# Analysis and Management of the Effects of Fluorinated Gases during Plasma Dicing

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## Abstract

The use of plasma etch as a singulation solution is approaching a level of maturity where the prior levels of concern about the exposure of finished die to plasma etch chemistry are much better understood and, for the most part, resolved. For silicon wafers, the etch step is of relative simplicity when compared to the challenges raised in the integration of the process into the backend and assembly flows. Solutions to the needs of providing patterning, in some form, to define the etched regions have been realized with options including both LASER grooving and photolithography steps.

More recently, the most significant effort has gone in to establishing material and process regimes that help to ease the adoption of plasma dicing, in particular the management of fluorine. Data from critical die testing regimes will be presented showing the impact of these methods on wire bond strength, as measured, for example, by ball shear testing after thermal and humidity treatment, and electrical characterization of finished, packaged devices following exposure to a series of accelerated ageing conditions.

## Key words

Bond Pads, Dicing, Fluorine, Plasma Dicing, Reliability

## I. Introduction

The Bosch [1] process method for deep, anisotropic etching of silicon uses repeated loops of fluorinated gases to create a protective CFx polymer coating on the structure sidewall and then to conduct isotropic etch steps. As plasma dicing is effectively a deep trench etch, this process method is ideal. At the end of the dicing etch, the sidewalls of the die may retain a thin patina of the generated CFx polymer and remnants of the etch chemistry on the die surface.

The vast majority of die will have either bond pads or bumps on the top surface, ready for whatever interconnect step follows. In the case of Al bond pads, the surface reaction that occurs when F is present causes corrosion in the form of $Al_xF_yO_z$ compounds. These compounds impede the successful application of the subsequent wire bond, leading to yield loss or premature failure in service of the finished device.

Initially observed after etching operations in the final stages of the front-end manufacturing flow, these phenomena are now well characterized and countered through effective fluorine cleaning processes such as argon sputtering. However, the addition of a fluorine-based dicing process at the start of the backend and assembly flow leads to the risk of reproducing these effects before the bonding steps. Whilst similar cleaning methods could be implemented here, preventative solutions are also available and preferred to simplify the integration of the technology.

## II. Results and discussion

### *A. Plasma dicing integration scheme*

F remaining on bond pads or bumps can give rise to reliability issues such as corrosion or increased non wettability. In order to remove/prevent F on the bond pads or bumps, there are several options available; to protect the bondpads/bumps from the F in the plasma by coating/covering the area or post treatment of the bondpad/bumps after plasma dicing by either dry or wet treatments figure 1. The method chosen will depend upon the plasma integration scheme.

Laser groove methods will have a coating present, work has shown that this can be a successful method to protect the Al bond pads or bumps however it is dependent on the coating selection. The coating collects the debris (dust, molten material) from the laser groove process and prevents it from adhering to the wafer surface however the coating can also be used in the plasma dicing process as a mask, defining the features to be etched.

Careful selection of the coating is required as it needs to be selective enough for the plasma dicing process to ensure the coating is still present at the end of the process and prevent F migration through the coating to the bond pad or bump. The work in this paper focuses on this integration scheme.

For lithography methods, the Al bond pad or bump will be exposed to the F throughout the plasma dicing process and a post treatment will be required.

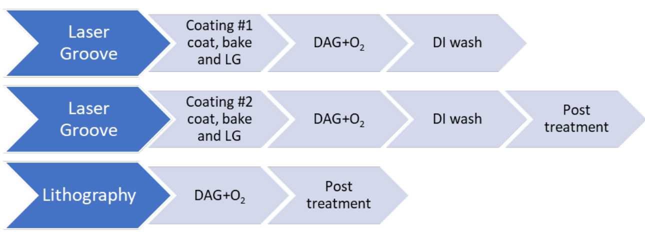


Figure 1: Schematic of plasma dicing schemes

EDX (Energy-dispersive X-ray spectroscopy) was used for the majority of analysis using a low accelerating voltage (1.5kV) to achieve as surface sensitive measurement as possible for F. This was correlated with XPS (X-ray photoelectron spectroscopy), a surface sensitive analysis technique typically sampling the top ≤10nm, measuring die from the same test.

The atomic ratio F:O was used as a relative measurement, with a specification of <0.15. This figure had been used in production for blade dicing for the product and is known to yield good die. The experimental results showed the same trends for both EDX and XPS and therefore deemed that EDX was an acceptable measurement technique.

Initial data indicated that depending upon the coating, a post treatment may not be required. This was further tested by using a peel test to measure F penetration through the coating via EDX and comparing the coating property suitability for plasma dicing, Table I.

A series of tests were conducted on the Al bond pads with different coatings and post treatments. Coating #1 had F:O levels meeting spec without a post treatment whereas coating #2 required a post treatment (after DI wash) to meet the target specifications. The Ar sputter removes F on the surface and the $O_2$ removes C components, shown in Table II.

Table I: Summary of laser grooving coating properties and suitability for plasma dicing/F protection.

| **Property** | **LG Industry Standard** | **Coating #1** | **Coating #2** | **PR Reference** |
|---|---|---|---|---|
| Selectivity main Si plasma dicing etch | 250:1 | 1000:1 | 200:1 | 1000:1 |
| LASER response | Medium | Excellent | Excellent | Not tested |
| Adhesion (to Si) | Moderate | High | High | Not tested |
| Coating removal DI wash | OK | OK | OK | Not water soluble |
| Direct Fluorine Penetration | Yes | No | Yes | Not tested |
| Peel Test F:O | 4.35 | 0.07 | 2.09 | |

Table II: Summary of coatings and post treatment trials on the Al bond pads

| **Test** | **EDX measurement At%** | | | | |
|---|---|---|---|---|---|
| | **C** | **N** | **O** | **F** | **F/O Ratio EDX** |
| **Reference (no treatment) M10-24-3-20** | 15.8 | 22 | 57.1 | 5.2 | 0.09 |
| **Coating#1 no post treatment** | 35.64 | 12.42 | 46.63 | 5.31 | 0.11 |
| **Coasting#2 no post treatment** | 16.67 | 4.61 | 55.33 | 23.39 | 0.42 |
| **Coating#2 5min $O_2$ post treatment** | 23.74 | 2.25 | 69.31 | 4.7 | 0.07 |
| **Coating#2 Ar sputter + $O_2$ flash post treatment** | 49.5 | 3.7 | 40 | 6.9 | 0.17 |

The samples were also tested with XPS, the F:O levels were within specification, <0.15 (See Table III). Coating #1 was selected as the integration scheme and bond reliability tests were carried out.

Table III: Correlation of EDX data (1.5kV) and XPS data for the same test.

| **Test** | **EDX measurement At%** | | | | | **XPS measurement At%** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | N | O | F | F/O Ratio EDX | C | N | O | F | F/O Ratio EDX |
| **Reference (no treatment) M10-24-3-20** | 15.8 | 22 | 57.1 | 5.2 | 0.09 | 35.77 | - | 40.97 | 2.64 | 0.06 |
| **M10-21-1-20 LG coating #1** | 36.1 | 11.6 | 47.3 | 4.9 | 0.1 | 54.3 | - | 36 | 2 | 0.06 |
| **M10-21-1-20 LG coating #2+PT Ar O2 flash** | 49.5 | 3.7 | 40 | 6.9 | 0.17 | 52.5 | - | 34.9 | 5.2 | 0.15 |

*B. Wire Bonding Evaluation*

**Method**

Following the surface analysis used to determine the efficacy of the techniques described above for fluorine contamination control, especially on the aluminum bond pad surface, a more practical method was deployed for the evaluation of the impact on the wire-bonding reliability. The method used is well known in the semiconductor industry and involves the application of the typical wire-bonding process using a range of values for the main input variables and then testing the strength of the resulting wire to pad bond both immediately after the wire bonding step (denoted as T0) and after subsequent exposure of the samples to accelerated stress conditions through the application of humidity and/or heat. This was performed on a qualified production device and the comparison included a reference sample obtained with the blade sawing dicing process normally used for the product. For bonding to the aluminum pads CuPd wire of 8 mils diameter was used, this being a material sensitive to the formation of the intermetallic layer that could be affected by the presence of extraneous halides. None of the samples were molded on the substrate so the wire bond was in direct contact with the environment created by test conditions.

The two wire bonding process parameters varied were the force and ultrasonic energy applied to the wire during the actual bonding step. The latter was adjusted using the input parameter of the current applied to the ultrasonic frequency generator. Based on the specification for the device used in the test the conditions used were identical for each sample and are described in Table I where LSL and HSL refer to low and high specification limits respectively.

Table IV: Wire bonding conditions (WB leg) for bond reliability evaluation

| **Condition Description** | **Applied Force** | **Ultrasonic Energy** |
|---|---|---|
| LL-10% | LSL-10% | LSL-10% |
| LL | LSL | LSL |
| NN | Center of specification | Center of specification |
| HH | HSL | HSL |
| HH+10% | HSL+10% | HSL+10% |
| LH | LSL | HSL |
| HL | HSL | LSL |

To assess the bonding performance after completion of the wire bonding step two principal tests were carried out. The bond pull test (BP) uses a force applied to the wire, perpendicularly to the die surface, and the force measured at the point of failure is registered. The bond shear test (BS) sees the force applied laterally to the ball where the wire is attached to the pad surface and the test equipment measures the bond shear force at the point of failure. Several failure modes are possible in each case and are also significant in the evaluation of the result. Some failure modes are considered acceptable as they are attributable to causes not directly related to the reliability of the bond interface. For example, the breakage of the wire during the bond pull test is assessed as an extrinsic failure if the bond itself is left intact.

An initial test of the bond strength was performed at T0 for direct comparison of the basic process performance. To obtain data on the bond reliability the samples were subjected to high temperature stress (HTS) at 175°C and tested after both 108hrs and 217hrs of treatment. Further reliability data were obtained through an additional test involving temperature and humidity stress (THS) at 85°C with 85% R.H. for 24hrs on the unmolded units.

**Results**

Fig. 2 shows the data for bond shear and pull force at T0, directly after wire-bonding, for the two plasma dicing processes studied and the reference sample. For the bond pull test samples all failures were attributable to neck breakage of the CuPd wire itself, indicating good integrity of the bond until the test failure point. Considering that this failure mode applies across the full range of pull test data the small differences observed between some samples are not significant in the context of this trial.

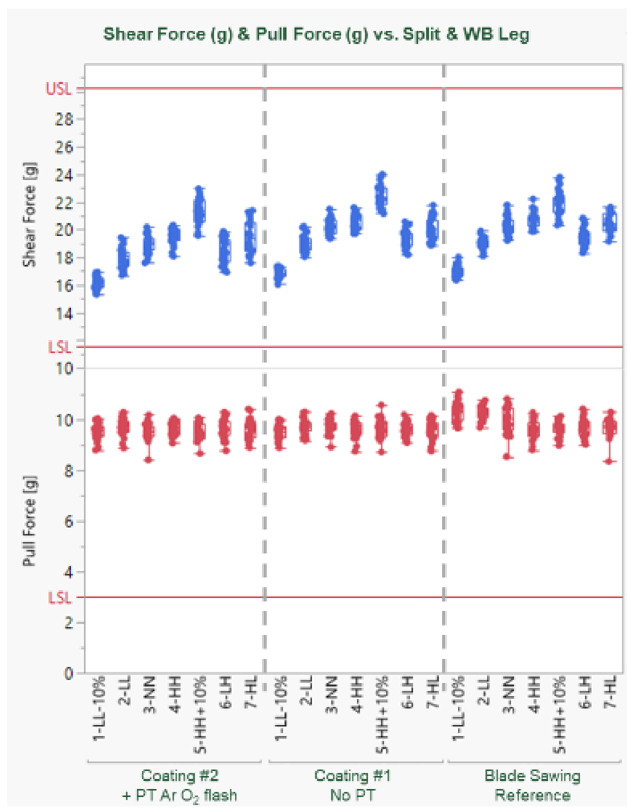


Fig. 2 Shear and Pull Force at T0

In the case of the bond shear test the failure mode observed for all samples was aluminum shear within the aluminum pad, so not related to any weakness at the bond interface and therefore considered acceptable. Variation in shear force values is consistent with the different wire-bonding conditions applied and follows the same pattern for the plasma process splits and the reference samples. No major differences are apparent between samples from the same WB leg but closer statistical analysis using the student's t test, shown in Fig.3 reveals that for all WB legs the bond shear force distribution for samples with coating #1 is closely aligned to the reference whereas the distribution of values for samples with coating #2 with Ar + $O_2$ flash post-treatment is significantly lower.

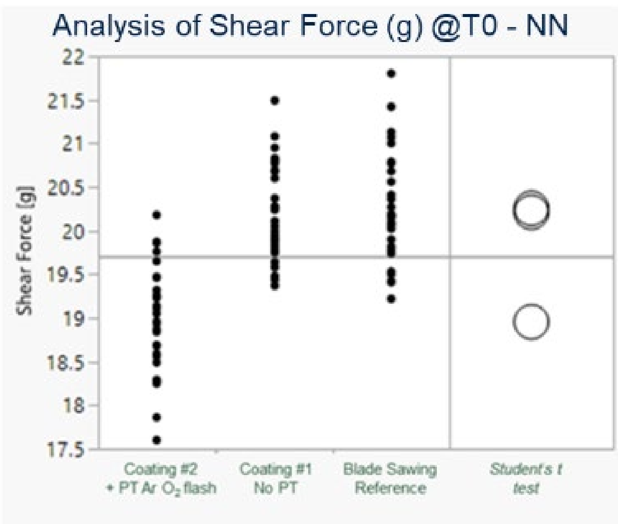


Fig. 3 T-test comparison of BS force for NN leg at T0

Figs. 4 and 5 present the results of both tests after the two stages of the HTS reliability assessment, at 108hrs and 217hrs. In the data for the bond pull test, whilst the measured values all remain within specification limits, some outliers are present where the failure mode is identified as peeling of the aluminum surface at the bonding interface (represented by triangular marker). However, the same failure mode is encountered on a few of the reference samples and an analysis of historical data from the same technology and pad structure confirms some sensitivity to peeling after HTS.

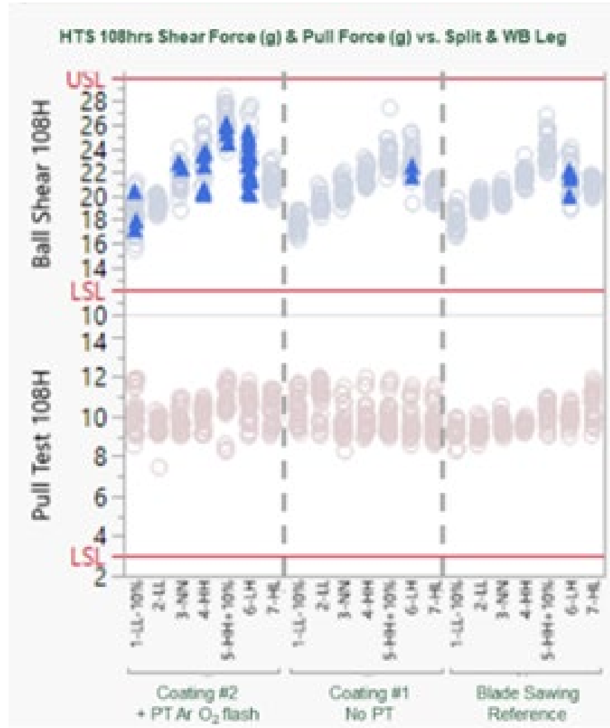


Fig. 4 Shear and Pull Force at 108hrs HTS

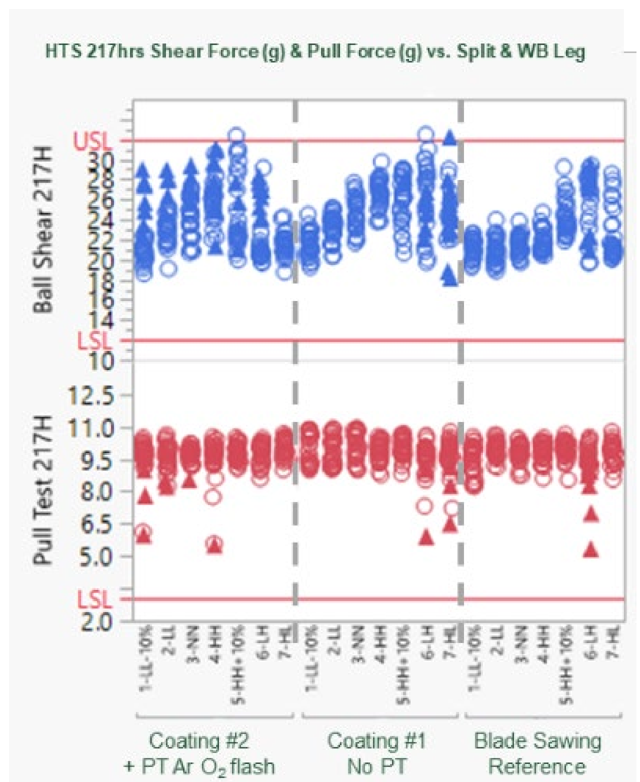


Fig. 5 Shear and Pull Force at 217hrs HTS

Table V: Summary of HTS data by process split and WB condition

| Process Split | | LL-10% | LL | NN | HH | HH+10% | HL | LH |
|---|---|---|---|---|---|---|---|---|
| Blade Saw Reference | BS Mean (SD) T0 | 17.03 (0.37) | 19.01 (0.40) | 20.26 (0.62) | 20.77 (0.55) | 21.99 (0.85) | 19.51 (0.67) | 20.50 (0.68) |
| | BS Mean (SD) 217h | 21.15 (0.99) | 21.10 (1.22) | 21.48 (0.94) | 21.93 (1.09) | 20.87 (0.57) | 26.20 (1.90) | 24.21 (1.77) |
| Coating #1No PT | BS Mean (SD) T0 | 16.84 (0.32) | 19.03 (0.57) | 20.21 (0.56) | 20.60 (0.56) | 22.43 (0.81) | 19.36 (0.60) | 20.11 (0.80) |
| | BS Mean (SD) 217h | 20.15 (1.06) | 21.50 (1.29) | 22.94 (1.29) | 24.25 (1.39) | 20.84 (0.73) | 26.66 (1.69) | 26.68 (1.47) |
| Coating #2 O2 flash | BS Mean (SD) T0 | 16.18 (0.41) | 17.98 (0.74) | 18.95 (0.61) | 19.50 (0.52) | 21.34 (0.97) | 18.42 (0.90) | 19.45 (1.15) |
| | BS Mean (SD) 217h | 20.73 (1.02) | 23.10 (1.30) | 24.32 (1.96) | 26.39 (1.75) | 21.55 (1.13) | 27.10 (2.38) | 27.23 (2.26) |

Table VI: Summary of THS data by process split and Wb condition

| Process Split | | LL-10% | LL | NN | HH | HH+10% | HL | LH |
|---|---|---|---|---|---|---|---|---|
| Blade Saw Reference | BS Mean (SD) 24h | 17.08 (0.65) | 18.73 (0.60) | 19.36 (0.50) | 20.43 (0.41) | 22.23 (0.71) | 20.22 (0.58) | 19.33 (0.58) |
| Coating #1No PT | BS Mean (SD) 24h | 17.02 (0.56) | 19.02 (0.53) | 19.80 (0.47) | 21.00 (0.67) | 22.33 (0.71) | 20.74 (0.57) | 19.36 (0.55) |
| Coating #2 O2 flash | BS Mean (SD) 24h | 16.40 (0.41) | 18.22 (0.41) | 19.14 (0.52) | 19.81 (0.54) | 21.55 (1.09) | 19.39 (0.52) | 19.17 (0.76) |

In terms of the change in mean values for bond shear force between T0 and after 217hrs HTS, summarized in Table V, there is no evident degradation in bonding strength for any of the process splits as a result of the accelerated stress conditions applied. In most WB legs higher mean values are obtained after heat stressing. Some increase in dispersion is observed for all splits during the HTS trial, most noticeably after 217hrs, and in particular for the process using coating #2 with post-treatment in bond shear force, although it must be noted that no outliers representing low force values are apparent. The surface area affected was small and within specification. A higher occurrence of peeling was found in the bond shear test data for the process using coating #2 with post-treatment, linked to the increase in dispersion.

The THS condition was used for a more rigorous assessment of the bond reliability because of the additional stress provided by high relative humidity in addition to high temperature as described above. Table VI summarizes the data obtained from the same tests after 24hrs of exposure to these conditions. Both the mean values and standard deviation of bond shear force obtained were very similar between splits. No major anomalies were apparent and all test data within specification. More importantly, especially considering the presence of humidity, the failure modes were characterized as unattributed to the bond interface, being shear failure in the aluminum in the case of bond shear and wire neck break in the bond pull test.

## III. Conclusion

The bond pull and bond shear data indicate that both plasma dicing process splits achieve similar wire bonding performance as the qualified reference process using a typical mechanical blade sawing process. Both meet the prescribed criteria for bond strength performance, including those applied after HTS or THS treatment for accelerated reliability assessment, based on a comparison of mean values.

However, closer statistical analysis reveals that some important differences can be discerned, especially in the comparison of the process using coating #2 with $O_2$ flash post-treatment with the reference. Whilst still within acceptable limits the bond shear force resulting from this process is significantly lower than the reference sample mean value immediately after the bonding process at T0. After HTS treatment there is also a noticeable increase in dispersion for all WB legs and, importantly, a greater occurrence of the peeling failure mode associated with the wire bond interface.

The plasma dicing process using coating #1 produced results much more closely aligned to those obtained from the blade sawing reference, in terms of mean values, dispersion and failure mode. Additionally, an important advantage of this solution to the fluorine control question is that no subsequent post-treatment is necessary. This simplifies the integration of the process in plasma dicing flows using a laser grooving masking step to define the scribe lane opening and avoids the need for a dedicated process module for the plasma cleaning process.

## Acknowledgment

SPTS would like to thank the Etch Applications team, field team and the staff at ST Microelectronics for their assistance.

## References

[1] F. Lärmer, A. Schilp, “Method of Anisotropically Etching Silicon”, German Patent DE4241045