PHOTOMASK

BACUS—The international technical group of SPIE dedicated to the advancement of photomask technology.

BACUS N • E • W • S

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EUV Lithography - Invited Paper

2020 Mask Makers Survey Conducted by the eBeam Initiative

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ABSTRACT

Captive and merchant mask makers participated in an anonymous survey in the summer of 2020, despite the challenges of the global COVID-19 pandemic, to capture the profile of the mask industry for the period of July 2019 through June 2020. The eBeam Initiative's sixth Mask Makers Survey in 2020 covers a number of questions related to the profile of the mask industry, from overall number of masks to pattern generation type. The survey respondents – 10 different captive and merchant photomask manufacturers versus those who participated in last year's survey – reported 558,834 masks this year. Among the results of the Mask Makers survey, the number of masks written with multi-beam writers more than doubled versus last year's survey, while the average mask write time reported using multi-beam writers (which was recorded for the first time in this year's survey) was 12.14 hours. In addition, EUV mask yield was reported at 91 percent. The use of mask process correction (MPC) increased at leading-edge ground rules (nearly tripling for sub-16-nm ground rules). The eBeam Initiative also conducts an annual survey of industry luminaries which can be found at www.ebeam.org.

1. Introduction

For the past six years, the eBeam Initiative has sponsored a survey that aims to enhance the level of understanding of the unique and critical issues faced by the mask industry. Results from this annual survey are used to provide a snapshot of the mask industry during a given year as well as highlight long term trends. Beginning in 2017, the results have been included in the main program of the SPIE Photomask Technology and EUV Conference.

The survey includes input from both merchant and captive (in-house) mask shops from around the world to provide an objective assessment of the industry. Each year's survey covers the past 12 months from July of the previous year to June of the current year. The survey is prepared by the eBeam Initiative and administered by David Powell, Inc. to protect the information as well as preserve participant anonymity. The content of the survey repeats nearly all the questions from the 2019 survey in order to provide trend analysis. However, due to the participants changing from the previous year, we report primarily about the 2020 results without year-to-year comparisons. In some cases, a straight forward weighted average analysis was used to look at the results, computed by averaging each company response multiplied by that company's percentage share of all reported masks in a particular category.

The ten participating mask shops in the 2020 survey were: Advanced Mask Technology Center (AMTC), Dai Nippon Printing (DNP), HOYA, Intel, Micron Technology, Photronics (including PDMC), Samsung, Semiconductor Manufacturing International Co. (SMIC), Taiwan Mask Shop (TMC) and Toppan Photomasks, Inc. The survey results reflect only masks made by these respondents.

2. Results

2.1 Masks Reported by Ground Rule

For the 12 months ending June 2020, there were 558,834 masks that were reported to have been delivered by the 10 participating companies. Figure 1 shows the breakdown by ground rules as reported by the participants. The masks delivered as reported in the 2019 survey are also shown in Figure 1 but represent a different set of participating companies as previously noted.

2.2 Number of Masks per Mask Set

In 2020, the weighted average of masks per mask set was 64 for ground rules below 16nm down to and including 11nm as shown in Figure 2. The largest number of masks per mask set reported was 75. The number of respondents ("n") for ground rules below 11nm down to and including 7nm was less than 3. To protect the privacy of participants, the results aren't reported if n is less than 3. So no data is reported for that range in 2020. The reported data for the past three years in the upper right of Figure 2 had shown a decline in the number in 2019, but we do not know if that trend continued into 2020. The question asked was: What

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SPIE.

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Editorial

Where are our Students?

Larry Zurbrick, Keysight Technologies

I recently had the pleasure of participating on our BACUS Student Scholarship Committee. It was an eye opener to see the talent and passion that the candidates are bringing to the optical sciences and to think about the impact they will make to their respective fields of study. However, it was noted that few students seeking scholarships were involved with lithography in general and none were involved in any aspect of photomask technology as part of their past or present studies. This included any student intern experience with mask related content at any company or organization. Perhaps we, the BACUS organization, haven't promoted the BACUS Scholarship widely enough at universities around the world. But there is another way to make our industry and technology known to students.

One possible outreach to undergraduate and graduate students would be to offer internships at our respective companies and organizations. This would accomplish three things. First, it would make students aware of the photomask and photomask-related industries. Second, the internship could be used to make the student intern aware that there is a scholarship available for research related to solving issues related to photomask technology. Third, it would provide them with a paycheck during their internship that would likely exceed the usual scholarship amounts awarded.

My experience with student interns is that they bring new ideas and the latest skills to the table. Interns bring much enthusiasm and focus to the tasks put before them. They have created solutions to real world problems at hand and in many cases returned as full-time employees after graduation. The student intern in return receives hands-on experience in industry, the satisfaction of making a real contribution, starts to grow their professional network and receives a paycheck!

Long ago I was a student intern. The lessons I learned then gave me a head start in my career and are still with me today. Consider paying it forward at your company and hiring an intern!

BACUS

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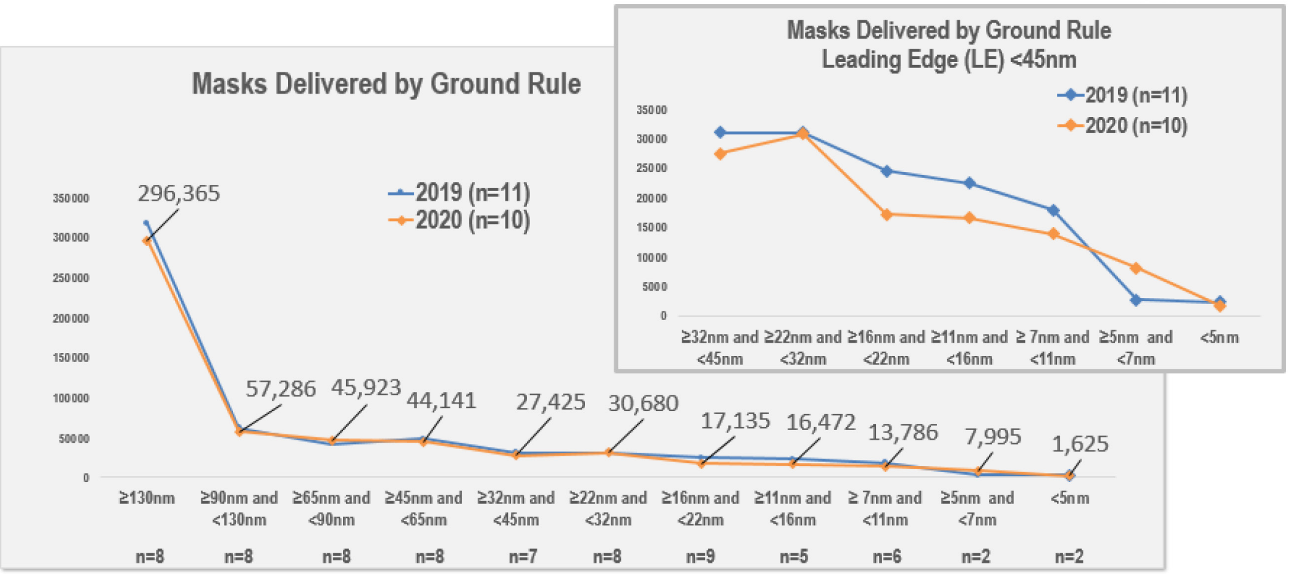

Q: What was the number of masks delivered?

Q: Percentage of the total number of masks in the preceding question by Ground Rules of the critical layers?

Figure 1. Historical mask shipments by ground rule – 2020 Mask Makers Survey..

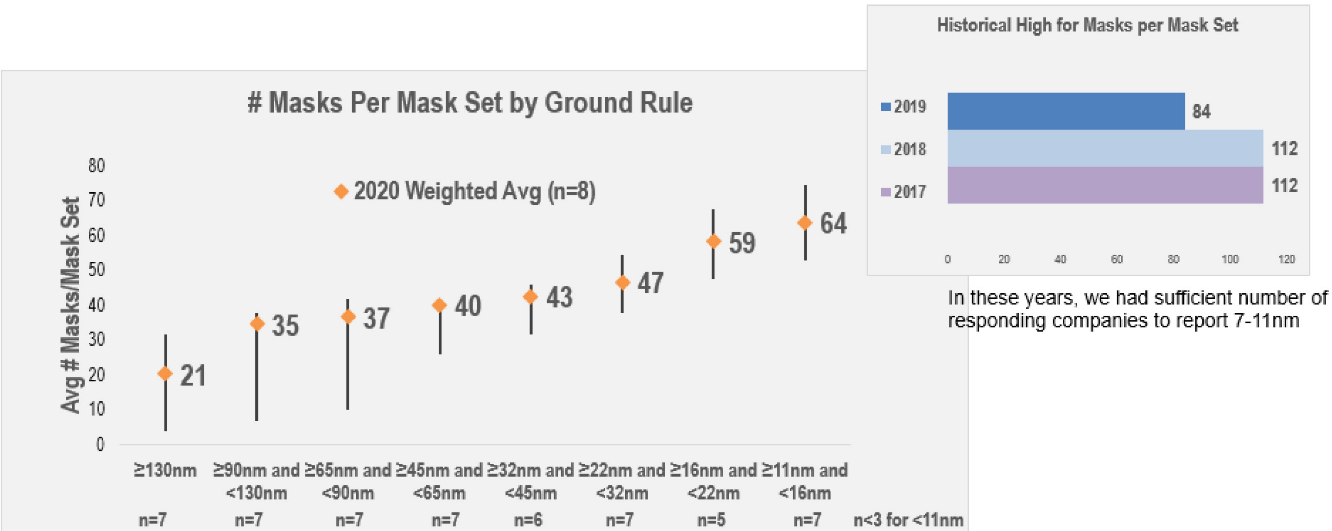

Figure 2. Weighted Average # of Masks per Mask Set by Ground Rule – 2020 Mask Makers Survey.

was your average number of masks per mask set by Ground Rules of the critical layers?

2.3 Pattern Generation Type

The use of Multi-Beam pattern generation was affirmed in the 2019 results and more than doubled in the 2020 results reported as shown in the chart on the right of Figure 3. Variable-Shaped eBeam (VSB) pattern generation was used on 26.2% of the mask shipments reported as shown in the chart on the left of Figure 3. Lasers were used to write 72.4% of the masks reported in 2020 as shown in Figure 3. The question asked was: What was the percentage written by the following pattern generation? (eBeam (VSB), eBeam (multi-beam), eBeam (raster), LASER, Other)

2.4 Average Write Time

For the first time due to sufficient participants, the weighted average write time for Multi-Beam writers was reported as 12.14 hours as shown in Figure 4. Weighted average write time for VSB writers was 7.91 hours and 2.33 hours for laser writers as shown in Figure 4. The question asked was: What was the average write time over the past 12 months (July 2019-June 2020) for each type of pattern generation? (eBeam (VSB), eBeam (multi-beam), eBeam (raster), LASER, Other) Results are reported when n > 2.

2.5 Longest Write Times

The longest reported mask write time reported in the 2020 survey was 57.14 hours for VSB eBeam and 19 hours for laser as shown in Figure 5. Because the participating companies are not the same as previous years,

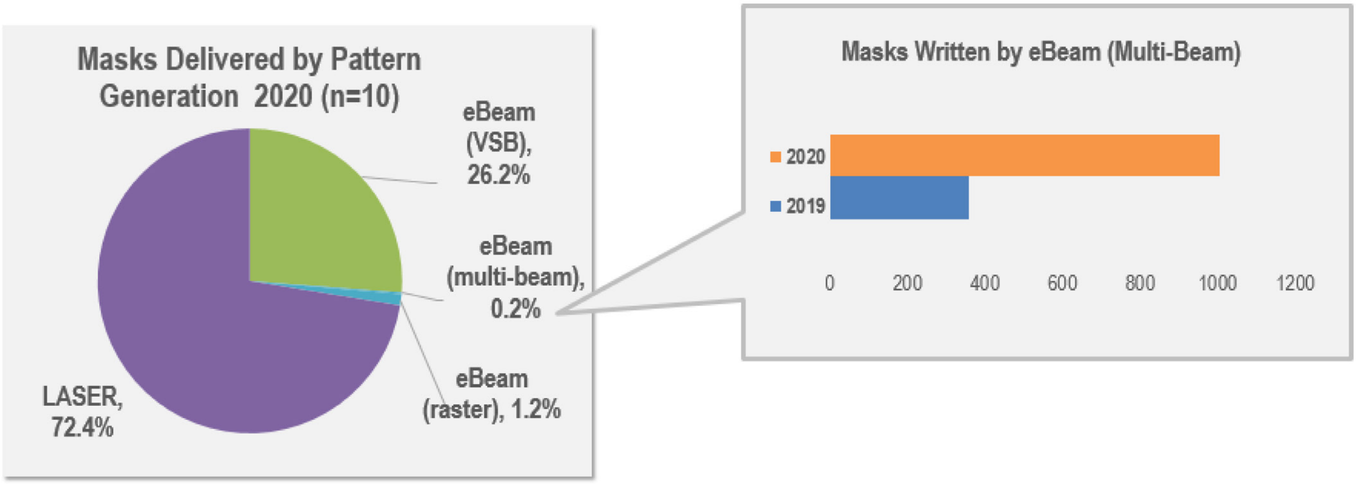

Figure 3. Mask shipments by pattern generation type – 2020 Mask Makers Survey.

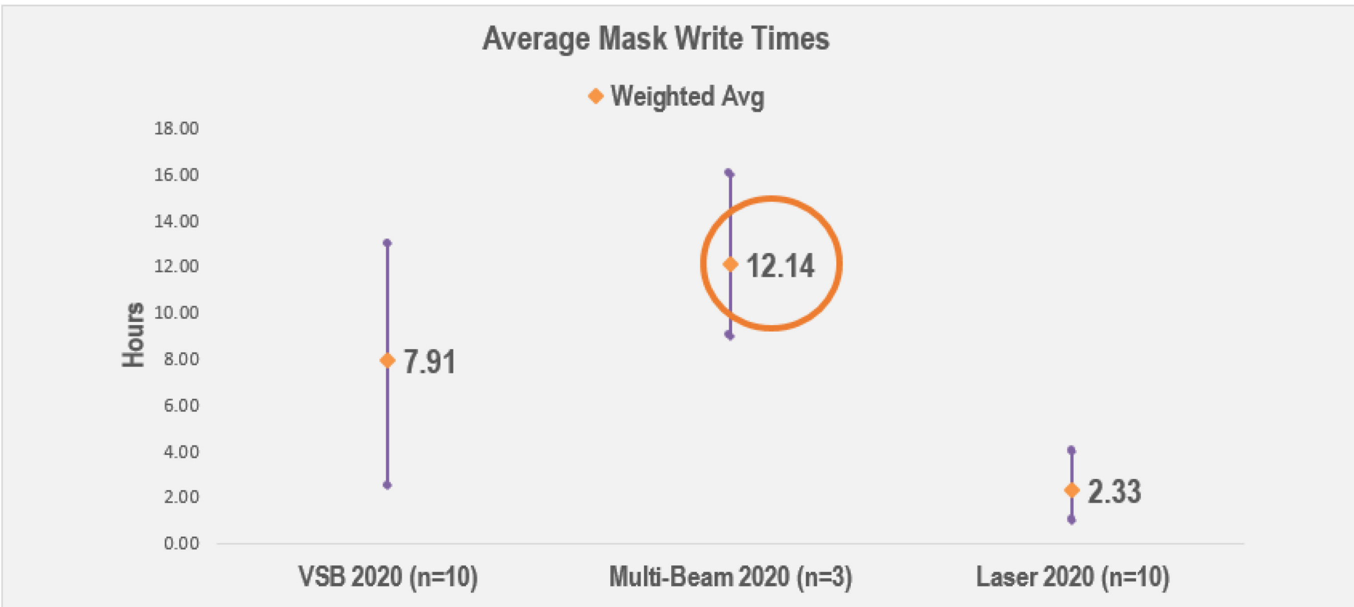

Figure 4. Weighted average mask write times by writer type – 2020 Mask Makers Survey.

yearly comparisons are inconclusive. The question asked was: What was the longest write time over the past 12 months for each type of pattern generation? (eBeam (VSB), eBeam (multi-beam), eBeam(raster), LASER, Other)

2.6 Largest Data Volume

For VSB writers, the range of the largest data volume reported in 2020 was 7.1 TeraBytes (TB) with the median of 1.1 TB as shown in Figure 6 (median reported for the first time in 2020). For laser writers, the largest data volume reported in 2020 was 110 GigaBytes (GB) with the median of 8.3 GB in 2020 also shown in Figure 6. The question asked was: What was the largest data volume for any mask level for each type of pattern generation over the past 12 months? (eBeam (VSB), eBeam (multi-beam), eBeam (raster), LASER, Other) Results are reported when n > 2.

2.7 Masks Delivered by Type

There were 1629 EUV masks (0.3% of the total) reported in the 2020 survey as shown in the pie chart in Figure 7. The question asked was: What was the percentage by..? (Binary, AttPSM, AltPSM, EUV, Other)

2.8 Highest Dose Resist Used

The highest dose resist used was reported for EUV. The median of the highest dose used (shown for the first time in 2020) for EUV was 61.3 $\mu C/cm^2$ as shown in Figure 8. Because the participating companies are not the same as previous years, yearly comparisons are inconclusive. The question asked was: In the past year, what was the highest dose resist used in production for each category?

2.9 Mask Yield

Mask yield overall was reported at 94.2% in 2020. For EUV masks, the reported yield was 91% as shown in Figure 9. Because the participating companies are not the same as previous years, yearly comparisons are inconclusive. The questions asked were: What was your overall percent mask yield? What was your percent mask yield by category? (Binary, AttPSM, AltPSM, EUV)

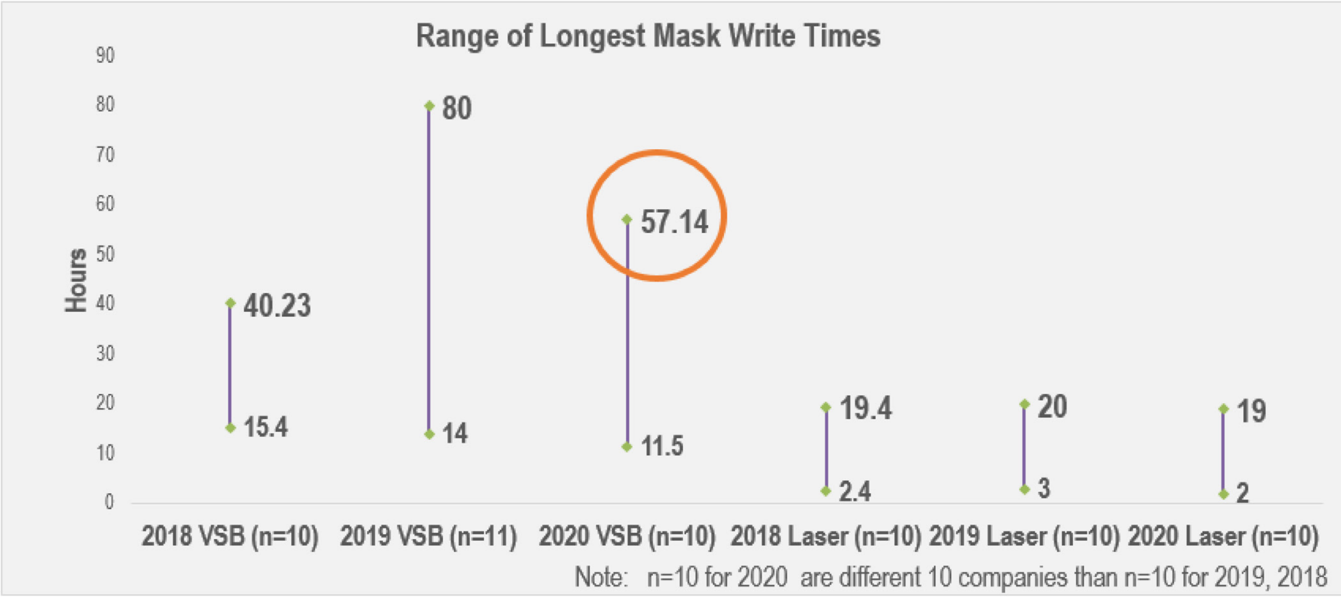

Figure 5. Range of longest mask write times by writer type - 2020 Mask Makers Survey.

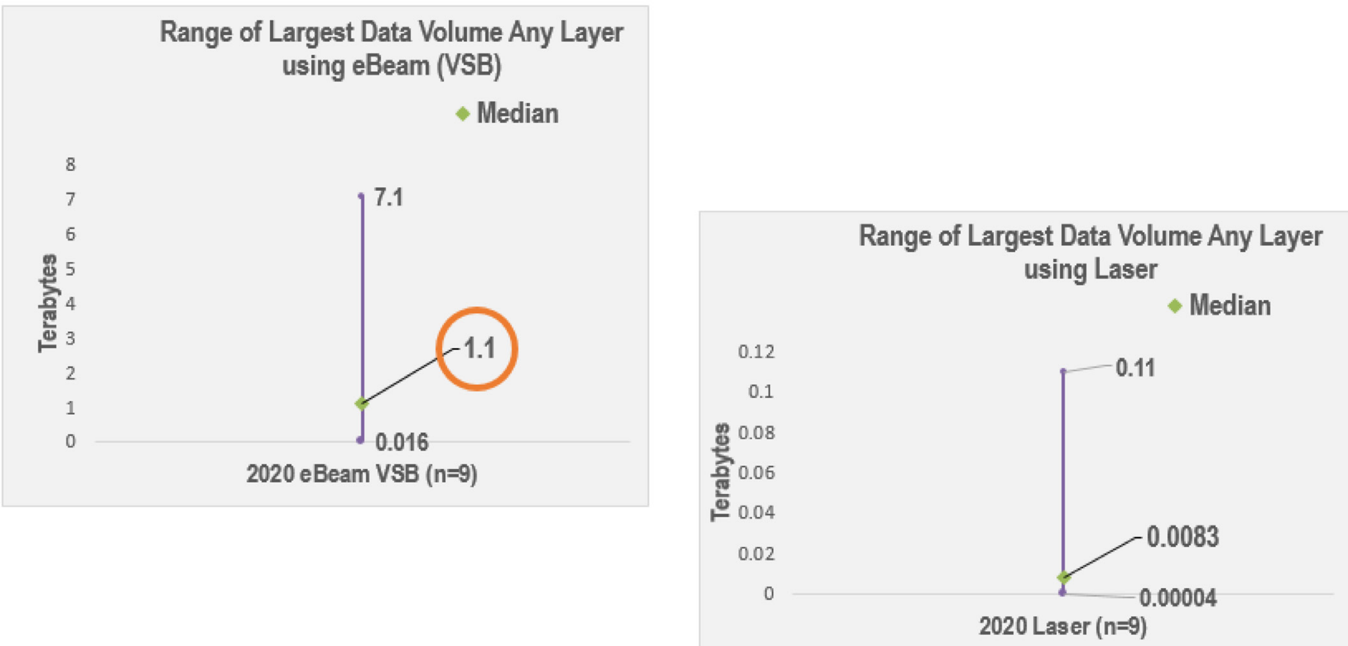

Figure 6. Range of largest data volume and median for VSB and Laser writers – 2020 Mask Makers Survey.

2.10 EUV Defects Affecting Yield

A new question was added for the 2020 survey about defects affecting EUV yield. The question asked was: For EUV masks, what defects affected the yield by category? "Clear defect of absorber" was the largest category at 39% based on the weighted average of the participants responding as shown in Figure 10.

2.11 Average Number of Defects by Mask Type

For all masks in 2020, the average number of defects per mask for opaque was 3.89 and was larger than clear at 1.17 as shown in Figure 11. Because the participating companies are not the same as previous years, yearly comparisons are inconclusive. The question asked was: What was the average number of defects per mask? (Clear, Opaque, Other)

2.12 Masks Delivered by Substrate

Chromium is the dominant substrate at 81.2% as reported in the 2020 survey as shown in Figure 12. The question asked was: What was the percentage by substrate type? (Chromium, OMOG, MoSION AttPSM, Other)

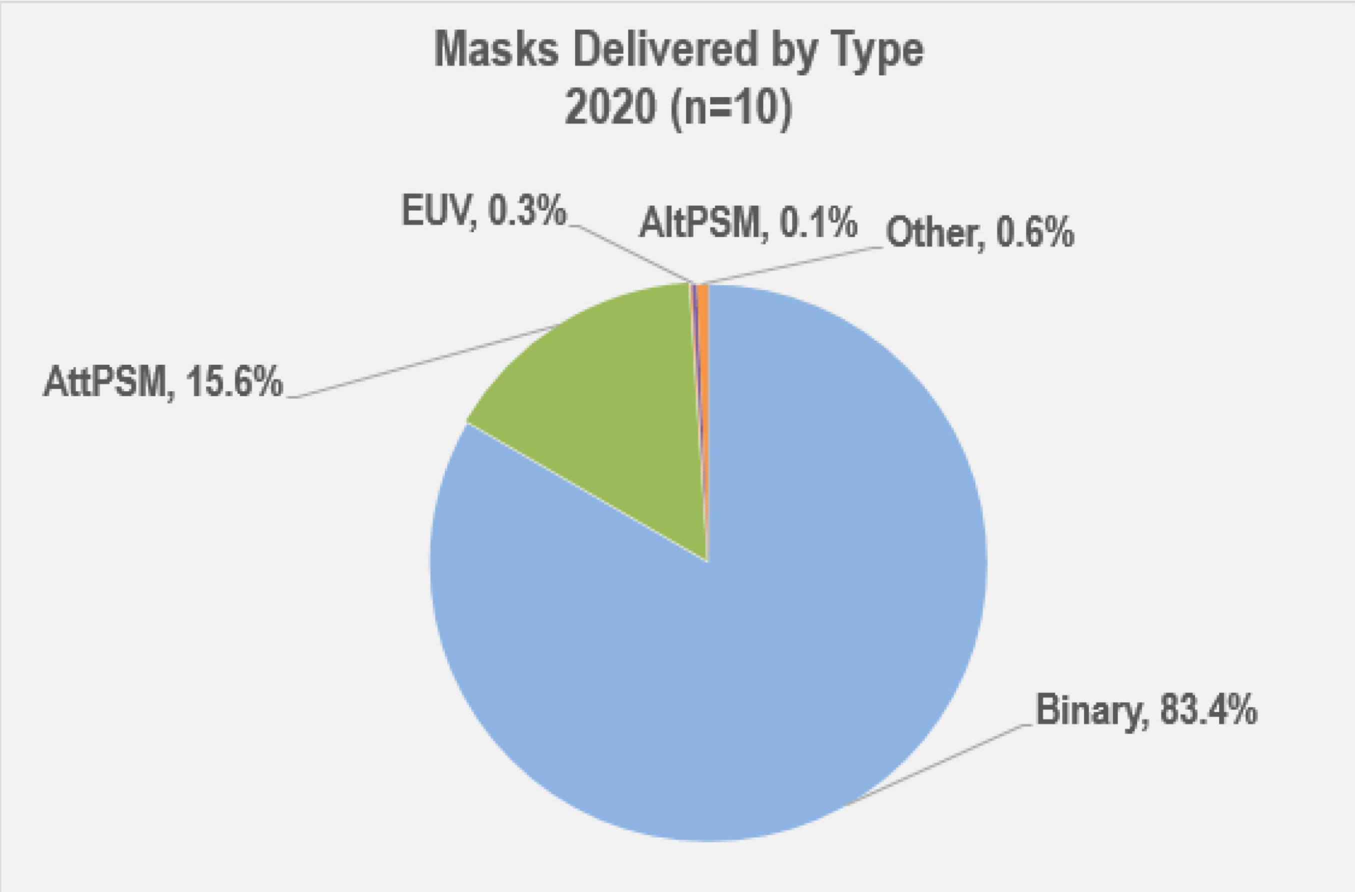

Figure 7. Mask shipments by type - 2020 Mask Makers Survey.

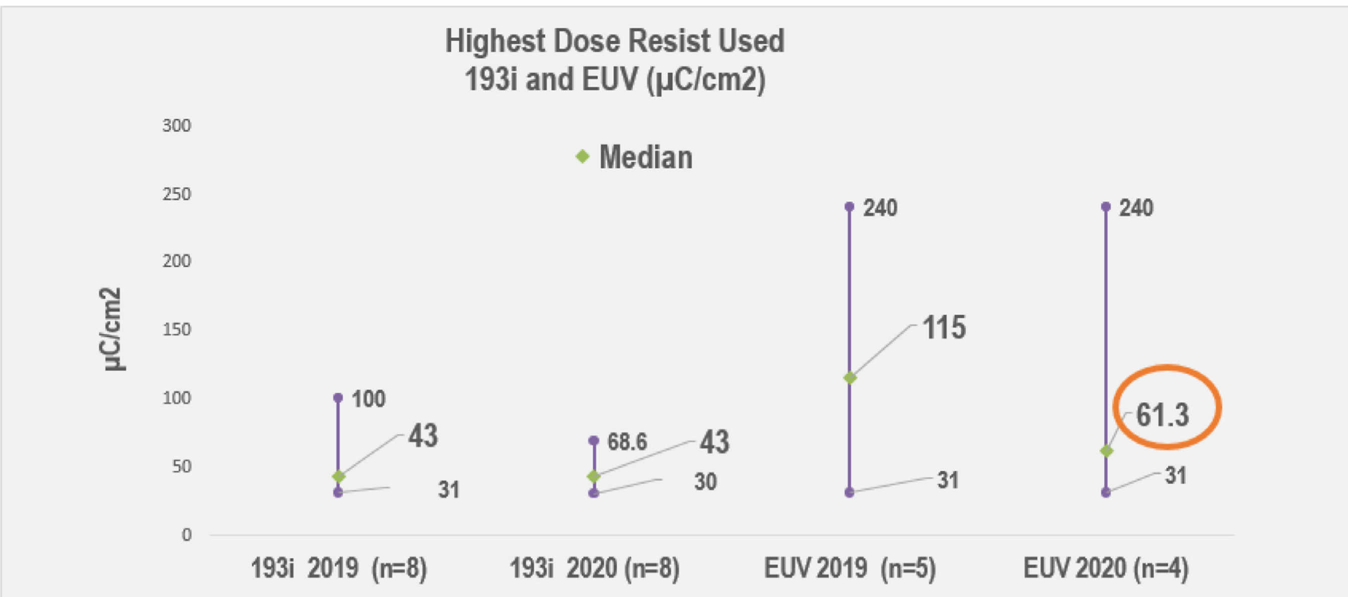

Figure 8. Highest Dose Resist Used for 193i and EUV – 2020 Mask Makers Survey.

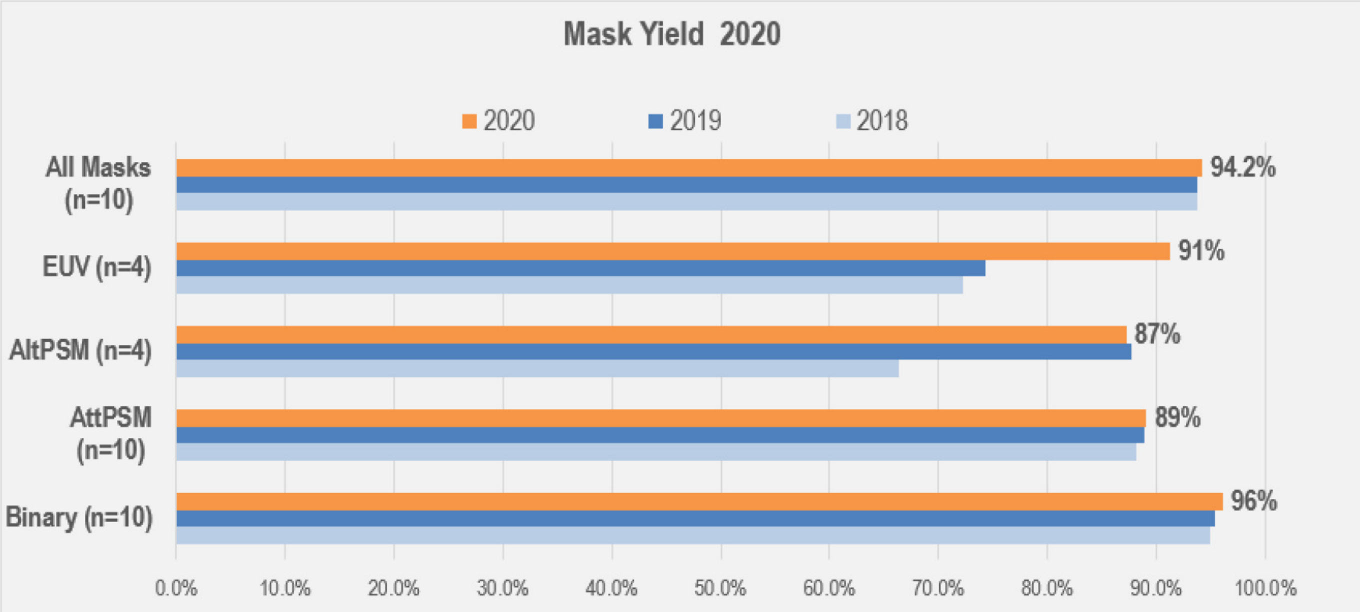

Figure 9. Mask yield by mask type – 2020 Mask Makers Survey.

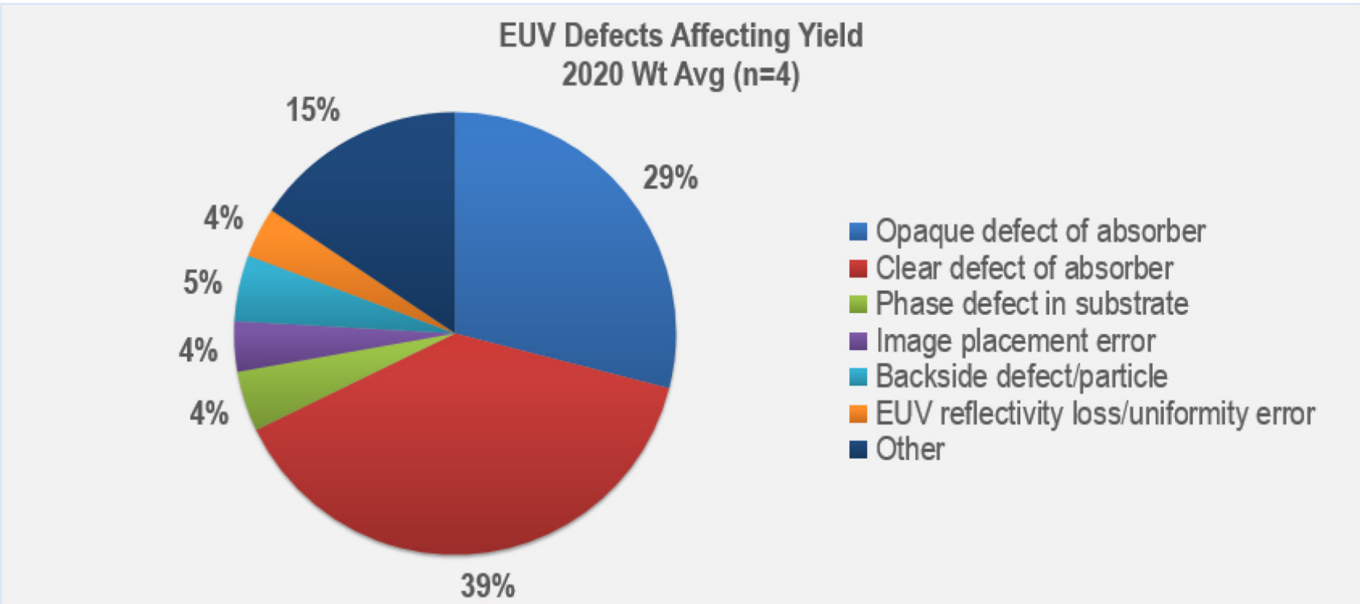

Figure 10. EUV Defects Affecting Yield – 2020 Mask Makers Survey.

2.13 Etch

Dry etch was used on 36% of the reported masks and wet etch was used for 64% as shown in the chart on the left of Figure 13. Leading edge masks at nodes <90nm accounted for 37% of the reported masks, shown in the chart on the right of Figure 13, and corresponds to the usage of dry etch. The question asked was: What was the percentage by...? (Wet Etch, Dry Etch)

2.14 Mask Repair by Type

In 2020, no mask repair was reported for 65% of masks and laser repair was used for 18% of the masks reported as shown in Figure 14. Because the participating companies are not the same as previous years, yearly comparison are inconclusive. The question was: What was the percentage of masks repaired by....? (No Repair, eBeam, LASER, Nanomachining, FIB)

2.15 Mask Returns

Participants in the 2020 survey reported that 0.19% of masks were returned from the fab. Soft defects was the most frequently reported cause of returns at 34% as shown in Figure 15. The questions asked were: What percentage of the masks were returned from the fab? Of the masks returned from the fab, what percentage were attributed to the following causes? (Soft Defects, Hard Defects, Mask data prep errors, OPC/ILT er-

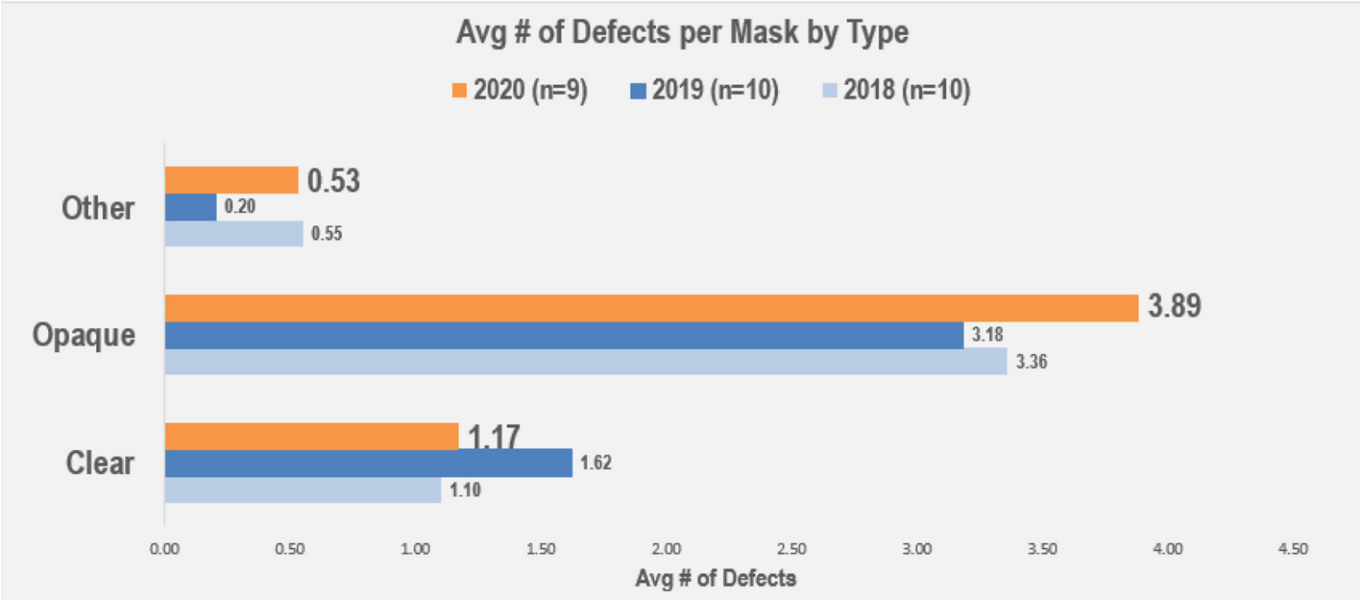

Figure 11. Average # of defects per mask by mask type – 2020 Mask Makers survey.

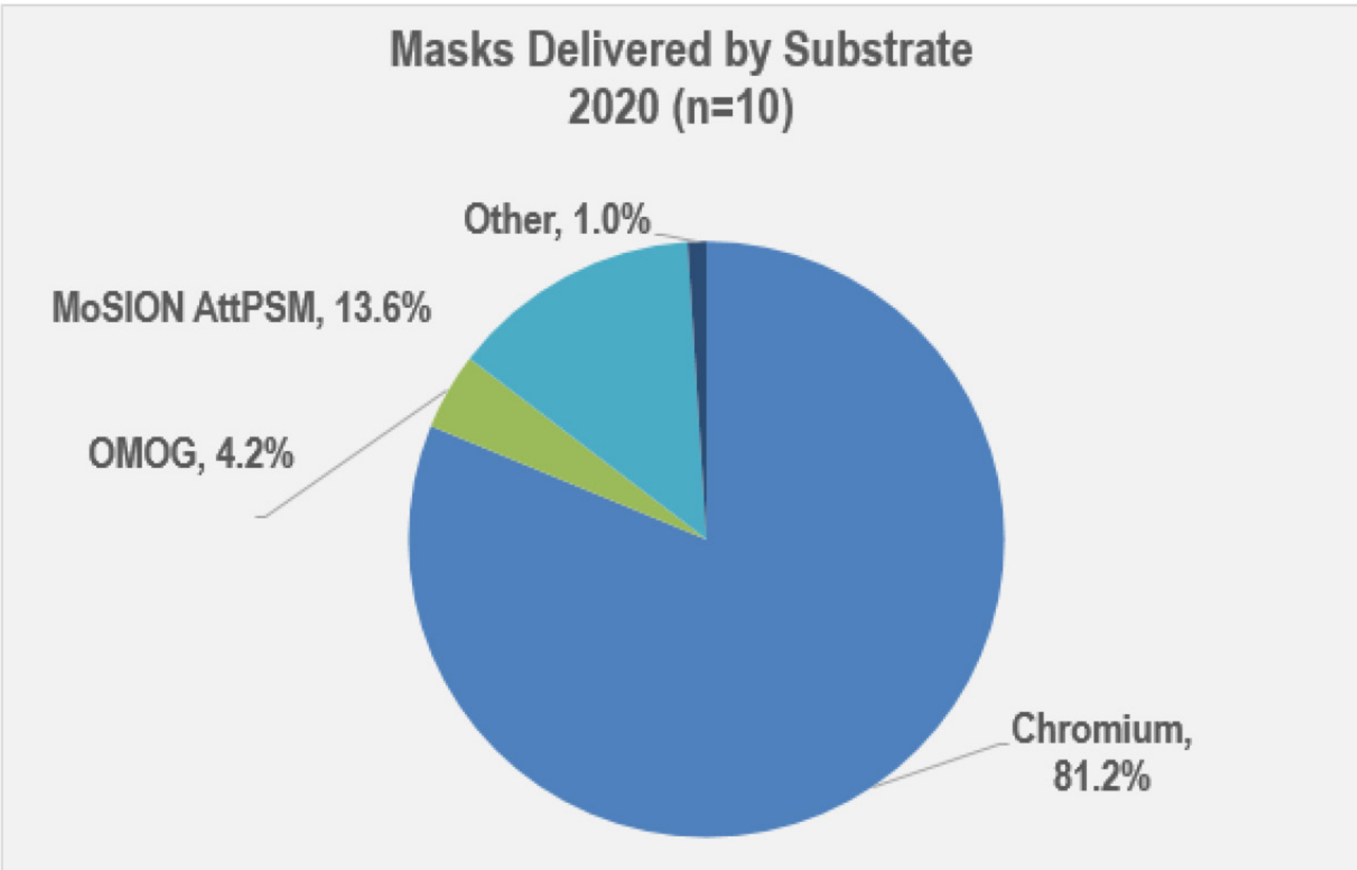

Figure 12. 2019 mask shipments by substrate.

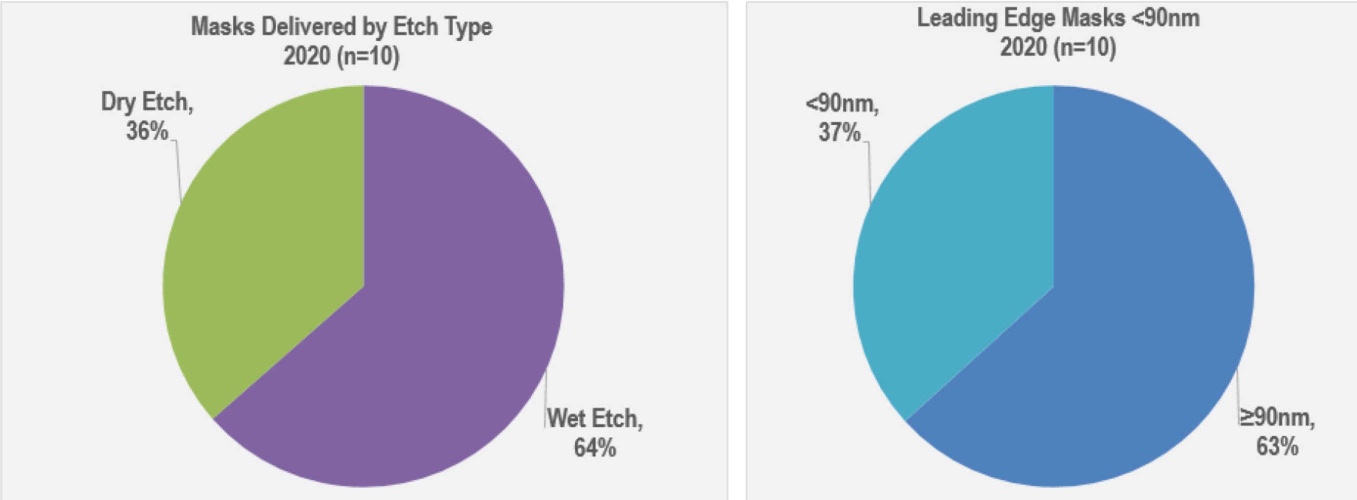

Figure 13. Masks by etch type – 2020 Mask Makers survey.

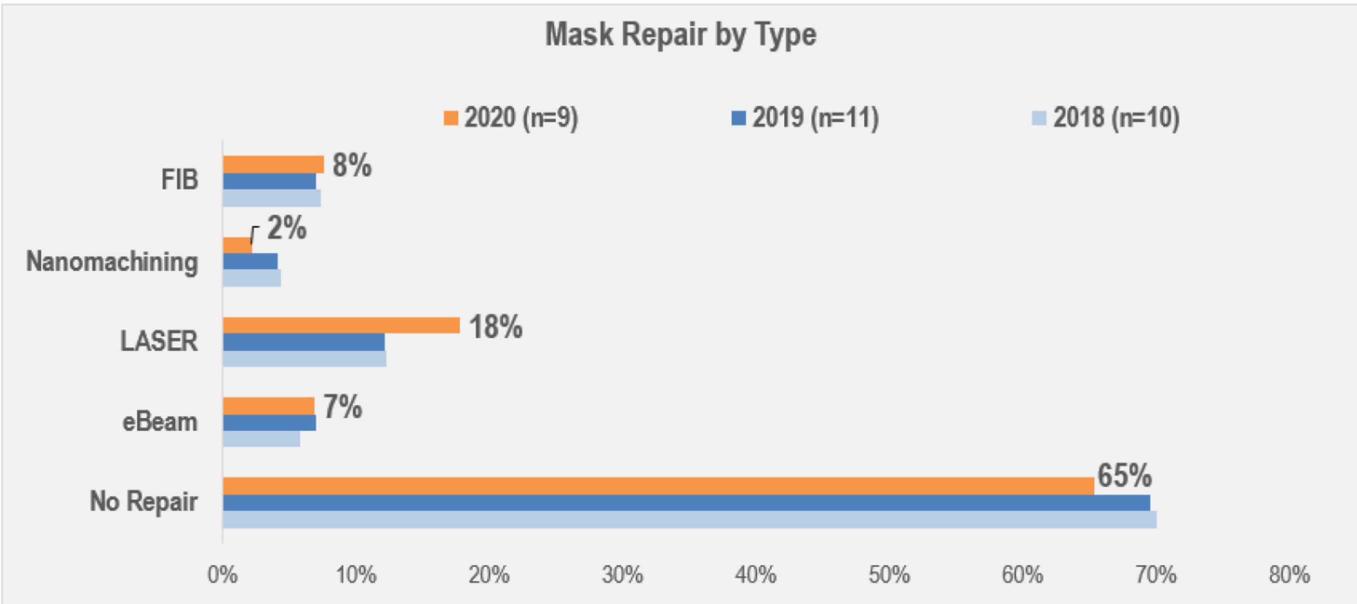

Figure 14. Mask repair by type – 2020 Mask Makers survey.

rors, Bad repair, Wrong Pellicle/Damage, Haze, Other)

2.16 Turnaround Time

The 2020 survey report produced an anomaly in the turnaround time (TAT) trend. In past years, the smallest ground rules (most leading edge) took longer TAT than the previous generation. The weighted average TAT reported in the 2020 survey for ground rules including 7nm but below 11nm was 7.53 days compared to 9.73 days for masks below 16nm down to and including 11nm as shown in Figure 16. The data was analyzed again by normalizing the average TAT reported by each participant at ground rules including 7nm but below 11nm by taking a ratio of a company's response to that company's response for ground rules including 11nm but below 16nm. The normalized plot is shown in the upper right of Figure 16 and shows the averages of the normalized ratio. The question asked was: What was your average Turn-Around-Time (TAT) by Ground Rules in the past year?

2.17 Mask Data Preparation

The 2020 participants reported the weighted average for mask data preparation (MDP) time of 18.9 hours at nodes below 16nm down to and including 11nm compared to 17.26 hours at leading edge ground rules below 11nm down to and including 7nm as shown in Figure 17. This is an anomaly in the trend compared to past years where TAT increased as geometries got smaller. Using the same normalization analysis as in section 2.16, the historic trend of greater TAT at smaller ground rules can be seen in Figure 17 in the chart in the upper right, with an anomaly at 16nm down to and including 11nm The question asked was: What was the average data prep time (starting point defined as RET output) per mask for critical layer masks by Ground Rules?

2.18 Mask Process Correction (MPC)

The % of masks using MPC increased at leading-edge nodes with 44% reported for ground rules less than 16nm down to and including 11nm

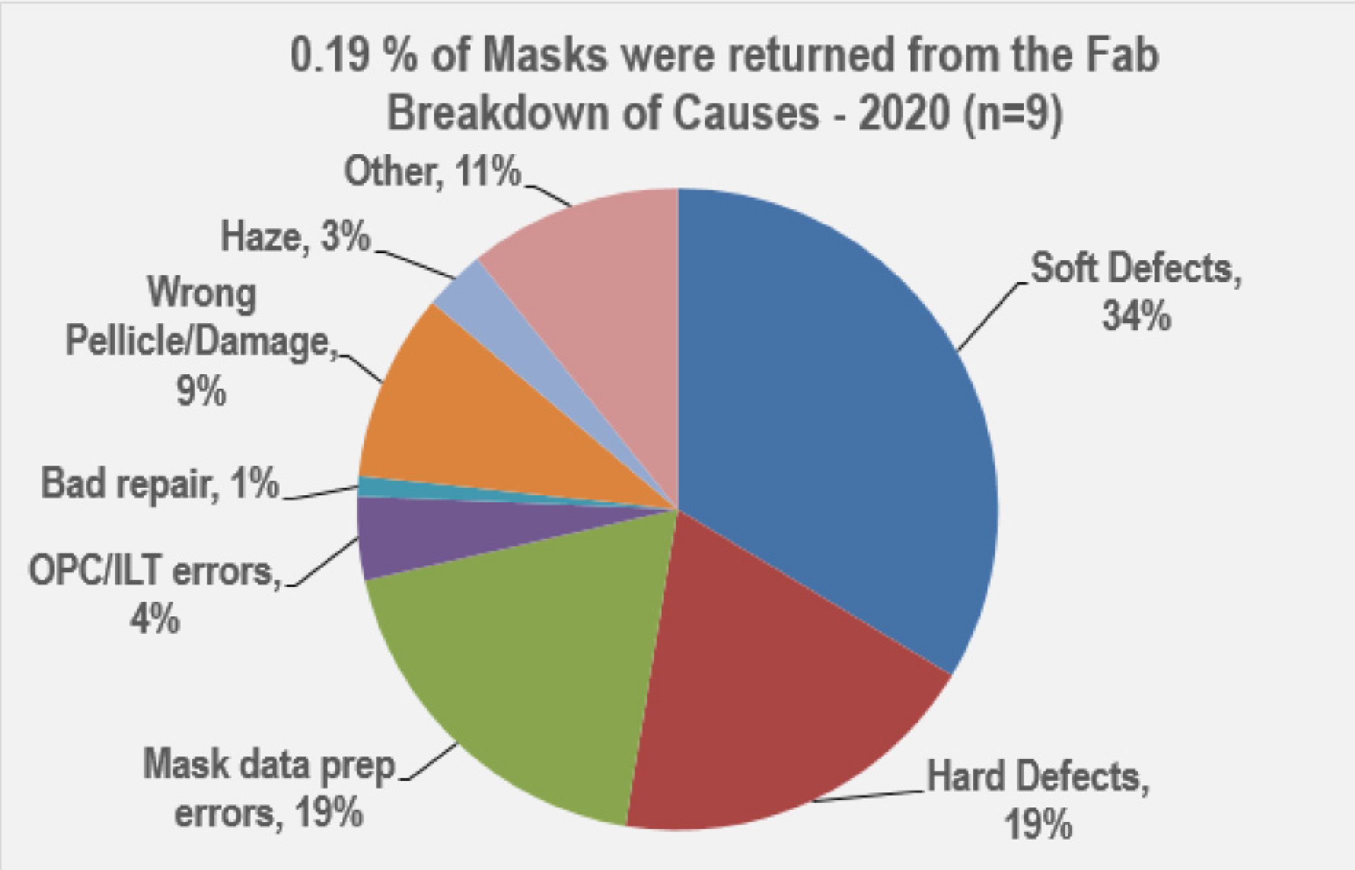

Figure 15. Causes of Mask Returns – 2020 Mask Makers survey.

Figure 16. Turnaround Time (TAT) Weighted Average – 2020 Mask Makers survey.

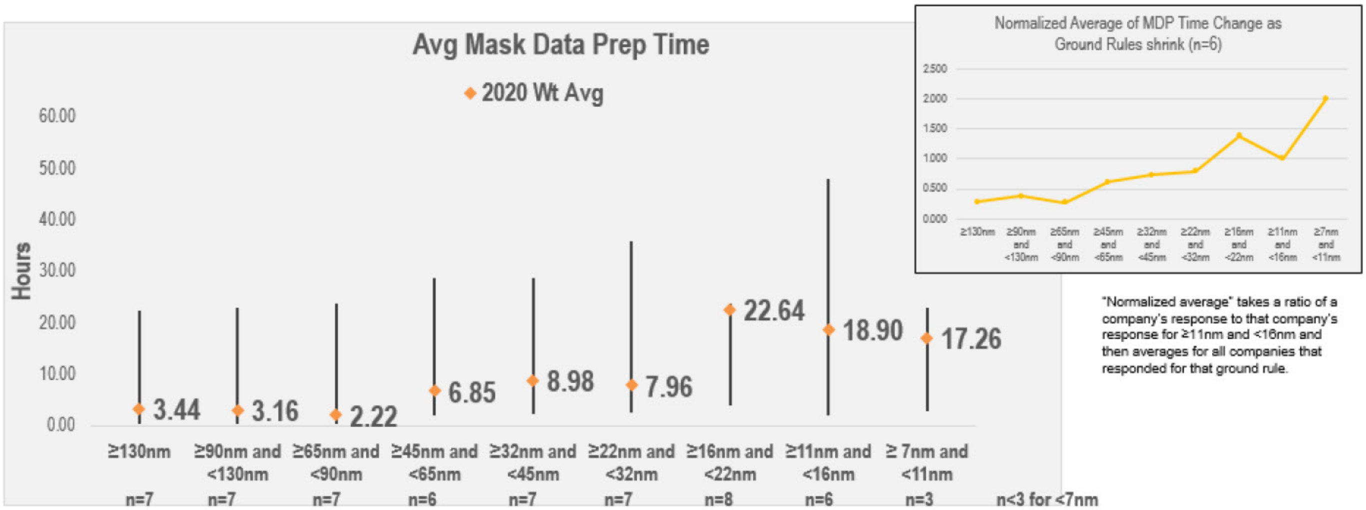

Figure 17. Mask data preparation (MDP) time by ground rule – 2020 Mask Makers survey.

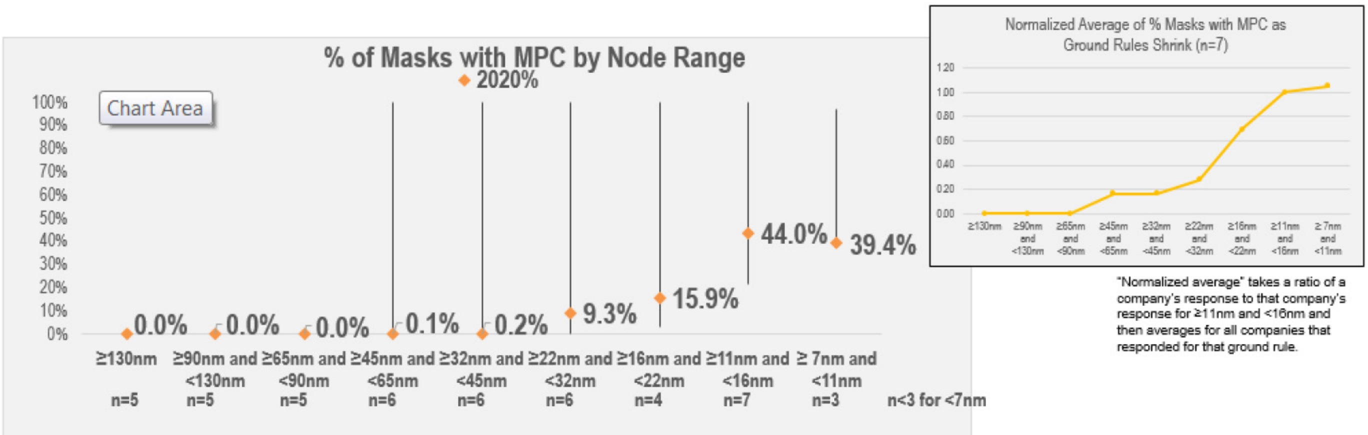

Figure 18. % of masks using MPC by ground rule – 2020 Mask Makers survey.

and 39.4% for ground rules less than 11nm down to and including 7nm as shown in Figure 18. The data was analyzed using the same normalization approach as in 2.16 and 2.17 with the trend of increasing MPC usage at the smallest nodes shown in the chart in the upper right in Figure 18.

At the request of some participants, the definition of MPC was included in the 2020 survey question asked: "What % of masks by ground rules had Mask Process Correction (MPC) applied? (Please note, this question is only asking about critical layer masks, not the percentage of all masks. MPC is defined as offline manipulation of geometry and/or dose of mask shapes during mask data preparation of the specified mask shapes received from OPC/ILT in order to more reliably manufacture the specified mask shapes on the physical mask or to maintain site-to-site compatibility. PEC, LEC, FEC, and other corrections performed by the writer are not considered MPC. But if, for example, EUV mid-range correction is performed offline during mask data preparation instead of using the inline writer capability, then this should be considered MPC.)"

3. Acknowledgements

The authors would like to thank the following organizations and people:

- AMTC, DNP, HOYA, Intel, Micron Technology, Photronics (including PDMC), Samsung, SMIC, TMC and Toppan for participating in the survey.
- Brian Grenon, an eBeam Initiative member, for contributing questions and historical perspective in creating the survey questions.
- Dede Adams at David Powell, Inc. for administering the survey.

Industry Briefs

Global Chip Shortage to Persist Until 2Q22, says Gartner

Jessie Shen, DIGITIMES, Taipei

The chip shortage started primarily with devices, such as power management, display devices and microcontrollers, fabricated on legacy nodes at 8-inch foundry fabs, which have a limited supply. It has now extended to other devices, and there are capacity constraints and shortages for substrates, wire bonding, passives, materials and testing, all of which are parts of the supply chain beyond chip fabs. These are highly commoditized industries with minimal flexibility/capacity to invest aggressively on a short notice.

Worldwide semiconductor revenue to grow 13% in 2021 despite chip shortage

Worldwide semiconductor revenues are forecast to surge 12.5% to US$522 billion in 2021, driven by continued-robust growth in consumer, computing, 5G and automotive semiconductors, according to IDC.

https://www.digitimes.com/news/a20210513PR200.html

What's Next In Fab Tool Technologies?

Mark Lapedus

Semiconductor Engineering sat down to discuss extreme ultraviolet (EUV) lithography and other next-generation fab technologies with Jerry Chen, head of global business development for manufacturing & industrials at Nvidia; David Fried, vice president of computational products at Lam Research; Mark Shirey, vice president of marketing and applications at KLA; and Aki Fujimura, CEO of D2S.

https://semiengineering.com/whats-next-in-fab-tool-technologies/

IBM Unveils World's First 2 Nanometer Chip Technology, Opening a New Frontier for Semiconductors

PRNewswire

IBM unveiled a breakthrough in semiconductor design and process with the development of the world's first chip announced with 2 nanometer (nm) nanosheet technology. Semiconductors play critical roles in everything from computing, to appliances, to communication devices, transportation systems, and critical infrastructure.

https://newsroom.ibm.com/2021-05-06-IBM-Unveils-Worlds-First-2-Nanometer-Chip-Technology,-Opening-a-New-Frontier-for-Semiconductors

EU Discusses Chip Manufacturing With Intel, TSMC

Anne-Françoise Pelé

The European semiconductor industry's CAPEX spending has stagnated at around 4% of total expenditure (Asia-Pacific: 63% in 2019). Increasing this figure is key to improving the EU industry's level of competitiveness, but Roland Berger recommended that "EU semiconductor producers partner with a non-EU technology player. Working together, partners can shorten technology development timelines and ensure better access to R&D resources."

https://www.eetimes.eu/eu-discusses-chip-manufacturing-with-intel-tsmc/

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About the BACUS Group

Founded in 1980 by a group of chrome blank users wanting a single voice to interact with suppliers, BACUS has grown to become the largest and most widely known forum for the exchange of technical information of interest to photomask and reticle makers. BACUS joined SPIE in January of 1991 to expand the exchange of information with mask makers around the world.

The group sponsors an informative monthly meeting and newsletter, BACUS News. The BACUS annual Photomask Technology Symposium covers photomask technology, photomask processes, lithography, materials and resists, phase shift masks, inspection and repair, metrology, and quality and manufacturing management.

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CALENDAR

2021

The 36th European Mask and Lithography Conference, EMLC 2021
22 June 2021
Digital Event
www.emlc-conference.com/en

SPIE Photomask Technology + EUV Lithography
26-30 September 2021
https://spie.org/conferences-and-exhibitions/puv

2022

Photomask Japan
25-27 April 2022
PACIFICO Yokohama
Yokohama, Kanagawa, Japan
www.photomask-japan.org

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You are invited to submit events of interest for this calendar. Please send to lindad@spie.org.