Investigation of MIM Top Metal Peeling in Relation to Transitional Flow during Metal Deposition Process

Chang'e Weng, Tertius Rivers, Moreen Minkoff, Ron Herring, Richard Ducusin, Jinhong Yang and Joseph Chinn

Qorvo, 2300 NE Brookwood Parkway, Hillsboro, OR 97124, Email: Change.Weng@Qorvo.com, ph: 503-615-9820

Keywords: MIM, Transitional flow, Peeling, Sputter, Metal, Knudsen number, Capacitor

Abstract

Investigation of a capacitor leakage related test failure revealed correlation between Metal-Insulator-Metal (MIM) top metal peeling and metal deposition tool Knudsen flow.

INTRODUCTION

Metal-Insulator-Metal (MIM) capacitors are important components for GaAs based RF technologies[1,2,3,4]. A MIM capacitor is composed of a bottom metal plate, a dielectric layer, and a top metal plate. Fabrication of MIM capacitors involves multiple process steps. Interconnect Metal-zero layer normally serves as the MIM bottom plate. Defects underneath or on top of that metal can lead to MIM capacitor defects[4]. Silicon nitride or oxide is widely used as the capacitor dielectric layer and is deposited using a PECVD process. Variations in dielectric layer thickness and roughness directly affect capacitor performance. Evaporated or sputtered Ti/Pt/Au metal stacks are commonly used as MIM top metals. Since MIM top metal is connected to the next upper metal layer through inter-layer dielectric vias, defects formed during MIM metal deposition could also cause both capacitor- and via-related parameter failures.

Due to the complexity of the MIM process, defects which are not detectable in-line during the process can form at various process steps. Depending on the nature and location of the defects, Process Control Monitor (PCM) and diesort test can screen out some of the defective die, but some defects may not be detectable unless a more destructive test is used. MIM capacitors with defects passing PCM and diesort test are therefore a reliability concern. Research from both mobile phone makers and RF device fabrication companies has shown that MIM capacitor failures are a leading cause for many early-stage field failures [1,3,4].

At Qorvo, a voltage ramping approach was developed to detect MIM capacitor defects[4]. Each individual die is assessed, and defective die are screened out in a low voltage region[4]. Process improvements are often required to address capacitor related test failures. In this paper, we discuss an investigation of capacitor leakage failures detected at diesort that are related to MIM top metal peeling. Process improvements were implemented at the deposition tool eliminating this defect.

RESULTS AND DISCUSSION

Capacitor Shortage and Failure Mode

Capacitor failures are normally due to defects under vias and are difficult to detect. For our voltage ramping test approach at Qorvo, a voltage stress is applied to the capacitor and high capacitor leakage screens out weak capacitors[4]. Figure 1 shows a diesort wafer map that had via-related parameter failures. Failed die were randomly located across the entire wafer and up to 10% of the die could be affected. Failure analysis was performed and showed the via related parameter failure was due to missing or peeling MIM top metal causing shorting between the via and bottom capacitor metal.

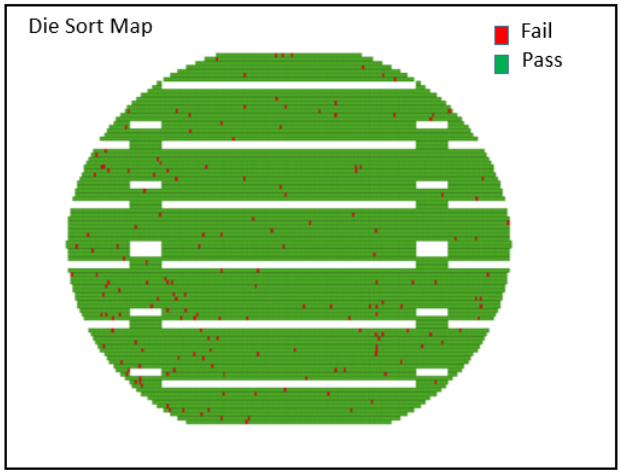


Figure 1. Diesort pass/fail wafer map. Random capacitor leakage failures are seen across the wafer.

Figure 2 shows FIB cross sections of failed die. In Figure 2(a), MIM top metal was partially missing and in 2(b), MIM top metal peeling was observed. In both cases, via metal contacting bottom MIM metal caused shorted capacitors.

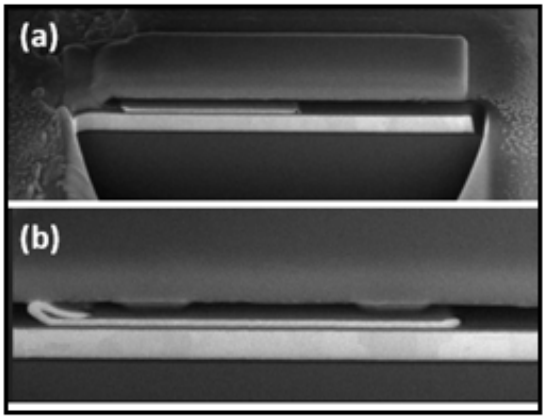


Figure 2. FIB cross section results of failed die showed MIM top metal missing or peeling.

MIM Top Metal Defect Investigation

Investigation of the root cause of MIM top metal peeling was focused on top metal deposition, lift off processing, and pre-clean steps. 100% Automated Optical Inspection (AOI) of MIM structures was performed after top metal liftoff. Figure 3 shows a die with MIM metal peeling. Inspection results indicated that for all affected lots, only one wafer had this defect as shown in Figure 4. Since the wafer order may change multiple times during MIM layer process, it was challenging to determine if this is a "first" or "last" wafer effect. Wafer order changed again when lot was tested but Die sort test had the same conclusion with one wafer yielding low within a lot as shown in Figure 5.

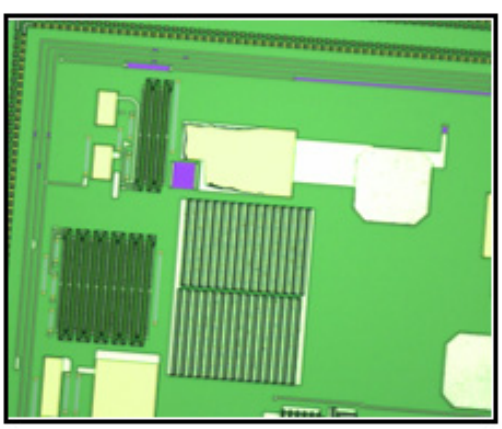


Figure 3. In-line AOI inspection shows MIM top metal peeling after metal liftoff.

Further commonality analysis indicated that most affected lots were from the same metal deposition tool. All other affected lots were processed through a different metal deposition tool and were all small lots of 12 or less wafers.

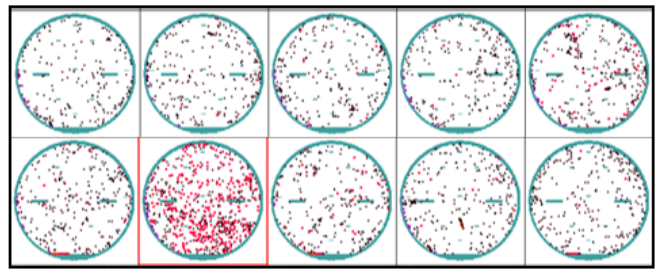


Figure 4. AOI results of MIM structures after top metal liftoff process.

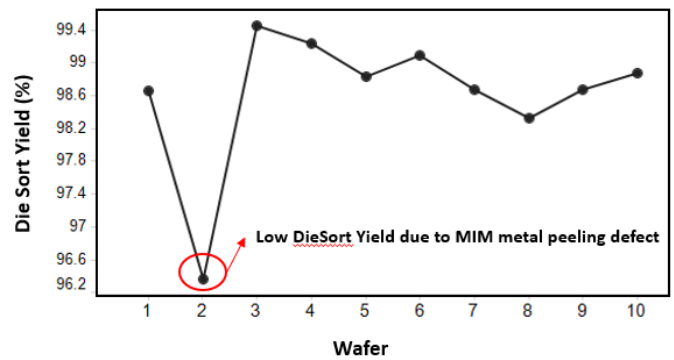
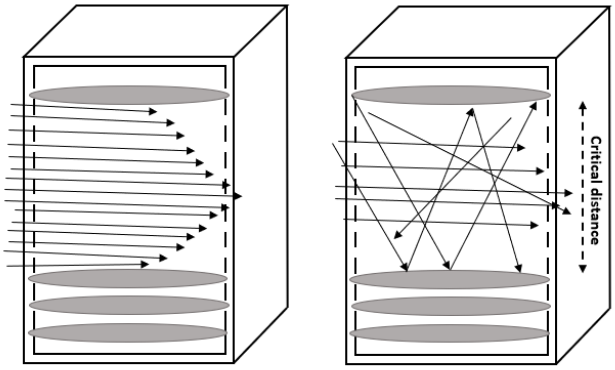


Figure 5. Die Sort yield of affected lots indicate single wafer effect.

Wafer ordering experiments were conducted at the metal deposition tool. These revealed that the peeling defects were related to the pumping process inside the loadlocks, which also explained a "last wafer effect". It was found that when an open-top type cassette was used, the wafer at top of the cassette always had the metal peeling defect. When a closed-top type cassette was used as shown in Figure 6, the top wafer may or may not have the peeling defect depending on two factors - pumping pressure inside of the loadlocks and distance between the top wafer surface and the top of the cassette (critical distance). Those two factors defined the flow inside the loadlocks. During the loadlock pumping process from atmosphere, the change from continous flow to transitional flow (also known as Knudsen flow) led to a wafer surface condition change. Interaction between gas molecules and residue on the wafer surface caused relocation of residue particles. Those residue particles accumulated on the edge of MIM features which then resulted in metal adhesion loss after metal deposition.



(a) Continuous flow **(b) Knudsen flow**

Figure 6. Continuous flow (a) and Knudsen flow (b) inside of loadlocks at different pressure.

Atomic Force Microscopy (AFM) images of a MIM feature before and after metal depositon tool loadlock pumping are shown in Figure 7. The wafer was loaded into the loadlock and was pumped down to Knudsen flow and then ejected for measurement without metal deposition. A surface morphology change was observed with higher roughness (Ra of 1.44 nm) after pump down compared with before pump down (Ra of 0.949 nm). Large particles formed on the MIM feature during the loadlock pump down then lead to adhesion loss after first layer of top metal deposition.

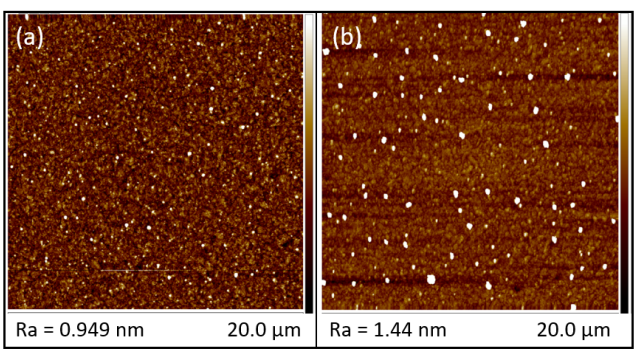


Figure 7. AFM images of the MIM feature (a) before and (b) after loadlock pumping.

Our study showed that based on different critical distances and pumping pressures inside of the loadlock, when the Knudsen number was greater than about 0.2 the metal peeling defect was observed. Also, wafers pumped for a longer time under Knudsen flow had an increased severity of peeling defects with up to 10% of the die affected. With implementation of a closed-top type cassette and control of critical distances of the top wafer by loading the wafers from top slot, this type of MIM metal peeling defect can be eliminated.

CONCLUSIONS

This paper discussed an investigation of MIM capacitor leakage failure due to MIM top metal missing or peeling. The Root cause was found to be pumping wafers under Knudsen flow before MIM top metal deposition leading to metal adhesion issues, especially when the Knudsen number is greater than 0.2. Process improvement by changing the pumping pressure or the critical distance can eliminate these defects and improve both yield and device reliability.

ACKNOWLEDGMENTS

The authors would like to thank Edward Beam from Qorvo's Texas site for the AFM measurements.

REFERENCES

[1] J. Lu, B. Cao, W. Wu, Y. Dai, C. Huang and G. Mura, *MIM Capacitor-related Early-stage Field Failures*, 2012, Microelectronics Reliability, Vol 52, issues 9-10.

[2] P. Leber, M. Hollmer, D. Schrade-Kohn, J. Thorpe, R. Behtash, H. Blanck, H. Schumacher, E*valuation of Existing GaAs MIM-Capacitor Processes for Use with High-Voltage GaN MMIC Technologies*, CS Mantech Conference, 2011

[3] J. Gurganus, T. Alcorn, A. Mackenzie and Z. Ring, *Investigation and Improvement of Early MIM Capacitor Breakdown with a Focus on Edge Related Failures*, CS Mantech Conference, 2010

[4] B. Roesch and D. Hamada, *Discovering and Reducing Defects in MIM Capacitors*, Microelectronics Reliability Vol 81, 2018

ACRONYMS

MIM: Metal-Insulator-Metal
AOI: Automated Optical Inspection
AFM: Atomic Force Microscopy
PCM: Process Control Monitor