Visual and Electric Ohmic Metal Degradation From Later Process Steps

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ABSTRACT

Ohmic metal degradation caused wafers to fail at wafer final test due to high contact resistance. A change in the morphology of the ohmic metal near first interconnect metal was associated with the increase in contact resistance. It was found that previously good Ohmic contacts were ruined by overheating in O_2 plasma tools near the end of the fab process. Reducing time in plasma at that step solved the problem without compromising the quality of the plasma clean.

INTRODUCTION

For one of its SAG PHEMT processes [1], TriQuint Semiconductor employs an evaporated AuGeNi metal stack to form the ohmic contacts (see Fig. 1). AuGeNi ohmic contacts have been widely used in the GaAs industry for over 30 years. Their fabrication is relatively easy since conventional metal deposition (sputtering or evaporation) and lift-off methods can be used. Annealed at relatively low temperatures, they provide low contact resistance. Further processing can cause ohmic metal degradation with disturbing visual and electrical effects. This paper reviews those effects and how the process was stabilized.

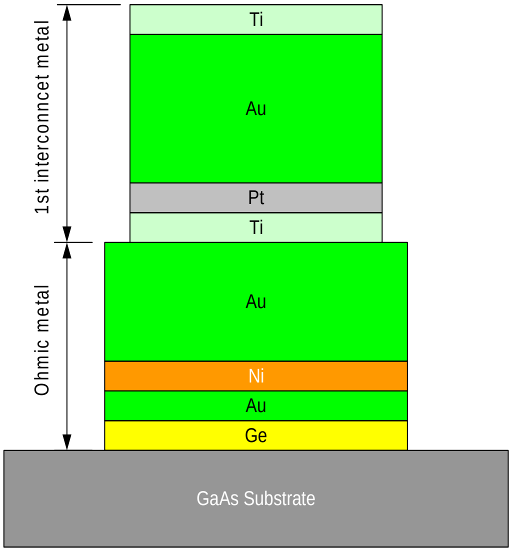


FIGURE 1: Ohmic and 1st interconnect metal stack

ELECTRICAL EFFECTS

After the alloy of the ohmic metal stack in a RTA at 390°C for 60 sec, the contacts show typical morphology and good parametric test results. The contact resistance (RC) is measured on a transmission line model (TLM) structure by an automated parametric test system and is typically 100 Ω*µm. After the parametric test, called ohmic test, MIM capacitors and interconnects including air bridges are fabricated. We found that at wafer final test the RC sometimes changed dramatically, losing uniformity and exceeding its upper specification limit.

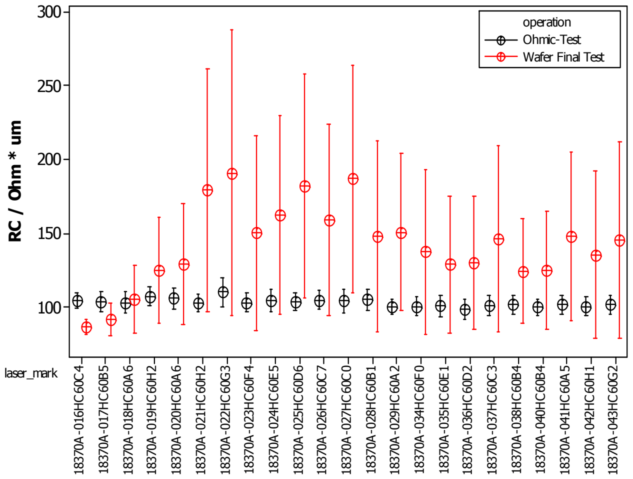


FIGURE 2: Electrical effect: The same lot at Ohmic & final test

Figure 2 shows an example. RC at ohmic test is typical with good uniformity. But at wafer final test RC and the uniformity deteriorated badly. Even though the first two wafers showed an RC reduction, which can be explained by a reduced resistance through additional Au on the test pads and the first interconnect metal on the TLM feeds, the wafer average increased by a factor up to two and the uniformity collapsed by a factor up to 10.

VISUAL EFFECTS

Associated with the increase of contact resistance is a change in the morphology of the ohmic metal where the first interconnect metal is close by. As shown in Figure 3, the

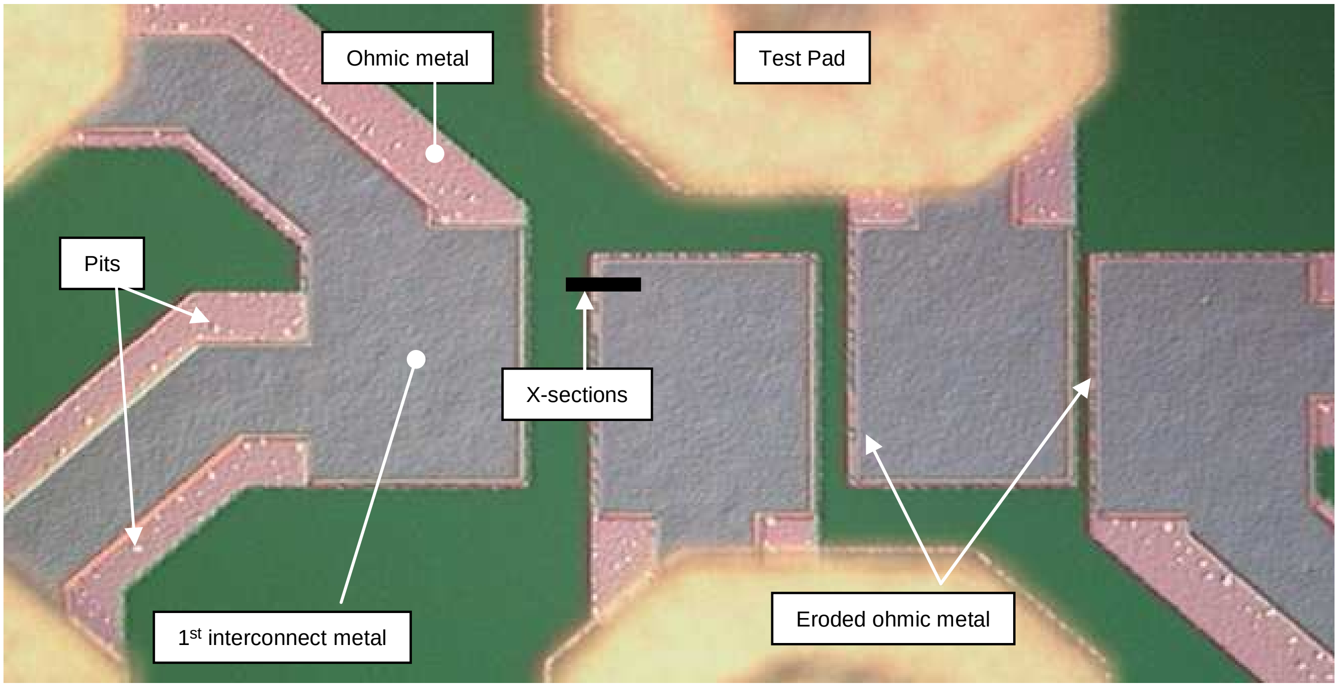


FIGURE 3: The visual effect demonstrated on a TLM structure.

ohmic metal erodes at the edges of the contact, an effect we called *mouse bites*. Larger areas of ohmic metal are riddled with pits. Ohmic metal without connections to the first interconnect remains unchanged.

As part of our investigations, cross sections of TLM structures were performed. The location is shown in Figure 3, where the arrow indicates the view direction.

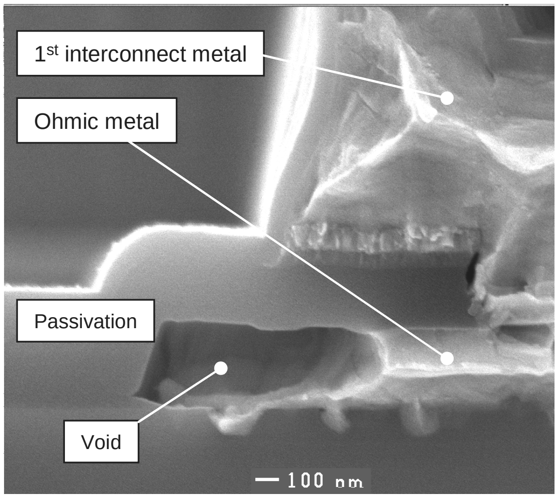


Figure 4: Cross section of the edge of an Ohmic contact

Figure 4 shows the edge of an ohmic contact. The ohmic metal is gone, leaving a void under the passivation that was deposited after alloy. The same description applies to the larger areas of ohmic metal riddled with pits. The ohmic metal is eroded, leaving a void underneath the passivation. Surprisingly, in all the cross sections we did, we could never find the missing metal underneath or adjacent to the void.

MICROSTRUCTURE ASPECTS

There are numerous publications about AuGeNi ohmic contacts, which are well summarized in [2], [3] and [4].

The alloy process is very complex. Au, Ge and Ni react with the GaAs forming new compounds:

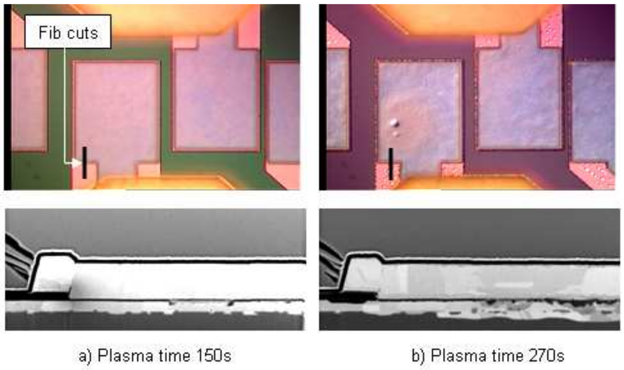
- Ga diffuses into the metal and reacts with Au, forming Au_7Ga_2 [2]
- Ge and Ni diffuse into the wafer forming NiAsGe [4]
- Ge comes to rest on the Ga sites acting as an dopant

To achieve low RC NiAsGe has to be present at the interface to GaAs. Au rich phases at the interface generally lead to higher RC [4, 5].

It is known that an adequate combination of temperature and time will cause a degradation of the Ohmic contact because of continuing diffusion of the components. But the effect shown in this paper is different. As shown in Figure 5b, the complete Ohmic / first interconnect metal stack is mixed. The alloy depth reaches 170 nm compared to 40 - 80 nm in an unchanged contact. This means that the alloy zone punched through the N+ GaAs cap, even through the channel. It is assumed that the visual effects, the voids underneath passivation, are caused by a material transport towards the reaction zone underneath the Ohmic / first interconnect stack. Obviously the stoichiometry of the contact has been changed dramatically, which is assumed to be the cause for increased and noisy RC. Pt, more Au, and the components of the epi stack have to be considered.

PROCESS STABILISATION

The described visual and electric effects of the ohmic metal degradation, with its impact on yield and reliability, are unacceptable for a high volume production of pHEMTs as done at TriQuint Semiconductor. A small team was formed to solve this issue. The complete process engineering group was integrated into the problem solving by virtual brainstorming using the TriQuint intranet.



a) Plasma time 150s b) Plasma time 270s

Figure 5: Examples of plasma time splits showing a) unchanged and b) ruined contact.

Based on the cross sections it was certain that the wafers were exposed to high temperatures between ohmic and wafer final test. There are plenty of single processes creating heat intentionally or not. Examples are CVD, plasma processes, e-beam cure, and tempering processes. As one can see in Figure 2, the degradation of the ohmic contact gets worse for wafers further down the run, an indication of a loading effect. A challenging factor was the intermittent behavior of this issue.

CVD processes were targeted first since their process temperature and time are close to the ohmic alloy process. Unfortunately, these efforts were not blessed with success. Following that, lots were processed under close surveillance. Visual inspections and parametric tests were performed whenever possible. Through this, the responsible process step was identified quickly. The previously good ohmic contacts were ruined by overheating in an O_2 plasma tool near the end of the fab process. The O_2 plasma is used to ash away photoresist on top of the passivation and underneath air bridges.

To stabilize the process several wafers were split between different plasma process times and three tools. For process times between 90 and 150 seconds the ohmic contacts remain unchanged. Depending on the tool, at a process time above 210 seconds the erosion is visible and at 270 seconds the ohmic contact is ruined.

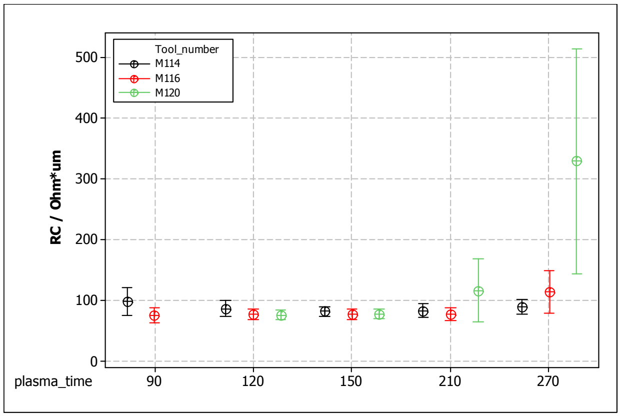


FIGURE 6: Change of RC with different O_2 plasma process times in different tools

Figure 5 displays the microscope images and the corresponding cross sections (FIB cuts) for process times of 150 s (a) and 270 s (b), processed in the same tool. As one can see, at 150 s no erosion is visible. The FIB cut shows a typical alloy zone, with an alloy depth between 43 and 82 nm. At 270 s the erosion pattern is clearly visible. The FIB cuts showed a changed alloy zone underneath the ohmic / first interconnect metal stack, reaching depths of 170 nm. Figure 6 shows the confirmation of the erosion in this experiment with a parametric test of RC. It also shows the different behavior of the three O_2 plasma tools used in that experiment. This explains the randomness of the described problem.

A reduction of the process time to 150 s from 240 s was the solution to prevent ohmic metal degradation with its visual and electrical effects. A shorter time would have been desirable, but this left photoresist residue on the wafer, especially underneath the air bridges.

CONCLUSIONS

Ohmic metal degradation causes disturbing electrical and visual effects. When covered by first interconnect metal, the previously good Ohmic contacts were ruined by overheating in O_2 plasma tools near the end of the fab process. Reducing time in plasma at that step solved the problem without compromising the plasma clean.

The overheating caused a mixed Ohmic / first interconnect metal stack, where the alloy zone punched through the N+ GaAs cap and channel, causing high RC. It is assumed that the visual effect of voids is caused by a transport of Ohmic metal towards the reaction zone.

Further investigations would need to be done to understand the composition of the resulting alloy zone of an eroded ohmic contact, but we were simply happy to have our good contact resistances restored.

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ACRONYMS

CVD:	Chemical Vapor Deposition
FIB:	Focused Ion Beam
RC:	Contact Resistance
SAG:	Self Aligned Gate
TLM:	Transmission Line Model