

PHOTOMASK

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

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Attenuated phase-shift mask with high tolerance for 193-nm radiation damage

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ABSTRACT

In the semiconductor technology using the 193nm ArF excimer laser, the problem of radiation damage on photomask becomes more serious. This phenomenon is regarded as serious issue for semiconductor device fabrication. Some approaches have been tried to prevent the radiation damage. One of reports indicates that the radiation damage can be reduced by using an exposure tool with ultra clean extreme dry air.¹ However, it is difficult to adopt dry air into all exposure tools due to high cost. In our previous work, two facts were ascertained; radiation damage is caused by MoSi film oxidation, and depends on MoSi film composition.² In this paper, radiation damage was tried to decrease by MoSi film modification of att. PSM. MoSi film composition for PSM is optimized in consideration of cleaning durability, mask defect repair and processability. The new PSM is named AID (Anti Irradiation Damage). Radiation damage of AID PSM can be improved by 40[%] from conventional PSM. Cleaning durability can be also improved by AID PSM. The other evaluation items such as CD performance, cross section, defect level and repair, are equal between the AID PSM and conventional one. Additionally, the lithography performances by simulation of AID PSM are equivalent with that of conventional PSM. Therefore, it can be expected that there is no difficulty in converting conventional PSM into AID PSM. From these evaluation results, development of AID PSM was completed, and preparation for production is now going.

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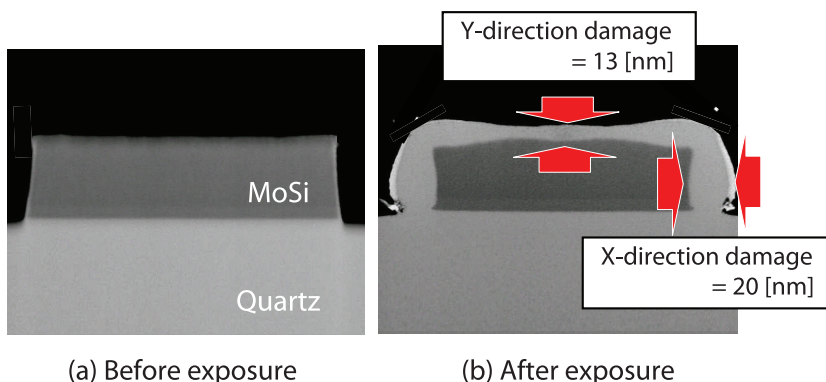


Figure 1. Cross section TEM image of radiation damage on att. PSM

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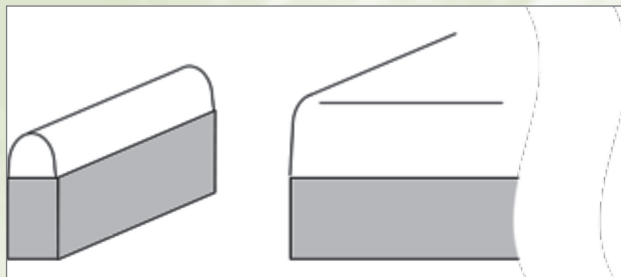
Needed: clear focus & strong leadership

Emmanuel Rausa, Plasma-Therm LLC

During the recent financial crisis, everyone was wondering what effect the crisis would have on the semiconductor world. Would the industry keep running the technology-at-all-costs treadmill or look for new and original solutions?

As an example in Photomask manufacturing, we can start by assessing several important issues with dry etch technology. For instance, the need to control particles is greater than ever. Overall, dry etch technologies have contributed significantly toward the goal of particle control. Most advanced dry etch systems have a history of achieving excellent first pass yields and very high machine uptime. Some etchers (e.g. the PlasmaTherm Mask Etcher V) need to be opened for cleaning no more than once every 12 to 18 months. Of course, most customers are asking for better particle control. And since existing equipment designs are never considered perfect, there is always room for improvements in things like chamber design and in the assemblies and selections of the materials which are 'plasma wetted' or in close proximity to the mask. Particle control is considered an ongoing and never ending development task.

With the unrelenting demand for better CD bias and uniformity a given, the next most critical parameter for dry etch is the selectivity to resist. Given the needs for resolution, there will typically be less than 900Å of resist remaining on the mask after the exposure and develop processes. This is not much to play with, and it becomes particularly tricky when this fairly soft material is protecting and defining very small features. The resist erosion is much faster sitting atop a small ridge or a contact like feature than it would be atop a large flat feature. The loss can easily double from one instance to the other.



Example: After Cr etch, resist erosion is much higher more eroded on the small feature.

The loss is both chemically and physically driven. The higher resist loss can be explained by a much larger surface to volume ratio of resist exposed to the plasma and the oxygen-based radicals. Also, the lateral ion bombardment effect becomes greater as the features become smaller. Chemical solutions and the tricks typically associated with wafer processing are not easily implemented in mask making because of the particle generation constraints. The thermal control used with wafers (Helium back side cooling) is not easily replicated in the mask world given the much lower thermal conductivity characteristics of the quartz substrate, and the fact that handling constrains do not allow contact anywhere but the outside 3mm edge of the mask backside. Other control parameters include micro and macro loading issues that also affect global CDs, as well as the need to minimize corner rounding. None of these parameters are completely new and they are very much a natural evolution of the requirements. They may not be easy to address and the solutions to correct them may require much more than just an improvement of the current hardware/process, but they are predictable. They can therefore be planned and budgeted for.

Advanced Lithography in San Jose is just over and we are no closer to identifying a compromise on what will be the lithography solution at 15nm and below. Many

(continued on page 5)

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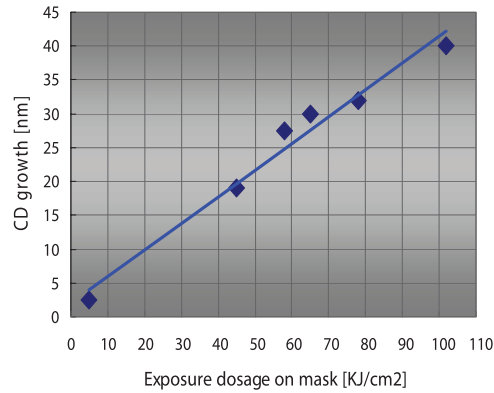


Figure 2. Correlation between CD growth and exposure dosage on MoSi att. PSM

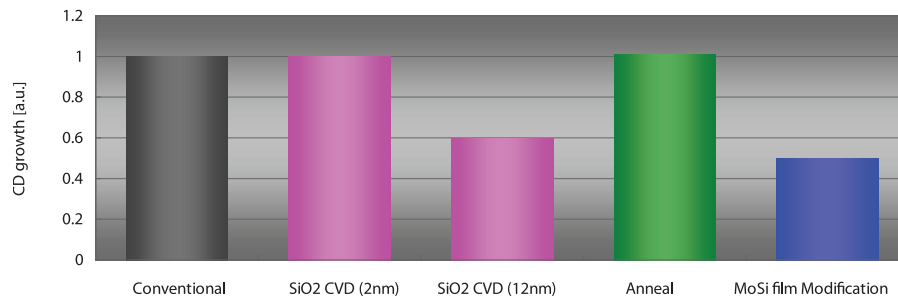


Figure 3. Comparison of CD growth by the approach from photomask.

1. Introduction

The transition of lithography, KrF to ArF, brings increase of the photon energy of light source. And the improvement of lithography technology with ArF laser enhances throughput of semiconductor fabrication. As the result, mask tends to be exposed by more photons with higher energy, and some problems on mask have been seen in ArF lithography, which have never been seen in KrF lithography. One of the serious problems is radiation damage on mask. Figure 1 shows cross section TEM (Transmission Electron Microscope) images of att. PSM that was exposed by high dosage of 193nm ArF excimer laser. In this figure, the radiation damage of MoSi film can be seen and its damage area is about 20nm in Xdirection and 13nm in Y-direction. This radiation damage causes CD growth on mask. Figure 2 shows the correlation between CD growth and exposure dosage on mask. The higher exposure dosage induces linear growth of CD, which means the radiation damage becomes severer as the accumulation of exposure dosage becomes higher. The radiation damage changes CD, phase and transmission of MoSi film. These changes induce the degradation of lithography performances, such as CD on wafer, NILS, DOF, MEEF and the optimal exposure dosage.

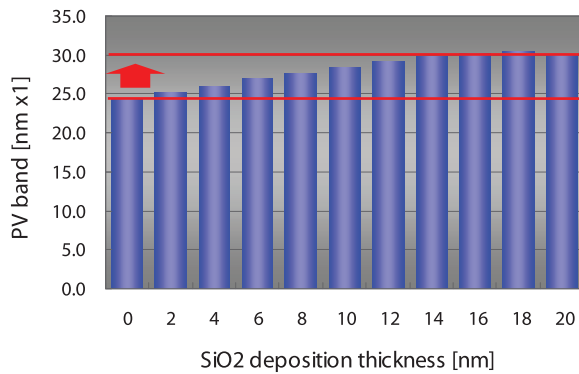
1.1 Approach from exposure tool

To solve the radiation damage problem, two approaches, from exposure tool and photomask, were evaluated. As for the approach from exposure tool, it was reported that the ultra

clean extreme dry air (less than 1ppm H₂O) in exposure tool is effective against the radiation damage on mask.¹ Therefore, the exposure tool with dry air is obviously preferable to that with normal humid air. However, it is difficult to convert the all exposure tools into the dry air system due to high cost.

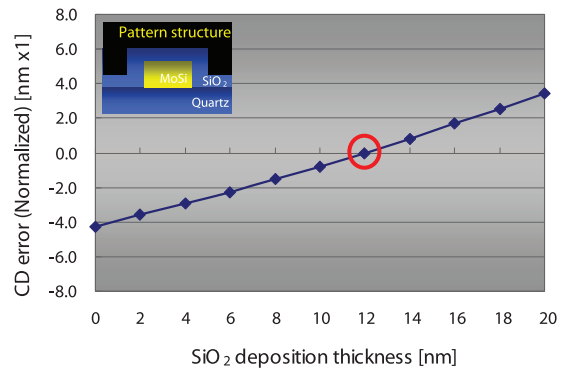
1.2 Approach from photomask

As for the approach from photomask, passivation SiO₂ film formation, changing MoSi anneal temperature, and MoSi film composition modification were tried.² The passivation SiO₂ film was deposited by using TEOS (Tetraethoxysilane) CVD. The anneal temperature was changed to be higher than normal condition. Figure 3 shows comparison of CD growth by the approach from photomask. In this figure, SiO₂ CVD deposition (12nm) and MoSi film modification are effective for radiation damage. Because there is a possibility that SiO₂ CVD deposition may have bad influence on lithography performance, PSM with and without SiO₂ deposition was compared by lithography simulation. Figure 4 (a) shows results of PV band at hp40 [nm x1] L&S pattern. It is clear that SiO₂ CVD deposition makes PV band worse. Figure 4 (b) is CD error versus SiO₂ deposition thickness. These values are obtained by using threshold of SiO₂ deposition thickness = 12 [nm], and normalized by CD of SiO₂ deposition thickness = 12 [nm]. If CD is required to be the range under 2 [nm x1] on wafer, SiO₂ deposition thickness range must be controlled under 4 [nm x4] within mask full area and it is too severe. One possibility solution of thickness



*Target CD =40 [nm x1]
Pitch = 80 [nm x1]
Mask CD =+/-4 [nm x4]
Focus = +/-50 [nm]
Dose = +/-3.5 [%]

(a) PV band



*Normalized @ SiO₂ deposition=12 [nm]

(b) CD error

Figure 4. Lithography simulation results for SiO₂ CVD deposition structure

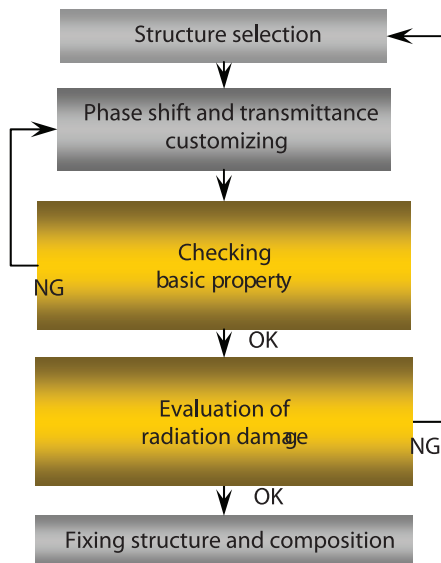


Figure 5. Blanks development flow.

Table 1. Blank property

	Conventional PSM	AID PSM
Film thickness	75nm	72nm
Optical density: 193nm	1.2	1.2
Transmittance: 193nm	6.0 % (Qz ref)	6.0 % (Qz ref)
Film side Reflectivity (193nm)	17.0%	14.6%
Phase shift: 193nm	177 deg.	177 deg.
Flatness (ΔTIR)	0.032 [μm]	-0.013 [μm]
Sheet resistance	2.02E+9 [Ω/□]	1.69E+9 [Ω/□]

MoSi film, named AID (Anti Irradiation Damage), has been selected for achieving lithography performance compatibility with conventional 6% PSM blanks. Table 1 shows blank property. Film thickness of AID PSM is thinner than that of conventional PSM. And flatness and film side reflectivity are improved by AID PSM. Another blank properties are almost equal to conventional one. Figure 6 shows transmittance and MoSi film thickness on blanks. Transmittance range is 0.13[%], and MoSi film thickness range is 1.0[nm]. It is no problem for using production mask.

3. Radiation Damage of AID PSM

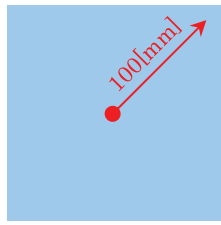
3.1 Experimental procedure

The radiation damage on mask is evaluated by the acceleration exposure unit. Figure 7 shows the diagrammatic illustration of acceleration exposure unit. AID PSM and conventional PSM are evaluated by using this unit. In this unit, the temperature is kept at 23°C and humidity is kept at 40% during the irradiation. To evaluate the radiation damage at severer condition, humidity in the unit is set higher than typical condition in exposure tool. The mask patterns are isolated opaque, nested opaque and isolated clear. There is pattern of varied sizes from 100[nm x4]

control is fully covering mask patterns with SiO₂ deposition and flatly grinding. However, the refractive index of MoSi film is different from that of air and MoSi film becomes too thick for achieving phase shift effect. As a result, pattern collapsing by cleaning on mask would be induced. Therefore, this paper considers only MoSi film modification, because SiO₂ deposition is not practical.

2. MOSI Film Optimization

Figure 5 shows blanks development flow. MoSi film composition for PSM is optimized in consideration of not only reducing radiation damage but also cleaning durability, mask defect and repair processability. This



Measurement direction
at blank full area

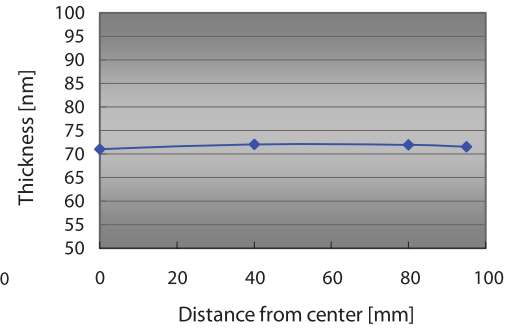
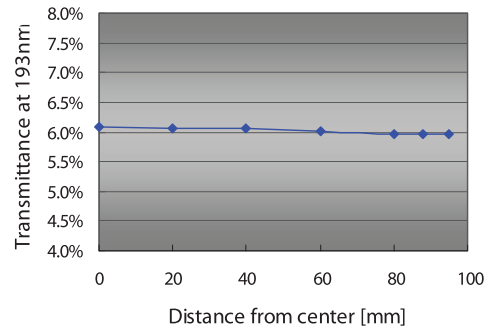


Figure 6. Transmittance and thickness on blanks.

to 2000[nm x4]. Pellicle is not mounted on mask, because it is considered that the pellicle affects the radiation damage. Table 2 shows the condition of ArF excimer laser and exposure unit. ArF excimer laser has max pulse energy = 250[mJ/cm²/pulse] and repetition frequency = 200[Hz]. The exposure area is 2cm x 2cm, and CD growth is defined as the difference between CDs before and after. These CDs are measured by CD-SEM. And CD growth is the average of various size pattern from 100[nm x4] to 2000[nm x4].

3.2 Radiation damage results

Figure 8 shows radiation damage of AID PSM and conventional PSM. In this figure, it is found that radiation damage can be decreased for AID PSM. New material can improve radiation damage about 40[%] than conventional material.

4. New Mask Performances

The AID PSM performances are compared with conventional PSM as shown below. The items are cleaning durability, CD performances, cross section, defect level, repair and lithography simulation. The AID PSM and the conventional PSM are processed with the same condition.

4.1 Cleaning durability

Cleaning durability of the AID PSM is confirmed. Figure 9 shows experimental flow for evaluation of cleaning durability. Phase shift of AID PSM and conventional one are evaluated by alkaline, O₃ and cleaning for production, respectively. Figure 10 is evaluation results. Phase shift of conventional PSM is normalized to 1.0. It can be seen that cleaning damage is decreased for the AID PSM.

4.2 CD performance

CD performances are evaluated by using pCAR and nCAR process. Figure 11 shows CD linearity. This figure contain various patterns such as isolated clear, nested clear and isolated opaque, and the CD linearity curves are shown by subtraction (AID PSM - conventional PSM). These results indicate that the CD linearity performances of AID PSM are equivalent as that of conventional PSM in both pCAR and nCAR.

Figure 12 shows results of CD uniformity. These CD maps also show subtraction (AID PSM - conventional PSM). The mask patterns are isolated-clear, nested clear and isolated opaque, and the design CD is 200nm. These results show

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large companies are still saying that everything is on the table. This means of course multiple patterning (expensive but proven), EUV (because of its potential in reducing mask design rule complexity as a result of the shorter exposure wavelength) and imprint (because the relative simplicity of the concept has the potential for lower cost).

There is nothing etch solution providers can do about direct write. Being aware of the threat is enough.

The list above is not exhaustive; a photomask dry etch solution provider biggest challenge is the lack of industry standards and that the visibility of which lithography technology may emerge on top is unclear at best. Not only are the lithographic solutions unclear, but the materials, exact chemistries, and their respective thicknesses and stacking are still being debated. That is not a small concern because this spreads the amount of money available in the R&D budget thinner at the risk of doing a little bit of everything poorly. With new materials a lot more work needs to be done to understand the implications to new production technique interactions. As an

example, how does the Ru layer behave under wet clean after a dry etch step?

The tendency to dry strip resists is welcome development as it does result in reducing the excess capacity of dry etch tools installed. Hopefully with time (Did I just say that? What a great business model!), it will lead to selling equipment with more advanced dry strip technologies.

Right now the mask dry etch community is full of very interesting subjects and there are potentially a lot of new applications requiring dry etch solutions. The good news is that since no definitive decisions are being made, we have more time to study the issues and design solutions for them. The bad news is that a limited amount of R&D funding cannot be spread effectively over both time and a myriad of options.

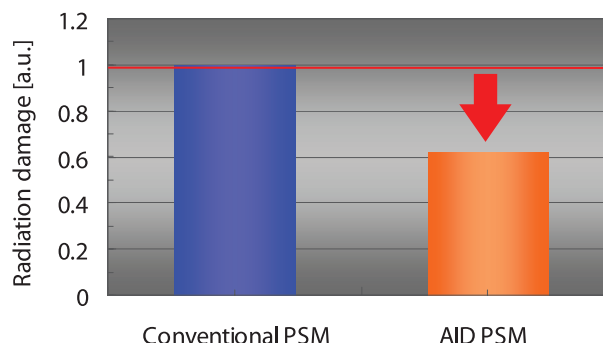
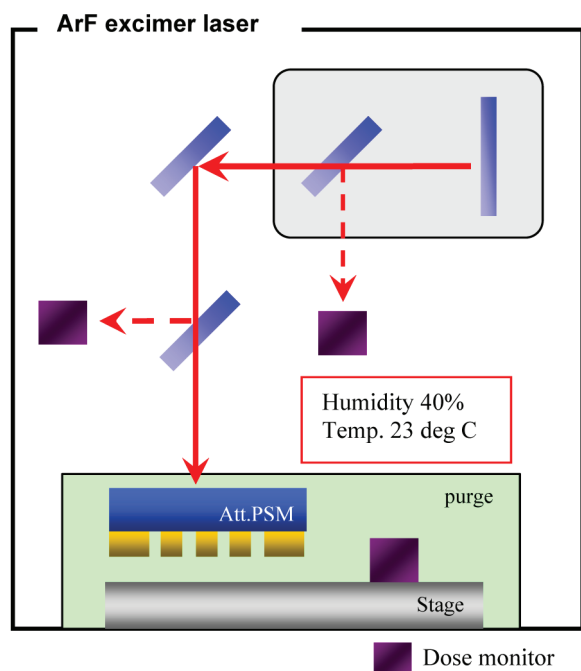


Figure 8. Radiation damage of AID PSM and conventional PSM.

Table 2. The condition of ArF excimer laser and exposure unit.

(a) ArF excimer laser property

ArF excimer laser	Wavelength	193nm
	Max pulse energy	250mJ
	Max pulse repetition frequency	200Hz
	Max regulated output	400W

(b) Exposure unit property

Exposure unit	Exposure spot	2x2cm
	Uniformity	+/- 5%

CD uniformity of new MoSi film is very similar with that of conventional MoSi film.

A comparison of the resolution is shown in figure 13. These figures are resolution limit of various patterns showing the same performance for conventional and AID PSM. Therefore, all results indicate that AID PSM and conventional PSM are compatible for CD performance.

4.3 Cross section

The cross sectional SEM images are shown in figure 14. The pattern size is fixed at 100nm. The cross sections of AID PSM and conventional PSM are completely same at each pattern.

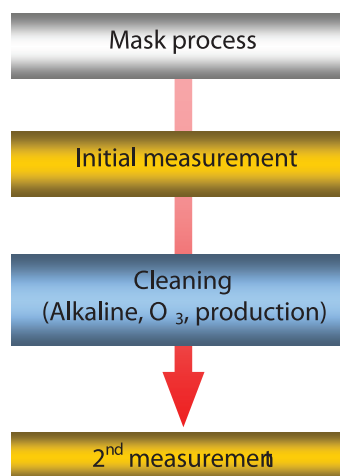


Figure 9. Experimental flow for evaluation of cleaning durability.

4.4 Mask defect level

Mask defect level is one of the most important factors for mask production. Figure 15 shows number of mask defect on AID PSM which was detected by inspection tool. The results are normalized by average number of mask defect on conventional PSM. The test plates include various patterns, such as Line & Space, Hole and Dot. Although the number of test plates is few for final decision, the defect level of AID PSM is regarded to be same as conventional PSM.

4.5 Repair

This part indicates processability of defect repair by EB repair tool on AID PSM. Figure 16 shows defect repair property; it contains SEM image and wafer print image by AIMS 193i before and after repair. From these figures, there is no problem for defect repair and wafer print image. Furthermore, the confirmations of various types of defect are shown in figure 17. Figure 17 (a) shows SEM image of programmed defect and figure 17 (b) shows etched depth of after repair. The target depth is 75nm so that phase shift is 180degree. In this figure, various defects can be stably repaired at target depth by EB repair tool.

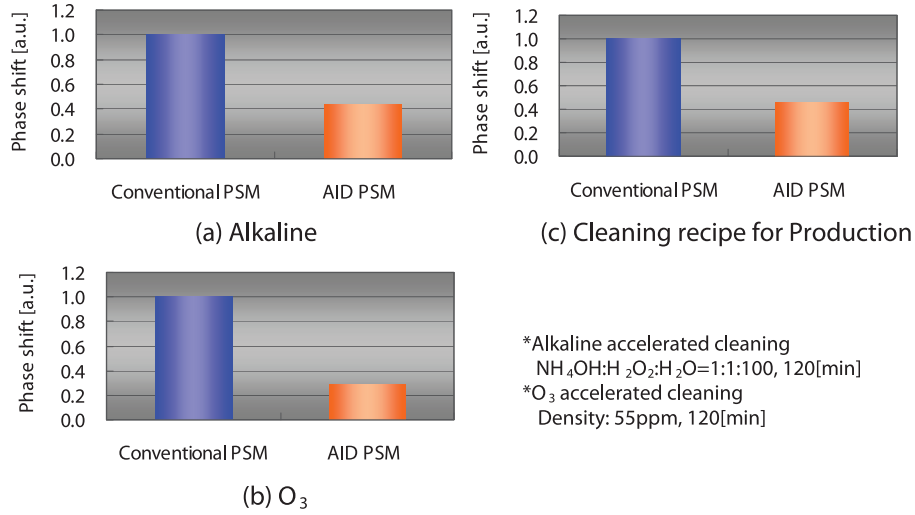


Figure 10. Cleaning durability for each cleaning methods.

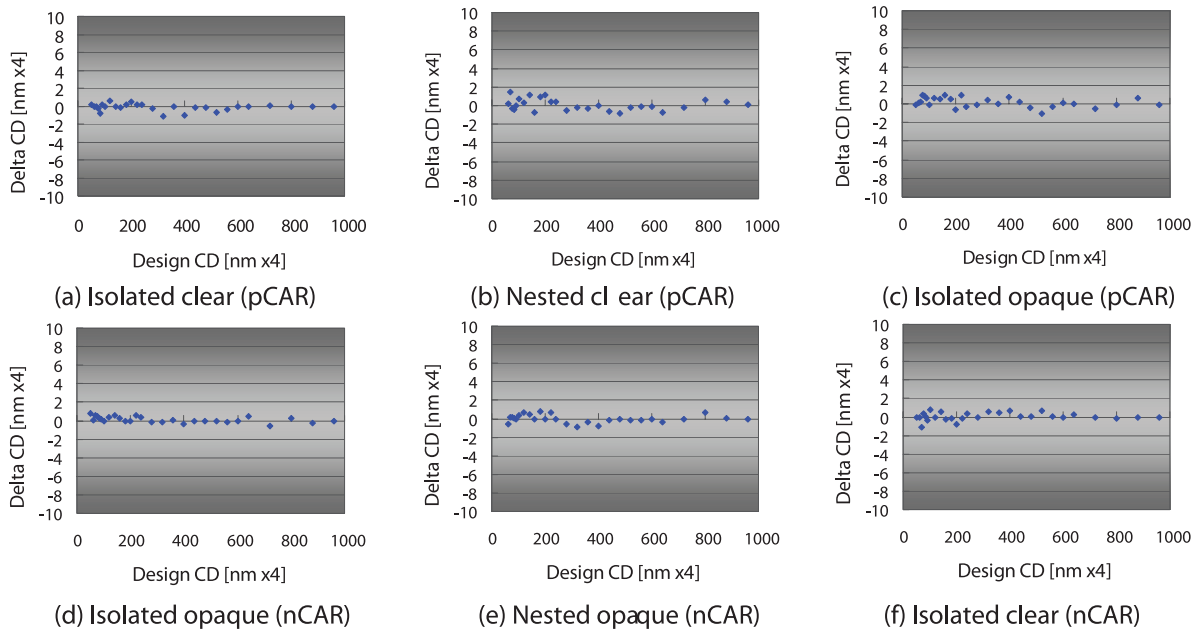


Figure 11. CD linearity (AID PSM - conventional PSM).

4.6 Lithography simulation

In the above chapters, it is confirmed that AID PSM can decrease radiation damage and improve cleaning durability, and is equal to conventional PSM about CD performance, cross section, defect level and repair. In this chapter, the lithography simulations are done in order to compare lithography performance of AID PSM with that of conventional one. The patterns for simulation are line, dot and any angle for hp 25[nm]. Simulator is Prolith ver.X3.2 3D, and aerial image was evaluated. These simulations used common illumination settings. Simulation results are shown in figure 18. There is no difference of NILS, MEEF and DOF at all patterns. Therefore, it is found that lithography performances are equivalent between each PSM.

5. Summary and Conclusions

In this paper, radiation damage was tried to decrease by MoSi film modification of att. PSM. MoSi film composition for PSM is optimized in consideration of cleaning durability, mask defect repair and processability. The new PSM is named AID (Anti Irradiation Damage). Radiation damage of AID PSM can be improved by 40[%] from conventional PSM. Cleaning durability can be also improved by AID PSM. The other evaluation items such as CD performance, cross section, defect level and repair, are equal between the AID PSM and conventional one. Additionally, the lithography performances by simulation of AID PSM are equivalent with that of conventional PSM. Therefore,

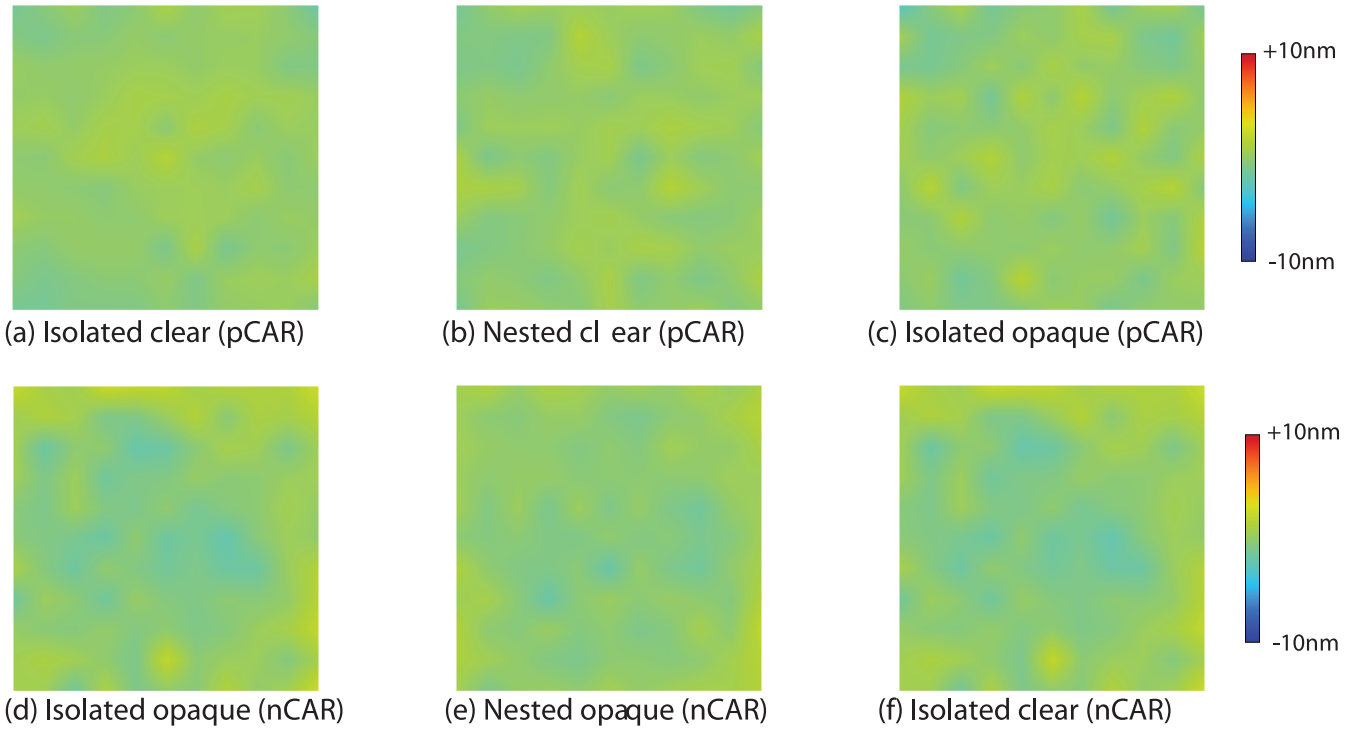


Figure 12. CD uniformity (AID PSM - conventional PSM).

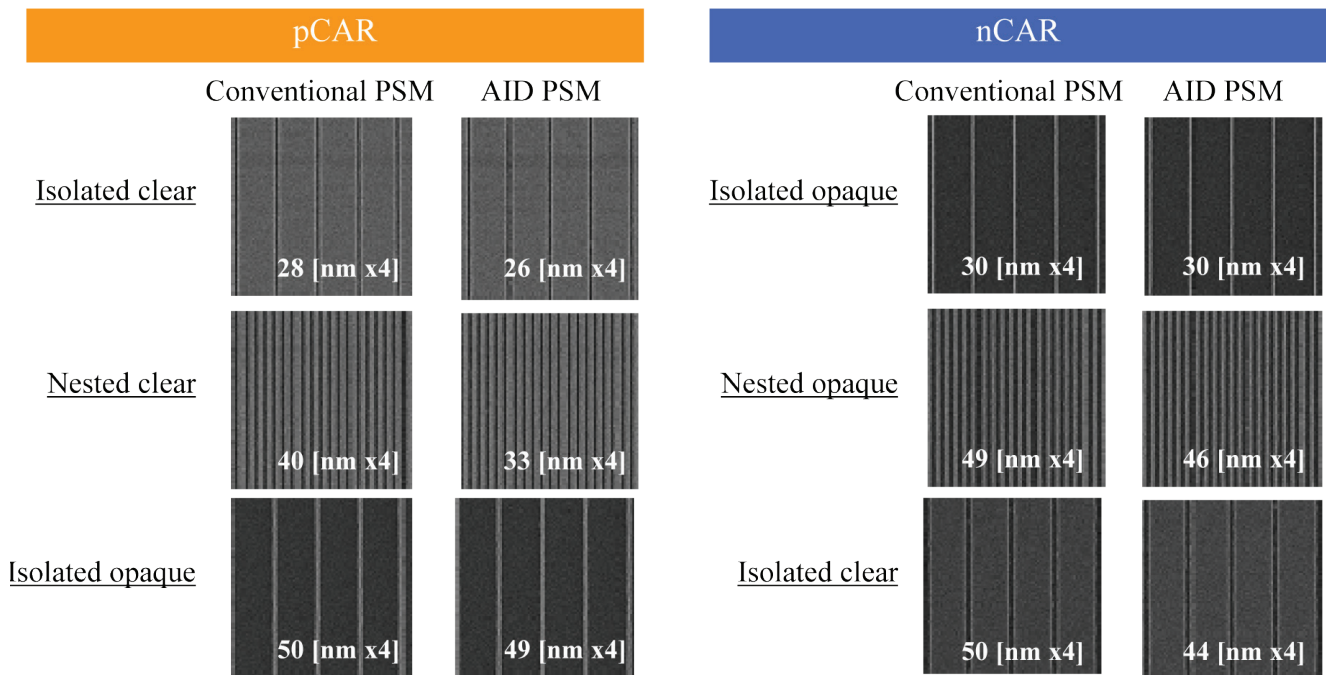


Figure 13. Resolution.

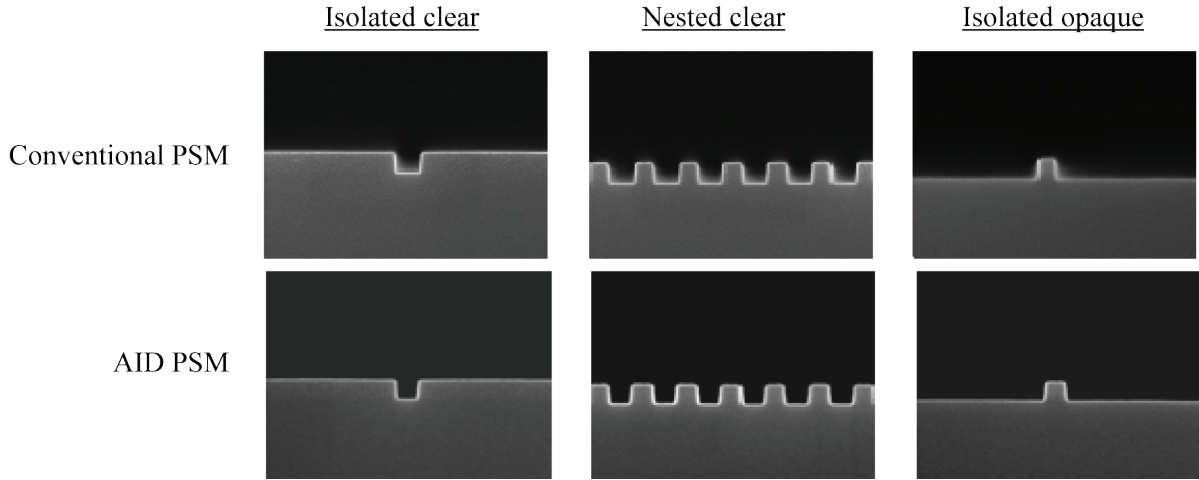


Figure 14. Cross section.

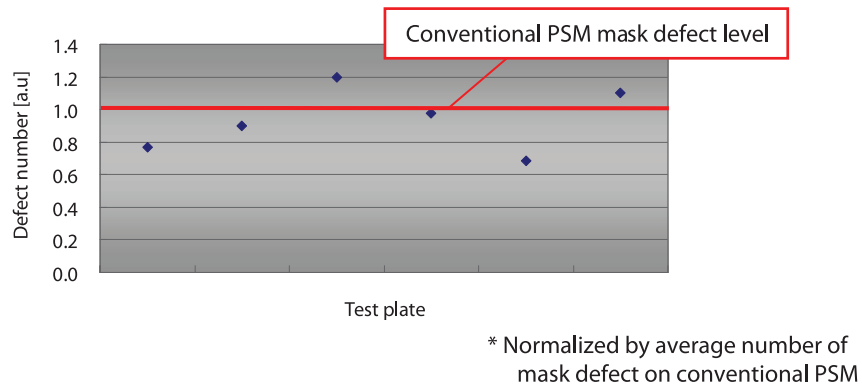


Figure 15. Number of mask defect on AID PSM.

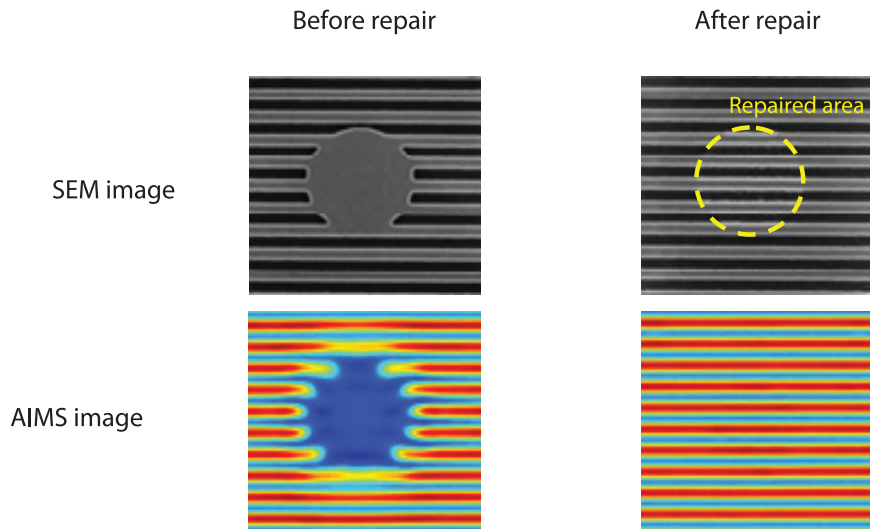
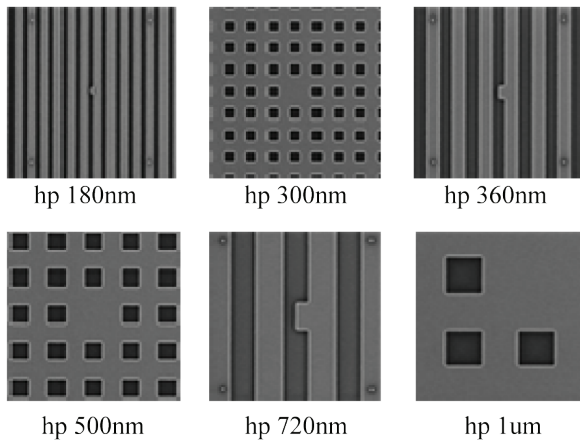
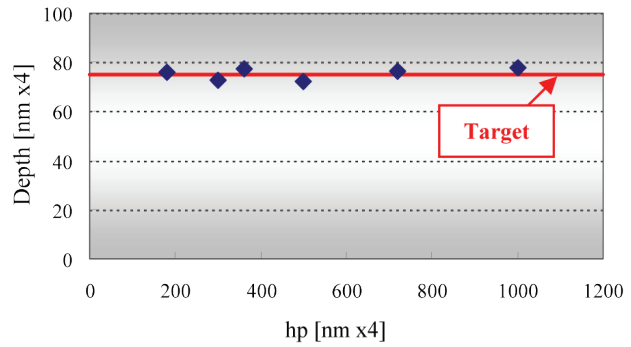


Figure 16. Defect repair by EB repair tool.



(a) SEM image of programmed defect



* Target is depth of phase shift = 180degree.

(b) Etched depth after repair

Figure 17. Repair of various patterns.

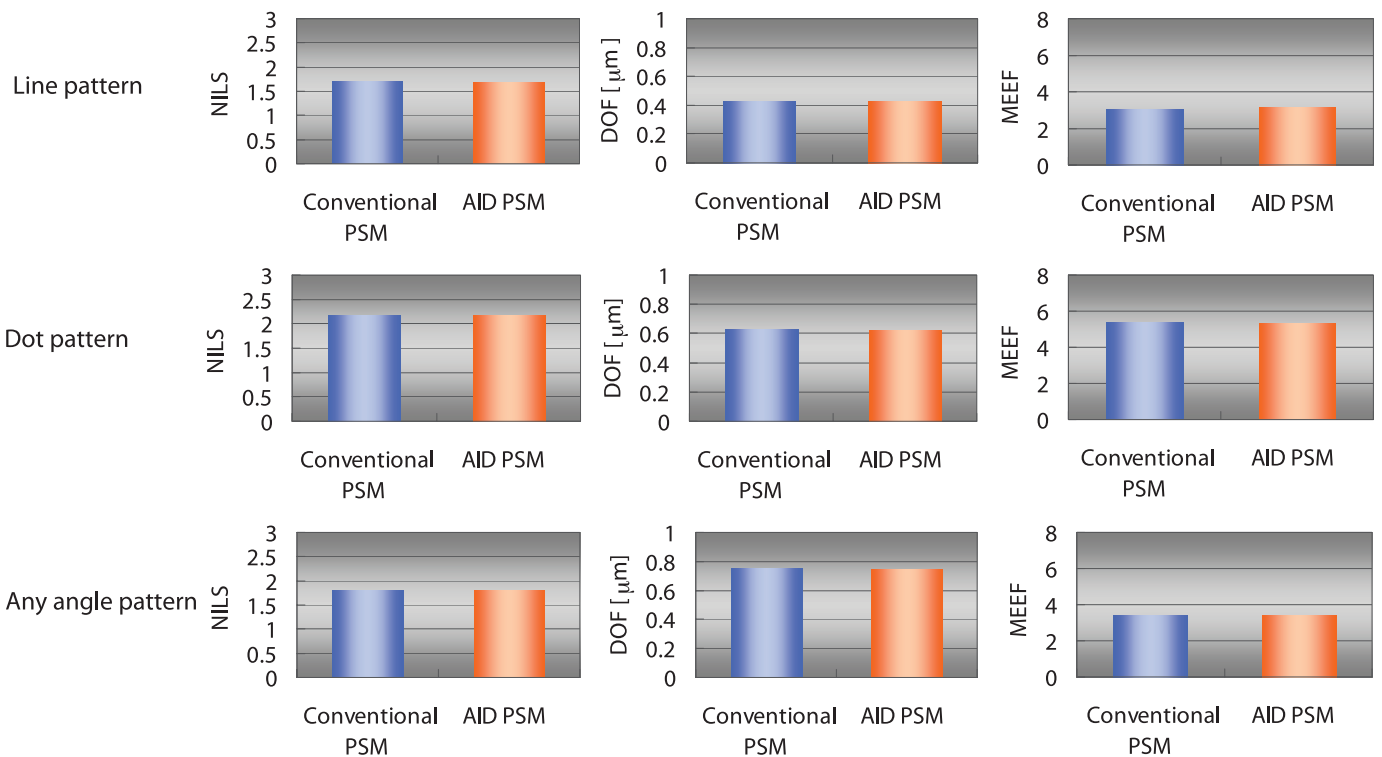


Figure 18. Simulation results.

it can be expected that there is no difficulty in converting conventional PSM into AID PSM. From these evaluation results, development of AID PSM was completed, and preparation for production is now going.

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Industry Briefs

Darkhorse Litho Technologies Stay in NGL Race

By Dylan McGrath, EETimes

The continually slipping target date for insertion of extreme ultraviolet lithography into volume production has enabled several other intriguing lithography technologies to hang around the next-generation lithography race, which not long ago was considered all but over.

Much to the chagrin of many backers of extreme ultraviolet (EUV) lithography, the technology's continually slipping target date for insertion into volume production has enabled several other intriguing lithography technologies to hang around the next-generation lithography race.

Most in the lithographer community still expect EUV to overcome remaining technical hurdles and take over for 193-nm optical lithography as the mainstream lithography technology. But EUV's stumbles have left the door open for technologies such as nano-imprint lithography, e-beam direct write and the hot newcomer, directed self-assembly (DSA) lithography. Proponents of each believe they could still yet play a role in future chip production, even if EUV assumes the mantle of mainstream production lithography.

"I'm convinced there is a role for several different technologies," said Moshe Preil, manager of emerging lithography and tools, during a panel discussion at the SPIE Advanced Lithography Conference.

Preil and other panelists see the possibility of some or all of these technologies being used in production as part of a multitechnology strategy. E-beam direct write, for example, could find a role in creating prototype chips, thus saving the cost of building photomasks for products being considered for development. Nano-imprint, which promises superior resolution and no limitations on the types of shapes that can be imaged, could be implemented in memory chip production in the next 18 months, according to S.V. Sreenivasan, chief technology officer at Molecular Imprints Inc., which provides nano-imprint lithography systems.

But all of the technologies still have significant development challenges to overcome. For e-beam direct write, which has always been enticing to chip makers because of the promise of eliminating the need for buying photomasks, the knock has always been throughput.

After many years of hoping that e-beam direct write technology will come to fruition, many in the industry remain skeptical of reported progress. "I'm no closer to believing that [e-beam] direct write is actually going to land," said Franklin Kalk, chief technology officer at Toppan Photomasks Inc. Questions about nano-imprint lithography generally center around defect density. Sreenivasan said recent developments have made a lot of progress in that area.

DSA, virtually unheard of just a few years, has quickly emerged, becoming the hot technology at this year's SPIE. Last year, about 10 papers on DSA were presented; this year, there are more than twice that many on the SPIE agenda. The technology promises high resolution, good line width roughness and high pattern fidelity. It works in conjunction with existing optical lithography technology. "The fact that we can implement DSA with standard lithography techniques and reach high resolution is quite compelling," said Raluca Tiron, R&D advanced lithography process engineer at CEA-Leti.

EUV, which was initially targeted for production in 2005, had been more recently expected to be ready by the 22-nm node, which Intel Corp. is implementing now. Intel now wants to put EUV into production at the 10-nm node, starting in the second half of 2015. Samsung Electronics Co. Ltd. plans to insert EUV into volume manufacturing as soon as 2013. But EUV has been delayed multiple times, most prominently by the inability to develop a light source with the power and reliability necessary to support throughput that would make EUV economically viable. Cymer Inc., the supplier of EUV light sources to No. 1 lithography vendor ASML Holding NV, and Ushio Inc., another potential supplier, are scheduled to report progress on their light source development at SPIE Thursday.

Cymer Reports Major Progress on EUV Power Source

By Dylan McGrath, EETimes

Cymer was set to reveal significant improvements in EUV source power, availability and dose control. Cymer Inc. revealed it has made significant progress in the development of a power source for extreme ultraviolet (EUV) lithography over the past few months. David Brandt, senior director of EUV marketing at Cymer, detailed significant improvements in source power, availability and dose stability for the company's laser-produced plasma EUV source.

Cymer revealed it has demonstrated the capability for average power of roughly 50 watts at high duty cycle (80 percent) using a newer exposure technique that makes use of a pre-pulse on the company's HVM I source. Less than three months ago, the company was unable to demonstrate anything above 10 watts using the same equipment and technique. The 50W achievement is also a 15X improvement from Cymer's results at the time of last year's SPIE, Brandt said.

Brandt cautioned that the result was achieved in open-loop testing, minus the controls placed on systems in the field to improve stability, which typically reduce power by about 25 percent (though the company is working to implement the controls with less power loss). Cymer has not yet implemented these controls in the system using the pre-pulse technique. The pre-pulse conditions the target—causing the liquid tin target to vaporize—so that it more readily absorbs the dose. "It's a good step forward," Brandt said. "It's encouraging to see that the average source power is increasing very significantly," said Hans Meiling, director of product management for EUV at lithography tool vendor ASML Holding NV, during a presentation earlier in the morning Thursday.

While the improvement to 50W average power is significant, Cymer acknowledges that it still has a ways to go. The goal for putting EUV systems in the field with adequate throughput of 60 wafers per hour is 100W average power. The ultimate goal is to achieve 250W power for throughput of 125 wafers per hour.

"Long term, we need to go to higher power levels to sustain 125 wafers per hour, maybe more," Meiling said. The Cymer paper also reported that the availability of the five HVM I sources Cymer currently has in the field, the time that the sources were available for use as opposed to being serviced, improved to 70 percent in the fourth quarter of 2011, up from about 50 percent in the third quarter and the less than 40 percent reported at last year's SPIE conference. Development of an adequate power source has proven the most cumbersome stumbling block to putting EUV lithography into volume semiconductor production. ASML NXE:3100 pre-production tools in the field have a throughput of less than 10 wafers per hour. Both ASML and Cymer have acknowledged that development of an adequate power source has been slower than expected, but ASML has pledged to ship production tools in the second half of this year with throughput of 60 wafers per hour by the end of this year.



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2013

✿ Advanced Lithography

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