The Study of Dendrites Formation Mechanism to Enhance Gold Plating Process Yield, Throughput, and Solution Lifetime

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Abstract

Two factors, Au content of the plating bath and the duty cycle ratio of pulse plating, were studied to improve the dendrite phenomenon of backside Au plating process. Dendrites formation shortens the bath lifetime, and has a potential risk of yield loss at the subsequent process steps. Dendrite phenomenon was improved significantly and effectively with a higher duty cycle ratio, and could be eliminated completely by DC plating.

INTRODUCTION

Market requirement for increased RF performance; higher power and improved thermal dissipation have necessitated optimization, not only in frontside, but also in the area of backside processing. One of the key steps in backside processing is the electro-plating of a conformal gold layer on the backside surface and into through substrate Via holes. Backside metallization also provide the support to the ultra-thin and fragile 6-inch GaAs wafer. A manufacturable and high-yield Au plating process needs to meet several important requirements. Conformal coverage of the plated Au inside the Via holes is desired to meet the conductivity specifications. In addition, the morphology of plated Au not only affects the electrical performance, but also impacts the yield in subsequent processes. Due to the precious Au plating solution, to extend the solution lifetime without suffering the plating quality is also important in a high-volume production foundry. In this study, we first report a yield-killer, dendrite formation at the Au plating, and then discussed the possible formation mechanism. With a better understanding on the dendrite, we were able to optimize Au plating to eliminate the dendrite problem and increase the yield. In addition, this new approach also enhances the plating throughput and the solution lifetime.

DENDRITE PHNOMENON

Figure 1 shows the dendrites phenomenon near the backside Via edges observed by OM and SEM. Generally, the height of dendrites is about 5μm, and could be higher than 10μm at the worst case. Dendrites formed around the opening of Via holes were radically distributed on wafer.

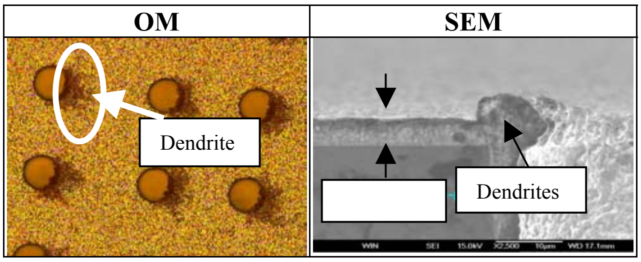


Figure 1 The dendrites phenomenon near the backside Via edges observed by OM and SEM.

The formation of dendrites always happened at the same location of each Via hole edge and seems relate to the plating solution flow direction. Dendrites occur only on wafers with backside Via holes, and are independent of Via hole shapes (circular or slot Vias). Dendrites will not be found in fresh plating solution but after a period of processing, the dendrites grow gradually. As time goes by, the dendrites become detrimental that have a potential risk of yield loss at the subsequent step of tape mounting and die separation. Then the entire bath of plating solution needs to be replaced in order to eliminate the dendrite problem. Therefore, it is import to study the mechanism of dendrite and eliminate the dendrites formation to maintain the high quality of Au plating and yield.

PLATING THEORY [3]

Non-cyanide, sulfitic-based gold plating solution was used in this study. The sulfitic gold complex, $Au(SO_3)_2^{3-}$ is a primary ingredient of the plating solution. $Au(SO_3)_2^{3-}$ decomposes into Au and sulfite ions in the solution (Eq. 1).

$$Au(SO_3)_2^{3-} \rightleftarrows Au^{+} + 2SO_3^{2-} \qquad (1)$$

Free aurous (Au^{+}) will combine with electrons which is provided from cathode; to deposit solid metal gold on wafers placed at cathode. Sulfite ions (SO_3^{2-}) also play important roles in the solution. Once the solution been prepared, SO_3^{2-} ions begin to oxidize into SO_4^{2-} (sulfate) according to equation 2.

$$2SO_3^{2-} + O_2 \rightleftarrows 2SO_4^{2-} \qquad (2)$$

Au^{+} ions are reduced to Au precipitation to form plating defect and nodules when the concentration of uncomplexed Au ions is locally exaggerated by anodic oxidation of sulfite (SO_3^{2-}) to sulfate (SO_4^{2-}). Dithionite ($S_2O_4^{2-}$) formed from sulfite at cathode could also reduce the aurous ions to gold precipitates. SO_4^{2-} is an inevitable product of the plating solution, which concentration increases continuously till the specific gravity or pH value of solution is out of specifications, then the plating solution need to be replaced. To avoid the high concentration of $S_2O_4^{2-}$ in the solution, stabilizer is used to oxidize $S_2O_4^{2}$ into SO_3^{2-} to extend the solution lifetime.

EXPERIMENTAL PROCEDURES AND EQUIPMENT

6-inch GaAs wafers thinned down to 4 mil are used for the plating study. Two kinds of shapes, circular and slot Via holes are used to the experiment. The dimension of circular Via is 50μm in diameter and 100μm in depth, with aspect ratio of 2 : 1. The dimension of slot Via is 30 ×150×100μm (W×L×D). After Via hole formation by dry etch, seed layer metal is sputtered subsequently. De-scum treatment before plating process is necessary to ensure good contact between seed layer metal and plated metal. A dual tanks with individual power supply plating system is used for the experiments. Temperature control variation is ±2℃, and flow control variation is ±0.5 LPM (Liter per minute) . After plating, the morphology is inspected preliminary by optical microscope to identify the dendrites and Via hole coverage. SEM is used to investigate dendrites phenomena.

Some key factors of solution, for example, Au content $SO_3^{2-}$and SO_4^{2-} concentration are very difficult to monitor and measured accurately. Most users send the samples to the certified laboratory for analysis. The Au content in the solution was analyzed by vendor using ICP Emission Spectrometer.

HYPOTHESIS OF DENDRITE FORMAION

In general, pulse plating was utilized to make solution exchange well and get a better step coverage with gold inside the backside Via holes. However, plating current spikes from the relay switches during the on-off duty cycle is one possibility to create dendrites. Another possible cause of dendrites formation is the gold content in plating solution. Gold ions are consumed and need to be replenished to maintain the gold concentration. Once the gold content of solution is getting lower, combined with the current spike, dendrites are easy to form. Dendrites phenomenon is similar to the partial burnt deposition that is due to low gold content and high current density. Figure 2, shows the flow path around the Via holes. The gold concentration profile could be different at region A, B and C. Even though the fresh solution with rich Au ions might reach region C directly, turbulent flow could also happen there, and therefore hinder the Au replenishing in region C.

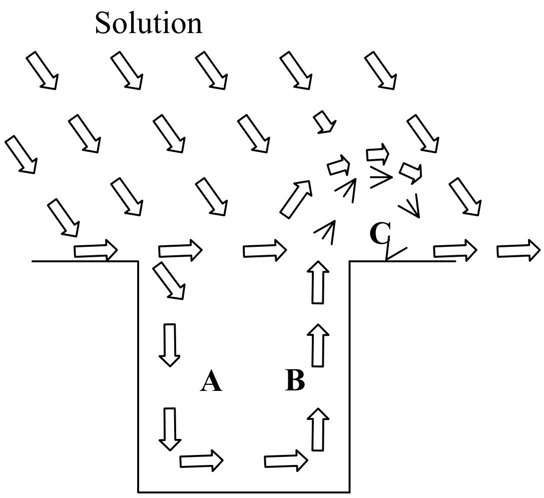


Figure 2 The gold content distribution and flow in the solution

The lowest gold concentration is probably at area C due to the turbulent flow. Therefore, the point discharge phenomenon at C corner with lower gold content in the turbulent flow is possible to cause the uncontrollable deposition like dendrites. The formation of dendrites always happen at the same location of each Via hole edge suggests that the formation is related to the plating solution flow direction. Particles exist in bath are considered as a seed of dendrites growth. Foreign impurities could come from solution preparation, operation environment and of plating equipment itself. Installing filters in piping system and operation cleanliness control can avoid most of foreign particles. However, Au particles, generated from reaction of plating bath, are an uncontrollable source. Small Au particles and other impurities could deposit on the edge of opening of Via holes more easily where there is high electric fields. Such a reaction is undesirable. Not only do the Au particles generate, but also the concentration of $S_2O_4^{2-}$ will become higher, and the precipitation causes solution unusable, which reduce the plating solution lifetime..

FACTOR ONE：AU CONTENT

In order to verify the root cause of the dendrite formation, the effect of the Au contents on the plating quality was studied first. Since the fresh solution in plating is not easy to form dendrites during the plating, we used the deteriorated solution for the experiments and studied how to improve the plating result and extend the solution lifetime.

1.1) Experimental Procedure

Table I shows the experimental plan to study the effects of Au contents on the dendrite formation. The Au content is about 10g/L before replenishing. After replenishing, Au content was increased to about 12g/L. Both Samples are pulse plated with 1 : 2 duty cycle. Two samples are processed with the same cathode, current density, plating temperature and flow rate.

TABLE I.
The experimental plan of Au content

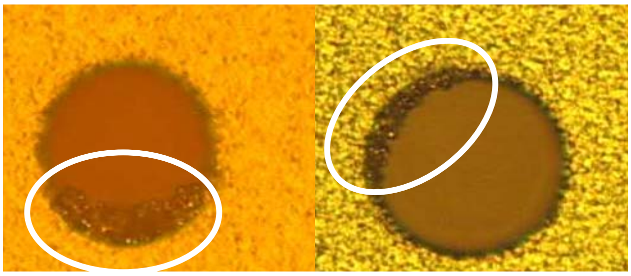
	Au content	**Plating method**
Sample 1	10 g/L	Pulse
Sample 2	12 g/L	Pulse

1.2) Results and Discussion

Table II and Figure 3 shows the results of Au content experiment with two different Au concentration.

TABLE II.
The result of Au content experiment

	Dendrite issue
Sample 1	Yes
Sample 2	Yes, but better than sample 1



(a) before replenish (b) after replenish
Figure 3 Au content affects dendrites formation

The result shows that higher Au content could slightly improve dendrites but could not completely eliminate it. It also suggests that the dendrites are more severe after consumption of the Au content. Therefore, it is important to keep a constant Au concentration in plating solution by adding Au replenisher.

FACTOR TWO：DUTY CYCLE

The second experiment was to vary the duty cycle of the plating current in order to find out the effects of plating current spikes on dendrites formation.

2.1) Experimental Procedure

Different duty cycle ratios have different relay switch on-and-off rates. In other words, more duty cycles created more spikes during the plating. Table III shows that fours samples were plated at different duty cycles with current spikes of sample 3 > sample 4 > sample 5 > sample 6. The plating system is with dual tanks and individual power supply, so this experiment was divided into two batches ; samples 3 & 5, and samples 4 & 6. All other plating parameters were the same. Two batches are processed subsequently, to ensure the same Au contents and conditions in the plating solution.

TABLE III.
The experimental plan of Au content

	Duty cycle		
	Ratio	ON (sec)	OFF (sec)
Sample 3	1 : 5	0.1	0.5
Sample 4	1 : 1	0.5	0.5
Sample 5	5 : 1	0.5	0.1
Sample 6	1 : 0	Continuously	0

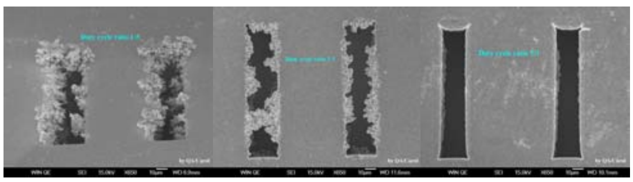
2.2) Results and Discussion

TABLE IV shows that the dendrites were improved as duty cycle became higher. The DC plating eliminated dendrites completely.

TABLE IV.
The result of duty cycle experiment

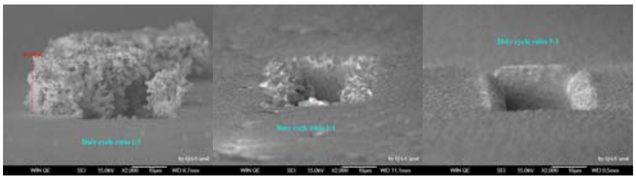
	Film thickness	**Dendrites**
Sample 3	3.0μm	Worst
Sample 4	2.6μm	Better than sample 3
Sample 5	6.4μm	Few
Sample 6	4.0μm	No dendrites

Figure 4 shows top view of dendrites phenomena with different on-off plating current duty cycle ratio from 0.2 to 5. It is obvious that dendrites phenomenon was getting better as duty cycle ratio increased. The opening of Via hole of sample 5 in Figure 4(c) deformed due to high plating Au thickness, but no dendrite formation was found.



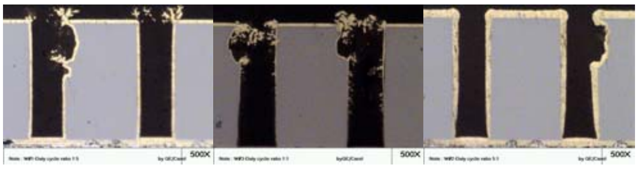
(a) (b) (c)
Figure 4 The top view of plating Au morphology of slot Via with (a) 1:5 duty cycle, (b) 1:1 duty cycle, (c) 5:1duty cycle.

It suggests that higher duty cycle ratio can restrain dendrites from growing even the plating Au thickness is larger than low duty cycle ratio samples (Figure 5). Notice that the surface roughness of plated Au of three samples was almost the same on the plain surface area, and dendrites only formed on the edges of holes, this suggests that spikes on the edges generated much higher electrical fields than other areas. Figure 6 shows the dendrites phenomena in Via hole cross sections. Serious dendrites closed up the opening of holes, and possibly cause poor Au coverage inside the Via holes.



(a) (b) (c)

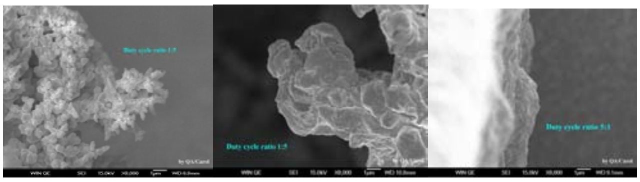
Figure 5 The height difference of dendrites (a) 1:5 duty cycle, (b) 1:1 duty cycle, (c) 5:1duty cycle.



(a) (b) (c)

Figure.6 The cross section of dendrites in Via hole with (a) 1:5 duty cycle, (b) 1:1 duty cycle, (c) 5:1duty cycle.

Figure 7 shows different grain structures at various duty cycle ratios. Au formed a loose crystalline structure with duty cycle of 0.2; with duty cycle of 5, dense structure formed. This suggests that the frequency of relay switch is the major cause of dendrites formation. Shorter relay switch on/off period with higher relay switch frequency made worse dendrites. Loose structure also results in rough surface, which looks dark at the OM inspection; denser structure with finer surface will results in brighter reflection in OM.



(a) (b) (c)

Figure 7 The grain structures of different duty cycle ratios (a) 1 : 5 (b) 1 : 1 (c) 5 : 1

DC PLATING

According to the results of duty cycle experiments, we concluded that the longer duty cycle could get better result. Therefore, DC plating without relay switching was implemented to confirm the results. All other plating parameters are the same from the previous experiments. Figure 8 shows the morphology of plating gold around the Via hole by DC plating and Figure 9 shows the cross section by SEM. No dendrite was formed, and the fine grain size was observed with smooth morphology.

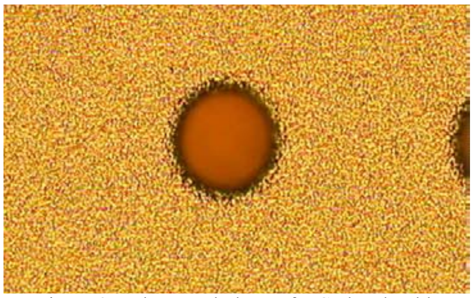


Figure 8 The morphology of DC plated gold

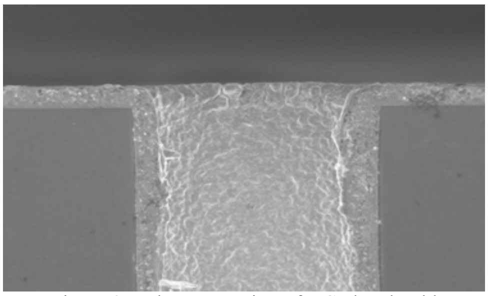


Figure 9 The crossection of DC plated gold

CONCLUSION

Non-cyanide based plating solution is very sensitive to oxidation. Oxidized solution contains high concentration of sulfate ions (SO_4^{2-}) and that will increase viscosity of solution as well. To maintain non-cyanide sulfate solution is always a difficult job in plating process. The dendrite is the one of phenomena to indicate the decay in solution. DC plating was implemented to solve the problem. It was found that DC plating could greatly improve the dendrites. DC method extends the margin of solution maintenance to avoid the dendrites issue. The plating time will be also shortened 20-25%substantially. Once the dendrites been suppressed, the formation of undesirable Au particles will be reduced. Therefore, DC plating not only resolved the dendrites issues and increased the throughput of plating process, but also extended the lifetime of expensive plating solution.

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