eBeam Community Speaks Out on Future Directions for Photomask Manufacturing

Jan Willis, Co-Founder, eBeam Initiative

As has been the case for many years and for the near future down to the 7-nm logic node, electron-beam (eBeam) mask writing is pushing the limits of acceptable write times and quality. The eBeam community has responded to these challenges through innovation, engineering and collaboration. In 2009, the eBeam Initiative was launched to provide a stronger voice and educational platform for eBeam technology within the photomask and semiconductor design and manufacturing ecosystem. For the fourth consecutive year, as the photomask community heads to the annual SPIE/BACUS Photomask Symposium in Monterey, the eBeam Initiative has conducted a survey on photomask-related trends and perceptions. This annual perceptions survey has been instrumental in confirming key areas to align the Initiative's efforts on to guide the industry ecosystem forward in supporting the introduction of new eBeam technologies. At the request of the community, an additional mask survey was conducted this year by the eBeam Initiative to include trends on key mask metrics that help serve as a barometer for mask makers. The complete results of both surveys are available for download at www.ebeam.org. Below is a summary and analysis of the key findings.

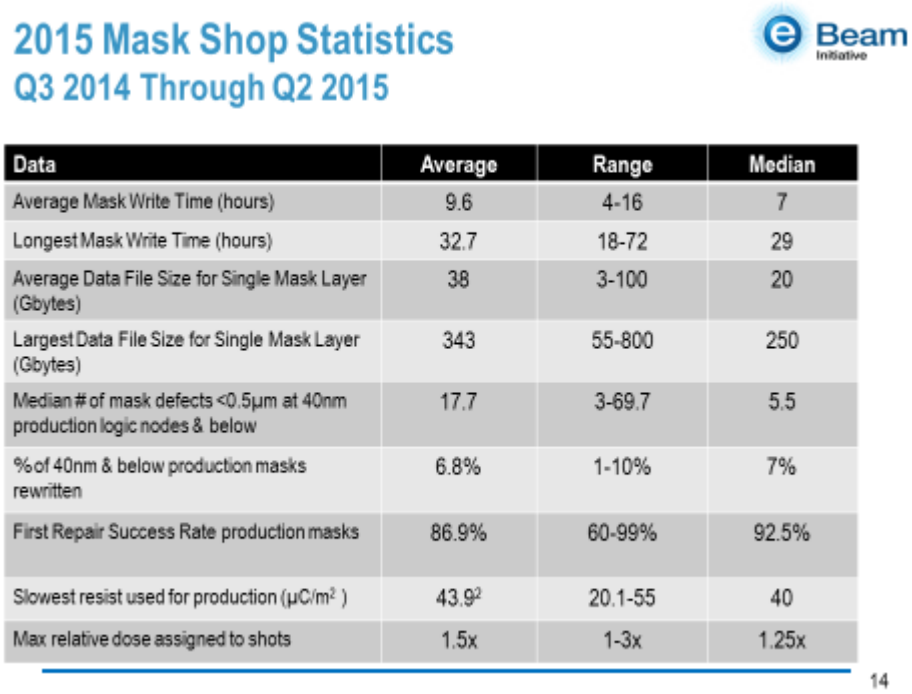
Mask Makers Have Their Say

Participants in the 2015 perceptions survey represented the breadth of the semiconductor ecosystem, from design to manufacturing, with 36% of the respondents representing the mask makers. Those who participated were invited based on their luminary status in the industry or as a senior representative of an eBeam Initiative member. The survey represents the views of 64 individuals from 35 different companies. Separately, 13 merchant and captive mask shops were invited to participate in the mask survey. Eight companies participated in the mask survey and while all companies were encouraged to participate, it is understood that various reasons may prevent participation. While the responses from the majority of the major mask manufacturers allow the survey to be interpreted as representative of the industry as a whole, the survey should not be considered "complete".

Mask Complexity Continued to Grow in 2015

The mask survey provides the semiconductor industry with insight into the challenges and the opportunity space for this critical element of the supply chain. This survey also gives mask makers a way to assess their own progress relative to their peers. Starting with the number of masks per mask set, the survey results indicated that mask sets below the 22-nm logic node are exceeding 60 masks for the first time and that mask sets have seen a long term growth rate of 13% since the 250-nm node. The mask survey explored other aspects of complexity such as the use of dose modulation and the rate of mask defects as shown in **Figure 1** below. For example, the adoption of dose modulation – where energy levels emitted from the eBeam mask writer are manipulated per shot in a controlled manner to improve the print quality of the mask design – has been rapid in order to deal with mask complexities affecting the quality of masks. Only a few years ago dose modulation was not used on a per shot basis. For the Q3 2014 through Q2 2015 period, mask makers reported using per shot dose modulation. The assigned maximum dose that was reported per mask maker ranged from 1.2x to 3x nominal dose. 75% of mask makers also predicted that they would use >1x dose modulation by 2017.

Mask write time metrics are of upmost interest because of their direct correlation to costs and turnaround time. For the Q3 2014 through Q2 2015 period, the longest mask write time reported was 72 hours and the bottom of the range reported was 18 hours with the median longest write time of 29 hours. The median for the average mask write time was 7 hours. It's clear from this data that every mask maker is dealing with longer-than-average mask writing times for some masks. The urgent need for solutions to this problem is reflected in the continued optimism for multi-beam mask writing technology.



Data	Average	Range	Median
Average Mask Write Time (hours)	9.6	4-16	7
Longest Mask Write Time (hours)	32.7	18-72	29
Average Data File Size for Single Mask Layer (Gbytes)	38	3-100	20
Largest Data File Size for Single Mask Layer (Gbytes)	343	55-800	250
Median # of mask defects <0.5µm at 40nm production logic nodes & below	17.7	3-69.7	5.5
%of 40nm & below production masks rewritten	6.8%	1-10%	7%
First Repair Success Rate production masks	86.9%	60-99%	92.5%
Slowest resist used for production (µC/m^2)	43.9[2]	20.1-55	40
Max relative dose assigned to shots	1.5x	1-3x	1.25x

Figure 1. Mask metrics as reported in the 2015 eBeam Initiative Mask Survey for Q3 2014 through Q2 2015

Confidence Continues in Multi-Beam Mask Writing Technology as Timeline Predictions Slip

In the 2014 perceptions survey, new approaches such as multi-beam mask writing and complementary eBeam lithography (CEBL) were identified most often as the topics of interest for 2015. Optimism grew last year for the near-term readiness of multi-beam mask writing. In the 2015 perceptions survey, 62% of the participants believe that multi-beam for mask making will be used in production by the end of 2016, which sends a message of confidence in the development progress shown so far. As shown in **Figure 2**, the participants also predicted that more than 50% of the mask writers purchased in 2020 would be multi-beam writers. Mask makers appear to be more optimistic about the availability of multi-beam writers than even the equipment makers, which may seem surprising, as generally a customer is more pessimistic about the timing of a new solution than the supplier. When asked about the timing of multi-beam mask writing for high volume manufacturing (HVM), 96% of the mask makers said by the end of 2018. Further analysis of the total responses to this question indicate that there is a perceived slip of approximately six months for HVM using multi-beam mask writers when comparing the results to the same question asked in 2014.

Figure 2. More than 50% of all mask writers are predicted to be multi-beam in 2020 according to the 2015 eBeam Initiative perceptions survey.

EUV Optimism Increased for the First Time

The 2015 perceptions survey results explored perceptions of next-generation lithography (NGL) approaches such as extreme ultraviolet (EUV), directed self assembly (DSA), complementary eBeam lithography (CEBL), nanoimprint lithography (NIL) and eBeam direct write (EBDW). In one question, respondents were asked about their confidence of each of these NGL approaches being used in some stage of production manufacturing by 2020. The participants predicted EUV as the approach that would most likely be used in at least one manufacturing step by 2020, with an average confidence rating of approximately 62%.

For the first time in the four years that the eBeam Initiative has conducted its perceptions survey, the community surveyed communicated increased optimism that EUV would eventually be used in HVM. When asked what year EUV would be used in HVM, only 15% of those responding said "never". This contrasted with the trend over the previous years where the answer to the same question had increased to a high of 35% in 2014.

EUV does present more complications in mask making than what was once thought and appears to becoming better understood. A repeat question in the 2015 perceptions survey resulted in 73% of respondents indicating that EUV would lead to a requirement for modelling 3D mask effects (including shape-specific sidewall angles), whereas in 2014 only 48% believed that of EUV. In addition, as shown in **Figure 3**, 59% of 2015 perceptions survey participants believe that complex shapes will be required for EUV masks. Complex shapes require multi-beam mask writers or model-based mask data preparation (MB-MDP) in order to achieve acceptable write times.

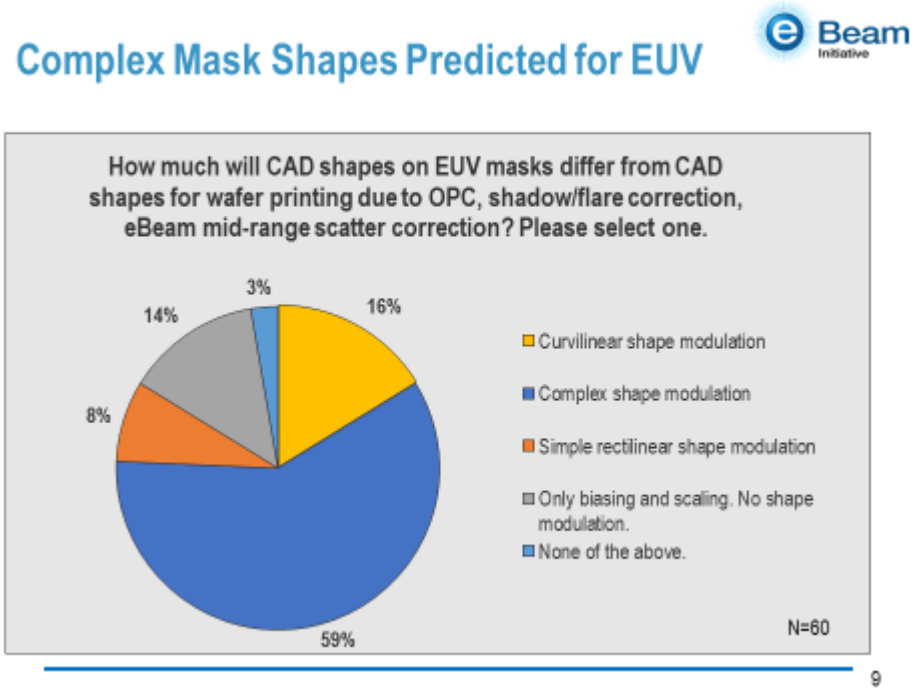


Figure 3. Complex mask shapes will be required for EUV according to 59% of the respondents in the 2015 eBeam Initiative Perceptions Survey

Prioritizing the eBeam Initiative's Educational Agenda for 2016

The educational agenda at the eBeam Initiative is set based on the priorities expressed through these surveys and various events throughout the year. The message this year has been to focus on technologies that will reduce mask write times, reduce mask costs, and enable the most advanced photomasks at the leading edge. The top three topics are all related to the use of multi-beam approaches but in very different applications. When asked in the 2015 perceptions survey what topics they would like to hear more about from the eBeam Initiative in the coming year, a clear majority of respondents (82%) indicated multi-beam for mask writing, followed by a new topic – applying multi-beam approaches to mask inspection (52%). CEBL (at 45%) remains in the top three topics again this year as it promises to combine existing optical lithography with multi-beam wafer writing to enable continued scaling at lower cost. The community also expressed its desire to learn more about dealing with complex mask shapes, which are now in the mainstream at the 10-nm node and will feature in EUV masks – from creation to MB-MDP to mask inspection.

About Jan Willis, Co-founder of the eBeam Initiative

Jan Willis is an executive with experience in all aspects of marketing from business development to communications, product definition, market research and strategic partnerships. She is passionate about creating and executing programs with excellence that contribute to a company's long term growth. With over 20 years of corporate experience, Jan has managed global programs and teams, including engineering functions, in both start ups and public companies. She started her engineering career at HP and then returned full-time for an MBA from Stanford University. Afterwards, she spent over 15 years in marketing management in the semiconductor/EDA industry at Synopsys, then Simplex Solutions and finally at Cadence as the senior vice president of industry marketing. Since 2008, she has been delivering consulting through coaching and hands-on marketing/business development in the semiconductor, security, IoT, SaaS and software development segments. She co-founded the eBeam Initiative with Aki Fujimura, chairman and CEO of D2S, Inc., in 2009.