

Cross-functional Optimization of Backside Metal Adhesion to GaAs

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Abstract

A cross-functional team was formed to investigate backside metal adhesion as die sizes shrunk in Skyworks' Newbury Park fab. Areas examined included wafer thinning, pre-seed surface treatment, metallization, UV tape exposure and storage, and die pick parameters. By making improvements in these areas, the GaAs-backside metal interface strength was increased to more than 1800g, as measured by a pull test, even for small die sizes.

INTRODUCTION

Backside thinning and metallization of wafers is common in the compound semiconductor industry. Through wafer vias (TWVs) provide an electrical connection from the front side devices of a wafer, through the substrate, to a fully metallized backside ground plane. The TWVs minimize the circuit impedance and thermal resistance, which allows smaller die sizes to be used and provides improved power efficiency. Due to the stresses applied to the backside metal during die singulation and die attach, it is important to ensure the plating seed layer has excellent adhesion to the GaAs wafer as die sizes shrink. Without adequate adhesion, the backside metal can peel off during subsequent processing, which can lead to yield loss and reliability issues. Skyworks' Newbury Park fab found that smaller dies were more susceptible to this type of failure.

Previous studies in the literature have focused primarily on the preparation of the wafer immediately prior to metallization, and on the metallization itself [1,2]. Skyworks instead addressed the issue using a cross-functional approach, forming a team including personnel from the fab, final process area, and our assembly plant in Mexicali. By involving people with diverse backgrounds, a number of optimization opportunities in addition to the metallization were found, starting with wafer thinning, and ending with die attach.

BRAINSTORMING MEETINGS

Although the through wafer via process consists of only two mask layers, maintaining a robust process can be

challenging as die sizes shrink. As with frontside processing, many of the process steps interact with each other. These interactions must be examined thoroughly to ensure the manufacture of high quality parts. For this reason, initial brainstorming sessions for backside adhesion were held with representatives from the majority of backside process steps present.

The team found that almost all of the process steps could influence backside metal adhesion. Owners were assigned to each area, and were responsible for coordinating activities related to the potential failure mode, and for reporting results at weekly status meetings. Figure 1 shows a flowchart of the backside process steps, along with functional areas. Shaded boxes indicate a possible influence on the backside metal adhesion. Before delving into too much detail, the team decided it was important to obtain a better understanding of the GaAs-TiW interface failure.

PRELIMINARY GAAS-TIW ADHESION ANALYSIS

An outside vendor analyzed the strength of the GaAs-TiW interface by performing a die-level pull test. Both the top and bottom surfaces of individual die were attached to small stubs with Krazy Glue® Gel. The strength of the weakest interface was then characterized during the pull test. At the beginning of this project, the GaAs-TiW interface was the weakest interface in all cases. As shown in Table I, the GaAs-TiW interface strength varied greatly across the wafer, ranging from weak (219g) to strong (1354g).

TABLE I
RANGE OF STRENGTH OF GAAS-TIW INTERFACE SEEN
ON NINE DIE PICKED FROM ACROSS A WAFER

# of die	Adhesive force range (g)	Bond Strength
2	1216 – 1354	Strong
3	556 – 853	Medium
4	219 – 472	Weak

X-ray photoelectron spectroscopy (XPS) was then performed on weak, medium and strong interfaces, to determine the chemical species that were impacting the adhesion strength. As expected, GaAs and its oxides were

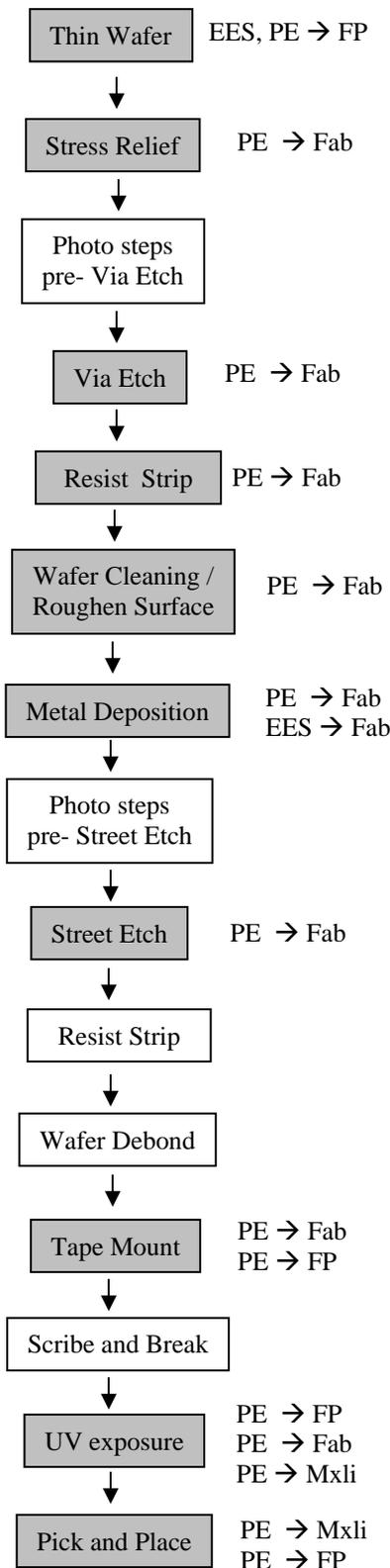


FIGURE 1. BACKSIDE PROCESS FLOW AND FUNCTIONAL AREAS. SHADED BOXES INDICATE A POTENTIAL INFLUENCE ON BACKSIDE METAL ADHESION. FP=FINAL PROCESS, MXLI=MEXICALI ASSEMBLY FACILITY EES=ENGINEERING EQUIPMENT SUPPORT, PE=PROCESS ENGINEERING

seen on both sides of the interfaces for all bond strengths, as shown in Table II. The weaker samples showed a higher concentration of carbon, and surprisingly, some silicon, possibly from a silicone source. Using this information, the team selected five areas on which to focus. The details of these investigations are described below.

TABLE II
ATOMIC CONCENTRATIONS (AT%) OF ELEMENTS AT THE FAILED GAAS-TIW INTERFACE. ND = NOT DETECTED

Element	Adhesive force 1216g		Adhesive force 556g		Adhesive force 218g	
	GaAs Side	TiW Side	GaAs Side	TiW Side	GaAs Side	TiW Side
Ga	24.0	7.7	10.8	3.2	14.5	7.3
As	22.1	6.2	9.4	1.1	13.9	4.4
W	0.1	14.5	ND	5.7	0.2	10.3
Ti	4.7	2.9	1.5	0.5	2.5	1.9
C	26.4	36.7	46.7	54.1	41.6	37.0
Si	ND	ND	ND	2.2	ND	ND
O	22.5	32.0	31.6	33.1	27.4	39.1

PROCESS AND EQUIPMENT OPTIMIZATION

1) Wafer Thinning

After being mounted on sapphire plates, the wafers are ground to 100um using a coarse, then fine grind process. When the grind is complete, an end effector picks up the wafer from the top, contacting the wafer on the freshly ground surface, using a parylene-coated silicone o-ring. The o-ring coating was found to be ineffective, which allowed silicone to contaminate the wafer surface.

A documented cleaning procedure was already in place to clean the residue off of the wafer. Additional chemical analysis showed that when performed correctly, no silicone was present on the wafer surface. However, since it was a manual process subject to operator variation, it was evident that either the process or equipment needed to be improved.

Equipment support and process engineering worked with the equipment vendor to solve the problem. The grinder end effector was modified to use a nitrile lip-seal o-ring, which prevented residues from being left on the wafer, and eliminated the need for manual surface cleaning following grind. Pull tests completed on die after the equipment modification showed the GaAs-TiW interface was no longer the weakest interface. Instead, the Crazy Glue© used for test sample preparation consistently failed during the testing, in the range of 1560 to 2220 g.

2) Pre-seed Surface Treatment

The pre-seed surface treatment is important for several reasons. First, it must ensure that no photoresist or other contaminants are left on the surface prior to seed deposition. Second, it must provide an acceptable chemical composition and roughness to allow good adhesion of the seed metal.

Two process changes were investigated to ensure both of these conditions were being met.

First, due to the known non-uniformity present in barrel ashers, the ash step was re-evaluated. To ensure all photoresist residue was removed, a double ash procedure was investigated. Although this method showed some preliminary success, it was found to have poor repeatability. The chemical nature of wafer areas that received too much ashing was detrimental to TiW adhesion. In extreme cases, backside metal peeling was seen as early as the street etch.

A separate effort was also undertaken to improve the pre-seed clean. Based on information from the initial process development, bleach (NaOCl) was known to roughen the wafer surface and improve adhesion. A 120 second 1:10 NaOCl:H₂O dip followed by a 30 second 15% NaOH dip was found to increase the surface roughness (Rq) to approximately 50Å on GaAs test wafers. These test wafers consistently passed a simple tape test after seed deposition. However, in order to make this process effective with ground product wafers, the bath needed to be preconditioned with sacrificial GaAs wafers prior to running production lots. In addition, a single wafer processing tool was not available for this treatment, which sometimes resulted in poor across-lot uniformity. Localized areas that received too much NaOCl resulted in reduced GaAs-TiW adhesion. Because of these limitations, the NaOCl treatment was determined to be impractical in our manufacturing environment.

Due to the poor repeatability of alternate pre-seed cleaning methods, the historical cleaning procedures were left in place. Instead of changing the pre-clean, an additional factor was investigated – the metallization material itself.

3) Metallization

TiW was originally chosen as the adhesion/barrier material for the backside metallization due to its high melting temperature compared to other alternatives such as Ti and NiV. At the time of development, the higher melting point was necessary to prevent gold from diffusing through the barrier layer during the solder die attach. Since Skyworks' die attach process now uses a conductive epoxy, having a high melting temperature is no longer critical. Therefore, the use of NiV as an adhesion/barrier layer was revisited (US patent 6596635).

Experiments showed that when deposited with high power and low pressure, as shown in Table III, that the GaAs-NiV interface had a high intrinsic strength. For all pull tests completed, the GaAs-NiV interface was stronger than the Crazy Glue®, which failed in the range of 1830 to 2300 g. This range was comparable to that found for the GaAs-TiW interface after o-ring improvements were implemented. However, the GaAs-NiV adhesion was found

to be more robust compared to the GaAs-TiW interface independent of the GaAs surface roughness. When the standard TiW seed layer was deposited on a bare, polished GaAs test wafer, it failed a tape test approximately 50% of the time. When the same test was carried out for the NiV seed layer, it never failed. Thus, a simple tape test can be used to monitor the NiV film integrity, where this was not possible with TiW. An additional benefit of the NiV seed layer is a low film stress, approximately 1e9 dynes/cm² (tensile), which is approximately one order of magnitude lower than that of the historical TiW stress.

TABLE III
RANGE OF POWER AND PRESSURE INVESTIGATED
DURING NiV DEPOSITION OPTIMIZATION

	Low	High
Power (kW)	2	5
Pressure (mbar)	1.9e-3	2.6e-3

Due to the change in metallization, a thorough re-qualification of the affected devices was necessary. The improved process passed high temperature operating life (125°C, 1000 hours), highly accelerated temperature and humidity stress test (135°C, 85%RH, 33.3psia, 96 hours), and temperature cycling (1000 cycles, -65 to +150°C, 15 min dwell) with no issues.

4) UV Tape Exposure and Storage

In addition to the intrinsic strength of the GaAs-metal interface, the tackiness of the UV tape after exposure is also important. If the strength of the UV tape-metal interface is stronger than that of the GaAs-metal interface, the backside metal may be compromised during die attach. To ensure this was not the case, the UV tape, exposure and storage were evaluated.

Four UV tapes were evaluated using both a fluorescent and a mercury vapor UV source. The UV tape was first put on a hoop. Metal tabs were then stuck to the UV tape. The tape was exposed, and the force required to pull the tab off the tape was measured. As shown in Table IV, all tapes had a significantly lower tackiness when exposed with the mercury vapor source.

TABLE IV
COMPARISON OF TAPE ADHESION STRENGTH
FOR DIFFERENT UV EXPOSURE LAMPS

Tape Designation	Exposure Time	TAPE ADHESION STRENGTH	
		Fluorescent Lamp	Mercury Vapor Lamp
Tape A	10 sec	270 g	210 g
Tape B	13 sec	625 g	485 g
Tape C	13 sec	390 g	380 g
Tape D	13 sec	415 g	180 g

An exposure time optimization was then completed with the two tapes with the least tackiness. As shown in Figure 2,

tape D had a significantly higher starting tackiness. However, it dropped to values comparable to Tape A with just a 3 second exposure using a mercury vapor source. With this information, an optimized tape and exposure time was selected. The process selected allowed the dies to be picked easily, but still remained tacky enough to prevent dies from coming loose on the tape during processing.

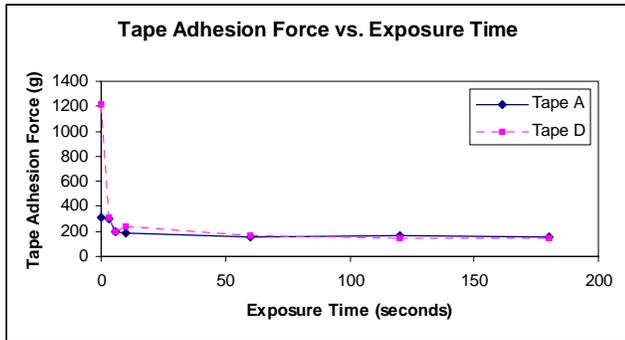


FIGURE 2. TAPE ADHESION FORCE VERSUS EXPOSURE TIME USING A MERCURY VAPOR LAMP.

A second DOE was conducted to study the effect of time lapsed before UV tape exposure. A yield loss of approximately 3% was found when wafers were stored for 80 days on tape before completing the UV exposure, compared to being exposed within several days of being mounted on the UV tape. The yield loss occurred due to dies being stuck too firmly to the UV tape, resulting in the inability of the pick and place tool to pick the dies. Based on this result, a close couple was implemented between tape mount and UV exposure.

Finally, due to concerns regarding high shipping temperatures during the summer months, an additional DOE was completed to study the effects of storage temperature on the UV tape tackiness. Results showed no significant increase in tackiness when wafers were held for as long as 14 hours at 75°C.

5) Die Pick Parameters

The last area investigated was the optimization of pick parameters during die attach. This was necessary to ensure that the backside metal was not damaged during the pick and place operation, regardless of die size. A DOE was carried out to investigate the effects of flat vs. rounded pins, and the pin size used during die pick. Reducing the pin size, and changing from rounded to flat pins significantly improved the die pick quality and yield.

CONCLUSIONS

By involving personnel across a diverse range of functions, many areas were investigated to optimize the backside metal adhesion for smaller die sizes. By making process improvements, such as changes in o-ring and metallization materials, and by optimizing UV tape exposure

and die pick parameters, a robust backside metal adhesion process has been realized independent of die size. The intrinsic backside metal adhesion was increased to more than 1800g, and damage to the backside metal was eliminated.

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ACRONYMS

- DOE: Design of Experiments
- EES: Engineering Equipment Support
- FP: Final Process Fab Area
- PE: Process Engineering
- Mxli: Mexicali Assembly Plant
- TWV: Through Wafer Via
- UV: Ultraviolet
- XPS: x-ray photoelectron spectroscopy