Low undercut Ti etch chemistry for Cu bump pillar under bump metallization wet etch process

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Abstract. This paper demonstrates how a low undercut Ti etchant developed by Technic France can be successfully introduced in a high volume manufacturing Fab for etching the under bump metallization (UBM). The Ti etchant has been tested in a high volume 300mm wafer production equipment in GLOBALFOUNDRIES. The Ti etchant evaluation has been carried out in collaboration with the Fraunhofer IZM-ASSID institute.

Introduction

In advanced packaging technology, Cu pillar bumping has become a common approach for flip-chip bonding. Using Cu pillars allows achieving finer pitch (<60 um) [1] than achieved with solder bumps. Because of the non-planarized passivation surface, often present on some recent technologies, wet etching is preferred to dry etching for under bump metallization (UBM) removal. However, the drawback of the wet etching approach is pillar undercut.
The aim of this work is to minimize the undercut created during the Ti barrier etch by using a novel H_2O_2 buffered etchant mix with a stabilizing complexing agent and to prove the manufacturability of this approach in a high volume production equipment.

Background

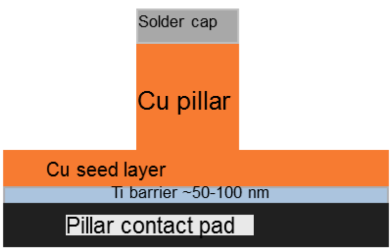


Figure1: Cu pillar before UBM etch

Figure2: Cu pillar after UBM etch

Figure 1 represents a Cu pillar bump structure before the UBM etch is performed. All bumps have been grown onto a seed Cu layer sputtered on the wafer. All the bumps at this stage are still electrically shorted. Wet etch is carried out to remove the metal layers (Cu seed and Ti barrier) to electrically isolate the bumps from each other. It is also important that metal residues are removed from the passivation surface to guarantee electrical isolation as well as good underfill adhesion in the packaging process. A problem arises when typical Ti etchants, such as dilute HF or BOE, are used to remove the Ti barrier, since they lead to larger undercut, normally in the range of 500-600 nm.

In order to reduce this undercut, TechniEtch TBR19 mix developed by Technic has been evaluated.

Experimental Work

Solution key attributes.

Based on the process limitations encountered with standard diluted HF for Ti based barrier etching, the specifications of the novel Titanium Barrier Remover were set to overcome most of the current etching mixtures drawbacks such as etch rate, undercut & pH control, bath ageing, metal compatibility, reclaimability, etc.

Product specifications:

Etch rate above 450Å/min for (Ti, TiN and TiW).

Compatible with Al, Sn, Cu, Ni (ER<10Å/min).

Possibility to be reclaimed over 6 hours.

Ready to use.

The mixture stability was monitored based on the British Standard 7546 & CEFIC Bulk Storage guideline (2012).

The stability tests involved the accurate measurement & monitoring of the hydrogen peroxide loss over a 16 h period at different temperatures (Figure 3). The same procedure has being used for estimating the shelf life of the ready-to-use version (TBR19 additives mixed with H_2O_2) in the different storage conditions of 10, 15 and 20 °C with results tending to confirm a great stability over 6 months.

The H_2O_2 loss monitoring was also a valuable mean to establish the best compromise between etching performance and stability while screening the chelating & stabilizers agents, hydroxyl alkali species, buffering additives, ingredients & hydrogen peroxide purity grade, additives ratios.

Figure 4, for instance is an example of how the stability test was directly used throughout the formulation stage to establish the final TechniEcth TBR19 ingredient concentrations.

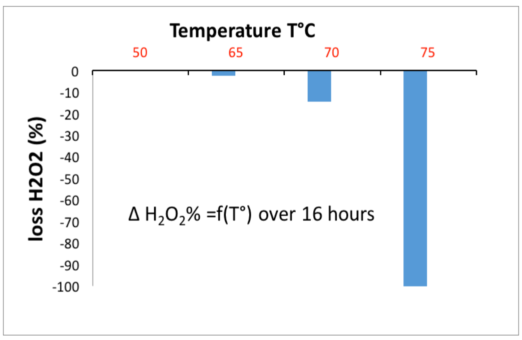


Figure 3: Peroxide concentrations loss vs temperature (16 h)

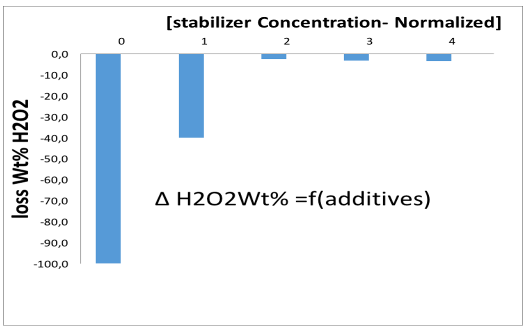


Figure 4: Peroxide loss vs stabilizer concentration

From the solution decomposition rate and Ti etching rate change with temperature, it is recommended to work at 50 °C to combine best bath ageing, metal etch rate, process control and solution stability attributes.

One extra singular attribute of the solution is the capability to etch several metals, such as W, TiW, Ti and TiN (Figure 5) likely to be stacked up as barrier and adhesion layers while being fully compatible with metal interconnections and contacts.

The following etching rate profile results (Figure 6) were collected on the tri metal layer stack (W/TiN/Ti) through four point probe measurements and confirmed the great etching stability and selectivity over a 6 hours process period. Similar process optimization were carried out on Ti/TiN/Ti stack, where the new etchant (TechniEtch TBR19) permitted to significantly reduce the number of process steps from six (HF/SC1/HF + rinsing) to two (TBR19/Rinse) with better Ti undercut control.

Finally, investigations on single tool platform over 24 hours were also carried out with the new etchant where Ti barrier undercut was monitored. The results showed a 9% drop in Ti Etch Rate and a Cu Etch Rate remaining at <3Å/min over the 24 hours. More interestingly, undercut monitoring on a copper pillar with a 200 nm thick Ti barrier while applying an overetch process of 50% led to a WIW feature undercut below 0.2 µm over the 24 hours period.

TechniEcth TBR19	Etch Rate (A/mins) @ 50C
Ti	450 <E/R<2000 Å/mn
TiN	120 (low stress)<E/R<900 Å/mn (thick BEOL)
TiW	1000<E/R<1400 Å/mn

Figure5: TechniEtch TBR19 standard etch.

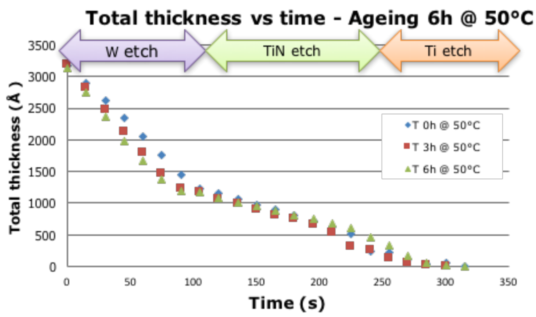


Figure 6: Etch rate stability over 6 hours for a trilayer W (2000Å) / TiN (700Å) / Ti (450Å) stack.

The TBR19/H_2O_2 mix can be prepared by Technic France and stored with a proven shelf life of 6 months. The ready-to-use mix represents an advantage in a manufacturing environment, as no mixing station is needed for this solution.

TBR 19 test method in a manufacturing environment

The etching chemical characterization has been carried out using a Raider AMAT tool in GLOBALFOUNDRIES. The tool has four single wafer chambers, two of which are connected to the tank containing TBR19 ready-to-use mix. This tank can be heated to 50 °C. During wafer etching, the chemical is sprayed onto the wafer through a series of nozzles and then reclaimed into the tank. Reclaiming the chemical after the etch step is necessary, otherwise single chemical use would lead to high consumption (up to ~5-6 liters per wafer), jeopardizing the process manufacturability.

The UBM etch (Cu and Ti) can be performed in sequence within the same chamber on each wafer.

The equipment has an optical end point detector (EPD). The EPD can be used only in a passive mode, i.e. the EPD data was collected and analyzed post processing to assess the Ti etch time (Ti clearance time from the wafer passivation surface). The aim of this test was to prove that TBR19 can be used on a high volume manufacturing equipment, whilst achieving pillar Ti undercut less than 200 nm without Ti residue on the wafer passivation layer. Moreover the process has to be highly selective to Al, Cu, Ni, Sn and Ag.

The test was carried out on structured wafers with the complete Cu pillar stack on top of the passivation layer. Structured wafers have also been used to age the chemical bath.

The Cu pillar Ti undercut measurement was carried out with a SEM cross section. The UBM metal residues assessment was carried out with XPS analysis at the center, half radius and edge of the wafer.

A 12 runs screening design of experiment (DOE) was carried out taking into account the following 4 factors with their respective high and low values.

- Temperature: 47 - 53 °C
- Concentration of TBR19 additive in H_2O_2 wt% : 5.7 - 6.3%
- Nozzles spray pressure 14 - 19 psi
- Bath age 0-50 wafers: 0-6 hours

The criteria of these high and low parameters values are as follows.

The equipment is capable of controlling the temperature and the pressure at least within +/- 2 °C and +/-2 psi, respectively. Also the concentration of the TBR19 mix can be controlled well within +/-0.3%. Therefore, a wider screening process window would assess the manufacturability of the process.

The 12 runs that have been carried out are shown in the table below:

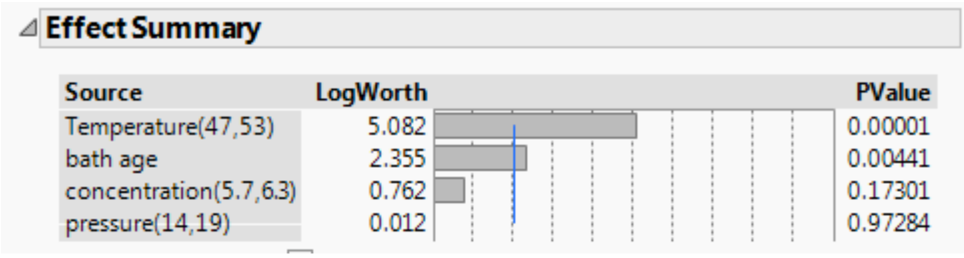
	Temperature	concentration	pressure	bath age
1	47	5.7	19	fresh
2	47	5.7	14	fresh
3	53	5.7	14	fresh
4	47	5.7	14	old
5	53	5.7	19	old
6	53	5.7	19	old
7	53	6.3	14	fresh
8	53	6.3	19	fresh
9	47	6.3	19	fresh
10	53	6.3	14	old
11	47	6.3	19	old
12	47	6.3	14	old

Table1: 12 DOE runs conditions.

The DOE output was Ti clearance time (s) measured with the chamber end point detector.

Results

The DOE Effect summary table shows that temperature and bath age have a statistically significant effect. Pressure and concentration (at least for the assessed process window) can be ignored as modulator of the Ti etch time (see Figure7).



Effect Summary

Source	LogWorth	PValue
Temperature(47,53)	5.082	0.00001
bath age	2.355	0.00441
concentration(5.7,6.3)	0.762	0.17301
pressure(14,19)	0.012	0.97284

Figure 7: parameters showing a p Value less than 0.05 have a statistically significant effect on the output (Ti etch time).

Figure 8 shows the shift in etch time due to the TBR19 bath ageing: the Ti etch time shifts upwards of about 20s at the end of the 50 wafer (6 h) bath life.

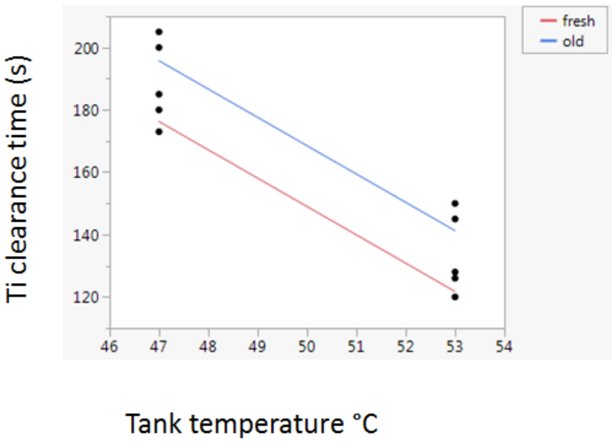


Figure 8: The Ti etch time shifts of about 20 s at the of the TBR19 bath life.

Figure 9 shows the time needed to clear the Ti from the surface as a function of the bath temperature when the bath is at the end of life (50 wafers and 6 hours).

At 50°C roughly 170s of Ti etch time is needed to completely remove the Ti from the passivation of the wafer. The complete Ti removal was confirmed by XPS analysis that showed no Ti residue present on the wafer with an accuracy of less than 0.1% at.

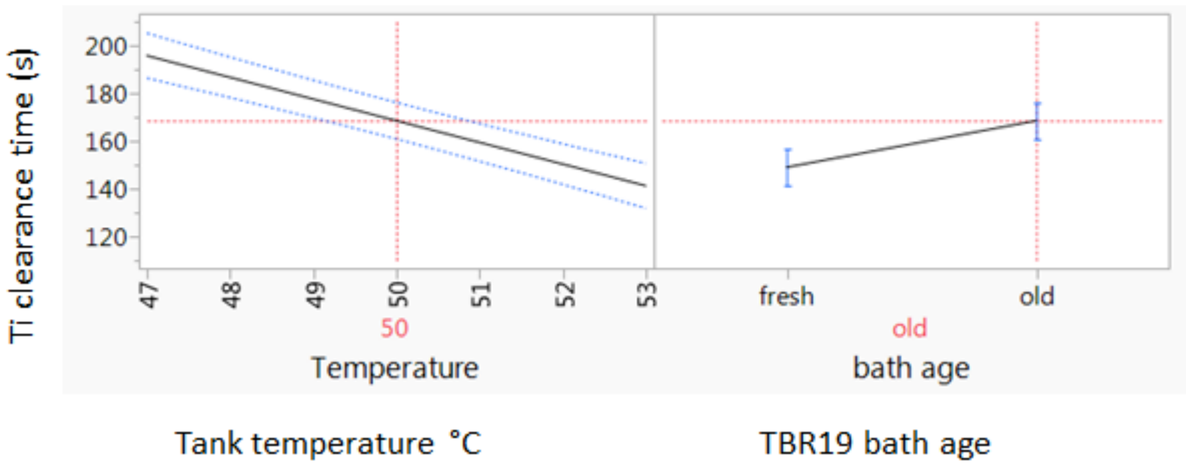


Figure 9: Ti clearance time vs Temp for aged bath.

The undercut has been also measured by etching a wafer with a fresh bath. Etching a wafer with a fresh bath is the worst case scenario for undercut as the etch rate is at its highest point. Figure 10 shows that, even with an etching time of 200 s at 50 °C, the undercut is still less than 200 nm.

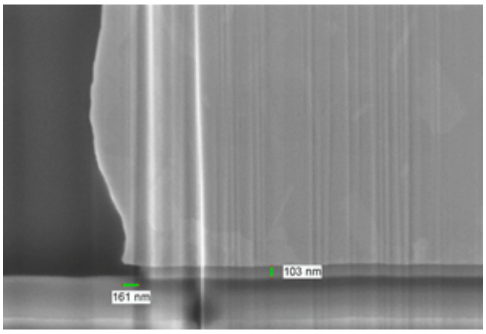


Figure 10: Ti undercut ~160 nm on micropillars with etch time of 200 s at 50 °C in fresh TBR19 bath.

Conclusions

The possibility of achieving a pre-mixed H_2O_2 based solution (TBR19 ready-to-use mix) to etch Ti with an undercut less than 200 nm has been demonstrated. Through stabilizers screening and pH control performed by Technic France, it has been possible to develop a H_2O_2 based mix that is stable enough to be used in a manufacturing environment. The possibility of reclaiming and re-using the solution ensures a consumption of less than 0.5 L per wafer. The tests performed in GLOBALFOUNDRIES show that the Cu pillar Ti undercut is greatly reduced compared to conventional HF based solutions.

Moreover, this solution has also proven good selectivity to other metals exposed in the Cu pillar process, such as Cu, Ni, Sn and Al. Figure 11 shows an overview of pillars after reflow at the end of the Cu pillar process. Neither cap nor pillar attack have been observed.

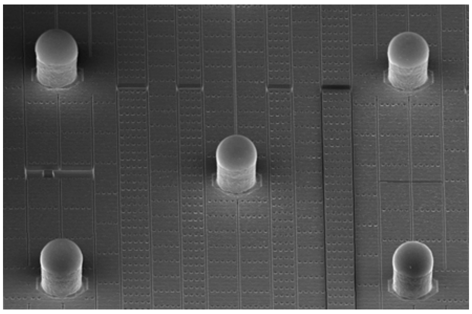


Figure 11: Overview of Cu pillar post UBM etch and post solder cap reflow.

References

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