The SEMATECH Berkeley MET: demonstration of 15-nm half-pitch in chemically amplified EUV resist and sensitivity of EUV resists at 6.x-nm

Chris Anderson[1], Dominic Ashworth[2], Lorie Mae Baclea-An[1], Suchit Bhattari[1], Rikos Chao[1], Rene Claus[1], Paul Denham[1], Ken Goldberg[1], Andrew Grenville[3], Gideon Jones[1], Ryan Miyakawa[1], Ken Murayama[4] , Hiroki Nakagawa[4], Senajith Rekawa[1], Jason Stowers[3] and Patrick Naulleau[1]

[1]Center for X-Ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA 94720
[2]SEMATECH, Albany, NY 12203
[3]Inpria Corporation, Corvallis, OR 97330
[4]JSR Mirco Inc., Sunnyvale, CA 94089

ABSTRACT

EUV exposures at the SEMATECH Berkeley Microfield Exposure Tool have demonstrated patterning down to 15 nm half pitch in a chemically amplified resist at a dose of 30 mJ/cm2. In addition, the sensitivity of two organic chemically amplified EUV resists has been measured at 6.7 nm and 13.5 nm and the sensitivity at 6.7 nm is shown to be a factor of 6 lower than the sensitivity at 13.5 nm. The reduction of the sensitivity of each resist at 6.7 nm relative to the sensitivity at 13.5 is shown to be correlated to a reduction of the mass attenuation coefficients of the elements involved with photoabsorption.

INTRODUCTION

Phase shift mask (PSM) imaging enables pitch splitting by suppression of the zeroth diffracted order from the line-space pattern on the mask. This is achieved by having a perfect phase shift between the line and the space while simultaneously having constant reflectivity from both the line and space. In such a case, the average field value (DC term) at the exit surface of the phase shift structure is zero and thus the zeroth diffracted order is suppressed.

Pseudo PSM imaging enables pitch splitting through spatial filtering of the zeroth at the Fourier plane of the mask pattern [1]. Efficient spatial filtering requires that the separation of the orders of interest is large compared to the pupil fill and that an aperture can be placed in the center of the pupil to block the zeroth order. Since the BMET is equipped with lossless pupil fill control and a central obscuration, both requirements are satisfied without any modification of the exposure tool. Figure 1 shows a schematic of the pseudo PSM process.

Extreme Ultraviolet (EUV) Lithography III, edited by Patrick P. Naulleau, Obert R. Wood II, Proc. of SPIE Vol. 8322, 832212 · © 2012 SPIE
CCC code: 0277-786X/12/$18 · doi: 10.1117/12.917386

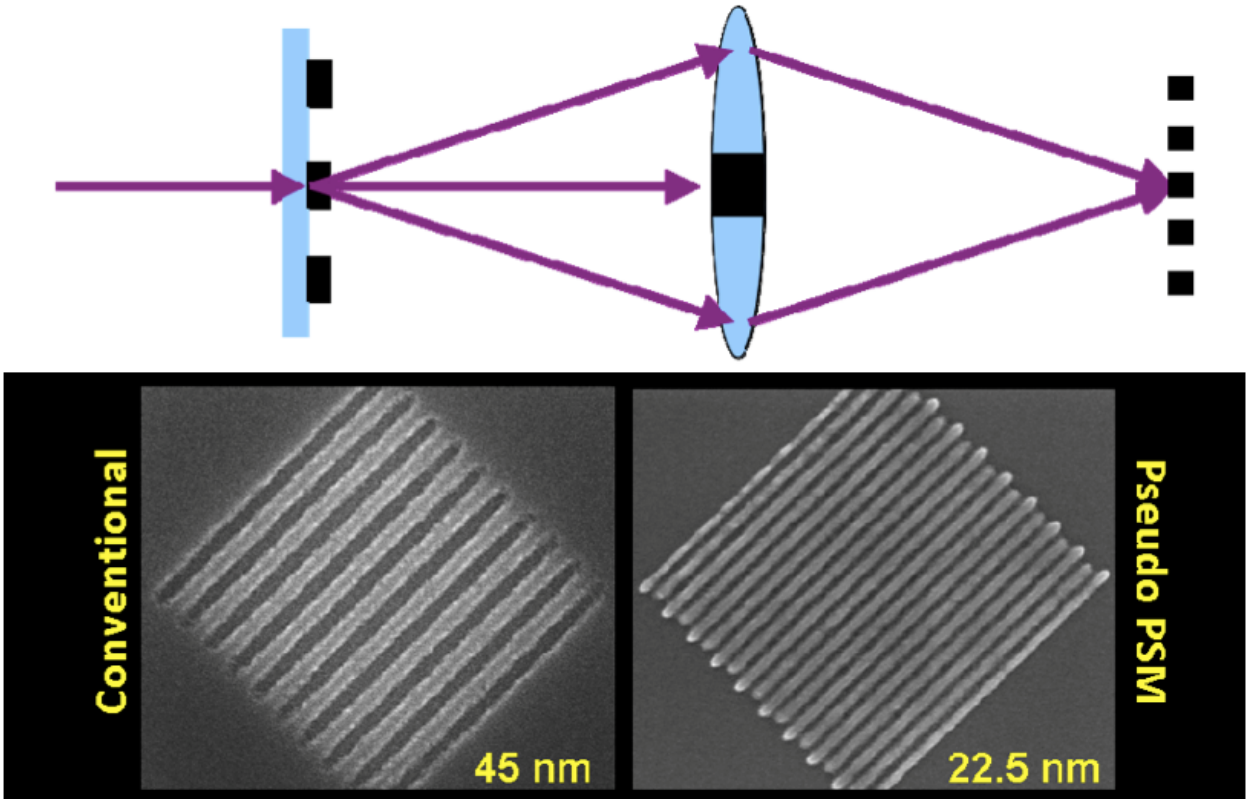


Figure 1. Schematic of the pseudo-PSM process along with exposures of 45-nm lines and spaces using both conventional illumination and the Pseudo-PSM method which results in twice as many 22.5-nm lines and spaces

RESIST SCREENING WITH PSEUDO PHASE SHIFT MASK IMAGING

In August 2011, a field optimized for pseudo PSM imaging was made available to BMET users. Figure 2 shows a schematic of the 60 µm x 60 µmµm unit cell of the pseudo PSM field. The pseudo PSM unit cell contains dense lines coded to print from 12 nm half-pitch to 30 nm half-pitch in 1 nm intervals when exposed with pseudo PSM illumination. Each set of dense lines is 2 µm wide and 60 µm tall. The 200 µm x 66 µm subfield contains a total of four unit cells at rotations of 0 degrees, 90 degrees, 45 degrees and -45 degrees. The 600 µm x 200 µm (full) field contains a 3 x 3 array of of the 200 µm x 66 µm subfield. Feature size labels in the unit cell are encoded on a 25 nm half-pitch spatial carrier so that they are diffracted into the clear aperture of the imaging lens and print when the zeroth order is blocked. Figure 3 shows exposures of coded 21-nm lines with 0.35-0.55 annular illumination (left) and pseudo PSM illumination (right). The labels show the half pitch as printed with pseudo PSM illumination.

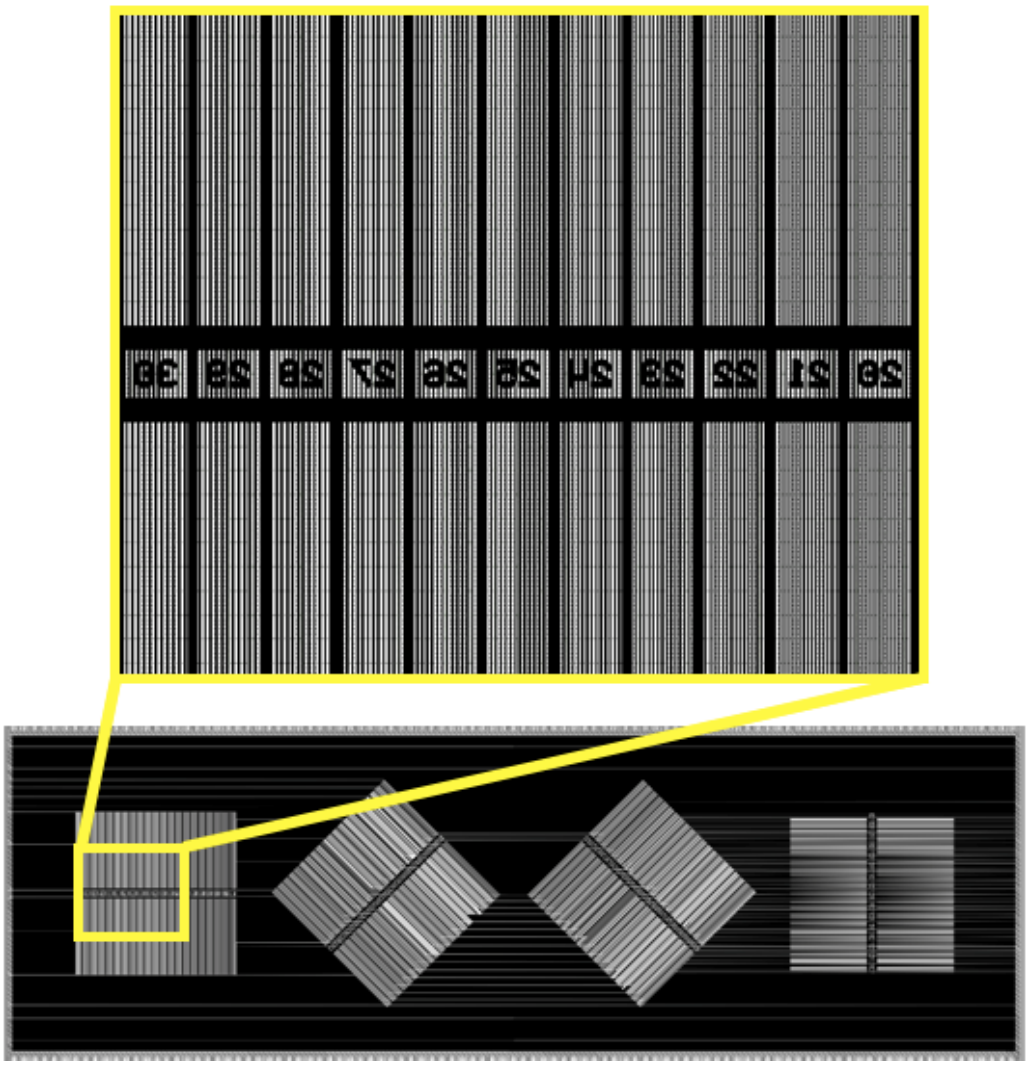


Figure 2. Schematic of the 600 µm x 200 µm subfield of the pseudo phase shift mask.

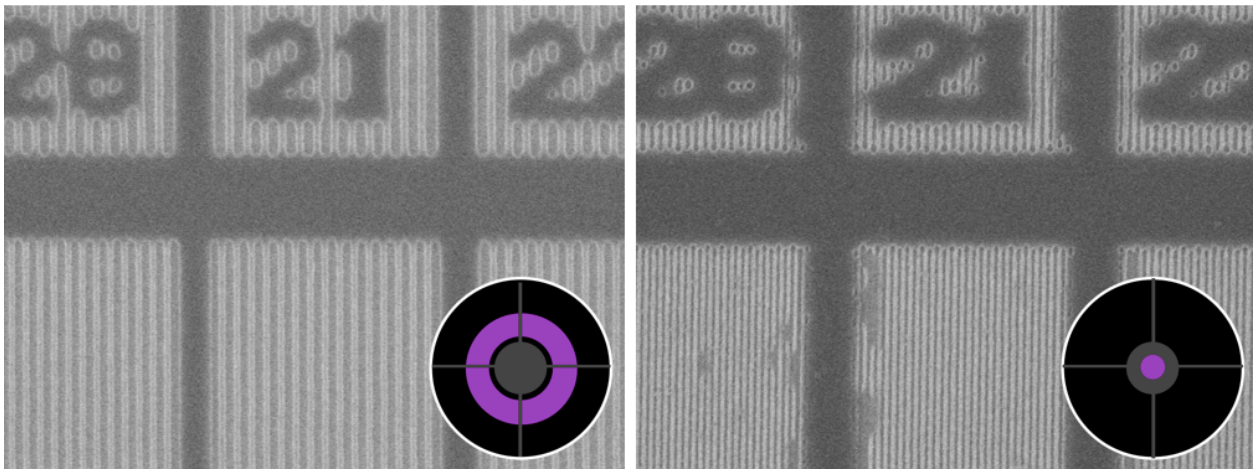


Figure 3. Exposures of coded 21-nm lines with 0.35-0.55 annular illumination (left) and pseudo PSM illumination (right). The labels show half pitch as printed with pseudo PSM illumination.

In August 2011, the pseudo PSM imaging method including the new reticle was benchmarked for ultimate performance using an inorganic directly imageable hardmask previously shown to support dense lines down to 16 nm half pitch [3]. Figure 4 shows printing of dense lines from 18 nm half pitch to 13 nm half pitch at a dose of about 80 mJ/cm2 in the directly imageable hardmask using the pseudo PSM imaging method with the new reticle, demonstrating an aerial image contrast above 50% down to at least 14 nm half pitch.

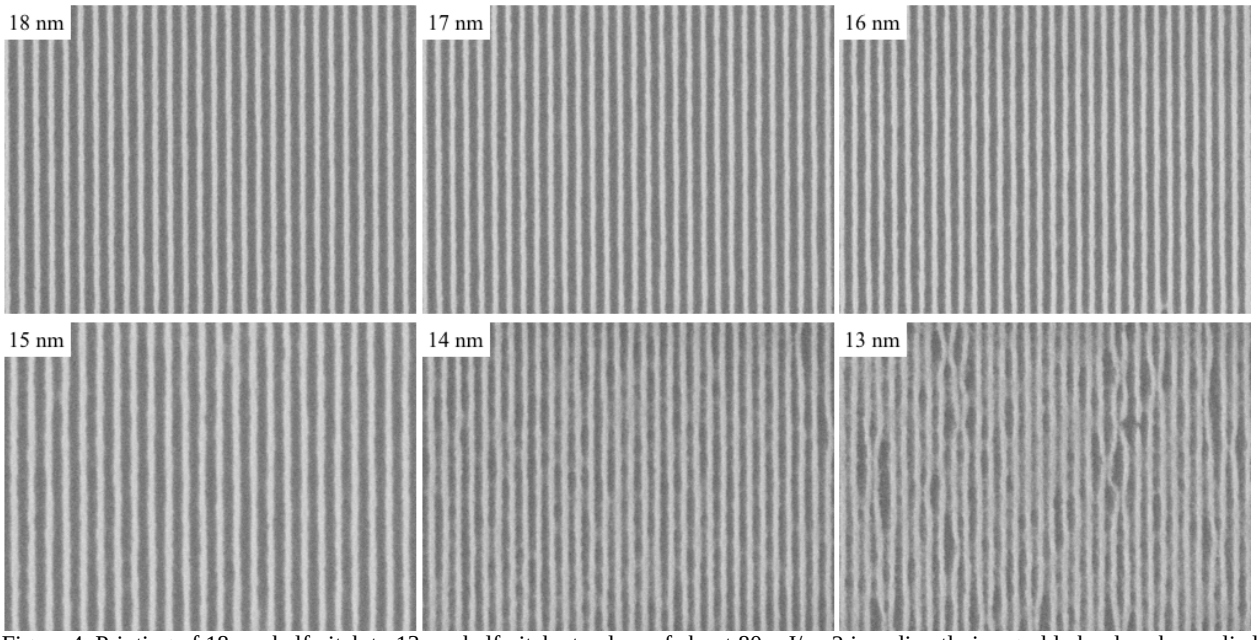


Figure 4. Printing of 18 nm half pitch to 13 nm half pitch at a dose of about 80 mJ/cm2 in a directly imageable hardmask supplied by Inpria Corp. using the pseudo PSM imaging method

Following initial benchmarking of the new pseudo PSM reticle, five chemically amplified resists previously shown to support dense patterning down to 20 nm half pitch [2] were screened with the pseudo PSM imaging method. Figure 5 shows patterning results from each resist from 20 nm half pitch to 17 nm using the pseudo PSM imaging method, demonstrating that patterning in each of these resists is resist-limited beyond 20 nm half pitch.

Late in Q3 2012, a new chemically amplified resist from JSR Micro, Inc. was identified as a potential champion candidate by exhibiting good performance at 22 nm half pitch with annular illumination. Once the pseudo PSM imaging method became available, this resist was exposed using the pseudo PSM imaging method. Figure 6 shows patterning of dense lines from 18 nm half pitch to 13 nm half pitch in the JSR resist at a dose of 30 mJ/cm2 using the pseudo PSM imaging method demonstrating patterning down to 15 nm half pitch and modulation down to 13 nm half pitch and marking a significant improvement in chemically amplified resist performance from the previous champion data.

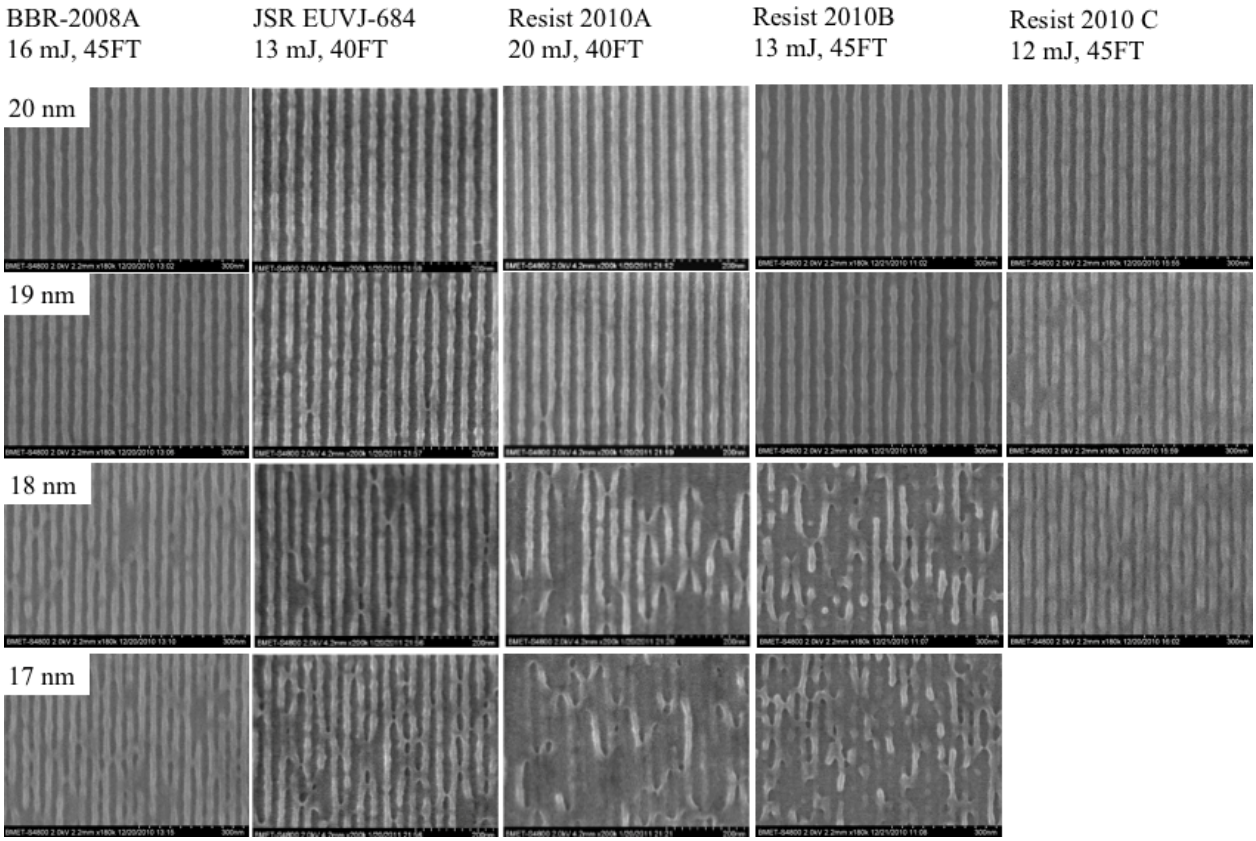


Figure 5. Printing of 20 nm half pitch to 17 nm half pitch in five champion chemically amplified resists using the pseudo PSM imaging method

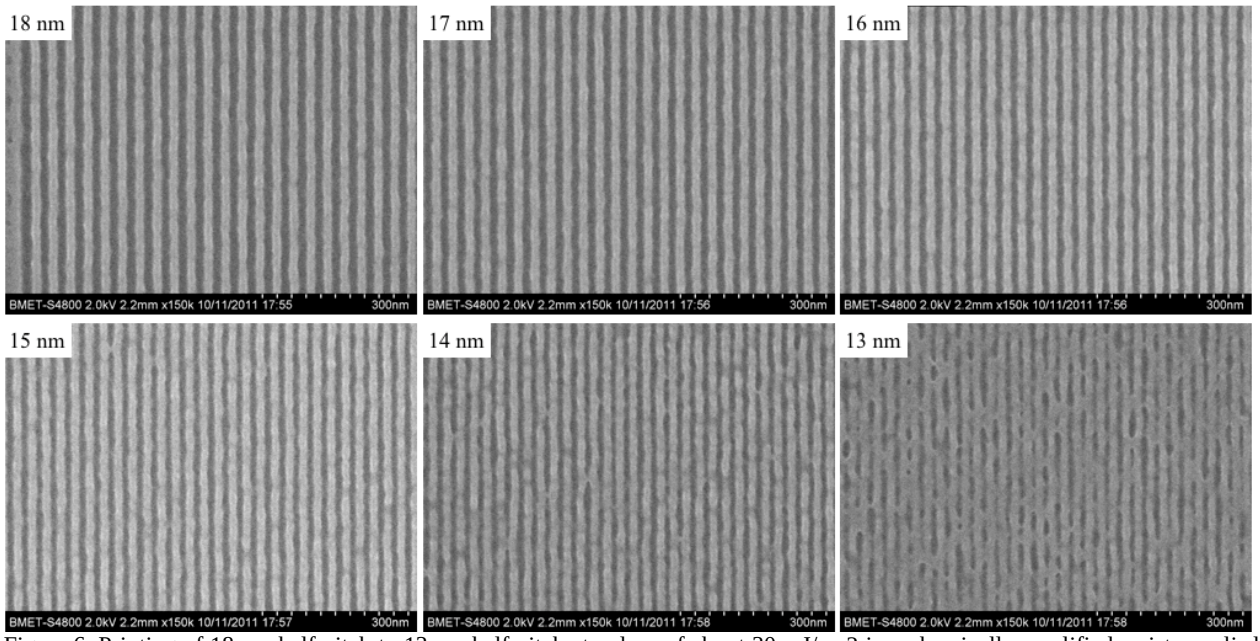


Figure 6. Printing of 18 nm half pitch to 13 nm half pitch at a dose of about 30 mJ/cm2 in a chemically amplified resist supplied by JSR Micro, Inc. using the pseudo PSM imaging method

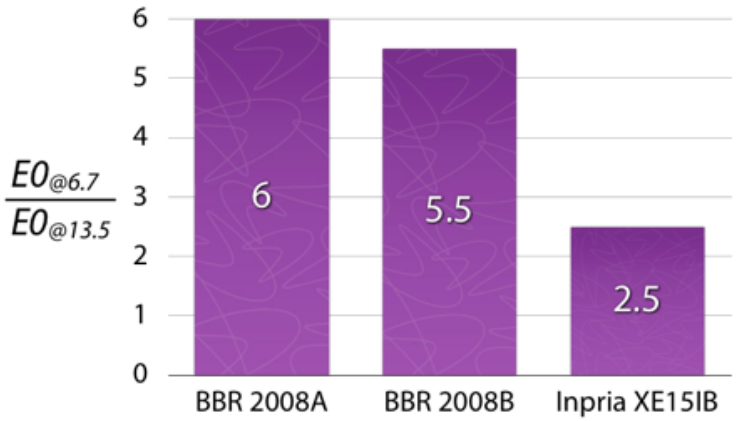
SENSITIVITY OF EUV RESISTS AT 6.X NM

If EUV lithography is extended to 6.x nm, suitable resist materials will need to be developed; a natural starting point is to base 6.x nm resists on 13.5 nm resists. One important factor to consider is the change of sensitivity that occurs when using 13.5 nm resists at 6.x nm. The Berkeley Dose Calibration Tool (BDCT) is well-suited for this study since it uses a syncrotron source that can be tuned to 6.x nm without modifying the system.

Recently, the BDCT was used to measure the the absolute sensitivity of three EUV (13.5 nm) resists at 13.5 nm and 6.7 nm:

1. BBR2008A: organic, chemically amplified
2. BBR2008B: organic, chemically amplified
3. Inpria XE15IB: inorganic, hafnium-based directly imageable hardmask

Figure 7 shows the ratio between the dose to clear at 6.7 nm and the dose to clear at 13.5 nm for each resist. Figure 8 (left) shows the mass attenuation coefficient of elements 1-78 as a function of atomic number and reveals that the reduction of the sensitivity of each resist at 6.7 nm relative to the sensitivity at 13.5 nm is correlated to the reduction of the mass attenuation coefficient of the elements responsible for photoabsorption: Carbon (Z=6) and Oxygen (Z=8) for



the organic resist, and Hafnium (Z=72) for the inorganic directly imageable hardmask.

Figure 7. The ratio between the dose to clear at 6.7 nm and the dose to clear at 13.5 nm for two chemically amplified resists and a directly imageable hardmask.

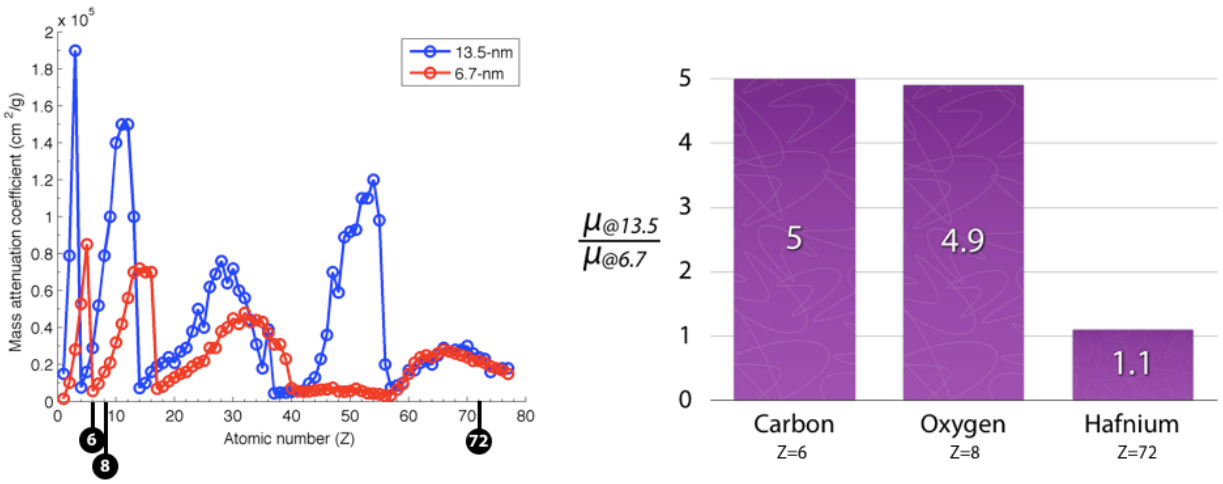


Figure 8. The mass attenuation coefficient of elements 1-78 as a function of atomic number (left) and the ratio between the mass attenuation coefficient at 6.7 nm and the mass attenuation coefficient at 13.5 nm for two chemically amplified resists and a directly imageable hardmask.

The factor of 2.5 reduction of the sensitivity of the inorganic directly imageable hardmask results from the division of photoabsorption events between hafnium and oxygen atoms; the reduction of the averaged mass attenuation coefficient of hafnium and oxygen is a factor of 2.5.

Since the reduction of the sensitivity of the organic resists at 6.7 nm is caused by the reduction of the the mass attenuation coefficient of the elements involved in photoabsorption, it is probable that other organic chemically amplified resists with the same polymer constituents will suffer a comparable reduction of their sensitivity.

SUMMARY

15 nm half pitch patterning has been demonstrated in a chemically amplified resist at a dose of about 30 mJ/cm2. The sensitivity of organic chemically amplified resists at 6.7 nm was shown to be a factor of 6 lower than the sensitivity at 13.5 nm; the reduction of sensitivity is caused by a reduction of the mass attenuation coefficient of the elements responsible for photoabsorption.

ACKNOWLEDGEMENTS

The authors are greatly indebted to the CXRO precision engineering team including Rene Delano, Jeff Gamsby, Bob Gunion, Farhad Salmassi, and Ron Tackaberry for building and maintaining the MET exposure tool. We also thank Jim Thackeray and Katherine Spear of Dow Chemical, Shinji Tarutani of Fujifilm, and Yoshio Kawai of Shin Etsu for excellent resist support. We thank Ted Liang, Robert Chen, and Guojing Zhang of Intel and Seong-Sue Kim and Sungmin Huh of Samsung for mask support. This work was funded by SEMATECH and we thank Bryan Rice and Stefan Wurm for continued support of the SEMATECH MET exposure facility at the Advanced Light Source. The work was performed at Lawrence Berkeley National Laboratory's Advanced Light Source synchrotron facility and was supported by SEMATECH through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231

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