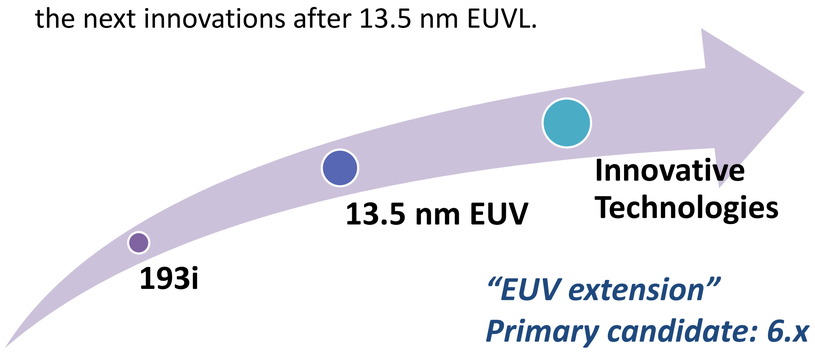
# Prediction of Resist Sensitivity for Extreme Ultraviolet Lithography at 6.x nm Wavelength


Tomoko Gowa Oyama[1,2], Akihiro Oshima[3,4], Dang Nguyen Tuan[3,4], Masakazu Washio[2], Seiichi Tagawa[3,4]

1. QuBS, Japan Atomic Energy Agency (JSPS Postdoctoral Research Fellow)
2. RISE, Waseda University 3. ISIR, Osaka University 4. JST, CREST, c/o Osaka University


## Introduction

The potential extension of EUV to the soft X-ray region ($\lambda$ < 10 nm) has been discussed as one of the next innovations after 13.5 nm EUVL.




We need
- High-intensity exposure source
- High sensitivity resists

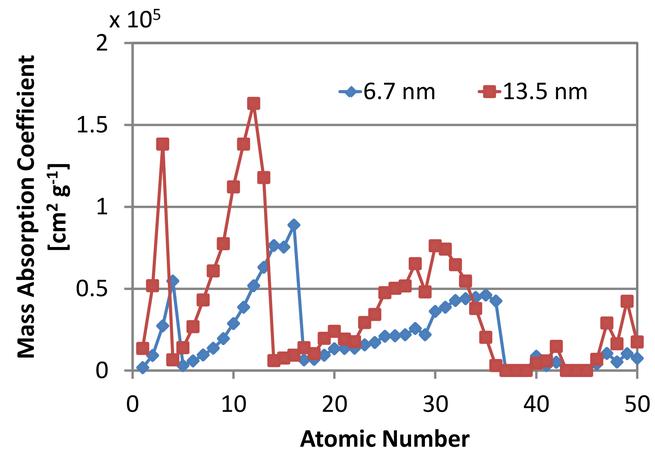
*"EUV extension"*
*Primary candidate: 6.x nm (6.6–6.8 nm)*
*Target feature size: < 11 nm [1]*

***Reports***

I. The resists containing some high absorption elements at the exposure wavelength showed high sensitivities [2].

II. Resists developed for 13.5 nm EUV showed low sensitivities at 6.x nm [3].

***Resist sensitivities (E) at 6.x nm ≠ E at 13.5 nm, due to the different absorption coefficients (α).***

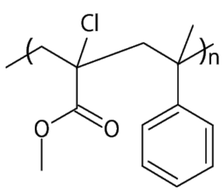



***Once the sensitivity for a certain wavelength is experimentally obtained, can we predict the resist sensitivities at any exposure wavelength?***

## Experimental

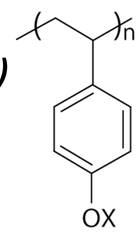
### Resists

***ZEP (ZEON Co.)***
(α-chloromethacrylate -co- α-methylstyrene)



**Chain-scission (Positive)**
ZEP520A and ZEP7000 with different *M*w.

***OEBR-CAP112 (Tokyo Ohka)***
(PHS-based chemically-amplified)



**Acid-induced polarity change (Positive)**

| | ZEP520A | ZEP7000 | OEBR-CAP112 |
|---|---|---|---|
| PAB | 180°C , 180 s | 180°C, 180 s | 90°C , 90 s |
| PEB | --- | --- | 110°C , 90 s |
| Development | ZED-N50, 60 s @ 13°C | ZED-500, 60 s @ 13°C | NMD-3, 90s @ 25°C |
| Rinse | ZMD-B, 10 s | ZMD-D, 10s | Deionized water, 10 s |
| Thickness | 80 nm | 80 nm | 95 nm |

### Exposure Source

***Monochromated EUV/soft X-rays***

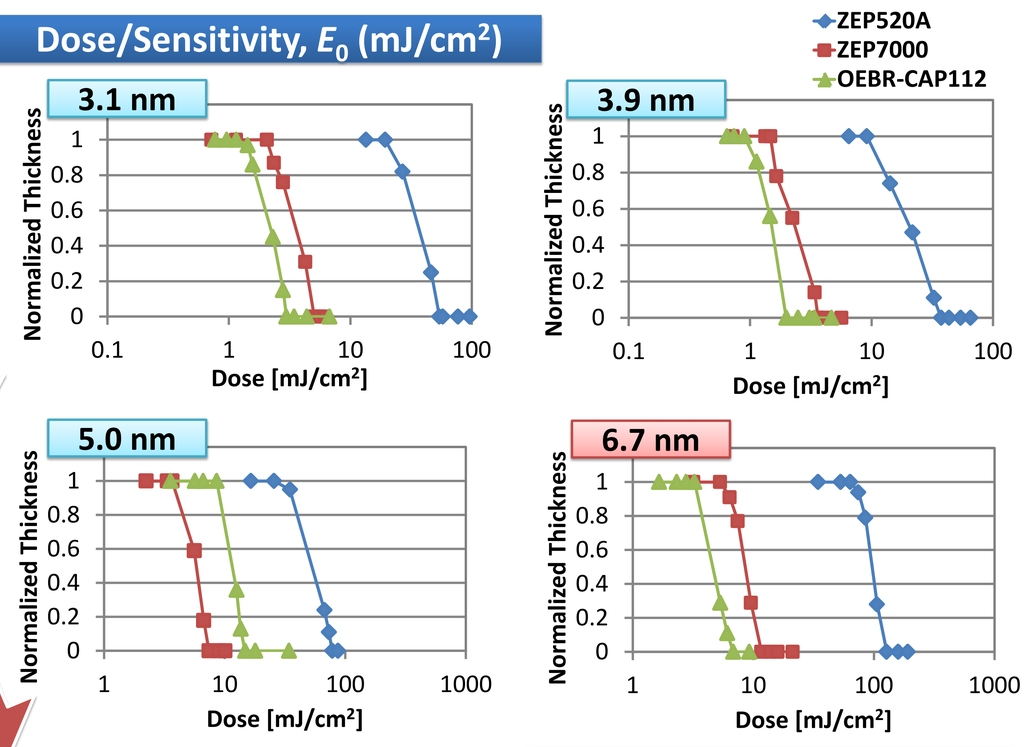
- ☐ SPring8 (8 GeV, 100 mA) BL27SU
- ☐ Energy spread: *E/dE* = 50,000
- ☐ RT under vacuum (< 1E-4 Pa)
- ☐ Flux: 2 × $10^{11}$ photons $s^{-1}$ $mm^{-2}$

***Selected wavelengths (energies)***
3.1 nm (400 eV), 3.9 nm (320 eV)
5.0 nm (250 eV), **6.7 nm (185 eV)**

**SPring8 BL27SU**

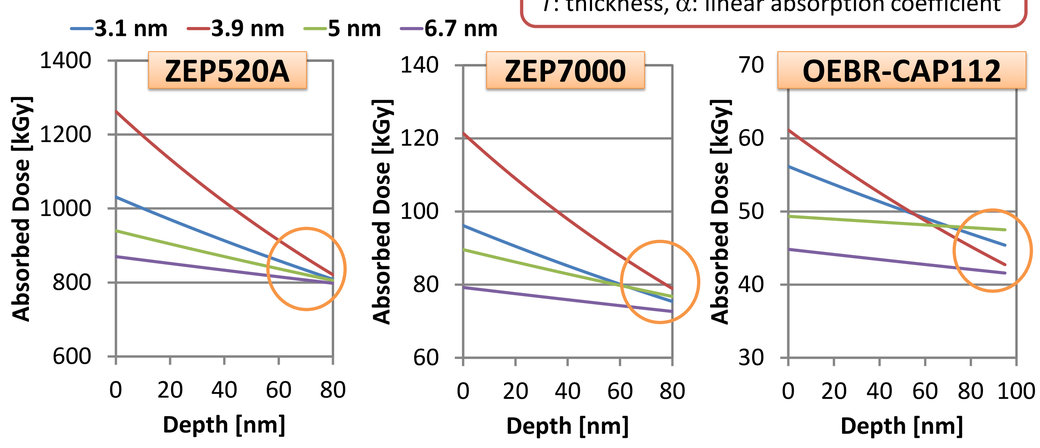
## Results & Discussion

### Dose/Sensitivity, $E_0$ (mJ/cm²)




### Absorbed Dose, *D* (J/kg =Gy)

$$D(T) = \alpha E_0 \exp(-\alpha T)$$
*T*: thickness, α: linear absorption coefficient




***Absorbed doses at the bottom of the resists ($D_0$) were almost constant for each resist !***

### Prediction of Sensitivities

Absorbed doses for EUV/soft X-rays, $D_0$ [kGy]

| λ (nm) | ZEP520A | ZEP7000 | OEBR-CAP112 |
|---|---|---|---|
| 3.1 | 808 | 75 | 45 |
| 3.9 | 821 | 79 | 43 |
| 5.0 | 805 | 77 | 47 |
| 6.7 | 798 | 73 | 42 |

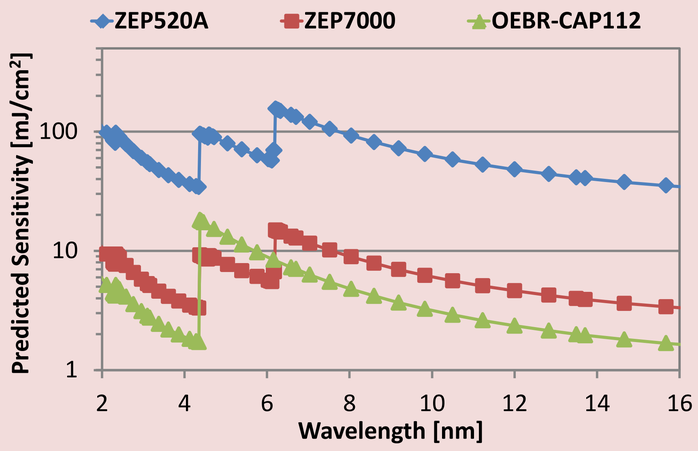
*"Each resist has a particular required absorption dose regardless of exposure wavelength" [3]*

Positive-tone: $D_0 = \alpha E_0 \exp(-\alpha T_0) = \text{const.}$
Negative-tone: $D_{0.5} = \alpha E_{0.5} \exp(-\alpha T_{0.5}) = \text{const.}$

Sensitivity at any EUV/soft X-ray wavelength can be theoretically estimated with the linear absorption coefficients and an experimentally obtained sensitivity at a certain wavelength.

*For example,*

### Prediction from Sensitivities for 3.9 nm




Predicted sensitivity and [Obtained sensitivity] (mJ/cm²)

| λ (nm) | ZEP520A | ZEP7000 | OEBR-CAP112 |
|---|---|---|---|
| 3.1 | 55.1 [54.3] | 5.3 [5.1] | 2.85 [3.0] |
| 5.0 | 79.5 [77.9] | 7.7 [7.4] | 13.1 [14.8] |
| 6.7 | 133 [129] | 12.8 [11.8] | 7.04 [6.8] |

***The experimentally obtained and theoretically predicted values agreed well !!***

***Sensitivities for 6.x nm can be predicted by experiments for 13.5 nm EUV.***

Linear absorption coefficient, α [/μm]

| λ (nm) | ZEP | PHS |
|---|---|---|
| 13.5 | 4.59 | 3.66 |
| 6.7 | 0.96 | 0.79 |

With the same sample thickness and the same development conditions,

$E_{0\,(6.7\,nm)}$ of ZEP ≈ 3.2 x $E_{0\,(13.5\,nm)}$
$E_{0\,(6.7\,nm)}$ of PHS-based resists ≈ 3.5 x $E_{0\,(13.5\,nm)}$

## Summary

- ✓ Prediction of the sensitivities for 6.7 nm was performed, assuming that each resist has a particular required absorption dose regardless of exposure wavelength.
- ✓ The obtained and theoretically predicted sensitivities agreed well, thereby confirming the validity of the prediction.
- ✓ Sensitivities for 6.x nm can be roughly predicted by ones for 13.5 nm EUV.
- ✓ The predictions of the resist sensitivity demonstrated here will be useful for the selection or novel development of high sensitivity resists for future extension of EUVL.

## Acknowledgments


T. G. O acknowledges support of a Grant-in-Aid for JSPS Fellows 21-04550 and 24-9069. The synchrotron radiation experiments were performed at the BL27SU of SPring-8 with the approval of the JASRI (No. 2011B1369 and 2012A1365). A part of this work was supported by the RISE project of Waseda University (11L01) and the "Nanotechnology Network Project" (Handai Multi-Functional Nanofoundry) of MEXT, Japan.


## References


[1] H. Meiling, presented at SEMICON West 2010 (2010), [2] C. Anderson, et al., Proc. SPIE 8322, 832212 (2012), [3] T. G. Oyama, et al., AIP Adv. 1, 042153 (2011).