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An effect of dummy cathode on thickness uniformity in electroforming process

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ABSTRACT

This study examines the solution for one of the most difficult problems of electroforming process "thickness deviation". As an effective solution, an auxiliary electrode (dummy cathode) is considered. Generally, the thickness of an edge plating area is almost twice the center area or greater. An auxiliary electrode (intentionally attached dummy cathode) has helped to achieve more uniform thickness of the electroformed-nickel layer by preventing excessive electric charge. In addition, computer-aided analysis was performed to determine the optimal condition of electroforming process and to confirm the experimental result.

Introduction

Plating process is being widely applied in various industrial fields due to the development of new technologies known as photo-resist film fabrication and photo-lithography.

In order to fabricate a micro-sized metallic structure, nickel electroforming is usually being used [1,2]. One of the processes, nickel sulfamate electrolyte is generally used to make micro-sized metallic structures. The electrolyte offers high deposition rate and the plated nickel has low internal stress [3].

The positions of cathode, anode and insulating film are important factors in the electroforming process, because they determine the potential field and the thickness of the deposited metal. According to previous studies, electric current tends to concentrate at the edge of the cathode, and as a result, the metal layer deposition becomes thicker than the center area. Various studies have been carried out to reduce the thickness deviation [4–8].

The thickness uniformity of electroformed objects was consistently observed. The deposited metal showed a concave shape distribution over the whole area of the plating base. The thickness of the edge plating area is almost twice that of the center plating area. The deposition process involves localized electrochemical deposition.

An ion must reach the electrode/solution interface, receive electrons to become an atom, and then join other atoms to form a new crystal. An electric potential difference must be applied between the anode and the cathode. In conventional plating processes, four steps of processes are carried out to supply metal ions to the depleted solution at the cathode, and to transfer them from the enriched electrolyte at anode to the cathode [9].

Electron transfer is considered as the main factor of electroforming. At equilibrium, there is a balance between the chemical and the electrical potential at the electrode/solution interface, manifesting itself as 1–30 nm thick charged region known as the double layer [10].

An auxiliary electrode (called dummy cathode) is one of the most popular and effective solutions for achieving more uniform current distribution at the cathode [11,12].

Yang contrived unique experimental apparatus devices to achieve a uniform thickness in the electroforming process. By adding an additional ring as a secondary cathode, the growth rate of the primary cathode is decreased. The purpose of using the secondary electrode is reducing local ion concentration of the "double layer" surface plating area [9]. But, the length and shape of the auxiliary electrode have been determined by the engineer's experience and trial-and-error. The objective of this study is to compare the results of experiment and FE analysis to determine the optimum condition for the fabrication of the probe needle with the consideration of the auxiliary electrode (dummy cathode).

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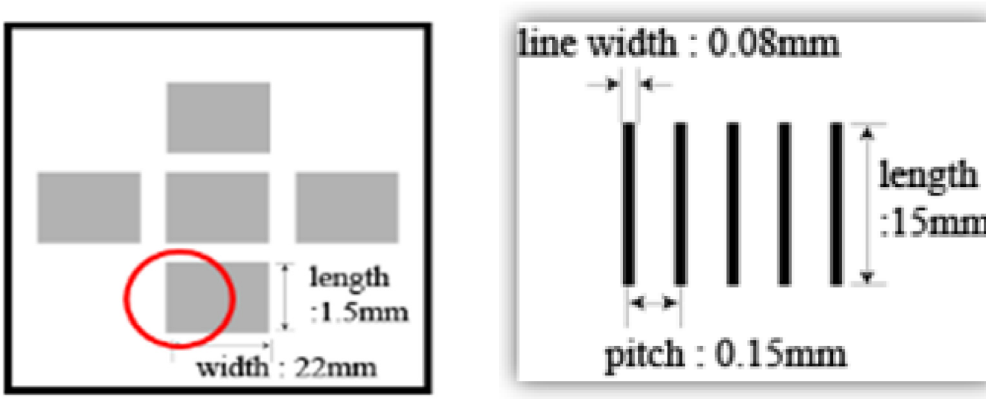


(a) shape and dimension of pattern (b) enlarged pattern shape

Fig. 1. Schematic diagram of electroforming pattern.

Dummy cathode

Electroforming pattern

Electroforming process needs a plating bath. Inside the bath, two electrodes (anode and cathode) are installed at each side to charge the electricity. Electrodes are designed to be easily moved to adjust distance, and T-pipe is designed to deliver a steady supply of electrolyte. Fig. 1 shows the schematic diagram of the electroforming pattern (width 22 mm × length 1.5 mm).

Finite element analysis

The principal parameters of the electroforming process are electric current density, concentration and pH of electrolytes, temperature of plating bath, etc.

In this study, simulation was performed using the general purpose FE program, MARC, considering all of constant variables.

Two types of plating patterns (with and without auxiliary electrode) were compared with respect to the electric field strength to investigate the effect of auxiliary electrodes. The FE analysis model of the electroforming bath is shown in Fig. 2. The boundary conditions are as follows.

(1) The potential of point at which the bath and electrode met is fixed.
(2) Voltage charge – 4 V at anode, and 0 V at cathode.
(3) The permittivity of medium property is set to 7.04e−10 farad/m.

Current density

The current density distribution is dependent on the size of electrode and concentrates at the cathode edge. And it makes the thickness of deposited metal change. This non-uniformity of thickness can be diminished by considering the dummy cathode [13].

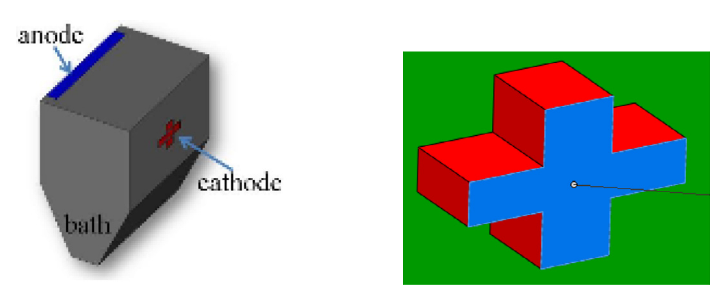
In order to investigate the effect of current density, a set of simulation was carried out, and a correlation between current density and electric field value is expressed, as the following;

$$J_e = \frac{E}{\rho_e} = \sigma_e E \qquad (1)$$

where ρ_e is the specific resistance, s_e is the electric conductivity, J_e is the current density (A/m^2) and E is the electric field (V/m).

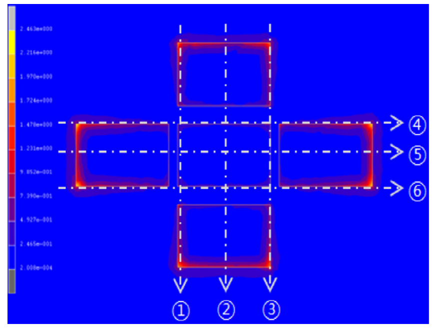
Fig. 3 shows the effect of the auxiliary electrode on the electric field. As depicted in Fig. 3(a), in the case where the auxiliary electrode is not considered, current is concentrated at the edge. On the other hand, Fig. 3(b) shows that current concentrates at the auxiliary electrode, and consequently, more uniform thickness layer can be expected at the inner part.

The difference of the electric field intensity in case with and without the auxiliary electrode is demonstrated in Figs. 4–9.

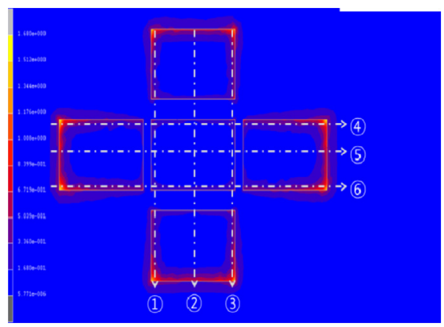


(a) FEM Model of electroforming bath (b) Shape of auxiliary electrode (area: 2112 mm^2, perimeter: 263 mm)

Fig. 2. FEM model of electroforming bath and shape of auxiliary electrode.

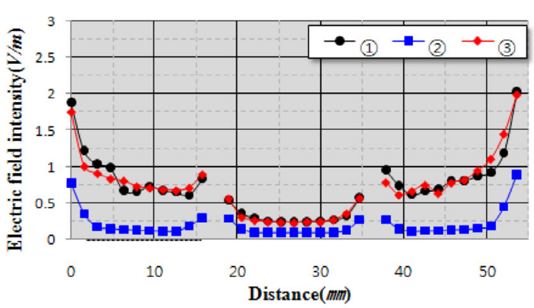


(a) Electric field distribution of conventional electrode (without auxiliary electrode)

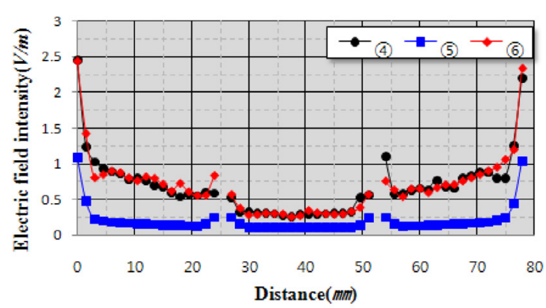


(b) Electric field distribution (with auxiliary electrode, distance between anode and auxiliary electrode is 35 mm)

Fig. 3. Computational analysis result of electric field distribution.

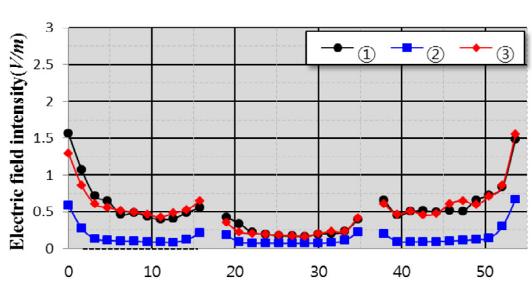


(a) Electric field intensity of vertical direction

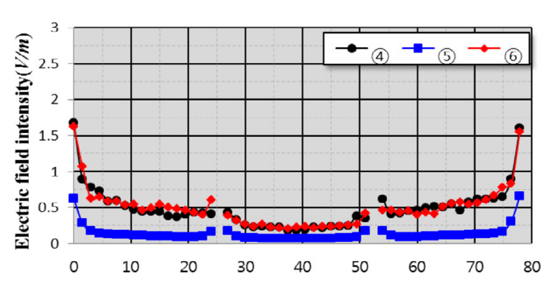


(b) Electric field intensity of horizontal direction

Fig. 4. Electric field intensity of vertical direction and horizontal direction without auxiliary electrode.

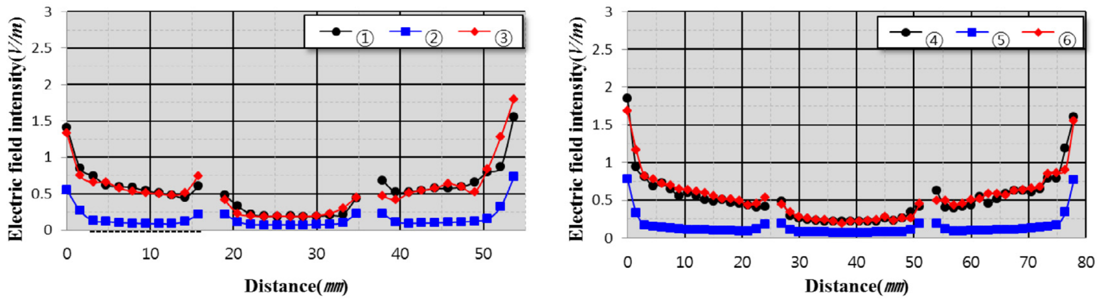


(a) Electric field intensity of vertical direction



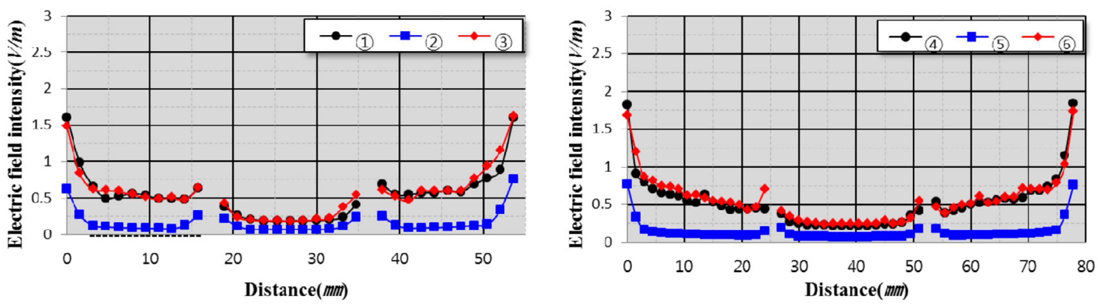
(b) Electric field intensity of horizontal direction

Fig. 5. Electric field intensity of vertical direction and horizontal direction at 35 mm distance gap.



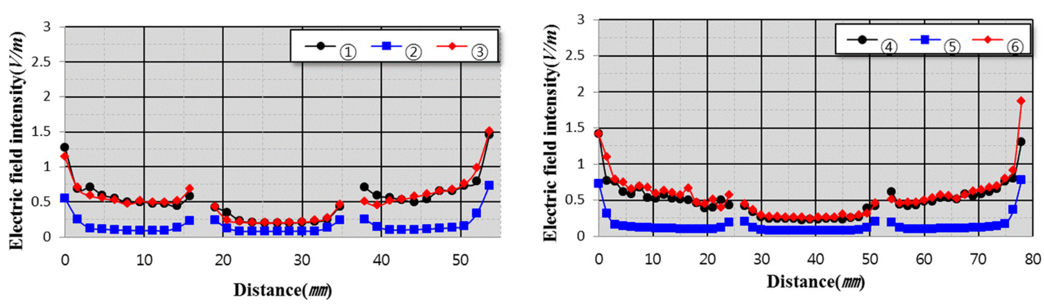
(a) Electric field intensity of vertical direction (b) Electric field intensity of horizontal direction

Fig. 6. Electric field intensity of vertical direction and horizontal direction at 70 mm distance gap.



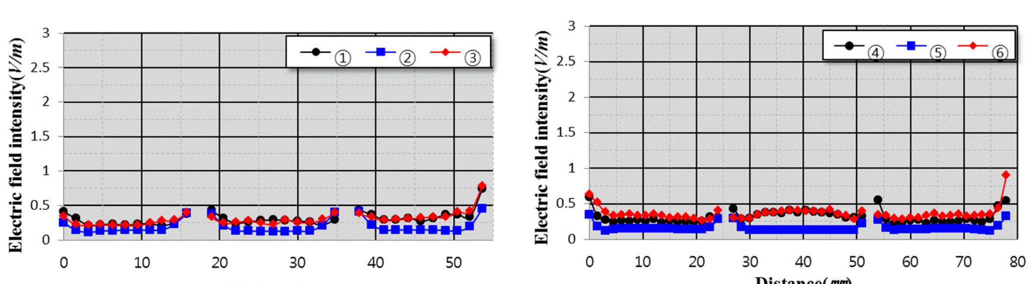
(a) Electric field intensity of vertical direction (b) Electric field intensity of horizontal direction

Fig. 7. Electric field intensity of vertical direction and horizontal direction at 105 mm distance gap.



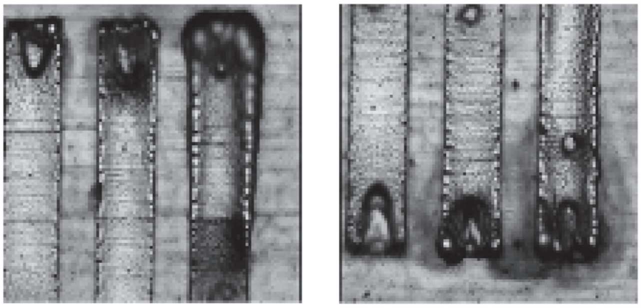
(a) Electric field intensity of vertical direction (b) Electric field intensity of horizontal direction

Fig. 8. Electric field intensity of vertical direction and horizontal direction at 140 mm distance.

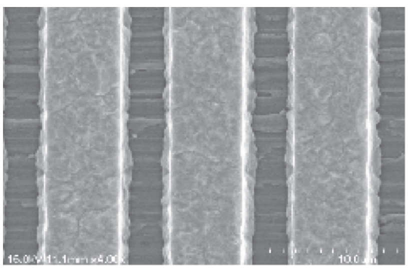


(a) Electric field intensity of vertical direction (b) Electric field intensity of horizontal direction

Fig. 9. Electric field intensity of vertical direction and horizontal direction at 168.5 mm distance.

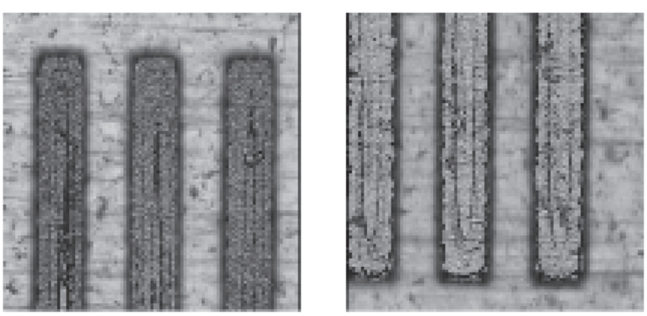


(a) fabricated probe needle without dummy cathode

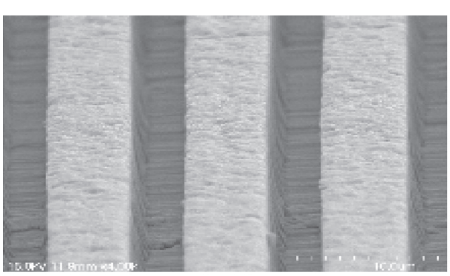


(b) SEM picture of fabricated probe needle without dummy cathode

Fig. 10. Fabricated probe needle and SEM picture without using dummy cathode.



(a) fabricated probe needle without dummy cathode



(b) SEM picture of fabricated probe needle without dummy cathode

Fig. 11. Fabricated probe needle and SEM picture with using dummy cathode.

As depicted in Fig. 5, at each side, the current density is much higher and of more uniform value than at center area. We can assume that the outer probe needle arrays played a "dummy" role. This phenomenon has to be avoided in mass production to meet the yield rate. Fig. 9 shows the remarkable effect of dummy zone. As easily compared in Fig. 4, a more uniform electric field density can be obtained by using the dummy cathode Fig. 10 shows the faricated probe needle without using the dummy cathode, and Fig. 11 shows the faricated probe needle with using the dummy cathode. As depicted Figs. 10, 11, we could easily know that dummy cathode helped to get more precise pattern.

Table 1 shows the comparison of electric field intensity value according to the auxiliary electrode. Under the condition of using the auxiliary electrode, the maximum value and the mean value of electric field intensity become smaller than when we did not use the auxiliary electrode.

Experiment result

Probe needles were fabricated under the optimal condition (fixed by simulation result). Electroforming was performed under the same condition including plating. Fig. 6 shows the result of specimen using electroforming process without the dummy cathode. As expected, excessive current concentration caused over-plating at the edge area.

On the other hand, a much more uniform result was obtained using the dummy, as depicted in Fig. 7.

Results and discussion

As depicted in Figs. 6 and 7, surface roughness was improved with the use of dummy electrode. In the case of the conventional type (without dummy), the deviation of the surface roughness was observed to be about 700 nm.

To disperse the current concentration, a dummy electrode was additionally installed near a cathode. The result shows the improved surface roughness to about 80 nm. Therefore, the auxiliary cathode (dummy electrode) was proved to be effective in the electroforming process.

Conclusion

A probe needle array was successfully fabricated by using electroforming process, and its quality was studied in this paper.

The following can be concluded:

1. The thickness of the deposited metal can be predicted by using the correlation of the factors of electroforming process.
2. In electroforming process, the thickness of the deposited metal layer can easily become irregular due to current density distribution at the edge of the cathode.
3. When the dummy electrode was used, the deviation of the roughness was reduced.

Table 1
Comparison of electric field intensity value according to auxiliary electrode.

Electric field intensity value		Vertical direction		Horizontal direction	
		Maximum value	Mean value	Maximum value	Mean value
No auxiliary electrode		2.015	0.857	2.501	0.875
With auxiliary electrode	35 mm	1.563	0.396	1.697	0.3741
	70 mm	1.801	0.419	1.847	0.407
	105 mm	1.621	0.427	1.835	0.411
	140 mm	1.505	0.404	1.857	0.394
	168.5 mm	0.777	0.267	0.891	0.277

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