Evaluation of resist performance with EUV interference lithography for sub-22 nm patterning

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ABSTRACT

The performance of EUV resists is a key factor for the cost-effective introduction of EUV lithography. Although most of the global effort concentrates on resist performance at 22 nm half-pitch, it is crucial for the future of EUVL to show its extendibility towards further technology nodes. In the last years, the EUV interference lithography tool at Paul Scherrer Institute, with its high-resolution and well-defined areal image, has been successfully employed for resist performance testing. In this paper, we present performance (dose, CD, LER) of a chemically-amplified resist for a range of 16 nm to 30 nm HP. Cross-sectional SEM images of the patterns are presented providing valuable insight into the resist's performance and failure mode. The reproducibility of our experiments are presented by repeating the same exposures with constant process conditions over the course of several months, demonstrating the excellent stability of the tool as well as the long shelf-life of our baseline resist. In addition, a comparative study of performance (dose, CD, LER) of different inorganic resists is provided. Patterns of 16 nm and 10 nm HPs are demonstrated with an EUV CAR and inorganic resists, respectively. Moreover, initial results of patterning with 6.5 nm wavelength are presented.

Keywords: Extreme Ultraviolet Lithography, EUV, interference lithography, photoresist, chemically-amplified resist, CAR, inorganic resist, soft X-ray lithography, 6.x nm lithography, BEUV, LER, 22 nm HP, 16 nm HP, 11 nm HP.

1. INTRODUCTION

EUV lithography (EUVL) is considered as the leading candidate for future technology nodes [1]. The performance of EUV resists is one of the key factors for the cost-effective introduction of EUVL [2]. However, due to aerial image limitations, most of the global effort has concentrated on resist performance at 22-60 nm half-pitch (HP) range. For the future of EUVL, it is crucial to illustrate and / or challenge the extendibility of the resist paradigm towards further technology nodes and to do so with enough lead time to ensure that any material solution can be commercialized. In the last years, the EUV interference lithography (EUV-IL) tool at Paul Scherrer Institute (PSI), with its high-resolution and well-defined areal image, stable source and interferometer, has been successfully employed for resist performance testing < 30 nm HP.

In this paper, we present performance of different resists using EUV-IL. We start with a brief description of the EUV-IL technique and the method of dose calibration used in this study. Performance of a standard chemically-amplified EUV resist (CAR) from Shin-Etsu is evaluated for half-pitches of 30 nm to 16 nm. Using this resist as our baseline resist, we present the long-term reproducibility of the tool and the baseline resist. We compare the performance of the inorganic non-CARs, such as the silicon-based (HSQ) and the hafnium-based (Inpria Corp.) resist platforms. In addition, their performance for sub-16 nm is evaluated, showing good resolution down to 10 nm HP. Whereas the performances of HSQ and Inpria resists are similarly excellent, the Inpria resists are significantly more sensitive than HSQ. Resolution

and sensitivity of CAR and non-CAR resists are compared. Furthermore, we present first results of patterning with a wavelength of 6.5 nm.

2. EUV INTERFERENCE LITHOGRAPHY

In interference lithography a periodic aerial image is generated by the interference of two or more coherent beams. Figure 1 shows the scheme EUV-IL setup installed at the Swiss Light Source (SLS), Paul Scherrer Institute, which employs diffraction gratings and spatially coherent EUV light in order to generate high-resolution periodic aerial images [3]. A spatially coherent beam of 13.5 nm wavelength generated by the synchrotron source is used the EUV source with 4% bandwidth. Mirrors and pinholes are used to coherently and homogeneously illuminate the grating mask. The gratings consisting of Cr lines are written with e-beam lithography on Si_3N_4 membranes of 100 nm thickness. The sinusoidal aerial image leading to dense line/space pattern necessary for resist analysis is produced by two gratings of equal period. The period of the interference pattern is half the period of the gratings if the first-order diffracted beams are used for interference. Unless large-area of a single pattern is required, the masks consist of several grating pairs enabling versatile nanostructures or different half-pitches at a single exposure. The gratings are arranged so that the overlap of higher order diffraction beams with the interference patterns is avoided. All areas outside the gratings on the mask are coated with a thick polymer film, which completely absorbs the zero-order beam. EUV-IL technique has infinite depth of focus, i.e., the aerial image is insensitive to gap variations. The gap between the mask and sample is adjusted to have maximum overlapping of the interfering beams whereas an error leads to a minor reduction of the patterned area.

EUV-IL technique and in particular PSI tool has been shown to enable patterning of photoresists with high resolution and played a significant role in the early days of resist testing [4, 5]. Since the installation of PSI tool, it has been always the leading tool in terms of resolution. With this tool 12.5 nm HP and 11 nm HP resolutions were demonstrated in 2007 and 2009, respectively [6, 3]. Recently we demonstrated resolved patterns down to 9 nm and modulation down to 6 nm HP [7]. Relative simplicity of EUV-IL and its low-cost compared to high-NA projection tools, make it a promising alternative for resist testing for future technology nodes as well as for academic research where high-resolution nanostructures are needed.

The profile of the aerial image delivered by the exposure tool has a strong impact on the responding processes in the resist and therefore on the behavior and performance of the resist. EUV-IL provides a well-defined and pitch-independent sinusoidal aerial image. This feature can be used to decouple the contrast loss from the exposure tool and the photoresist [8]. For an ideal resist, the dose-to-size is equal to factor two of the dose-to-clear, independent of the HP.

PSI tool was upgraded in 2010. In addition to significant increase in beam time availability by receiving it own undulator, a new process room is installed enabling on-site pre/post-processing in cleanroom conditions. Moreover, the new optics enables variable wavelength from 16 nm to 3 nm. This feature may also play a significant role in the evaluation of the resist performance at wavelengths other than 13.5 nm. In September 2011 we have made an upgrade of the optics, which improved the reproducibility significantly as will be seen below.

Figure 1. Schematic illustration of grating-based interference with two beams. Cr gratings on Si_3N_4 membrane diffract the EUV light. Only zeroth and first-order diffraction beams are shown. A sinusoidal aerial image is formed by the interference of first-order diffraction beams between the gratings.

3. DOSE CALIBRATION IN EUV-IL

In exposures with EUV-IL, dose calibration is a difficult issue due to the nature of the technique. In the through-dose experiments the flux before the mask is measured with a diode prior to experiments and the dose is adjusted with a shutter. The dose-on-wafer is defined by the transmission efficiency of the supporting membrane and the diffraction efficiency of the grating. A theoretical estimation of the diffraction efficiencies of individual gratings is very difficult. The straightforward method to determine the dose-on-wafer is to measure the transmitted light using a charge-coupled device (CCD) and determine the diffraction efficiency of the diffraction orders contributing to the interference pattern. However, this is possible only for large gratings and the measurements with CCD cannot be performed under the beam conditions used for the exposures because of the extreme sensitivity of the CCD.

To solve this problem we have developed a simple method where the tool factor, i.e. the ratio of the doses on the mask and wafer levels, can be obtained unambiguously and with reasonable accuracy under the exposure conditions. As seen in Fig. 1, in addition to interfering beams, there are also first-order diffraction beams that diverge from each other and are also printed on the wafer. Dose-to-clear curves were obtained on these fields of flat exposures for each grating. In addition, dose-to-clear curve of the same resist is obtained by exposures without a mask. The ratio of clearing dose in two cases provides the tool factor. Figure 2 shows the dose-to-clear curves of *Resist-A* obtained with PSI's EUV-IL tool and Intel's MET. Since the dose calibration of PSI's tool needs further improvement, for the calibration of tool factors we used the dose-to-clear curve of Intel's tool. Doses quoted in the following sections are based on these tool factors of the same mask and dose calibration of the Intel's MET.

Figure 2. Dose-to-clear curves of *Resist-A* with PSI's IL tool and Intel's MET tool. Samples were processed with PAB temperature of 100 °C for 60 s and PEB temperature of 95 °C for 60 s and were developed in 2.38% TMAH solution for 30s.

4. PERFORMANCE OF A CHEMICALLY AMPLIFIED RESIST

In this section we present the performance of a CAR for half-pitches between 30 nm and 16 nm. For the present study a standard EUV CAR from Shin-Etsu (*Resist-A*) was chosen because of its resolution and sensitivity. For the resist characterization, dense line/space patterns with half-pitches of 30 nm, 22 nm, 20 nm, 18 nm and 16 nm were exposed with the same mask and analyzed with top-down scanning electron microscopy (SEM) imaging. SEM images were captured at the same magnification and with an acceleration voltage of 1 kV in order to minimize the effect of the SEM inspection. The analysis of the critical dimension (CD) and line-edge roughness (LER) was performed with a commercial analysis and modeling software (SuMMIT®). 4-inch Si wafers were spin-coated with an underlayer. Subsequently, the photoresist was spin-coated to a thickness of 35 nm and baked at a temperature of 105 °C for 90 seconds. After the exposures the samples were baked at 90 °C for 90 seconds and developed in 2.38% tetramethylammonium hydroxide (TMAH) solution for 30 seconds followed by rinsing in DI water for 30 seconds. There were no significant delay between the steps and the complete procedure was carried out in the same cleanroom equipped with amine filters.

Figure 3 shows the SEM images at optimal doses at different half-pitches. Patterns are resolved down to 18 nm HP. For half-pitch of 16 nm significant necking, bridging, and resist collapse effects are observed. Cross-sectional SEM images for 30 nm HP are shown in Fig. 3, providing interesting details of the resist behavior. As seen in the through-dose images, at low doses the resist starts to clear in point-like features. At moderate dose resist footing is observed, indicating that the significant part of the LER comes from the resist footing. At higher doses the lines exhibit resist necking and narrow line-width (LW) is strongly correlated with the top-loss.

Figure 3. Top: SEM images of *Resist-A* for different half-pitches of 30 nm to 16 nm. Bottom: Cross-section of lines/space patterns with HP of 30 nm at different doses. Resist thickness is 35 nm. Samples were processed with PAB temperature of 105 °C for 90 s and PEB temperature of 90 °C for 90 s and were developed in 2.38% TMAH solution for 30s.

Figure 4. CD and LER of *Resist-A* as functions of dose for different half-pitches. Resist thickness is 35 nm.

Figure 5. SEM images of *Resist-A* with 16 nm HP at different doses. Resist thickness is 30 nm.

Figure 6. Through-dose behaviors of CD and LER of *Resist-A* for different half-pitches of 18 nm, 22 nm, and 30 nm, and for two different resist thicknesses of 35 nm and 30 nm.

The through-dose behaviors of the CD and LER are shown in Fig. 4. The resist exhibits a large exposure latitude for 30 nm HP. The CD can be varied from 20 nm to 36 nm for this half-pitch. Exposure latitude decreases with decreasing half-pitch. LER values (3σ) below 3 nm are obtained for half-pitches down to 20 nm. For 18 nm HP, the LER is below 4 nm. As seen in the figure, the performance of *Resist-A*, with its sensitivity of about 9.5 mJ/cm^2 and LER of below 3 nm, matches the required specifications down to 20 nm HP. For 18 nm HP, further optimization is needed.

We note that in these experiments the resist thickness was 35 nm instead of the mostly used thickness of 40 nm. Since our aim was exploring sub-22 nm HP regime and we observed in our initial tests that resist collapse already starts at 20 nm HP, we decided to reduce the resist thickness in order to avoid resist collapse straightforwardly. Nevertheless, resist collapse is still observed for 16 nm HP with the present resist thickness. Therefore we reduced the resist thickness further in order to evaluate the feasibility of the present resist for 16 nm HP. Through-dose response of the resist for 16 nm HP is shown with SEM images in Fig. 5. Although resist collapse is avoided with the thinner resist, the overall performance of the resist becomes worse. With the reduction of resist thickness, increased LER and resist necking become the major problems. The influence of the resist thickness on the CD and LER is shown in Fig. 6. Reducing the resist clearly increases the sensitivity. On the other hand, it has a substantially negative effect on LER. By reducing the resist thickness from 35 nm to 30 nm the LER values increased from 3 nm to 5 nm. It is clear that reducing the resist thickness is not a promising pathway to avoid the collapse problems. Alternative pathways, such as using different developers or surface treatments, should be developed in order to challenge 16 nm. For *Resist-A* with the present processing parameters, resist thickness should be at least 35 nm and if possible even more with resist collapse mitigation strategies.

5. REPRODUCIBILITY OF THE EUV-IL TOOL

Having shown the superior performance of the EUV-IL, an important question that arises is the long-term reproducibility of the same performance. This is a challenging issue for a multipurpose tool like the PSI tool, which is used for several other projects in addition to resist evaluation. Moreover, mask degradation might be a potential problem, particularly due to the facts that the masks are delicate thin membranes and during the exposures always in close proximity with the wafer, which may outgas. Figure 7 shows the CD and LER of *Resist-A* for the exposures performed within a time interval of 7 months. The dates of the exposures are provided in the figure inset. Although there are some outliers in the data, these data is not excluded in the figure. Same resist processing parameters, mask, and beam conditions were used. All exposures were performed with the same resist batch, demonstrating also the excellent shelf life of the resist. We note that there was a major upgrade of the optics in September 2011. The experiments after the upgrade are denoted in the figure with circles. It is clear, in particular for HP 18 nm, that the reproducibility has improved significantly after the upgrade, which is highlighted in Fig. 8 where CD and LER values at 18 nm HP obtained within the last 4 months are plotted. It should be noted that a part of the variations in the CD and LER comes from the analysis such as SEM inspection, which is done by a multipurpose SEM, for which tool stability and human factor also play a significant role.

Figure 7. CD and LER of *Resist-A* as functions of dose for different half-pitches for experiments performed in the course of 7 months. The results before and after the upgrade are denoted with squares and circles respectively.

Figure 8. CD and LER of *Resist-A* as functions of dose for HP 18 nm for experiments performed in the course of last 4 months under the same conditions.

Figure 9. Comparison of CD and LER of *Resist-A* as functions of dose for different half-pitches performed with a 7-month-old resist batch (black symbols) and with a fresh resist batch.

In Figs. 7 and 8 we do not see a trend of change in the sensitivity and the performance of the resist within the variations of the long-term data. In order to exclude the errors emerging from the exposure and the SEM analysis, we performed experiments with the 7-month-old resist batch and with a fresh resist batch. Both the exposures and the analysis were carried out subsequently without significant delay. The comparison of the results obtained with the old and fresh batches are shown in Fig. 9. The results indicate no observable change in the sensitivity and performance, demonstrating the excellent shelf life of the *Resist-A*.

6. PATTERNING WITH INORGANIC RESISTS

As shown in the previous section, *Resist-A* is certainly a high-performance resist with a well-balanced trade-off between resolution, line edge roughness, and sensitivity. Nevertheless, the resolution is limited by 18 nm HP due to the acid diffusion and mechanical stability. In contrast, there are several inorganic resists available that have very high resolution but at the cost of sensitivity. Hydrogen silsesquioxane (HSQ, Dow Corning XR-1541) is a negative tone resist, which has been repeatedly demonstrated to have high resolution with both EUV and electron beam lithography [7]. Inpria's hafnium oxide based resist platform has also been demonstrated to have high resolution. In addition, it is significantly sensitive to EUV photons due to the relatively high absorption cross-section of hafnium at this wavelength [9]. Two different formulations of the resist from Inpria were chosen for the experiments. Inpria (XE15JB) refers to a more sensitive resist formulation whereas Inpria (XE14IB) has higher resolution. Two different HSQ resists in fact refer to the same resist formulation but two different developers, namely in a TMAH-based developer and a NaOH-based developer. Compared to TMAH-based development the NaOH-based processing increases the contrast and the resolution at the expense of sensitivity. Table 1 shows some process parameters for the resists evaluated in this paper.

SEM images for 30 nm, 22 nm, and 16 nm HPs are shown in Fig. 10. All the resists show high performance down to 16 nm HP. Through-dose dependences of CD and LER for 22 nm HP are shown in Fig. 11. In addition to four inorganic resists, data for *Resist-A* is also provided in the figure for comparison. In the CD curves, the provided data does not necessarily cover the complete exposure latitude for all resists. The LER values for all inorganic resists are relatively low and about 2 nm at 16 nm HP. It should be noted that comparison of LER values of the different resists for 22 nm HP reveals a clear correlation between LER and the sensitivity. Lower LER for less sensitive resist can be an effect of the

photon shot noise on the LER and thereby on the ultimate resolution. In general, HSQ has slightly better resolution than Inpria while the latter is significantly more sensitive than HSQ. However, for a final conclusion on the ultimate sensitivity and resolution, further detailed analysis and extensive optimization of process conditions are necessary. The sensitivities of the resists evaluated in the present study are listed in Table 1. Note that the sensitivity of *Resist-A* is based on the reproducibility measurements provided in Fig. 7. The error value provided in the table refer to the full width of the variation of the dose of *Resist-A* at half-pitch and CD of 22 nm. Although we may report more precise values for the absolute sensitivities of the resists than the ones provided in Table 1, relative sensitivity of the resists should be fairly constant, since all the resists are tested with the same mask and under same beam conditions. It should be also noted that all the inorganic resists tested in this study have shorter shelf life and lower performance in terms of reproducibility than *Resist-A*, and therefore the reported sensitivities should be taken with caution.

Although the sensitivity values listed in Table 1 are only for 22 nm HP, the values for *Resist-A* at different HPs are also the same within the error bars. Since the aerial image profile of EUV-IL is independent of HP, for an ideal resist the dose-to-size at different HPs must be the same. As clearly seen, for instance, in Fig. 4, the obtained dose-to-size values for Resist-A at all reported HPs are within the provided value in Table 1.

Figure 10. SEM images of inorganic resists at different half-pitches. HSQ(TMAH) and HSQ(351) refer to the different developers of the same resist formulation. Process conditions of the resists are provided in Table 1.

Figure 11. Through-dose behavior of CD and LER of different inorganic resists at 22 nm HP. Process conditions are provided in Table 1.

Table 1. Process parameters of the resists used in this study and their resulting sensitivities with EUV-IL at 22 nm HP.

Resist name	Substrate	Spinning	PAB	Thickness	PEB	Developer / Time	Sensitivity @ hp 22 nm
Resist-A	Si/Underlayer	2500 rpm / 45s	105°C / 90s	35 nm	90°C / 90s	TMAH 0.26N / 30s	9.5 mJ/cm ² ±1.1 mJ/cm ²
Inpria(X15JB)	Si/O ₂ Plasma	2500 rpm / 45s	80°C / 120s	20 nm	80°C / 120s	TMAH 25% / 120s	80 mJ/cm ²
Inpria(XE15IB)	Si/O ₂ Plasma	2500 rpm / 45s	80°C / 180s	20 nm	80°C / 60s	TMAH 25% / 30s	163 mJ/cm ²
HSQ(TMAH)	Si	5000 rpm / 45s	No	35 nm	No	TMAH 2.6N / 60 s	229 mJ/cm ²
HSQ(351)	Si	5000 rpm / 45s	No	35 nm	No	351 / 30 s	659 mJ/cm ²

7. TOWARDS 16 NM AND 11 NM HALF-PITCH

As discussed in Section 4, *Resist-A* is a sensitive resist reaching resolution down to 18 nm HP. Inorganic resists, on the other hand, show excellent resolution down to 16 nm HP with low LER, nevertheless their sensitivity is significantly lower than that of *Resist-A*. For 16 nm HP, therefore, alternative pathways should be explored. Slower CARs or faster inorganic resists will be promising alternatives. Figure 12 shows the SEM images of another EUV CAR (*Resist-B*), which can resolve down to 16 nm HP with a sensitivity of 30 mJ/cm². This resist is currently the most sensitive resist platform for 16 nm HP. A detailed analysis and reproducibility of *Resist-B* will be published later.

As can be inferred from Fig. 10, the ultimate resolutions of inorganic resists presented in this study are far beyond the presented resolution of 16 nm HP in the figure. Recently, we have reported sub-10 nm resolution and modulation down to 6 nm with HSQ [7]. Since then we made further progress thanks to the recent upgrade as well as improved mask fabrication methods. This was enabled by the use of Inpria resist for mask fabrication owing to its high EUV absorption coefficient at the EUV wavelength and superior resolution with e-beam lithography. Figure 13 shows two SEM images as an example of high-resolution patterning achieved with the EUV-IL. High quality HSQ patterns with 10 nm HP and Inpria patterns with 11 nm HP are shown in the figure. Towards 11 nm HP and below, resist adhesion and pattern collapse problems become a major issue even for the inorganic resists like HSQ and Inpria, which are known for their great stability. For instance, although HSQ can achieve aspect ratio of up to 3 for a half-pitch of 30 nm [10], it becomes difficult to sustain aspect ratio of 1 for 11 nm HP and below. The challenging trade-off between stability and LER due to the resist thickness faced with CARs at 16 nm HP becomes also an important issue for inorganic resists at 11 nm HP.

We note that the ultimate resolution that has been achieved with EUV-IL is 8 nm HP. Figure 14 shows an SEM image of HSQ patterns with 8 nm HP. This result marks the current record in photon-based lithography. Although the resist thickness is below 10 nm, minor collapse problems are observable, which becomes significant for smaller HPs. Further reduction of resist thickness leads to increase in LER and non-uniformity in resist thickness, as well as to poor contrast for SEM inspection. Further studies will, therefore, include pattern collapse mitigation techniques such as super-critical drying.

Figure 12. SEM images of an EUV CAR (*Resist-B*) at different half-pitches. Resist thickness is 30 nm.

Figure 13. SEM images of inorganic resists at different half-pitches. (Left) HSQ lines/space patterns of 10 nm HP. (Right) Inpria resist of 11 nm HP.

Figure 14. SEM image of HSQ lines/space pattern with 8 nm HP.

8. PATTERNING WITH 6.5 NM LITHOGRAPHY

Since the realization of high-NA EUV projection tools will be a significant challenge for 11 nm HP and below, the option of reducing the wavelength is already being considered. Sources and multilayers have already been demonstrated for the wavelength of 6.x nm, and therefore it is considered as the potential extension of EUVL. Photoresist performance at this wavelength has been investigated theoretically [11].

Here we report for the first time patterning with BEUV (Beyond-EUV or, alternatively, deep-EUV, hard-EUV, soft X-ray) lithography at 6.5 nm wavelength. We used interference gratings similar to the ones that are used for EUV-IL providing resolution down to 22 nm HP. With the same mask we performed exposures at both 13.5 nm and 6.5 nm wavelengths. The efficiency of the diffraction gratings changes with the change of the wavelength and therefore the tool factors for EUV and BEUV are also very different. SEM images of HSQ patterns at 22 nm HP exposed with EUV and BEUV are shown in Fig. 15, demonstrating good patterning performance with BEUV similar to its performance with EUV. Since HSQ is a high-performance resist and its resolution is far below the 22 nm HP, the difference between the performances of the exposures with two different wavelengths may not be evident, if there is a minor difference in the performance. Figure 15 also shows comparison of the *Resist-A* patterns of 25 nm HP obtained with EUV-IL and BEUV-IL. The performance of the resist is significantly reduced with the reduction of the wavelength. Although more extensive experiments are in progress, these initial results show that a resist platform developed for EUV wavelength does not necessarily show a good performance at 6.x nm wavelengths. We note that, although the experiments at both wavelengths are performed with the same mask and the tool, we cannot absolutely rule out tool dependent factors, which can make a one-to-one comparison of the performance of a resist at two different wavelengths difficult.

Figure 15. SEM images of HSQ and *Resist-A* resists patterned with EUV and BEUV interference lithography.

9. CONCLUSIONS

Results with a standard CAR for 16-30 nm HPs are presented with the aim of resolved patterns with a CAR towards 16 nm HP. Line/space patterns are resolved down to 16 nm HP with LER increasing with decreasing feature size. Pattern collapse is observed at more aggressive pitches. This can be overcome by reducing the film thickness of the resist, but results in an increased LER. Cross-sectional SEM images of the patterns are presented providing valuable insight into the resist performance and failure mode. The reproducibility of our experiments are presented by repeating the same exposures with constant process conditions over the course of several months, demonstrating the excellent stability of the PSI's EUV-IL tool as well as the long shelf-life of our baseline resist. CD and LER are evaluated as functions of dose for different inorganic resists and processing, demonstrating resolution down to 16 nm HP for all the inorganic resists evaluated in this work. Patterning with a slower CAR is demonstrated with a resolution down to 16 nm HP. Initial results of patterning with deep-EUV (6.5 nm wavelength) are presented. These results demonstrate that EUV-IL is a powerful tool for the evaluation of resist performance for future technology nodes, helping to fill the time gap until higher-NA alpha tools are made available.

The comparative study of the CAR and inorganic resists shows that the current status of the EUV resist development is very promising. CAR platforms are already available for 22 nm HP, and even down to 18 nm HP with further process optimization, with a sensitivity of about 10 mJ/cm² and for 16 nm HP with a sensitivity of about 30 mJ/cm². For 11 nm HP resolution, inorganic resist platform of Inpria, offers the highest sensitivity. The general trend in the transition from 22 nm to 16 nm, and to 11 nm HP is the slower and thinner resists. We believe that this trend will be valid also in future.

The measure of progress in resist development for 16 nm and 11 nm nodes is set by the sensitivities of these available platforms. Future development for 16 nm HP should be towards faster CAR than the available materials without any significant compromise in resolution. For 11 nm HP, slower CARs and faster inorganic resists should be explored. With decreasing HP, pattern collapse becomes the limiting factor. The ultimate resolution of EUV-IL is in the range of single-digit HPs. It can be concluded from these results that secondary electron blur in EUV lithography will not be a limiting factor for 16 and 11 nm HPs or even below. Our initial results with BEUV show that resist development is necessary for going from EUV to BEUV.

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