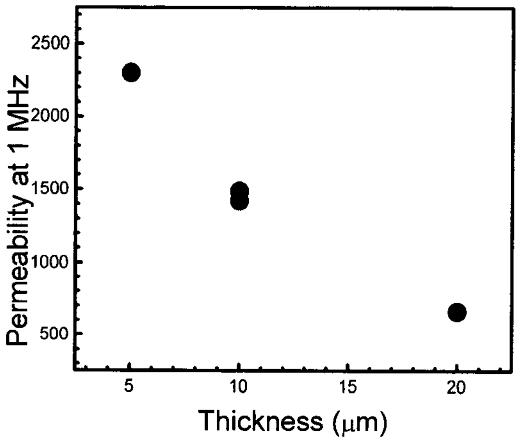

Fig. 9 The effect of thickness on permeability

4. Conclusion

Using flow cell, 80%Ni permalloy thin plate could be made at the rate up to 250 mA/cm^2. Fe content with current density, flow rate and concentration of ferrous ion was investigated and experimental equation could be made to predict it. Thickness and composition of the permalloy electroplated in flow cell was relatively uniform. The permeability of 5μm plated permalloy was over 2000 at 1 MHz.

References

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