Through-wafer Via Etch Throughput Improvement in a GaAs Semiconductor Device

Craig Carpenter and Sarah Woolsey

Skyworks Solutions Inc., 20 Sylvan Rd, Woburn, MA 01801
Email: craig.carpenter@skyworksinc.com Phone: (781) 376-3039

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Abstract:

At Skyworks Solutions throughput of the back side through-wafer via etch process was low because of a high rework rate. The high rework rate was due to an organic residue blocking the etch. A process was first developed to remove the residue and then integrated into the via etch process. The optimized via etch process resulted in a reduction in reworks and a significant increase in process throughput.

INTRODUCTION

A common process in the production of a GaAs semiconductor device is an electrical contact from the front side of the wafer to a ground plane on the back side of the wafer. This electrical contact is created by first etching a via hole through the wafer, followed by a metal deposition process [1]. At Skyworks Solutions the back side via is made by protecting and mounting the wafer (front side down) to a sapphire, thinning the wafer, exposing a via hole mask on the back side of the wafer with a photolithography process, etching the wafer with a RIE plasma system, removing the resist, and finally dismounting the wafer. This paper will describe how a via etch process with a high rework rate was analyzed and optimized resulting in a process with a low rework rate and a significant improvement in throughput.

PROBLEM DESCRIPTION

The back side via etch process is performed on an Oxford Plasmalab 90 RIE system using a 140W, 50mT, BCl_3/Cl_2 plasma with a chuck temperature of 20°C. The Plasmalab 90 is a load locked system in which up to four sapphire-mounted wafers can be loaded simultaneously onto a quartz platen.

The back side via etch process starts with a pre-etch visual inspection where it is determined if the photo pattern is fully developed and opened. After passing inspection the wafers to be etched are loaded in the RIE system and etched for 110 minutes. After etching a post-etch inspection is performed to determine if the via holes are properly opened and etched completely, clear, exposing the front side metal pad. If the via holes are not clear they are sent back to the RIE system for further etching, referred to as a rework. Rework times are in increments of up to 20 minutes, the time being set by the judgment of the inspector. Each rework is the followed by a visual inspection to determine if the via holes are clear. This rework and inspection cycle will be repeated until the via holes are clear. The back side process flow is summarized in Table 1.

TABLE 1
Back side Via Etch Flow Pre Optimization

Process Step	**Pre-Optimized Time**
Pre-etch inspection	4 minutes
Load etch system	12 minutes
Run etch process	110 minutes
Unload etch system	10 minutes
Post-etch Inspection	7 minutes
Total	143 minutes

There are 33 minutes of overhead (non-etch) time associated with this process. The problem arises when the rework rate is too high, limiting throughput. A high rework rate and amount of additional etching required were the problems encountered at Skyworks. At the height of this problem each pass required 2.3 reworks and 34 minutes of additional etch time on average. This totals 110 additional minutes of processing time per etch run, 76 minutes of which was overhead time, for a total process time of 253 minutes. It took over 4 hours to etch 4 wafers.

Clearly it was desirable to develop an etch process that fully etched the via holes in one pass and would require no additional etching. If reworks could be eliminated it would be acceptable to have a process that used a longer etch time than the standard 110 minutes.

PROBLEM ANALYSIS

It appeared that the problem was due to one of two possibilities. One possibility was that the etch rate was too low thus requiring more time to reach the front side of the wafer. The low etch rate problem could be constant or the etch rate could be dropping during the process. The other possibility is that some type of residue was blocking the etch and preventing the via hole from clearing. [2] Both of these possibilities were explored.

An experiment was designed to look at the etch rate of the process. Twelve monitor wafers with via mask on them were divided into three passes of four wafers each. The first pass was etched for 90 minutes, the second pass for 100 minutes, and the third pass for 110 minutes. The results can be seen in the Table 2.

TABLE 2
Etch Rate Experiment

Etch Time	Etch Depth	Etch Rate
90 min	91.4 μm	1.02 μm/min
100 min	90.3 μm	0.90 μm/min
110 min	92.5 μm	0.84 μm/min

Etch depths and rates represent averages of the four wafers in each batch, with three points measured per wafer. These results indicate that the problem was not etch rate related. Regardless of the etch time the same depth of approximately 90μm was reached. These results further indicate that some sort of etch block residue was present preventing the etch from reaching the target depth of 100μm.

To investigate the residue possibility experiments were run looking at three cleaning plasmas; an O_2 descum-BCl_3 pre-etch clean plasma, a high-pressure Cl_2 post-etch plasma, and an O_2 descum pre and during etch plasma. These three cleaning plasmas will be referred to as conditions 1, 2, and 3 respectively.

Condition 1 consisted of an O_2 descum being performed on an external RIE system followed by a in-situ BCl_3 only plasma. This pre-cleaning was then followed by the standard Cl_2/BCl_3 etch plasma. The theory behind this approach was that some type of residue not seen during optical pre-etch inspection was hindering the etch. This plasma would break through this residue and allow normal etching.

The idea of condition 2 was to create an isotropic plasma that would undercut and remove any etch residue after the main Cl_2/BCl_3 etch was done such that the proper etch depth was reached. Condition 2 was a high-flow; high-pressure Cl_2 plasma that results in an isotropic etch.

Another theory is that an organic residue is present prior to etch and is also formed during etch. Condition 3 was developed to remove the organic residue throughout the etch process. This condition is an external descum plasma that is performed prior to the etch and 80 minutes into the etch. The process flow would be a descum, an 80min etch, another descum, and a final 30min etch. The O_2 descum process is performed on an external RIE system.

All of the previously described conditions were then tested by splitting a production lot between the standard condition and the experimental condition. Thus these conditions were tested using 3 different lots. Table 3 summarizes the experimental conditions and the split lot results.

TABLE 3
Experimental Conditions

Condition	Where in etch process
1: O2 descum -BCl3	Pre
2: High -pressure Cl2	Post
3: O2 descum	Pre and during

Condition 1: O2 descum-BCl3 pre-etch

Condition	Etch Depth	Additional Etch Time
Standard	98.5 μm	20 minutes
Experimental	94.5 μm	11 minutes

Condition 2: High-pressure Cl2 post -etch

Condition	Etch Depth	Additional Etch Time
Standard	92.8 μm	25 minutes
Experimental	95.6 μm	23 minutes

Condition 3: O2 descum pre and during et ch

Condition	Etch Depth	Additional Etch Time
Standard	95.7 μm	50 minutes
Experimental	86.9 μm	23 minutes

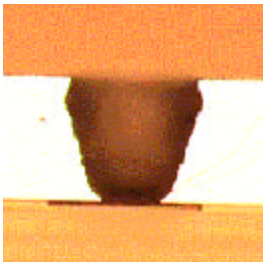
Final etch depths between all conditions in each of the three experiments were similar. A slightly lower etch depth is seen for the experimental condition in Table 3: Condition 3, but the via hole was clear at this depth. The lower depth is due to variation in the grind process. Etch depth results indicate that the etch rate, or the time to reach the interface, was not the problem. The important result is the additional etch time required. Condition 2 showed no improvement, condition 1 showed some improvement, and condition 3 showed significant improvement. It is not surprising that conditions 1 and 3 both showed improvement since both are operating on the theory that residue is present prior to etch. The results of condition 2 agree with rework results in that once the residue is formed it is not effectively removed with post-etch plasma.

Limited production was run for conditions 1 and 3 based on their positive results. The limited production consisted of changing the production process to condition 1 for a period of several days then changing process to condition 3 for a period of several days. Data recording the number of rework cycles and the total rework time was collected and can be seen in Figures 2 and 3. Prior to releasing each of the conditions to limited production the profiles of the via holes were looked at and found to be acceptable when compared to standard etch profile as shown in Figure 1.

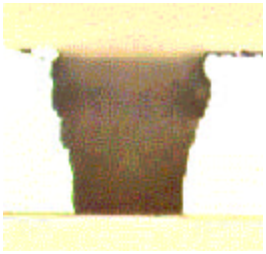
It can be seen from this data that the second limited production run utilizing condition 3, the external pre/during descum process, had the best results. This process was chosen to be the new standard process for the back side via etching.

FIGURE 1
Via Hole Profiles

Standard



Condition 1



Condition 3

FIGURE 2
Via Etch Processing Time

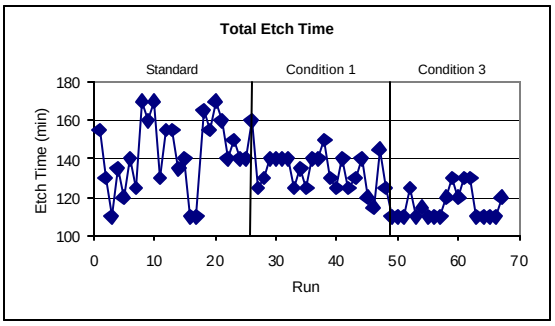
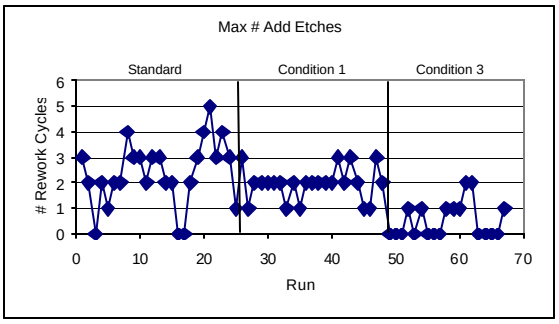


FIGURE 3
Number of Additional Etch Cycles



OPTIMIZATION

The results from the external descum etch process were significant but further optimizations were needed. Specifically the descum process was being performed on an external RIE descum system. This required unloading the wafers in the middle of an etch run, loading and processing wafers on an external RIE descum system, and finally loading the wafers back into the RIE etch system to finish the etch run. The old and new etch flows are summarized in Table 4.

The rework averages calculated for the new etch process were 0.7 reworks/pass with a rework time of 7.4 minutes. This is a 69% improvement in reworks/ pass and a 78% improvement in rework time compared to original etch process with 2.3 reworks/pass and a rework time of 34 minutes. When the overhead time is included it is found the rework adds 24 minutes to each etch cycle for a total processing time of 199 minutes. This is a 21% improvement in total processing time compared to the original etch processing time of 253 minutes. It is seen that much of the improvements seen in reworks/pass and rework time are lost in overall processing time. This is due to the fact that the descum was performed externally.

TABLE 4
Back side Via Etch Flows with External Descum

Process Step	**Pre-Optimized**	**External Descum**
Pre-etch inspection	4 minutes	4 minutes
External descum	None	5 minutes
Load etch system	12 minutes	12 minutes
Run etch process	110 minutes	80 minutes
Unload etch system	10 minutes	10 minutes
External descum	None	5 minutes
Load etch system	None	12 minutes
Run etch process	None	30 minutes
Unload etch system	None	10 minutes
Post-etch Inspection	7 minutes	7 minutes
Total	143 minutes	175 minutes

This data further displays the desirability of a process where wafers are etched in one cycle without having to be removed from the etch chamber. To achieve this ultimate goal an equivalent descum process would have to be developed using the etch system. This would allow an in-situ descum process to be integrated with the etch process, thus never having to unload wafers until etching is complete.

The most important characteristics to match were the etch rate and the via hole CD bias. A DOE was performed on the RIE etch system and a descum process was developed with similar characteristics to the extemal descum process. Results can be seen in Table 5.

TABLE 5
Etch System Process Parameters

Etch System	External	Oxford
Pressure (mT)	500	50
Power (W)	200	50
O2 Flow (sccm)	100	100
Chuck Temperature (°C)	20	20
Ash Rate (Å/min)	850	760
CD Bias (µm)	0	0

Although the first external descum process had the descum performed prior to etch and 80 minutes into the etch various integration times were explored. The pre-etch descum would remain unchanged. The criteria to evaluate would be via profile and amount of rework needed. Etch time split conditions for 80/30, 45/45, and 40/40/30 were evaluated and results can be seen in Table 6.

TABLE 6
Rework Time Required

Condition	Rework Time (min)
External 80/30	20
In-situ 80/30	0
In-situ 45/45	0
In-situ 40/40/30	0

These results show that in-situ conditions have better rework results. The via hole profiles were looked at for each condition and the best profile was seen with the 80/30 condition. Based on this data the in-situ 80/30 process would be used for the via etch.

FIGURE 4
Via Etch Processing Time

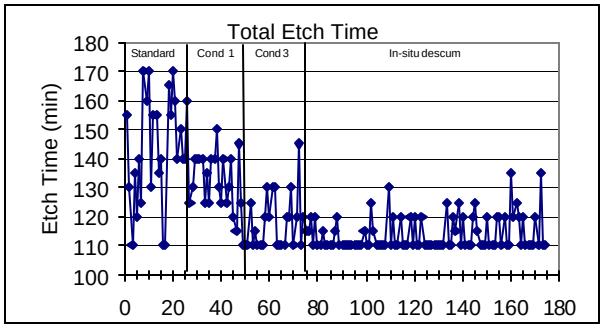


TABLE 7
Back side Via Etch Flows with In-situ Descum

Process Step	**Pre-Optimized**	**External Descum**	**In-Situ Descum**
Pre-etch inspection	4 minutes	4 minutes	4 minutes
External descum	None	5 minutes	None
Load etch system	12 minutes	12 minutes	12 minutes
Run etch process	110 minutes	80 minutes	115 minutes
Unload etch system	10 minutes	10 minutes	10 minutes
External descum	None	5 minutes	None
Load etch system	None	12 minutes	None
Run etch process	None	30 minutes	None
Unload etch system	None	10 minutes	None
Post-etch Inspection	7 minutes	7 minutes	7 minutes
Total	143 minutes	175 minutes	148 minutes

Figure 4 shows that the reworks remained low with the in-situ descum process. The in-situ descum etch process flow with the previous etch flows are shown in Table 7. The rework averages calculated for the in-situ descum etch process were 0.5 reworks/pass with a rework time of 4.8 minutes. This is a 78% improvement in reworks/ pass and a 85% improvement in rework time compared to the original etch process that had 2.3 reworks/pass with a rework time of 34 minutes. Including the overhead time associated with each rework cycle; the rework added 13.9 minutes to each etch cycle for a total processing time of 156.9 minutes.

Overall this results substantial improvement of 38% in total processing time compared to the original etch process with a processing time of 253 minutes.

CONCLUSION

It has been shown how a via etch process with a high rework rate and low throughput was analyzed and optimized. The optimizations resulted in a substantial reduction in the rework rate and increase in throughput.

The process was analyzed through experimentation and it was found an organic residue was blocking the etch. A new external process was developed to remove the organic residue and some improvements in rework rate and throughput were seen. By creating an in-situ process, based on the external process, the improvement in rework rate and throughput became substantial.

Overall these optimizations resulted in 78% reduction in number of reworks, an 85% reduction in rework time and an overall improvement of 38% in process throughput.

ACKNOWLEDGEMENTS

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REFERENCES

[1] R. Williams, *Modern GaAs Processing Methods,* pages 324 – 327

[2] Y. Cho and J. Thomas, *Compound Semiconductor: Removing the GaAs Via Hole Etch Process Bottleneck,* October 2002

ACRONYMS

RIE: Reactive Ion Etch
CD: Critical Dimension
DOE: Design of Experiment