EVALUATION OF HIGH SPEED PLATING FOR COPPER POST WITH FLAT TOP SHAPE AND IMPROVED POST HEIGHT UNIFORMITY

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ABSTRACT
In developing high-speed electro "copper post" plating bath, 2 specific attributes were considered, namely the shape of the post (flat top) and the uniformity of the post height throughout the wafer.

It was considered important to make the post shape less susceptible to liquid agitation. Since the performance of the plating solution is greatly affected by organic additives, the influence of additives on agitation was investigated by electrochemical measurement based on the above idea. As a result, influence of agitation could be reduced by using leveler showing strong suppression effect particularly on strong agitation. When post was plated with using this leveler, the top shape became flat.

Regarding the uniformity of the post height, study of the composition conditions considered from Wagner number and supply of copper ions to the current density was important. It can be said that decrease the copper concentration and increase the sulfuric acid concentration is necessary in order to improve the uniformity from the Wagner number. This tendency can be seen when the supply of copper ions to the plating surface was sufficient. However, for high-speed plating, the supply of copper ions could not keep up with the consumption rate when the copper concentration was low. This could be confirmed from the formation of nodules, leading to a decrease in uniformity. From the above, it was effective to decrease the copper concentration and increase the sulfuric acid concentration within a range where nodule did not form in order to improve the uniformity. A plating bath was prepared with based on these results and plated on a 300 mm diameter whole wafer, and as a result, improved post-top flatness and post height uniformity were obtained at 20 A/dm^2.

Key words: Electrolytic copper plating, High current density, Polarization curve, Flattening post top, Uniformity

INTRODUCTION
Copper post plating technology is widely used as a circuit connection technology for IC packages because copper has good electrical conductivity and heat dissipation properties. The post of which height is over two hundred micron meters have been used for recent package, then high current density plating is required from the viewpoint of productivity. It is necessary to align the heights of the posts within the wafer, and a process of polishing the post surface is performed after plating. Therefore, if the post height is uneven or the post top shape is not flat before polishing, the polishing amount will increase. An increase of current density affects flatness of post top shape and in-plane uniformity of post height. Thus, investigation of additive species, additive concentration and basic bath composition is needed to solve these problems. In the present case, planarization of the post top shape and in-plane uniformity were examined from the polarization curve and Wagner number, respectively. Bath conditions were designed based on these considerations and plating tests were carried out with using a 300 mm whole wafer.

EXPERIMENTAL METHODS
Electrochemical polarization measurements
The polarization curve of the copper sulfate plating bath was measured with using electrochemical measurement equipment. The measurement was carried out with a three electrode system as shown in Figure 1, platinum disk electrode was used as working electrode (W.E.), silver/silver chloride electrode was used as reference electrode (R.E.), and copper plate was used as counter electrode (C.E.). Electrochemical measurement conditions are shown in Table 1. The influence of the agitation strength on the polarization curve was investigated by controlling the rotational speed of the disk electrode at 400 to 1600 rpm.

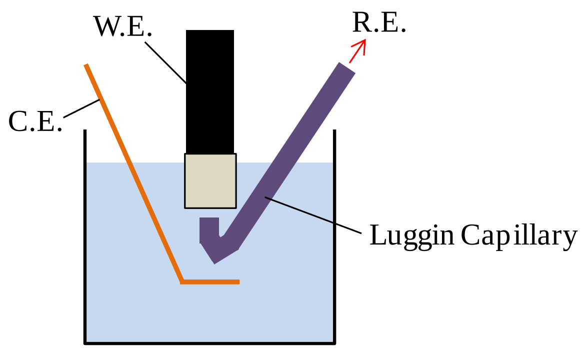


Figure 1. Three electrode system

Table 1. Test conditions of electrochemical measurement

Electrochemical measurement conditions	
Electrochemical measurement equipment	HOKUTO DENKO HZ-3000
Working electrode (W.E.)	Pt disk electrode (19.6 mm^2)
Reference electrode (R.E.)	Silver/Silver chloride electrode
Counter electrode (C.E.)	Copper plate
W.E. rotation speed	400 ~ 1600 rpm
Potential sweep speed	10 mV/s
Measurement potential range	Spontaneous potential ~ - 0.2 V

Post plating

The paddle agitation equipment for 300 mm wafer shown in Figure 2 was used for confirming post plating performance. The plating conditions are shown in Table 2. The solution on the cathode surface was agitated by reciprocating the paddle kept 6mm space from the wafer in the horizontal direction with respect to the wafer surface. An IrO_2/Ti electrode was used as the anode, and the anode was covered with bag to prevent the gas generated on the anode from adhering to the cathode surface. Shielding was set between the cathode and the anode in order to prevent current from concentrating on the peripheral portion of the wafer. The post diameter was 200 µm and the target post height was 225 µm.

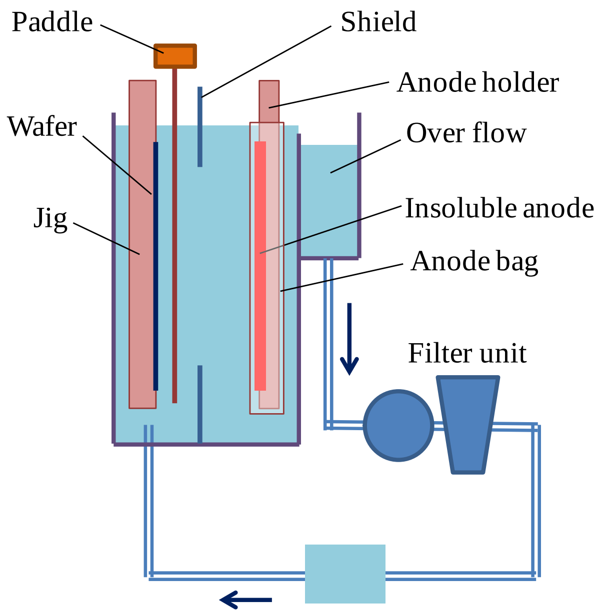


Figure 2. Paddle agitation plating equipment

Table 2. Test conditions of post plating

Post plating conditions	
Tank volume	27 L
Distance between wafer and paddle	6 mm
Paddle agitation speed	1250 mm/s
Anode	Insoluble (IrO_2/Ti)
Wafer diameter	300 mm
Post diameter	200 µm
Target post height	225 µm
Number of posts within wafer	100,000
Number of posts within one chip	400

FLATTENING OF POST TOP SHAPE

When post was plating, it is assumed that agitation strength at center part of the photoresist (PR) opening was strong, while agitation strength at PR wall-side part weakened due to shielding of PR as shown in Figure 3. When the current tends to flow easily by strengthening the agitation as shown in the polarization curve of Figure 4 (a), in other words, when the current at the center part of the PR is stronger than at PR wall-side part, the post has a convex shape. In order to flatten the post top shape, it is necessary to eliminate the difference between the current values of the strong agitation part and the weak agitation part, and it becomes ideal that the polarization curves of strong agitation and weak agitation overlap as shown in Figure 4 (b). The copper sulfate plating bath consists of inorganic chemicals such as copper sulfate, sulfuric acid and chloride ions and organic additives such as brightener, carrier and leveler. Promotion and suppression which are keys of the reaction can be controlled by organic additives. Therefore, the effect of each additive on the polarization curve was investigated in order to obtain an ideal polarization curve in this case.

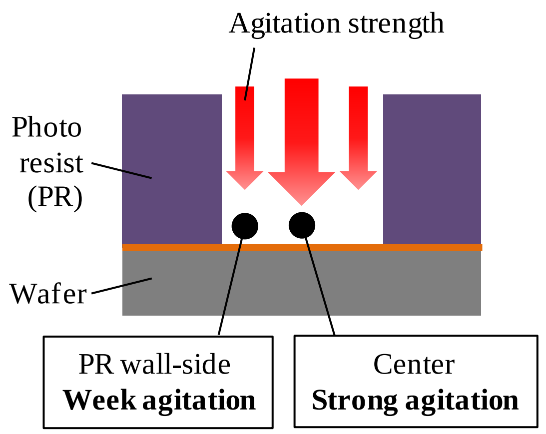
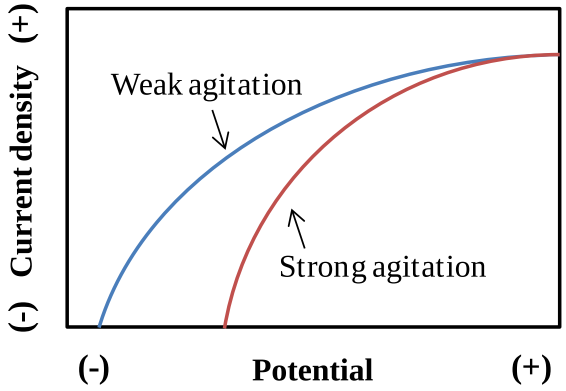


Figure 3. Agitation strength inside the PR opening

(a)



(b)

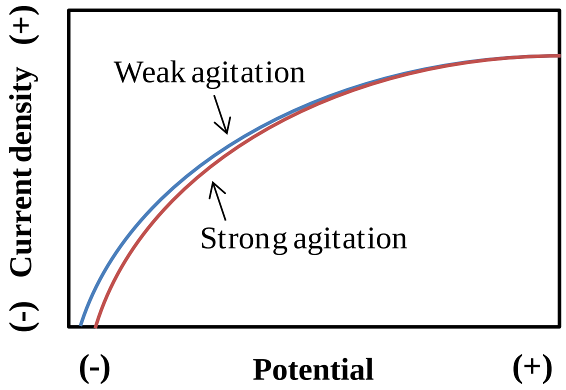


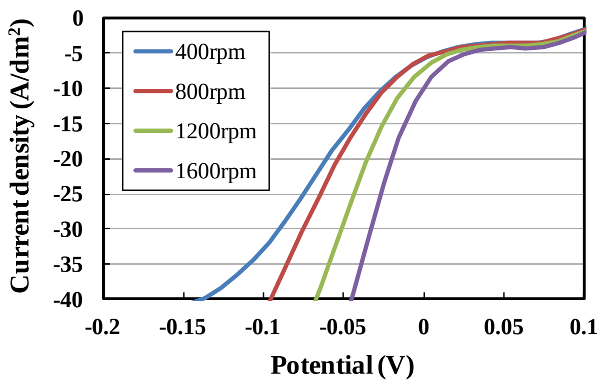
Figure 4. Relationship between polarization curve and post top shape (a) Convex shape, (b) Flat shape

First, as for the influence of the brightener, the shift of the polarization curves was confirmed when the brightener concentration was increased as shown in Figure 5. However, the curves did not overlap because all the curves shifted equally to the noble direction. The brightener has a function of promoting the formation of growth point of the copper electrodeposition reaction on the cathode surface[1]. The reason why the polarization curves shifted may be attributed to this function. Specifically, it was assumed that the electrodeposition reaction was likely to occur by increasing the brightener concentration, and the current value for the overpotential has increased.

Next, regarding the carrier, the effect of concentration change was not confirmed and the polarization curves of strong agitation and weak agitation did not overlap as shown in figure 6. The carrier is combined with chloride ions and forms a monomolecular film on the cathode surface, thereby uniformly suppressing crystal growth[1]. Once the monomolecular film is formed, it is considered that suppression effect does not change even if the carrier concentration is subsequently increased. Therefore, it is presumed that there was no influence of the carrier concentration on the polarization curve.

Finally, with respect to the leveler, the leveler usually adsorbs to a place where the agitation is strong (the diffusion layer is thin) and works to suppress the electrodeposition at that place. In present case, since suppression at strong agitation is particularly required, we focused on a leveler had high suppression effect so that the suppression effect greatly differs between weak stirring and strong stirring. Figure 7 shows the polarization curves when the leveler had high suppression effect was used. By adding the leveler, the electrodeposition reaction was strongly suppressed on strong agitation such as 1200 rpm and 1600 rpm, and the curves shifted to the base side. The polarization curves of strong agitation and weak agitation overlapped in the range of 0 to 20 A/dm^2 and the ideal polarization curve shown in Figure 4 (b) could be obtained. In order to investigate the post shape when this leveler was used, a plating test was carried out with the paddle agitation equipment of Figure 2. Figure 8 shows the profile measured with a 3D optical microscope for the post when plating on 20 A/dm^2. The difference between the height of the center part and the edge part of the post was as small as 5 µm or less, the post top shape was flat. From this result, it can be said that the relationship between the polarization curve and the post shape could be demonstrated.

(a)



(b)

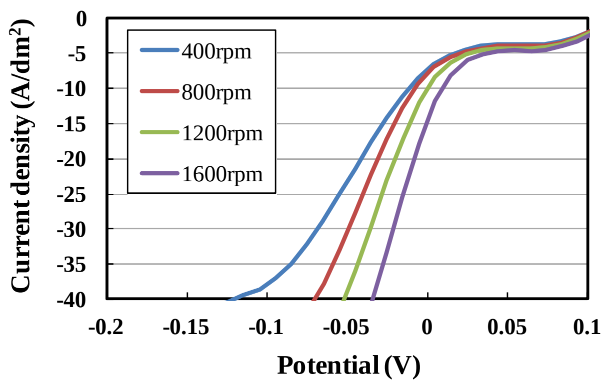


Figure 5. Influence of brightener concentration on polarization curve (a) Low brightener concentration, (b) High brightener concentration
(Legend is rotation speed of disk electrode.)

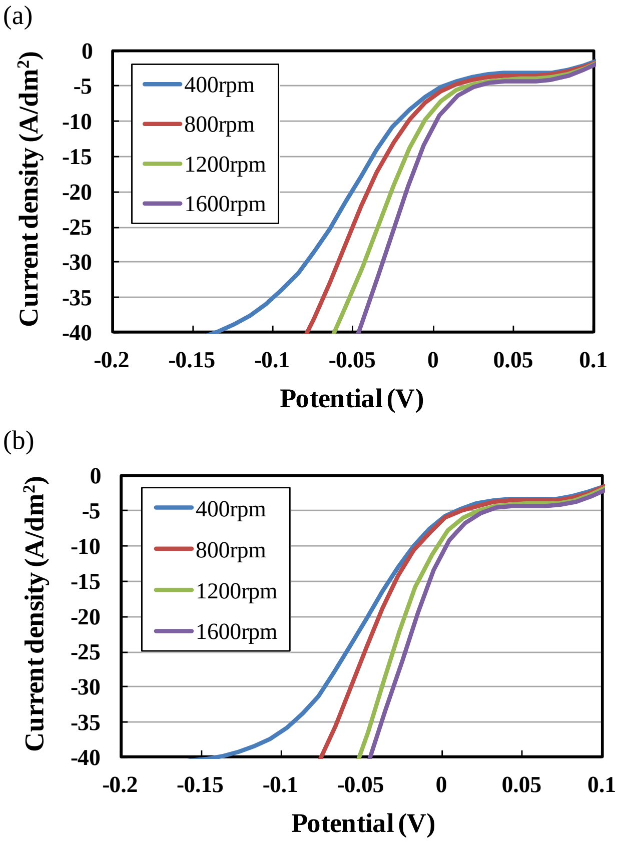


Figure 6. Influence of carrier concentration on polarization curve (a) Low carrier concentration, (b) High carrier concentration
(Legend is rotation speed of disk electrode.)

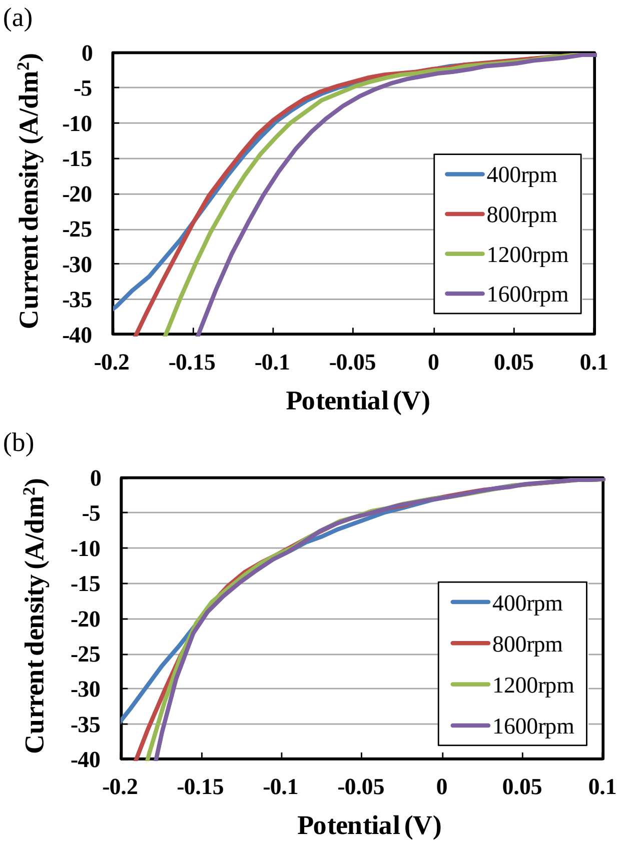


Figure 7. Influence of leveler concentration on polarization curve (a) Without leveler, (b) With leveler
(Legend is rotation speed of disk electrode.)

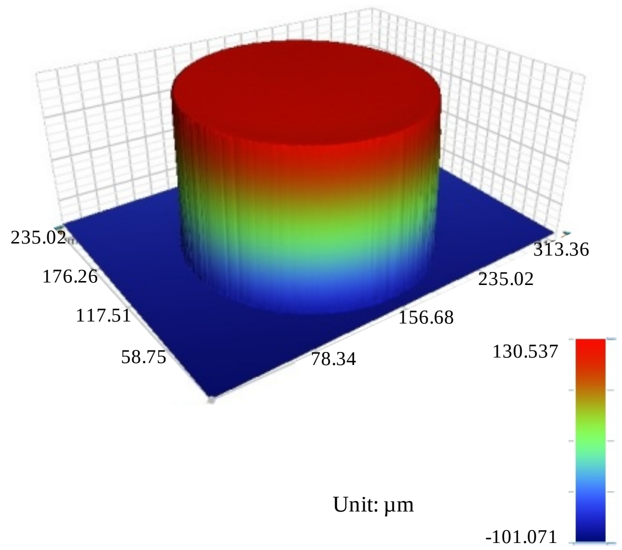


Figure 8. Plated post shape

IN-PLANE UNIFORMITY OF POST HEIGHT

Current line distribution for the electroplating is susceptible to pattern design of IC package. Figure 9 shows the influence of post density on the current line distribution. The current line concentrates and thus the post height becomes thick at a position where the post density is low. On the other hand, the current line tends to be dispersed and thus the post height becomes low at a position where the post density is high.

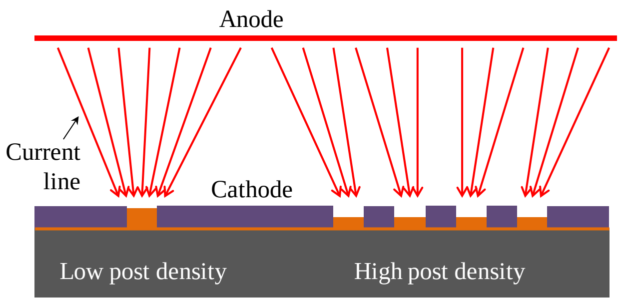


Figure 9. Influence of post density on current line distribution

In order to improve the uniformity of post height, it is effective to study composition condition such as copper concentration and sulfuric acid concentration, which can be considered by using Wagner number[2, 3]. The Wagner number is expressed by the value obtained by dividing the polarization resistance by the specific electrical resistance of electrolyte and the distance between the electrodes as shown in the following formula.

$$\textit{Wagner number} = \kappa / (\rho L)$$

κ = polarization resistance ($V \cdot cm^2/A$)
ρ = specific electrical resistance of electrolyte (ohm·cm)
L = distance between electrodes (cm)

Generally, in order to improve uniformity, it is necessary to increase the Wagner number. The polarization resistance of the above equation is the ratio of the amount of change in potential and the amount of change in current. As the copper ion concentration becomes lower, electrodeposition reaction hardly occurs, and the polarization resistance increases because the overpotential required for flowing the same current increases as compared with the case where the copper ion concentration is high. The electric conductivity of the electrolytic solution increases and the specific electrical resistance decreases by increasing the sulfuric acid concentration. In this way, the Wagner number can be increased by decreasing the copper concentration and increasing the sulfuric acid concentration. However, decreasing copper concentration is risky for high-speed plating. As shown in Figure 10, the in-plane post height range (the difference between the maximum value and the minimum value of the post height within the wafer) was large when the copper concentration was low. This was caused by nodules that were formed due to insufficient supply of copper ions. Nodule formation was suppressed and post height range was decreased by increasing the copper concentration. In addition, it was confirmed that the post height range increased with a certain concentration. This increase of post height range can be explained from the relation of Wagner number to copper concentration. Concentration that is the turning point of this trend is considered to be the threshold of diffusion limited region and charge transfer limited region. From these facts, confirmation of the optimum copper concentration is imperative.

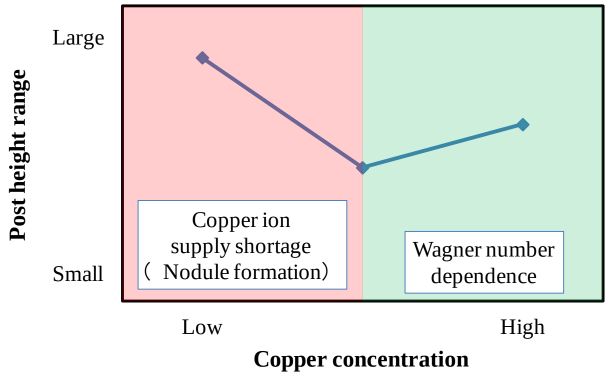


Figure 10. Influence of copper concentration on in-plane post height range

300 mm whole wafer plating test was carried out with using the plating bath designed based on the study of polarization curve and Wagner number. Figure 11 shows the distribution of post heights when average current density was 20 A/dm^2 and target post height was 225 µm. The difference between the maximum value and the minimum value of the post height was 32 µm within the wafer and an average of 30 µm within the chip. In other words, the variation in the post height was ± 7 % within the wafer and average of ± 6 % within the chip, which was a good result.

(a)

(b)

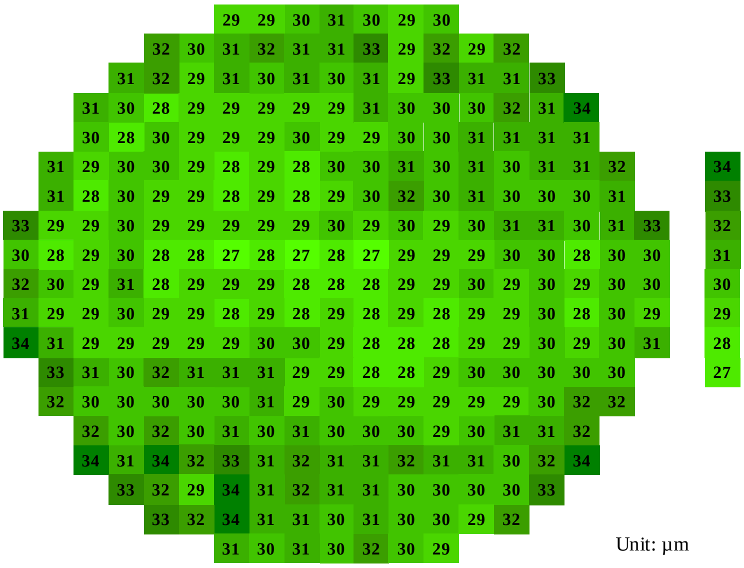


Figure 11. Post height distribution on 300 mm whole wafer (a) Average of post height (Each value was the average value within one chip), (b) Variation of post height (Each value was the difference between the maximum value and the minimum value within one chip)

CONCLUSIONS

The post top shape was shown to be predictable from the influence of the agitation intensity on the polarization curve. The conditions for improving post height uniformity were mentioned from the consideration of Wagner number. Control of post shape and uniformity is a very important factor for plating technology which is required to increase speed. It was possible to develop a copper post plating bath with excellent performance for high current density by designing the bath based on these investigations.

REFERENCES

[1] Kanako Matsuda and Shinji Tachibana, Journal of the Surface Finishing Society of Japan, Vol.65, No.8, 2014, pp.353
[2] Fumio Hine, Uyemura technical reports, No.37, 1996, pp.26
[3] Fumio Hine, Uyemura technical reports, No.43, 1998, pp.17