

PHOTOMASK

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PM16 Best Paper

Identification of a new source of reticle contamination

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ABSTRACT

Since the introduction of 248 and 193 nm lithography sub-pellicle contamination has been a significant problem and a major contributor to reticle costs and semiconductor yield losses. The most common contaminant identified has been ammonium sulfate commonly called haze, however there have been many other contaminants identified and grouped in the category as haze. In attempts to mitigate the cause of this problem various processes and manufacturing protocols have been put in place to either prevent the problem or identify the source of the problem before there is a negative impact in the wafer fab. In spite of efforts to manage the effects of sub-pellicle contamination in the wafer fab, the problem continues to exist. Over the years we have identified many of the compounds and their sources that exist on the sub-pellicle surface, however one has been elusive. This paper will provide both the identification of this compound and its source.

1. Introduction

Sub-pellicle contamination and the effects on reticle performance were first identified in 1999 by Grenon et al.¹ The first report identified the sub-pellicle contaminant as ammonium sulfate and was attributed to the mask cleaning process, environmental contamination and DUV exposure. Subsequent publications confirmed the original results and suggested mechanisms for haze formation.²⁻⁴ Additional reports of sub-pellicle haze formation began to surface identifying other compounds; cyanuric acid and ammonium carbonate.⁵ With the introduction of 193nm lithography and 300mm wafers the occurrence of haze in the wafer fab increased. Additionally, new types of haze were reported on Attenuated Phase Shifting Masks (AttPSM), these types of

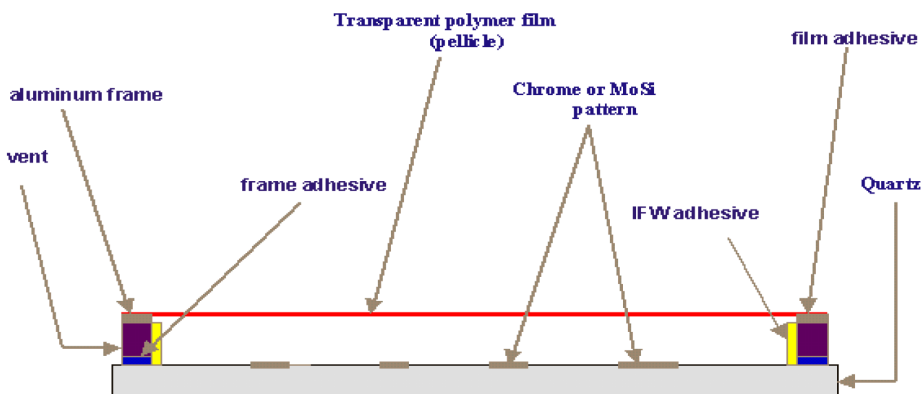


Figure 1. Reticle with pellicle with key components.

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EDITORIAL

Spring is in the Air

Patrick Martin, Head of Field Technology,
Applied Materials, Inc.

When February rolls around, it is time for another Advanced Lithography Symposium. Familiar faces and familiar places. Supplier receptions and after hour libations! Attending for well over twenty years, the excitement is still there and rightfully so based on the criticality of patterning to further fuel advances in semiconductor technology.

Anticipation around EUV adoption will certainly be a "hot" topic. Certainly source power has met the near term requirement for insertion and mask blank quality has made enough progress to meet a near term demand. Preliminary layer insertion has been well thought out; it is just a matter of implementation. Challenges with tool uptime for an extended time period, meaning more than a week at high utilization, the need for a Mask Pellicle, and some inspection technology to capture actinic relevant defects will be debated and shared in detail. Beyond the infrastructure challenges, advantages to the IDMs and fabless community from a device aspect will make us hungry for insertion.

But is EUV adoption an advantage for the commercial mask makers? Probably not near term at least and it is difficult to envision it makes sense long term. The value of the EUV mask and relative uncertainty for manufacturing drive the captive mask makers to retain the inherent EUV capability internal to the captive mask shop. Layout of a high end flow with redundancy in key areas within the IDM or Foundry seems to challenge the need for a commercial source even long term. In addition, patterning simplification through mask count reduction would also hit the commercial players in a negative way. The question is whether there will be a value proposition to acquire the captive in time and secure the advanced capability similar to what happened in the 80's and 90's. Another option is for the commercial mask makers to form a J/V aimed at EUV specifically where there would now be economy of size. Often discussed but presents a difficult business model to implement.

For the rest of the Semi Capital Equipment makers, EUV adoption offers further scaling challenges requiring materials innovation. It gets interesting for local interconnect and middle line applications. In addition, it offers a path forward for more end users to continue nodal scaling based on cost benefit provided EUV adoption is just not a technical position.

One thing for sure, it will be lively, there will be plenty of debate, and there will be enough fun mixed in to make it another successful event! Safe travels if you are attending and look forward to reconnecting with the community.



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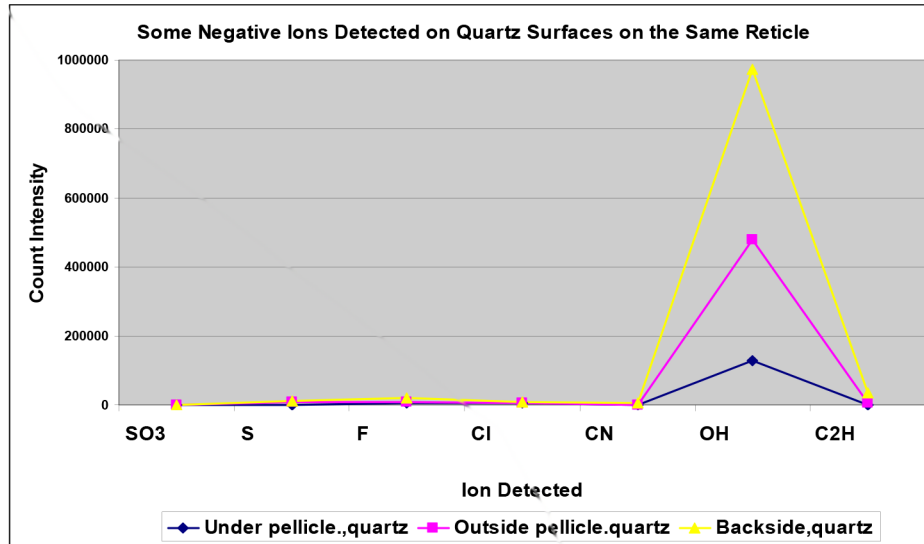


Figure 2. Shows the difference in surface chemistry on three different surfaces of the same reticle.

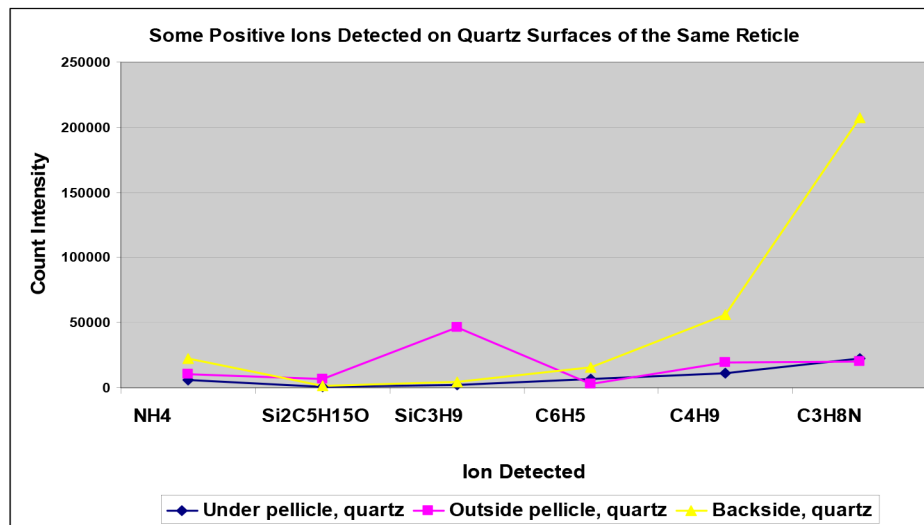


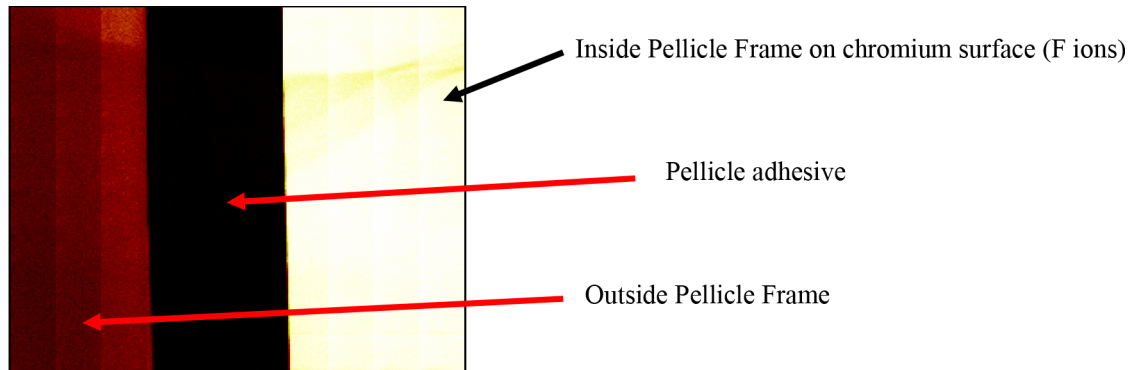
Figure 3. Shows the difference in surface chemistry on three different surfaces of the same reticle.

haze were attributed to degradation of the molybdenum silicide oxynitride (MoSiON) films.⁶

Many attempts to mitigate, manage and remove haze in the fab have been introduced; including improved cleaning processes, migrating to sulfate-free cleaning processes, improved mask storage, better environmental controls for sulfur oxides and ammonium contamination in the fab, removal of haze with Rhazer, monitoring the number of exposures, improving mask carriers and increasing reticle defect inspection frequency in the fab.⁷⁻⁸ All of the activities have resulted in reduced risks in the wafer fab but have not eliminated the risk completely.

Over the years we have done extensive analysis on many reticles and have identified other compounds that can possibly contribute to sub-pellicle contamination that can have a deleterious effect on wafer yield. Unfortunately, accepted meth-

ods of abating most of these contaminants require significant materials changes in both reticle construction and wafer fab environment. The primary sources of molecular contamination on reticles fall into these classes; residues from cleaning processes, out-gassing from mask storage/shipping boxes, mask fab environment, wafer fabs, pellicle degradation, and out-gassing from pellicle adhesives. It is important to note that what may appear as an insignificant material change in and around the reticle manufacturing process or environment can have catastrophic impact on wafer yield. For this reason we continue to investigate and monitor changes made in the reticle space. This investigation provides results based on a TOF-SIMS and FTIR analysis of a sub-pellicle contaminant that has been seen on many reticles, however, up to this point we have been unable to identify its source.



ION: F: 1.135×10^7 counts on chromium surface (5mm x 5mm)

Figure 4. TOF-SIMS image of fluorocarbon intensity, the brighter the image the higher the ion concentration. The scan was accomplished in a left to right direction.

2. Background

The pellicle and the sub-pellicle space have been areas of considerable interest since the introduction of 248 and 193nm lithography. Particularly, in the fact that yield losses, reticle maintenance and higher reticle costs are associated with contaminants that form under the pellicle during reticle exposure. The frequency and speed in which the printable contaminants (defects) form can be a function of mask cleaning process, mask film type, pellicle type, number of wafer exposures, mask level to name a few. In order to better understand the defect formation environment it is important to understand the pellicle/reticle structure and its surfaces. Figure 1 provides an overview of the critical surfaces on a reticle.

There are nine (9) key surfaces on a reticle, 1. quartz surface under the pellicle, 2. metal surface inside the pellicle, 3. image sidewall under the pellicle, 4. pellicle frame with frame wall adhesive, 5. inside surface of the pellicle film, 6. outside surface of the pellicle film, 7. backside quartz surface, 8. outside pellicle frame surface, 9. surface outside the pellicle frame on the image side of the reticle. The surface chemistry is generally different on all of these surfaces.

The TOF-SIMS data above clearly show significant differences in surface chemistry for different surfaces on the same reticle. We show this data for the purpose of indicating that surface chemistry can be significantly different as a function of location on a given reticle. These data led us to further investigate various surfaces on a defective reticle used in a production environment.

3. Experimental and Analytical Results

Sec. 3.1 TOF-SIMS Analysis

We received several production reticles that had been identified as having large amounts of haze that was not removed by conventional haze removal techniques. For the purpose of this study we only report the data for one of the reticles, however data from all of the reticles was similar. We completed TOF-SIMS analysis of the reticles using an ION TOF 300, both positive and negative surface ion analyses were done. Macro-scan of a large area that traversed the outside area of the pellicle across the pellicle frame adhesive and the surface inside the pelliclized area were completed.

The scan in Figure 4 indicates that the concentration of fluorine ions inside the pellicle space is extremely high, it also shows that the pellicle adhesive (dark area) does not contain fluorine. There are slight traces of fluorine outside the pellicle space (left side of image).

Sec. 3.2 FTIR analysis of pellicle films

Historically, we have seen various concentrations of fluorocarbon on reticle surfaces and have attributed the presence of the fluorinated compounds either to the use of fluorosulfonic acid surfactants in wet processes or as a result of pellicle degradation. Surfactants generally leave uniform mono-layers on the reticles surface; our data, shown later in this paper, clearly indicates that the fluorocarbon contaminant is not uniform. In fact the concentration decreases as a function of distance from the pellicle frame and the inner frame wall adhesive.

The other possible source is degradation of the pellicle. FTIR analysis indicated that the pellicle had not been degraded. Figures 7 and 8 show that the FTIR spectra for a reference pellicle and a pellicle removed from one of the sample masks that was used in production are identical indicating no degradation of the film.

Sec. 3.3 Analysis of Inner Frame Wall Adhesive (IFWA)

SEM analysis was conducted on several pellicle frames with and without inner frame wall adhesive. The results indicate that pellicle frames without the IFWA adhesive were cleaner and posed significantly less risk of particle contamination. The following micrographs provide examples of inner pellicle frame walls.

FTIR analysis indicates that the adhesive on the inside wall of the pellicle frame is a fluorocarbon polymer containing various unidentified compounds. For the purpose of this paper we provide FTIR data for various IFWA adhesives. It can be seen that the IFWA varies for different pellicle suppliers.

4. Discussion

The analytical results clearly indicate that the IFWA adhesive contributes to molecular surface contamination on critical surfaces of the reticle.

Figure 14 clearly shows the effects of the fluorocarbon based IFWA. The concentration of C-F species significantly decreases with distance from the frame wall. Additionally, the TOF-SIMS

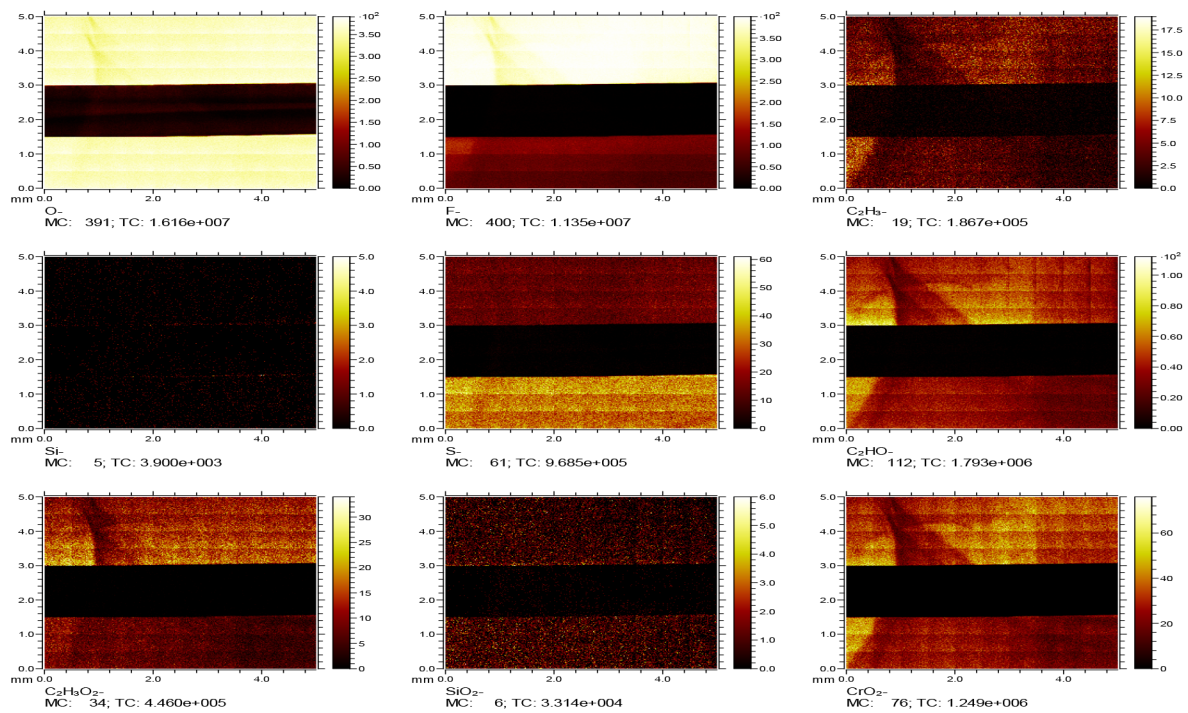


Figure 5. TOF-SIMS images of various negative ions detected around the pellicle frame. The top portion of each square represents the surface inside the pellicle frame, the dark band is the pellicle adhesive and the bottom represents the space outside the pellicle. Note the high fluorine intensity in the upper middle image. This is under the pellicle space.

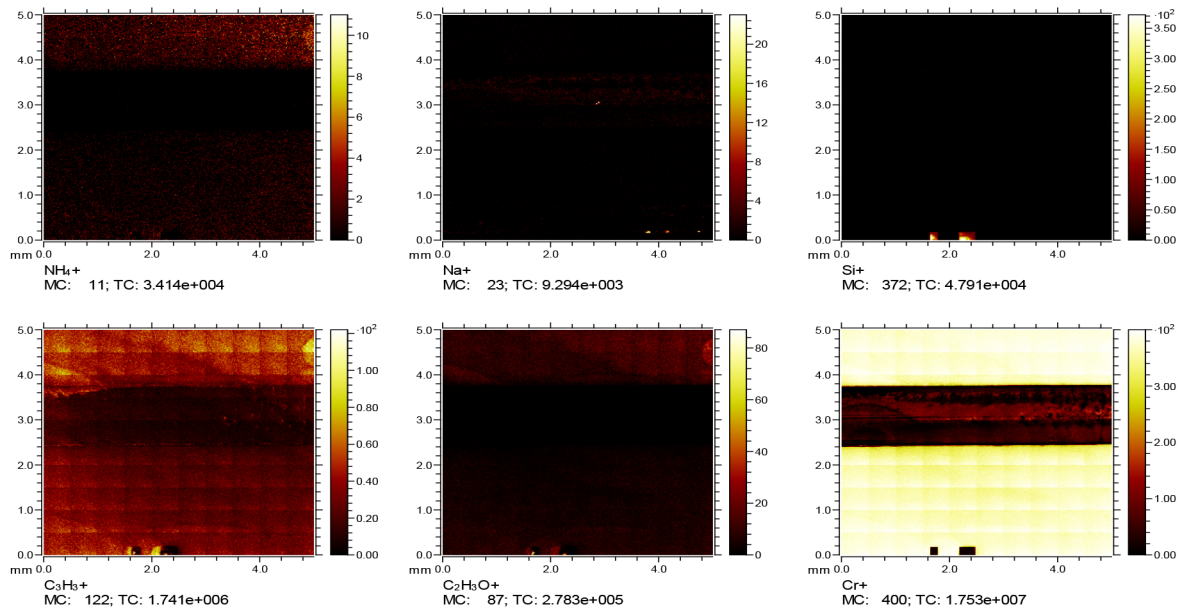


Figure 6. TOF-SIMS images of various positive ions detected around the pellicle frame. The top portion of each square represents the surface inside the pellicle frame, the dark band is the pellicle adhesive and the bottom represents the space outside the pellicle.

image in Figure 4 (the bright area) shows intense fluorine ion concentration proximal to the pellicle frame. FTIR analysis confirms that the fluorine contamination is not a result of the pellicle degrading from reticle exposure or time. The results of the analysis show a strong correlation between the IFWA and the fluorocarbon contamination on the surface of the reticle.

SEM micrographs indicate that the IFWA can possibly contribute to particle deposition on the reticle surface. It was also surprising that the IFWA was not particularly clean or uniform.

5. Summary and Conclusions

While the use of IFWA has been suggested as a getter to prevent particles from depositing on the critical surfaces of a reticle there is no empirical data to suggest that it is effective. In fact the data herein suggests otherwise. Based on the data we recommend that IFWA not be used on pellicles. These adhesives are clearly a source of out-gassing that can have catastrophic effects on the performance of critical optical surfaces.

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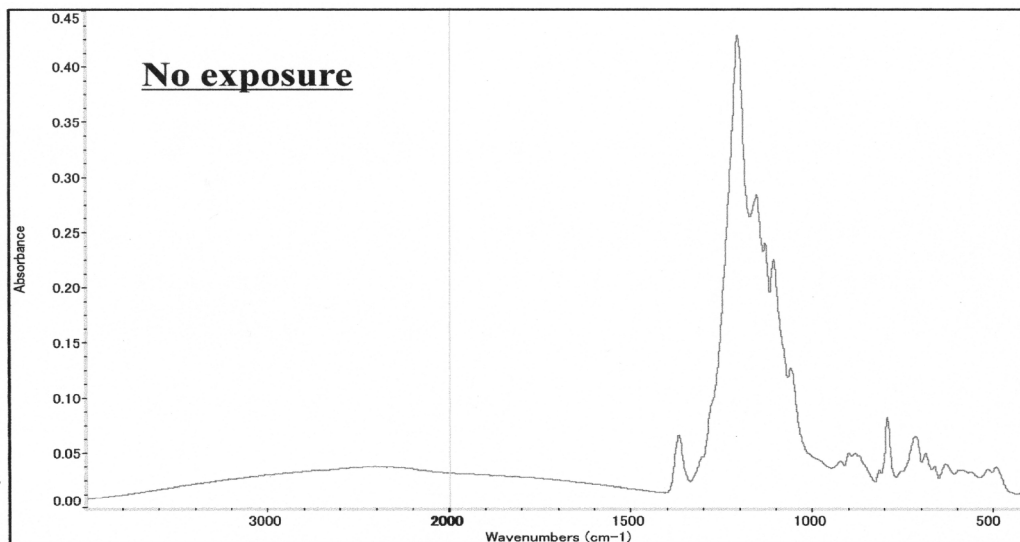


Figure 7. FTIR spectrum of an unexposed pellicle.

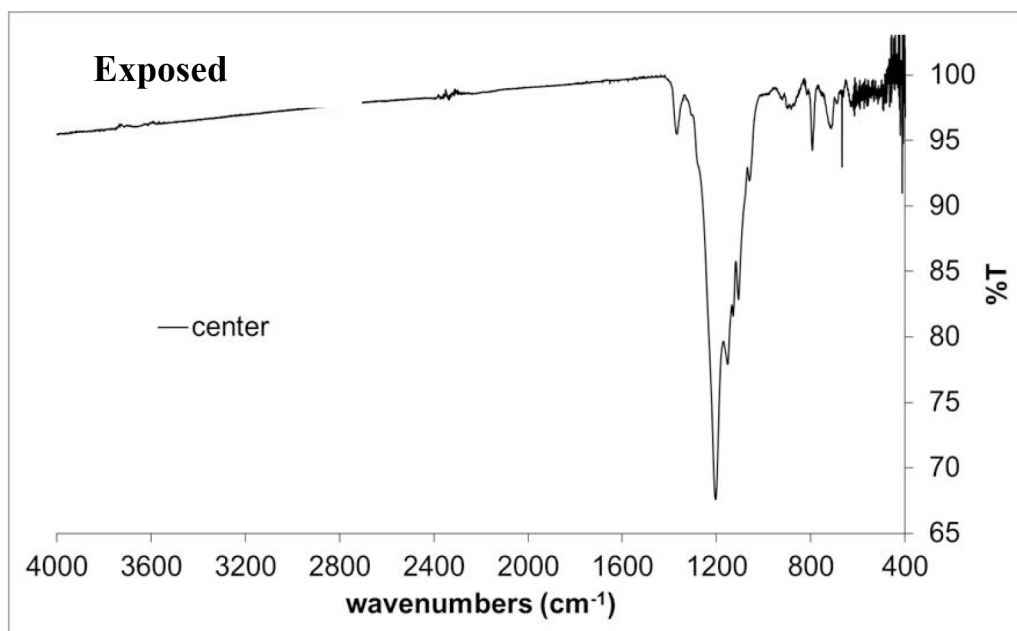


Figure 8. FTIR spectrum of exposed pellicle removed from "hazed" reticle.

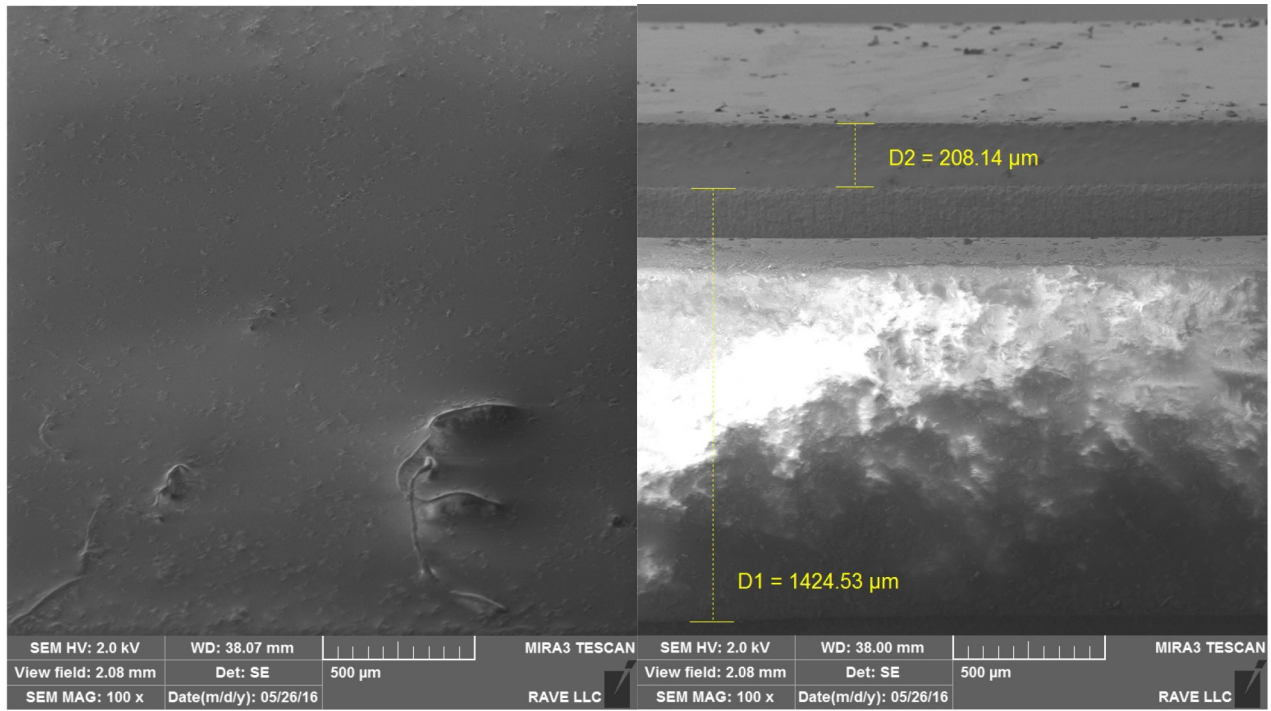


Figure 9. D1 shows the thickness of the pellicle frame adhesive, D2 shows the thickness of the IFWA. The image on the left shows particles that are embedded in the IFWA.

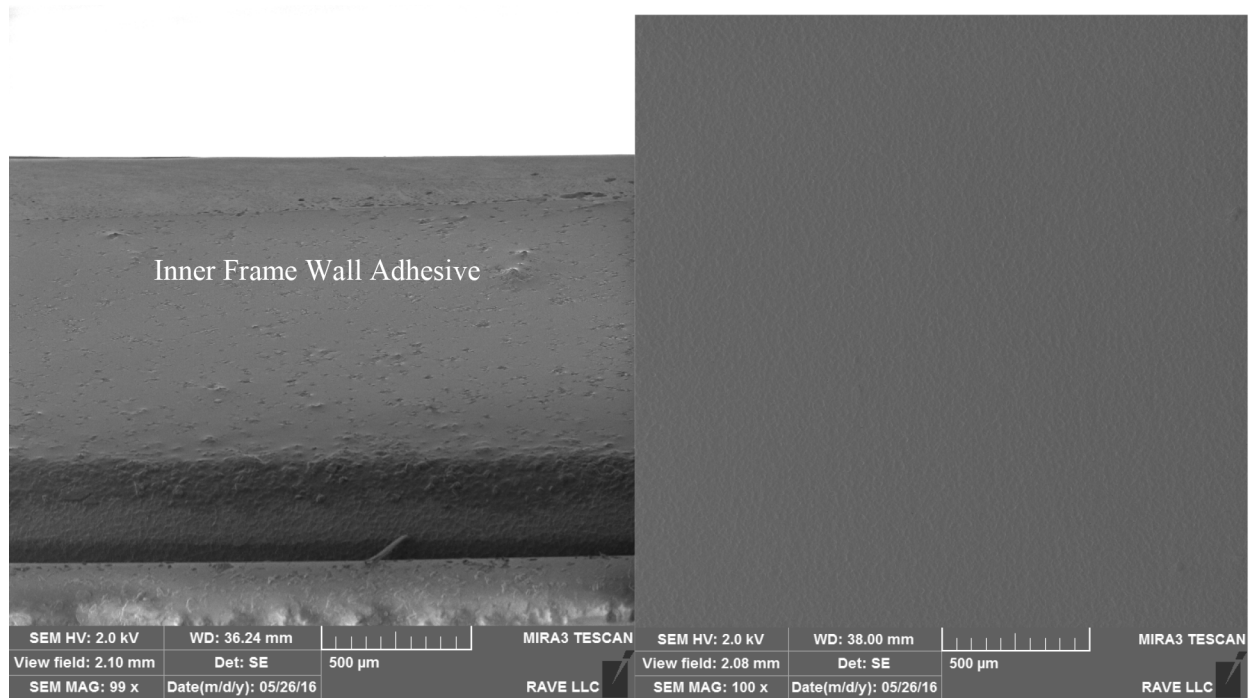


Figure 10. Shows the surface of the IFWA (Left), right image shows a standard frame without IFWA.

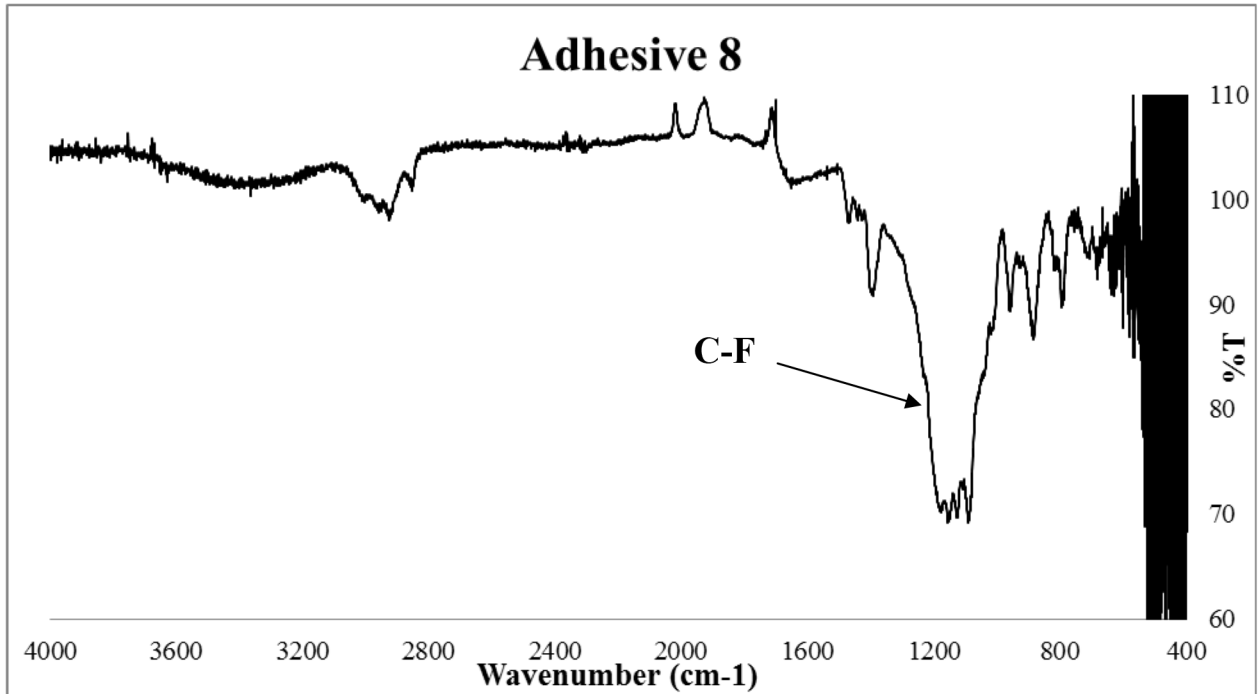


Figure 11. FTIR spectrum for the IFWA reported herein. Supplier A.

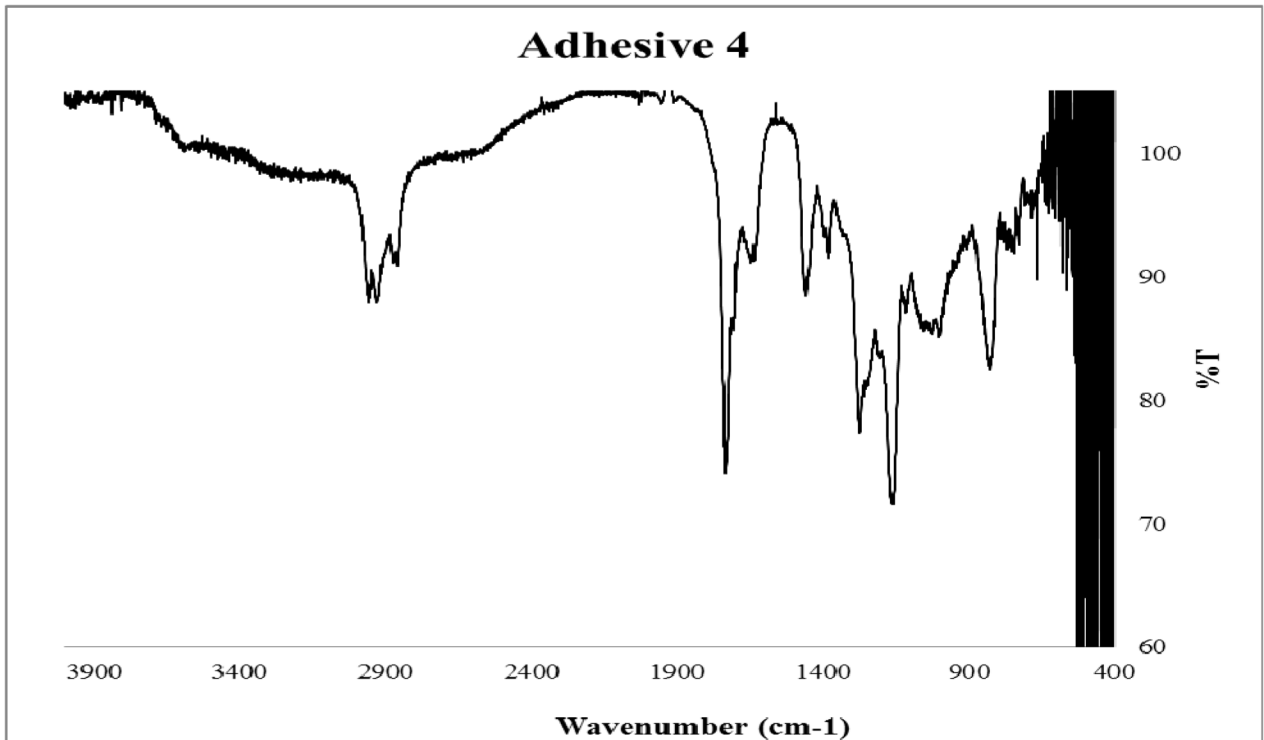


Figure 12. FTIR spectrum the IFWA. Supplier B.

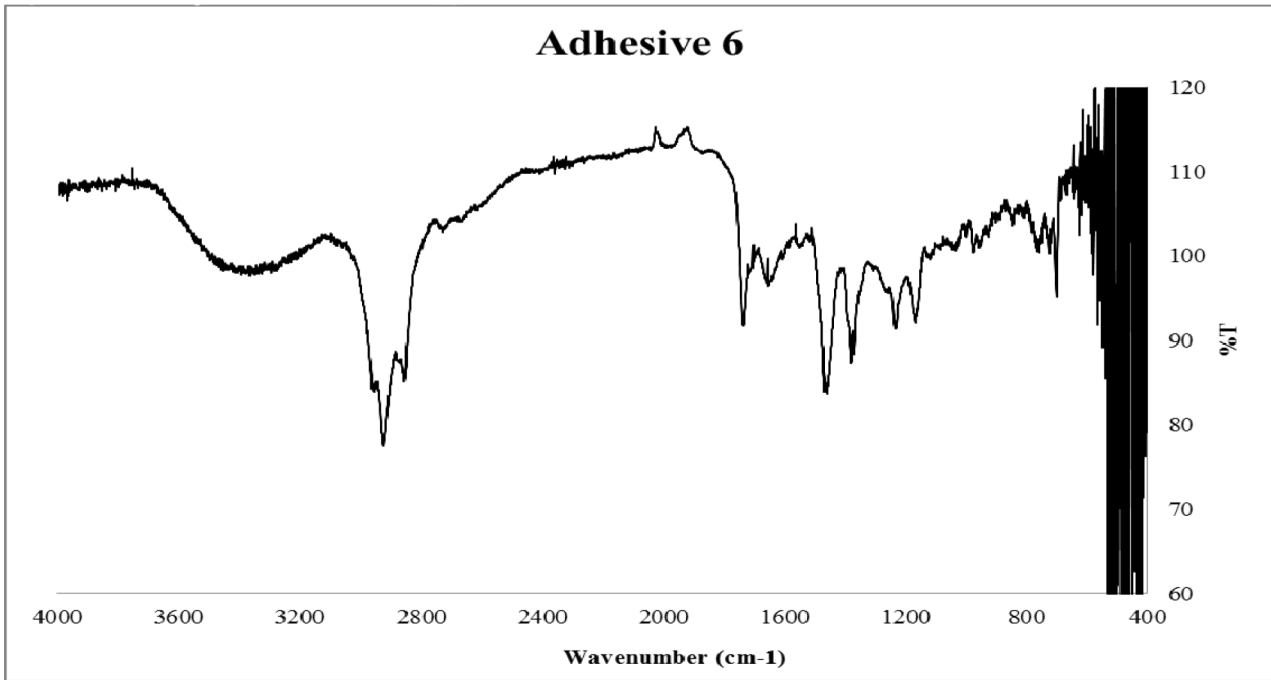


Figure 13. FTIR spectrum for IFWA. Supplier C.

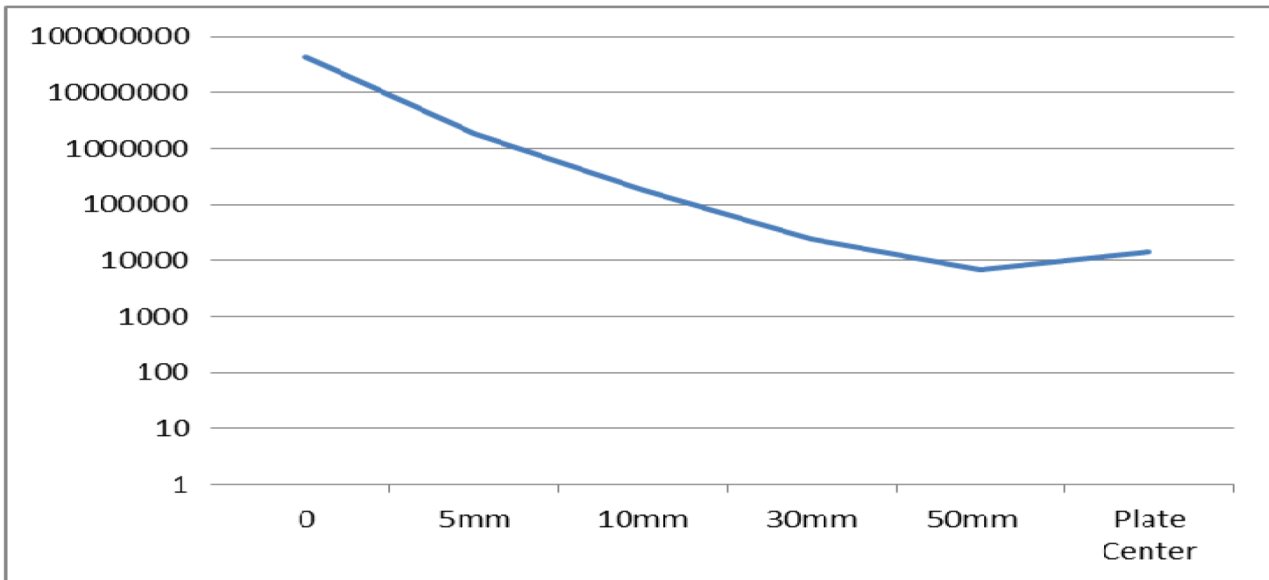


Figure 14. TOF-SIMS intensity counts of C-F species as a function of distance from the IFWA.



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Industry Briefs

■ IMS and JEOL Partner to Provide World's First Production Multi-Beam Mask Writer

February 17, 2017

IMS Nanofabrication AG ("IMS") and JEOL Ltd. ("JEOL") announced they have reached a long term agreement to extend their business partnership for the production of the IMS MBMW-101, the world's first commercial high volume manufacturing Multi-Beam Mask Writer (MBMW). IMS manufactures a multi-beam write engine providing 262-thousand programmable beams of 50keV energy. JEOL provides a novel platform with an air-bearing vacuum stage for writing most advanced patterns on 6-inch mask blanks. Together, IMS and JEOL will supply the MBMW-101 to the industry's leading edge photomask manufacturers.

The MBMW-101 has demonstrated production capability with sub 30nm resolution and very challenging Critical Dimension Uniformity and Image Placement specifications. The MBMW-101 supports these increasingly demanding requirements of mask manufacturing while maintaining a write time of < 10 hours for 100mm x 130mm mask layout fields.

<http://www.businesswire.com/news/home/20170215005023/en/>

■ Intel Continues to Drive Semiconductor Industry R&D Spending

February 17, 2017

Intel continued to top all other chip companies in R&D expenditures in 2016 with spending that reached \$12.7 billion and represented 22.4% of its semiconductor sales last year. Intel accounted for 36% of the top-10 R&D spending and about 23% of the \$56.5 billion total worldwide semiconductor R&D expenditures in 2016, according to the 20th anniversary 2017 edition of *The McClean Report*.

Among other top-10 R&D spenders, Qualcomm—the industry's largest fabless IC supplier—remained the second-largest R&D spender, a position it first achieved in 2012. Qualcomm's semiconductor-related R&D spending was down 7% in 2016 compared to an adjusted total in 2015 that included expenditures by U.K.-based CSR and Ikanos Communications in Silicon Valley, which were acquired in 2015. Broadcom Limited—which is the new name of Avago Technologies after it completed its \$37 billion acquisition of U.S.-based Broadcom Corporation in early 2016—was third in the R&D ranking. Excluding Broadcom's expenditures in 2015, Avago by itself was ranked 13th in R&D spending that year (at nearly \$1.1 billion).

<http://electroi.com/blog/2017/02/intel-continues-to-drive-semiconductor-industry-rd-spending/>

■ Ultratech Receives Multiple System Order for Fan-Out Wafer-Level Packaging Applications

February 17, 2017

Ultratech, Inc. announced that it has received a repeat, multiple-system order from a leading semiconductor manufacturer for its advanced packaging AP300 lithography systems. The AP300 systems will be utilized for high-volume, leading-edge, fan-out wafer-level packaging (FOWL) applications used to manufacture application processors. Ultratech will begin shipping the AP300 systems in the first two quarters of this year to the customer's facility in Asia.

The AP300 family of lithography systems is built on Ultratech's customizable Unity Platform, delivering superior overlay, resolution and side wall profile performance and enabling highly-automated and cost-effective manufacturing. These systems are particularly well suited for copper pillar, fan-out, through-silicon via (TSV) and silicon interposer applications. In addition, the platform has numerous application-specific product features to enable next-generation packaging techniques, such as Ultratech's award winning dual-side alignment (DSA) system, utilized around the world in volume production.

<http://electroi.com/blog/2017/02/ultratech-receives-large-repeat-multiple-system-order-for-leading-edge-fan-out-wafer-level-packaging-applications/>

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Monterey, California, USA



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5-7 April 2017
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The 33rd European Mask and Lithography Conference EMLC 2017

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