Optimization of a Metal Liftoff Process in a GaAs Semiconductor Device

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Abstract:

At Skyworks Solutions a defect was observed in a metal structure after a liftoff process had been performed. Investigation revealed the defect was due to damage caused by the liftoff process. The liftoff process was optimized for minimum defect level using DOE techniques. This paper will describe the defect and the investigations performed to understand it as well as a description of the DOE and the process modifications made based on it's results.

INTRODUCTION

An important process in the production of a GaAs transistor device is formation of ohmic contacts typically used for the source, drain, and bond pad regions. [1] At Skyworks Solutions the ohmic structure is formed using a conventional liftoff process consisting of sequential steps of photolithography, metal deposition, and solvent liftoff. A process change was made that increased the thickness of the ohmic metal layer. After the implementation of the process change damage to the ohmic metal layer was observed after liftoff. This paper will describe how the metal damage occurred, characterize the damage level to the metal thickness, and describe the DOE performed to minimize the metal damage.

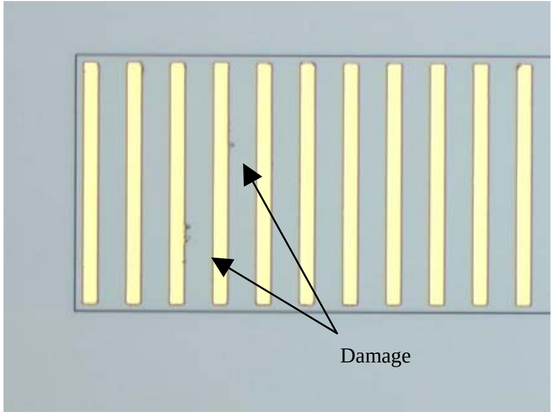
PROBLEM DESCRIPTION

The ohmic structure consisted of a Ni:Au:Ge metal stack with a total thickness of 2500Å. A process change was made that increased the ohmic structure thickness to 4000Å in order to achieve improved device quality and reliability. Qualification of the increased structure thickness showed no electrical yield degradations and visual inspections indicated no problems.

However when the 4000Å ohmic structure was released to high volume production problems were detected during post liftoff visual inspections as seen in figure 1. Specifically a defect referred to as metal flagging was noted to various degrees on many wafers.

The classification of metal flagging infers a problem with the photo resist and or metal deposition processes. [2] However SEM inspection as seen in figure 2 showed that these defects were not the usual defect associated with the term flagging

Figure 1
Optical Image of Metal Damage



Classically flagging refers to a defect where the solvent penetration gap between the metal on top of the photoresist and the metal on the GaAs surface is small to non-existent. This can be due to problems with the photolithography and/or metal deposition processes. [2] In this situation the metal on top of the photo resist is ripped from the metal on the GaAs surface leaving a thin veil or flag on the remaining ohmic metal structure. An incomplete metal liftoff will result if the solvent penetration gap is compromised over a large percentage of the wafer surface.

The defect discussed in this paper was not generated in the same manner as classic flagging. SEM images show trenches and gouges on the metal surface that result in flag like defects at the edges of the metal structures. In this case, the defect was due to mechanical damage and not a compromised solvent penetration gap.

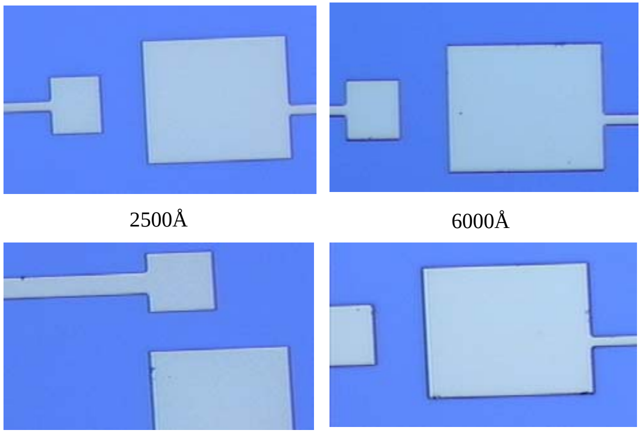
Figure 2
SEM Image of Metal Damage

PROBLEM INVESTIGATION

To understand the problem experiments were performed looking at the effects of metal thickness and liftoff method on the defect level.

To investigate the effect of metal thickness a set of wafers were generated using metal thicknesses of 2500Å, 4000Å, 6000Å, and 8000Å. All wafers were lifted off using the standard low pressure solvent spray (LPSS) system method. The images seen in figure 3 show that all thickness levels greater than 2500Å showed metal damage. Therefore it was established that the metal damage defect correlated with the process change that increased thickness of the ohmic structure to 4000Å

Figure 3
Metal Thickness vs. Damage Level Photos



2500Å

6000Å

4000Å

8000Å

To investigate the effect of the liftoff method experiments were performed comparing the standard LPSS system to an alternative immersion liftoff method.

The standard ohmic metal liftoff process is performed on a LPSS system using a NMP based solvent. The process recipe consists of a series of solvent exposure steps, rinse steps, and dry steps. The parameters involved in the solvent exposure steps will be the focus of this paper.

The solvent exposure steps consisted of a 10-second exposure to used solvent, a 70-minute exposure to recirculated solvent, and a final 10-second exposure to fresh solvent. The solvent is used at a temperature of 90°C, a spin speed of 20 RPM, and a flow rate of 0.8 gpm. The wafers were loaded using single spacing within the cassette.

The immersion system consists of a four bath solvent hood using the same NMP based solvent at 90°C. The system consisted of a fresh solvent bath, a used solvent bath, a QDR station, and an IPA bath. The process consists of performing the liftoff in the used bath and then transferring to the new bath for a fresh rinse. After liftoff wafers are moved to a QDR bath to rinse the NMP based solvent off the wafer and then soaked in the IPA bath. After rinsing each wafer is individually dried. The immersion liftoff process is entirely manual.

Wafers were processed using both liftoff techniques. Metal damage was seen for wafers processed on the LPSS system. No damage was observed for wafers processed in the immersion system. It was decided to closely observe the liftoff process in both the LPSS system and the immersion systems.

The LPSS liftoff process can be observed through a viewing window at the front of the system. The wafers spin during processing about an axis normal to the window surface such that the liftoff process can be seen for the first wafer in a cassette. The liftoff occurs while solvent is being sprayed on the wafers rotating at 20 RPM. The solvent spray is at a low pressure that provides only solvent coverage of the wafer. No mechanical action results from the low pressure spray. It was observed that the liftoff first occurred at the edges of the wafer and slowly progressed to the center of the wafer. Complete liftoff occurred in approximately 5 minutes.

As the metal liftoff progressed from the edge to the center of the wafer loose metal was generated. Loose metal is defined as metal that has lifted off and is detached from the wafer surface. The loose metal would either rip away from the areas of non-lifted metal and rinse off the wafer or stay anchored to the non-lifted metal and float over the wafer surface. Often there were large areas of loose metal floating over the surface of the wafer as the liftoff process neared completion. Once all metal was free the loose metal would slide off the wafer surface completely.

The open bath immersion is easily observed from the top of the bath. The liftoff begins at the edges with the outer 2.5mm of metal slightly curling away from the wafers surface. Ripples and wrinkles are seen over the entire wafer surface shortly after the curling is observed. The entire surface of metal separates from the wafer and sinks to the bottom of the bath after several minutes in this state. It is an important observation that the metal lifted off in one continuous sheet. Complete liftoff was achieved in approximately 10 minutes. The immersion liftoff process was more uniform than the LPSS liftoff process.

The damage to the ohmic metal structure during liftoff on the LPSS system was due to the non-uniform liftoff and the resulting floating loose metal. The floating loose metal is harmless as long as there exists a thin layer of solvent between the metal and the surface of the wafer. However at times the floating metal pierces this solvent layer allowing the floating metal to scratch, gouge, and damage the metal structures on the wafer surface.

To reduce the ohmic structure damage either the process needed to be transferred to the manual immersion hood or the LPSS liftoff process needed to be optimized. The manual immersion process did not have the capacity to support the ohmic metal liftoff process. Additionally it is generally desirable to remove manual handling steps from any semiconductor process. [3] It was decided to optimize the LPSS liftoff process for defects using DOE techniques.

The DOE would focus on parameters associated with the solvent exposure steps because this is where the metal damage was occurring. The DOE input variables were the process parameters of RPM, temperature, flow rate, and slot spacing. These parameters were considered to have the largest effect on the defect level. The output variable was a quantifiable manual inspection.

At 20 RPM centrifugal forces were low enough such that gravitational forces caused the loose metal to fall with every rotation. Increasing the RPM would make centrifugal force dominant causing the metal to stay in one place until it was ready to fall all the way off the wafer.

Increasing the temperature will increase the aggressiveness of the solvent and thereby reduce the overall liftoff time. By reducing the overall liftoff time the floating metal would have less time on the surface of the wafer thus having less time to damage the underlying metal structure.

Increasing flow rate would get more solvent to the center of the wafer and increase solvent penetration in that area. Poor solvent coverage at the center of the wafer could result in poor liftoff uniformity and increase the generation of floating loose metal. Getting more solvent to the center of the wafer would improve uniformity and generate less damage inducing floating metal.

Tight slot spacing could inhibit solvent penetration as well as physically prevent some metal from falling off the wafer. Increasing slot spacing from single to every other slot would allow solvent to easily reach the center of the wafer improving uniformity and allow any loose metal generated to easily fall off the wafer.

The DOE was performed with the following specific dynamic ranges: RPM 30 – 150, flow rate 0.5gpm to 1.5gpm, temperature 80°C to 100°C, and a wafer spacing of single and double slot. Approximately 500 wafers were inspected as part of this DOE.

The output variable was a quantifiable manual inspection. Batches of 12 to 24 wafers with an ohmic metal structure were processed with inspection performed on 50% of the wafers. Inspections were performed using a pre-defined 9-site pattern. Each site was inspected optically at a magnification of 500x and classified as either having the defect or not. For each wafer the sum of all 9 sites was taken and this result was averaged for all inspected wafers in a batch. In this manner a number representing average damage level for each batch was generated. This number in turn was put back into the DOE for analysis. The results of the DOE can be seen in figures 4 through 7.

All input variables had a statistically significant effect with P-values less than 0.05. [4] The RPM and flow rate are inversely proportional to defect level while the temperature and cassette spacing were directly proportional to defect level.

Increasing RPM resulted in less metal line damage. It was observed that the metal moved little until it was completely lifted off at which time the entire sheet of metal slid from the wafer surface. Metal contamination of the process chamber and wafer cassette was seen when the RPM was increased to 150. This was due to the metal 'flinging' off the wafer with enough force to stick to the chamber walls and the cassette. This contamination was not seen at RPMs below 100. It was decided an RPM of 100 would be the maximum level.

It was observed that increased solvent flow increased liftoff uniformity and reduced metal line damage. A pneumatic pump controls chemical flow and therefore there were hardware restrictions for maximum flow. A flow rate of 1.5 gpm was achieved by setting the CDA pressure of the pump at maximum value. Therefore a realistic pump setting for daily production was 1.2 gpm.

The inverse relationship seen due to temperature was unexpected. It was observed that the increase in temperature made no significant difference on the liftoff uniformity or time. Furthermore increasing the aggressiveness of the liftoff process by increasing temperature of the solvent may have negated improvements seen by other process variables. Reducing the temperature allowed other process variables to play a more significant role in the process characterization such that reduction in defect level due to other process variables could be seen.

It is difficult to explain why single slot spacing had a lower defect level than double slot spacing. It suffices to say that this is a favorable result since the capacity of the process would be reduced by 50% if all products had to be loaded double slot spacing.

Figure 4
RPM vs. Defect Level

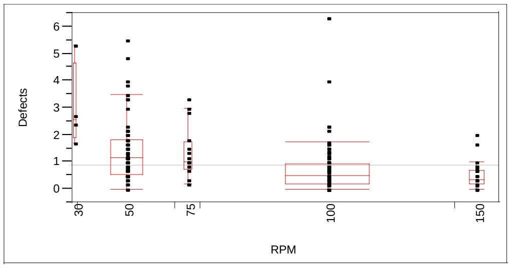


Figure 5
Flow Rate vs. Defect Level

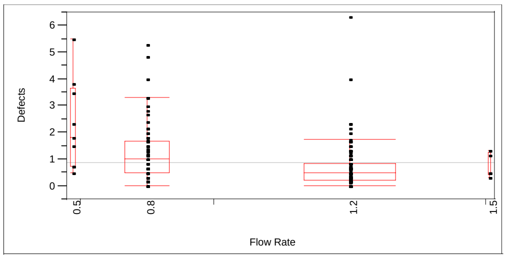


Figure 6
Temperature vs. Defect Level

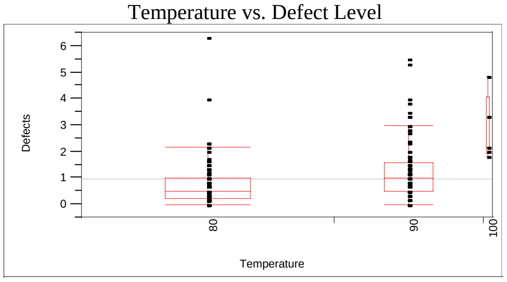
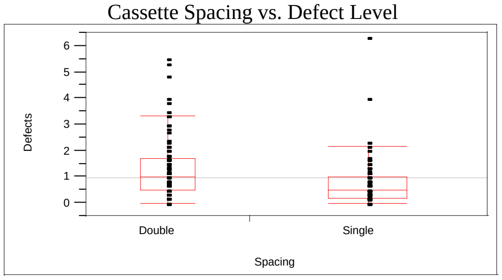


Figure 7
Cassette Spacing vs. Defect Level



PROCESS MODIFICATIONS

The ohmic liftoff parameters were modified from the original process using 20 RPM, a temperature of 90°C, and a flow rate of 0.8gpm to a new process using 100 RPM, a temperature of 80°C, and a flow rate of 1.2gpm. The cassette spacing was not changed since it was shown that single spacing had the lower defect level. The time to liftoff did not change and remained at approximately 5 minutes. The defectivity level dropped from an average of 3.5 defects/wafer with the original process to 0.06 defects/wafer with the modified process.

The production inspection criteria were modified to specifically inspect for this type of metal line damage. The old inspection involved 9-site pattern at a magnification of 200x. The new inspection involves the same 9-site pattern but using magnifications of both 200x and 500x. The documentation describing the modification was updated to include a detailed description with photos of the defect.

CONCLUSION

A process change was made that increased the ohmic metal structure from 2500Å to 4000Å. Despite rigorous qualification a defect was noted on the structure when it was released to full production. Investigation showed that the defect was due to scratching and gouging on the ohmic metal structure that occurred during the liftoff process. The liftoff process was examined on different pieces of equipment and the defect was isolated to the LPSS liftoff system. Closer examination showed that the lifted metal floated over the wafer surface prior to full liftoff causing the damage to the underlying structure. The LPSS liftoff process was optimized for minimized defectivity using a DOE technique. A new process using a higher RPM, lower temperature, and a higher flow rate was created with a significant reduction in the defectivity level.

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ACRONYMS

DOE: Design of Experiment
QDR: Quick Dump Rinse
RPM: Revolutions per Minute
CDA: Clean Dry Air
GPM: Gallons per Minute
NMP: N-methyl Pyrrolidone
SEM: Scanning Electron Microscope
IPA: Isopropyl Alcohol
LPSS: Low Pressure Solvent Spray System