

Reduction of Capacitor Metal Defect Formation in High Volume Manufacturing

Sarah Mason, PhD

Broadcom, 4380 Ziegler Rd, Fort Collins, CO 80525
e-mail: sarah.mason@broadcom.com Phone: 970.288.7025

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Abstract

Defects in the metal layers of capacitors cause HBT device failures [1]. The degree of capacitor breakdown can be characterized by the size and amount of defects present. Optimization of film stack deposition processes can reduce the effect of defects on devices [2]. There is no known mechanism to completely mitigate capacitor breakdown due to deformities in the metal layers. There are, however, ways to reduce the number and frequency of defects introduced during the capacitor metal layer depositions. In this paper, we present information on common causes of defect formation and methods of prevention in high volume manufacturing environments.

INTRODUCTION

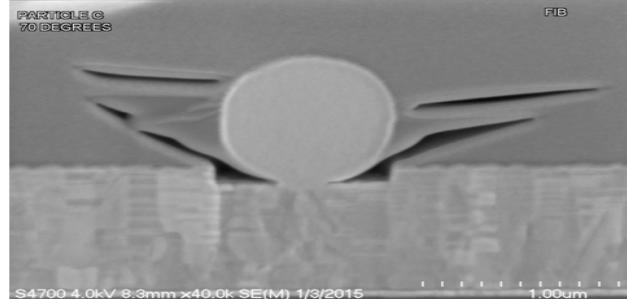
This paper will describe the types of defects that form during metal evaporation and ways they can be prevented. For this study the bottom plate of a Metal Insulator Metal capacitor (MIM Cap) was used, since previous reliability tests showed that capacitor failures are exceedingly sensitive to defects in this metal. The metal stack consists of 50nm Ti, 50nm Pt, 1um Au, and 10nm Ti. All films were deposited in an electron beam deposition system. The Au source material is evaporated from a tungsten crucible liner offset from the Cu hearth with a centering shim. Pt and Ti are evaporated directly from the copper crucibles. All metals are replenished using pellets. Tantalum is routinely added to the Au source material which binds with light elements and moves them away from the Au surface. Particle monitor wafers are processed with each batch of product wafers to monitor defect formation.

COMMON CAUSES OF DEFECT FORMATION

Gold ‘spitting’ [3] during the evaporation process is the most common cause of defect formation. Gold layer defects are typically caused either by light element contamination or by thermal shorting of the crucible liner to the water cooled copper hearth. When either of these issues occurs, increased e-beam power is required to maintain the deposition rate. Sharp fluctuations in power and/or rate are an indicator of

the Au source ejecting liquid droplets which form spherical nodules in the film.

Nodule defects in the film stack also form when gold evaporates from the outside walls of the crucible liner. This can happen for several reasons; the source material is prepared improperly, if the Ta amount is off target, or if gold build up from the surrounding hearth falls into the pocket with the crucible. Increased power for the same deposition rate is a sign that one of these events has occurred. These types of nodule defects are spherical in shape. They vary in size however; the majority of the nodules generated in an excursion event are under one micron in diameter.



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Figure 1- SEM cross-section of an Au nodule formed in a ‘spit event’ the last 20nm of deposition.

Another common cause of metal film defects arises from equipment conditions or malfunctions such as metals flaking from the chamber walls during deposition, crystal monitor faults, or comprised vacuum.

Metal flakes can imbed themselves in the metal layer when they delaminate from the chamber walls. They can also fall onto the hot source material and evaporate causing irregularly shaped defects.

Crystal monitor faults cause the power to vary and can result in spits from any metal if severe enough.

Compromised vacuum during deposition can also lead to defects. As Ti oxidizes, carbon and silicon particles present in the chamber from a compromised vacuum can adhere to the surface. These types of particles can be washed off if they are not trapped in the metal stack. Irregularities in the films from equipment malfunctions are commonly irregular shapes and vary in size.

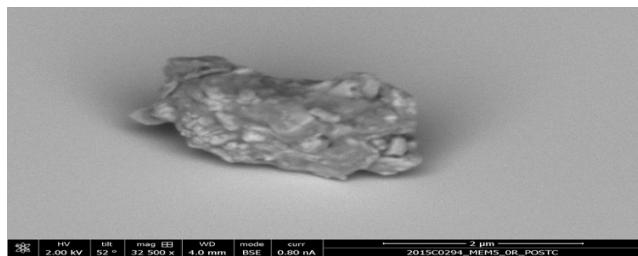


Figure 2- SEM cross-section of a Si and C particle attached to the top surface of a Ti film due to compromised vacuum.

Defects can also form during either the Ti or the Pt deposition steps, as the source material becomes deformed with use. When slug source material is repeatedly used and refilled it eventually loses its truncated conical shape. When this occurs, sufficient electrical contact between the hearth and the slug is lost causing arcing in the pocket. Deformation of the slug can trap air pockets near the evaporating surface which can then erupt when exposed. Again, shifts in the amount of power for a given deposition rate are an indicator of slug source material health, but is not an effective screening method for all excursion event causes.

Defects formed by these types of issues can vary in shape from irregular blobs to spheres (fig 3 and 4).

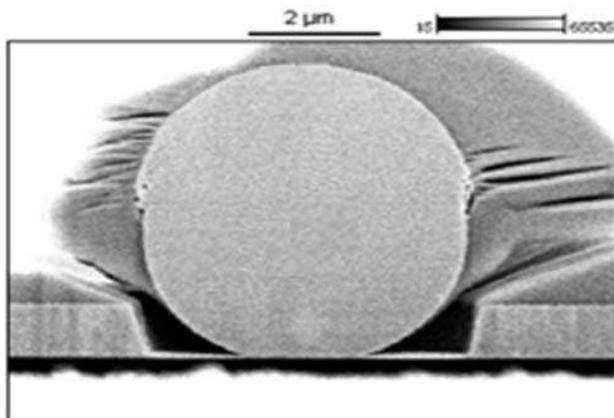


Figure 3- SEM image of a spherical Pt particle ejected from deformed source material.

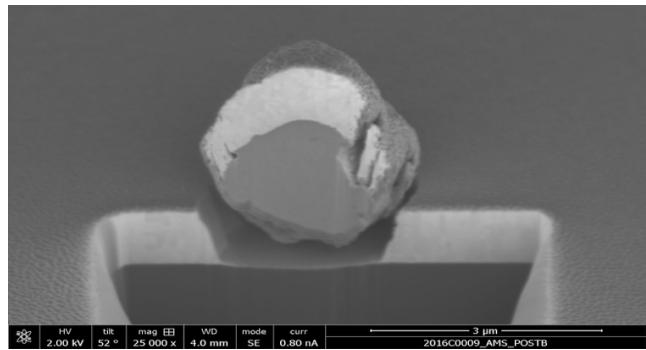


Figure 4- SEM image of an irregularly shaped Pt particle.

METHODS TO REDUCE DEFECT FORMATION

While residual light element contamination in the source material is unavoidable, the addition of tantalum to Au each time it is replenished prevents it from causing spits. For this to be effective tuning the Ta to Au composition ratio is vital. Each evaporator runs a multitude of processes, which require the source materials to be replenished at irregular intervals. It was found that when the ratio becomes too low, the likelihood of a high particle count increases (Fig 5).

Adding Ta to Au to control spitting increases source preparation overhead. It is critically important to remove the resulting TaC buildup from the outside of the crucible liner each time Au source material is replenished. Failure to remove the buildup will cause the gold to wick out of the crucible with the Ta resulting in Au being deposited from the outside of the crucible. It is necessary to add Ta each time the source is replenished to control the amount spent and available Ta for light element removal. The removal of the buildup and the handling procedures for replenishing the source materials needs to be documented in detail and strictly adhered to.

It is our experience that differences in the interpretation and implementation of the source preparation procedures caused differences in particle counts from shift to shift (fig 6).

Using an accumulation based PM cycle rather than total lots processed based cycle also reduced particle counts and utilizes maintenance resources in a more effective manner. This measures the total amount of metals deposited on the chamber walls while taking into account the type of metal. Various metal stacks delaminate from the chamber walls at different frequencies. Depositing only gold on the chamber walls delaminated less frequently than depositing a mix of metals. This was a factor in determining the appropriate accumulation based PM cycle.

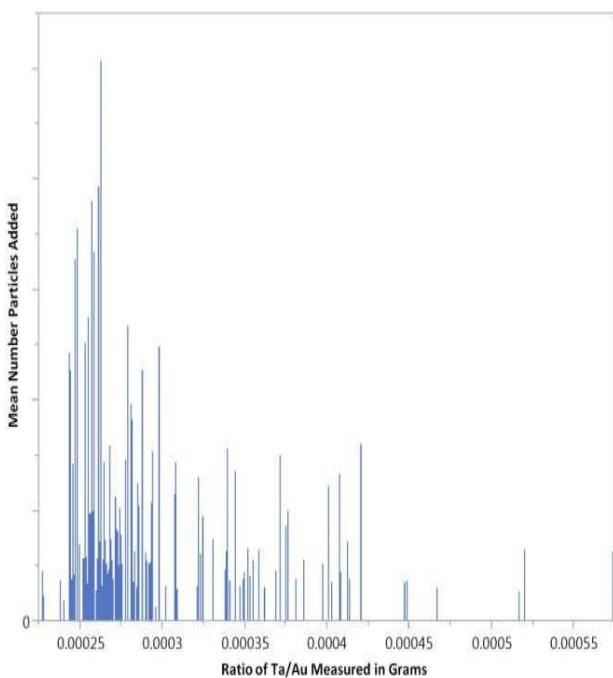


Figure 5- Plot of the Ta to Au ratio measured in grams vrs numbers of particles added during deposition of the bottom plate capacitor metal stack.

Maintaining source materials with a uniform slug shape reduces the likelihood of Ti or Pt material ejection onto the wafers. Maintaining the shape of the slugs is more manageable when starting with preformed starter slugs from the precious metal supplier. Well documented procedures, expertly trained source material handlers, and strict adherence to established guidelines are essential when replenishing the slug source materials.

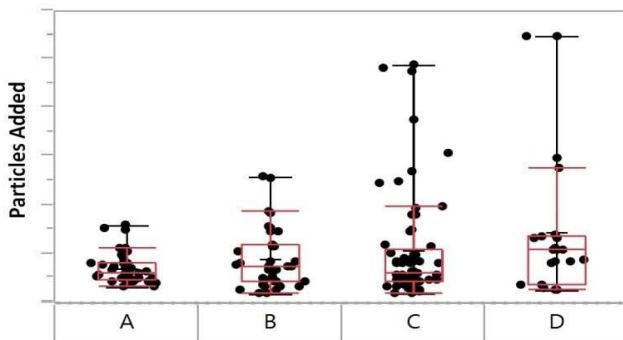
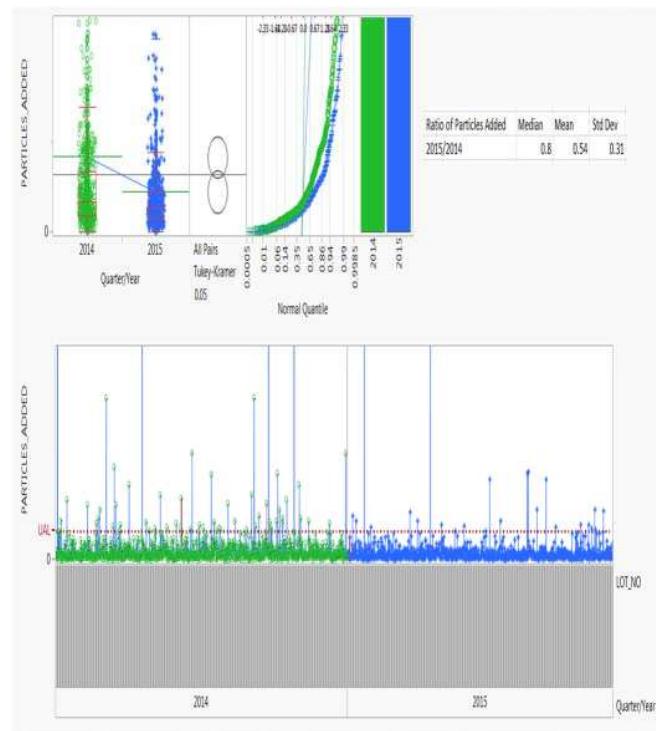


Figure 6- Plot of particles added by shift that prepared the source material

Monitoring tool data such as deposition rate, e-beam power, and vacuum pressures during processing can detect shifts that can cause high defect counts. Detecting these shifts in the conditioning phases of the deposition processes is the most effect way of preventing excursions. This requires the ability to monitor in real time and compare moving range, statistically significant, historical data.

RESULTS

In the graph below data collected from particle monitors processed during the bottom plate capacitor deposition over time is presented. Particle reduction efforts began at the end of 2014. Since then, the methods presented in this abstract have reduced the number of high defect count excursions. The baseline amount of particles added has been reduced by more than half and the run to run variation has been reduced by approximately one third.



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Figure 7- Plots of particle added during the bottom plate capacitor deposition sorted by date.

CONCLUSIONS

Capacitor defects lead to HBT device failures. Irregularities in the bottom plate capacitor metals can be reduced through various methods. The major contributor to high defect counts were from Au spitting that was reduced by tuning Ta/Au ratios, implementing refined documentation and training methods for handing the source material, and implementing real time statistical data monitoring. Secondary causes of particle excursions due to equipment malfunctions and slug source material conditions are being addressed in order of frequency and severity. The methods described in this paper have resulted in significantly improved processes and products and further methods of improvement are ongoing.

ACKNOWLEDGEMENTS

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ACRONYMS

HBT: Heterojunction Bipolar Transistor

MIM: Metal Insulator Metal