OPTIMIZATION OF ELECTROPLATING PROCESSES FOR COPPER BUMPS

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ABSTRACT

Ramping up a given semiconductor process is always a challenge. Lessons learned from pilot lots help in lowering potential risks that may occur during high volume production process, but some fine tuning is still needed to make the production process robust. This paper aims to describe the optimization performed to achieve a robust semiconductor manufacturing process for electroplating Copper Bumps on gallium arsenide and silicon wafers.

INTRODUCTION

In 2011, the TriQuint Oregon and Texas facilities started making Cu Bumps using a laminated resist based photolithography process. Copper is first electroplated on a negative resist followed by tin. Cu Bumps are placed on a variety of mask sets. Open areas of these mask sets range from 3 to 20%. As the developed process was ramped up, variability in the process was exposed, resulting in non-uniformity of the plated bumps. Certain areas of wafers were found to have taller bumps than target bump heights while other areas had shorter or missing bumps. Other issues found while ramping volume included: Copper and tin dendrites, Oxidized tin on Cu Bumps, and Tin voids after reflow during packaging.

Resolving these challenges and locking down the electroplating processes for Cu Bumps using the new laminated photo resist based process required an integrated approach of controlling process inputs. Figure 1 is a qualitative graphical representation of analyzing the problem. The critical inputs found were Plating bath solution stability, Hardware configuration, and Operations procedures. Prior to optimizing the process, the wide variability from these 3 major inputs was reflected in the variability of the output, i.e., variability in the quality of the Cu Bumps as shown by the white distribution curves in the figure. Process sensitivity determines how sensitive output variation is to the incoming variation. As the 3 major inputs were tightened, the variation in output mimicked the decrease in input variation as represented by the green, narrower curves in Figure 1. Two important learning from controlling variability in input are: (1) Process output is a reflection of process input; and (2) Process sensitivity impacts variability in process output. Finally, new metrology tool was put in place to provide 100% die level inspection and to provide capability for investigating further process improvements.

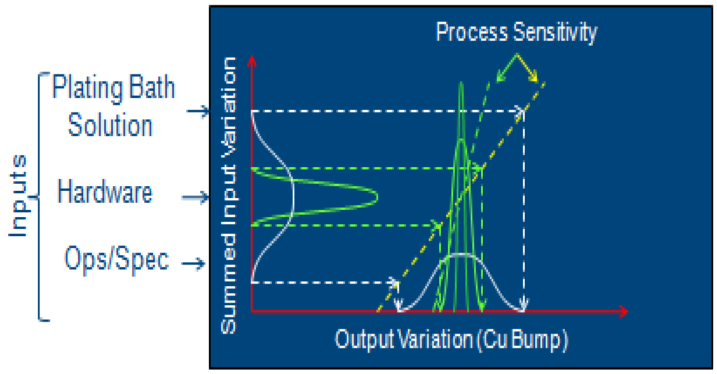

Figure 1. Controlling Input to Electroplating Processes

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PLATING BATH SOLUTIONS

Initially, the electroplating sink used for depositing copper and tin was configured such that a tin plating tank was beside copper plating tanks (Figure 2). In this way, a direct copper-tin electroplate process could be carried out. However, it was found that the benefit of direct Cu-Sn plating did not outweigh issues of cross contamination of chemistry between tanks leading to poor quality of bumps. Thus, the two plating chemistries were segregated.

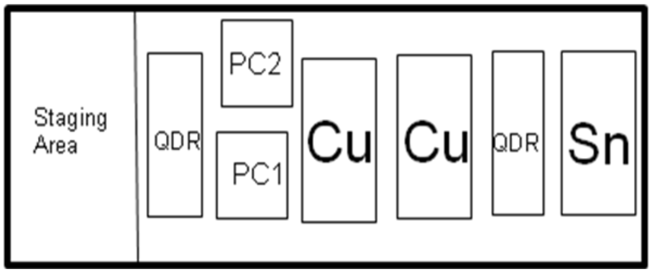

Figure 2. Plating Sink Configuration.

Once cross contamination had been prevented, the concentrations of components in the plating bath solution were optimized and tightly controlled. This was achieved by:

- establishing a reliable chemical monitoring system;
- re-targeting concentrations of components in tin plating chemistry based on DOE's that analyzed all of the failure modes mentioned previously as outputs;
- tightening control limits for concentrations of components in plating bath solution; and
- proper conditioning of plating chemistry.

The chemical monitoring system (Figure 3) involves chemical analysis of the plating bath solution on a regular basis. Cyclic voltammetric stripping technique is used in measuring the effective concentration of most of the organic components in the plating bath solution. Potentiometric titration, on the other hand, is used in determining concentrations of inorganic components in the plating bath solution. As more data was collected, the control limits for their concentrations were established. Once the concentrations in the plating bath solution reached certain limits, a plating bath adjustment would be made. A tool qualification then followed after bath adjustment before turning the tool back to production.

Figure 3: Chemical Monitoring System

Implementing all of the described changes and the changes on hardware and operations to be described in the next 2 sections, the yield for Cu Bump Process improved significantly (Figure 4).

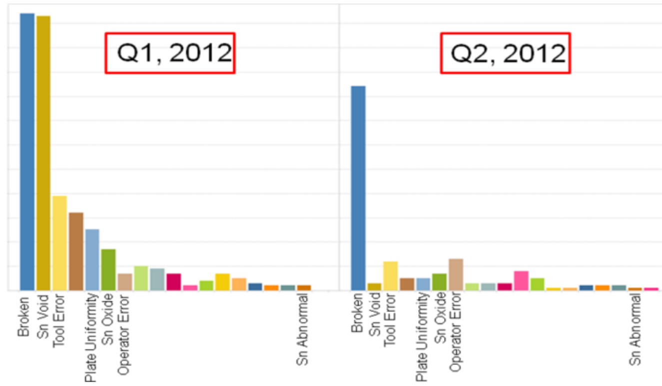

Figure 4: Yield Pareto Diagram in Q1 and Q2 of 2012

As shown in the Yield Pareto Diagram, significant quantity of wafers was lost in the first quarter of 2012 due to presence of tin voids, poor plating uniformity, operator error, breakage and tin oxide. Minimizing interference in the plating bath and its better control played a major role in eliminating tin voids leading to almost nil occurrences on second quarter of 2012. Working on operational procedures helped in decreasing wafers' loss due to operator's error. More details on changes in operational procedure will be discussed later. A decrease in breakage was also observed after introducing operational changes. More work and testing are currently being investigated to decrease wafer loss due to breakage.

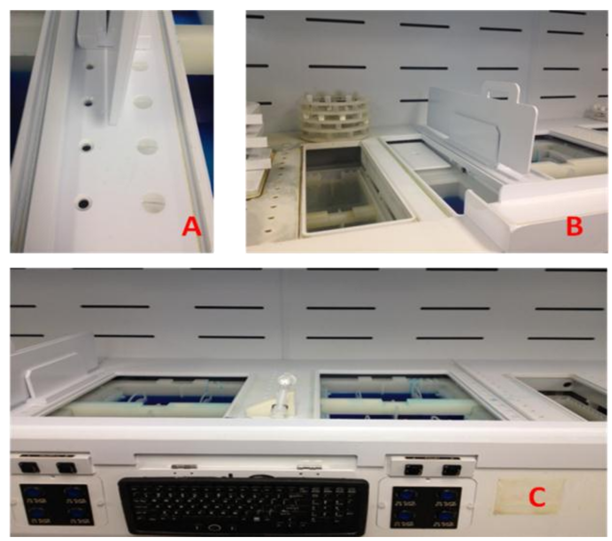

Figure 5: Modifications to Plating Bench

HARDWARE

The plating bath sinks were modified to help control the plating chemistries (Figure 5). First, holes on the deck (Figure 5A) that were placed to allow liquid drain during deck cleaning were found to be dripping water into the edge of plating tanks. These holes were plugged to prevent dilution or contamination of plating tanks. Second, a tank cover (Figure 5B) was fabricated to serve 2 purposes: (1) to prevent water getting into the tanks while spraying wafers; and (2) to cover the Pre-Clean Tank when not in use. The amount of water getting into the electroplating tank nearest to the location where wafers are wet was significant. Putting the cover across the Pre-Clean and the electroplating tank led to tighter control of concentrations of components in the electroplating solution. Without the cover, the electroplating solution had to undergo bath adjustment almost every 2 weeks. With the cover blocking any splashing of water, the bath adjustment was reduced to once every month. Finally, the sink was modified by adding a trough in front of the sink (Figure 5C). This allowed the operators to move wafers across this trough instead of across tanks. Thus, by implementing all of these 3 hardware changes, critical causes for either diluting the electroplating tank with water or contaminating the tank with chemicals were eliminated. Bath adjustment is now carried out only every 2 months. Finally, preventive Maintenance procedures were revised to reduce intrusion to the plating bath solutions allowing further control of chemistry consistency. Sufficient conditioning of anodes is carried out when a given PM activity involves some form of intrusion on anodes.

OPERATIONS

Auditing across shifts identified inconsistent interpretation of specified procedures. Operators in different shifts position wafers for wetting prior to plating in different ways. As more data was collected, it was found that positioning of wafer played a critical role in achieving better plating uniformity. Another practice that was found to be different across shifts was the way wafers were set up for unloading. Some operators who have shorter arms tend to set up the wafers for unloading in series at the front of the deck. By arranging the wafers in series from left to right, the fourth wafer ended up just right on top of the plating tank. As this wafer was soaked with water and removed from pallet and ring, the rinsing started dripping into the tank. Thus, improvement to the procedures designed to reduce bath contamination risks were identified as well. Specifications were revised to reflect changes. Procedures for the manual loading and unloading of the plating pallets, wetting wafers and moving wafers across tanks were updated and detailed to prevent any ambiguity. Operators were re-trained across all 4 shifts. Critical procedures were put on video so that operators can review the procedure in action as needed. The videos are now included in the specification and are revision controlled.

METROLOGY.

A 3-D Automated Optical Inspection was introduced to perform 100% inspection of die on the wafer. The 3-D AOI results are provided both in the form of a wafermap (Figure 6) and in the form of a table of results. Through these results, a rapid feedback for any new issues or changes to tool or processes is obtained. The 3D AOI results are used in testing ideas or plans that could potentially make additional improvement to the process as well. The 3D AOI data is constantly reviewed to identify yield improvement opportunities by tool, pallet, process change, shift or even operator.

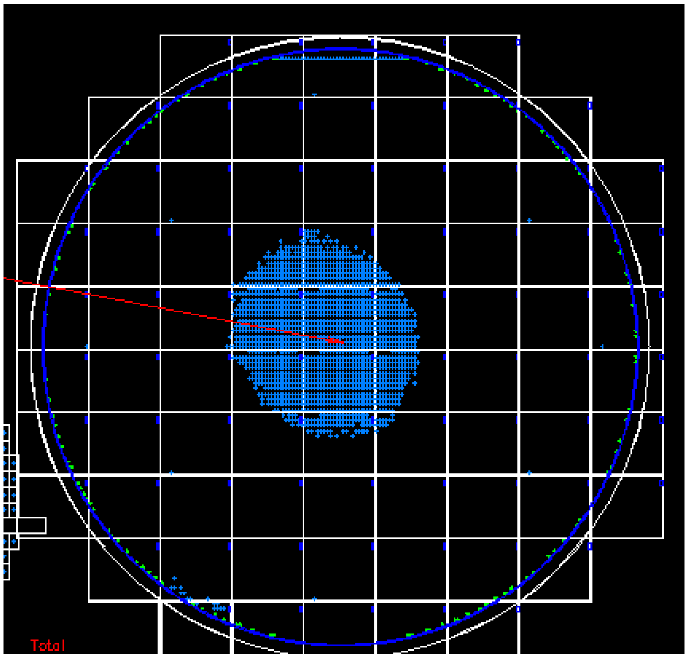

Figure 6: 3D AOI Wafermap showing defects on the center of the wafer

Figure 6 shows a wafermap where the Cu Bumps in the middle were taller than the rest of the Cu Bumps on the wafer. The taller bumps were suspected to be caused by insufficient wetting of wafer. This wetting of wafer is believed to be critical in making chemistry penetrate through a negative resist and consequently a complete fill of the bumps with copper. More data is being collected to prove if the model holds true.

The insufficient wetting of wafers typically happen more on the edge (Figure 7) than on the center (Figure 6). Taller Cu bumps tend to cluster at the edge forming a crescent shape.

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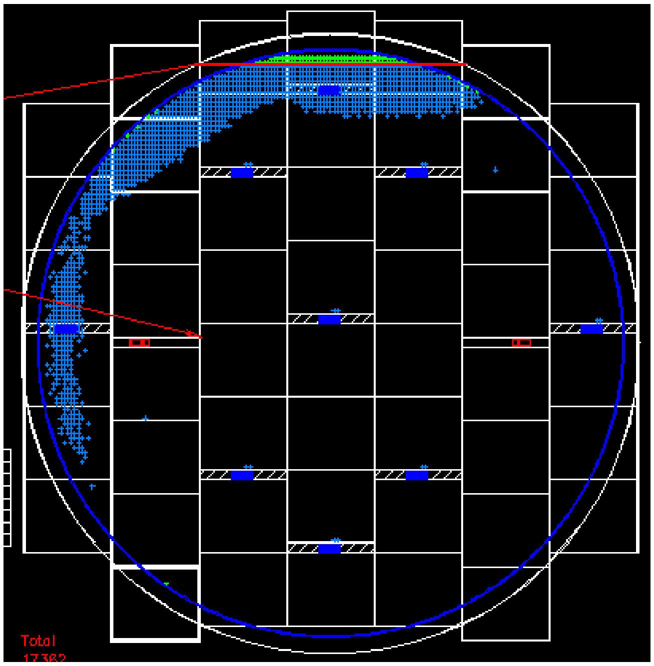

Figure 7: 3 D AOI wafermap showing defects on the edge of the wafer

Another example where 3D AOI results were used for improving die yield results was on detecting any form of deterioration of pallets and rings. A leaky ring or a compromised seal on the ring which may not be obvious during inspection prior to electroplate typically generates a wafer map with certain areas of the wafer with shorter bump heights. Once such wafer map had been detected at 3D AOI, the pallet and the ring used for this specific wafer would be griped down. Both pallets and rings are tracked during electroplate.

Above examples are the commonly encountered cases where 3D AOI results are found to be useful. 3D AOI results were found to be a powerful tool in detecting any non-uniformity issues ranging from missing bumps, shorter bumps, and taller bumps, missing Cu or missing Sn.

CONCLUSION

Through tight chemical monitoring of the plating bath solution, sufficient conditioning of chemistry, hardware changes and operations re-training, variability in the electroplating processes of copper and tin on Cu Bumps is reduced. The electroplating process for Cu Bumps on a negative laminated resist is currently more robust. Quality on Cu Bumps has been achieved and maintained at high production volumes. Further studies and testing are conducted to achieve higher line yield and make the process more cost effective.

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ACRONYMS

PC: Pre-Clean Tank
QDR: Quick, Dump and Rinse