EUV Resist Sensitivity to Out of Band (OOB) Radiation

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Outline

- The problem of OOB radiation (with wavelength from 100 – 350 nm)
- Experimental data on absorbance and sensitivity of EUV resists to OOB radiation
- Discussion on expected sensitivity of next generation EUV resists to OOB radiation.
- Conclusions

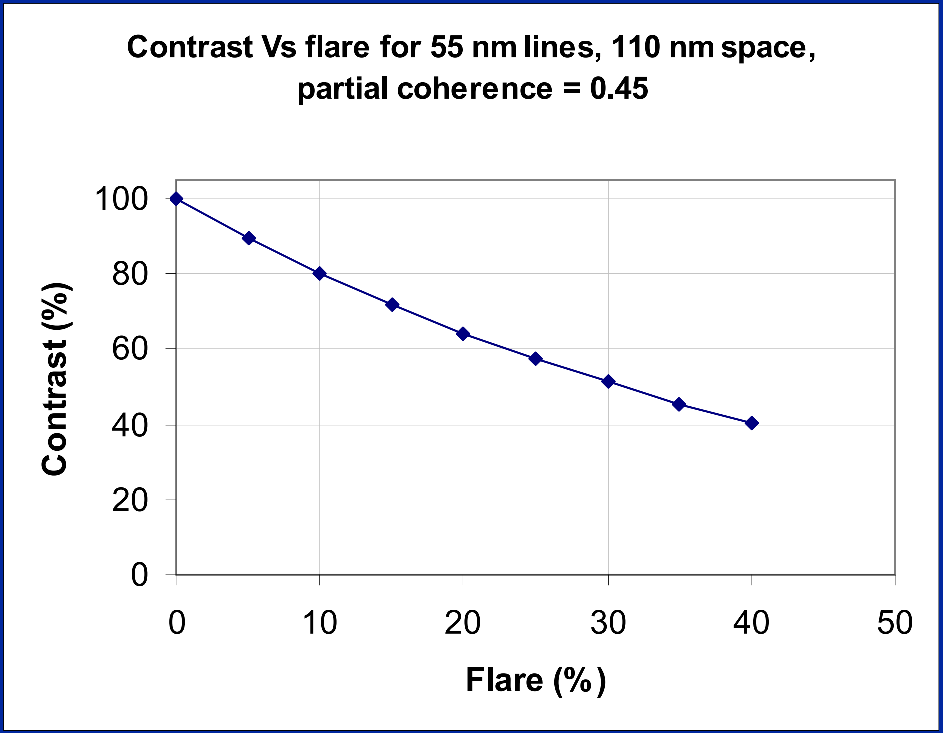
What causes the OOB problem?

OOB radiation is expected to act like flare, reducing the aerial image contrast, since the following three conditions occur:

- EUV sources generate OOB radiation

- EUV optics efficiently reflect the OOB radiation to the wafer plane

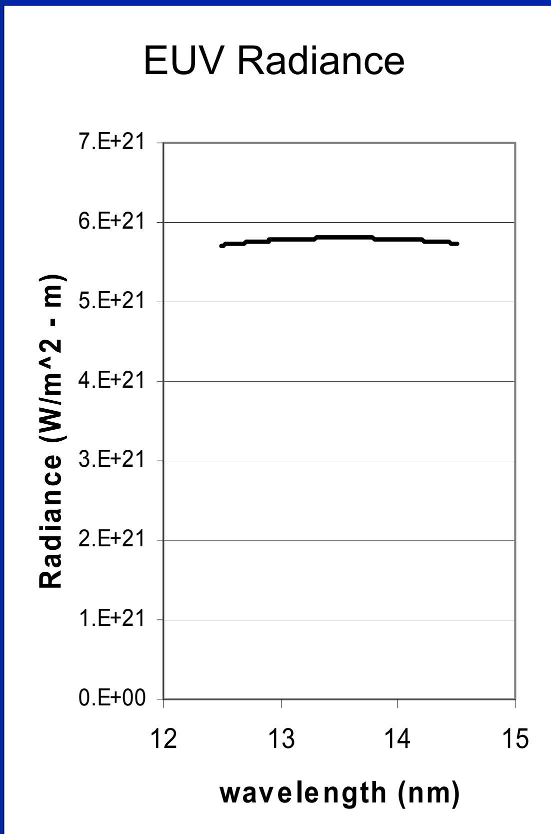
- EUV resists are sensitive to the OOB radiation that has been projected to the wafer plane

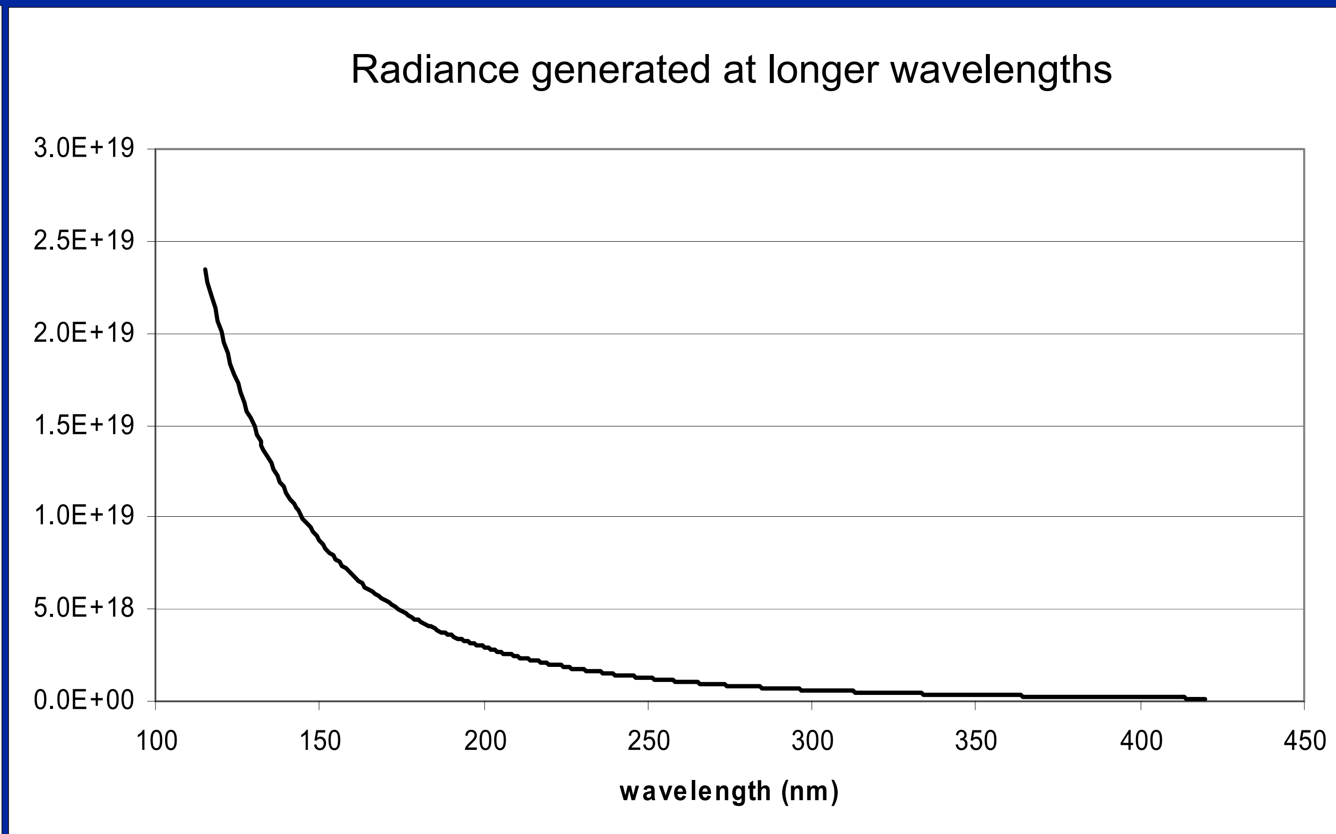


A Spectral Purity Filter would eliminate OOB radiation at the price of a large reduction in EUV power and hence throughput.

Source emission

EUV sources will generate some OOB radiation; below shows 18.5eV blackbody as a simple model.

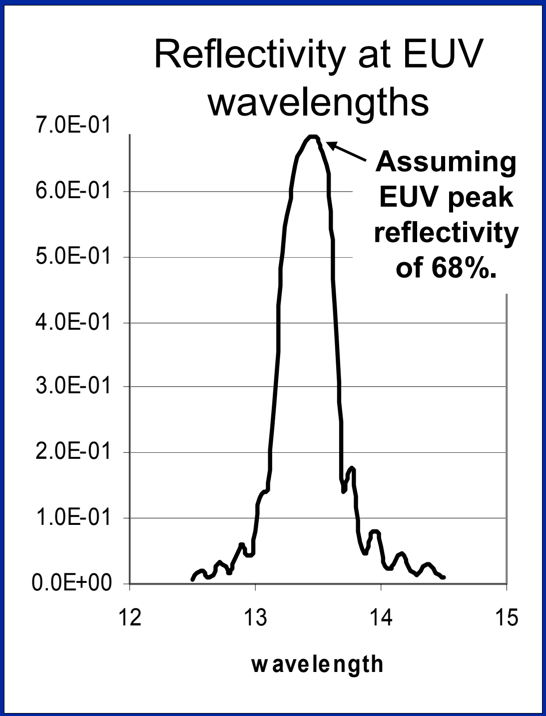


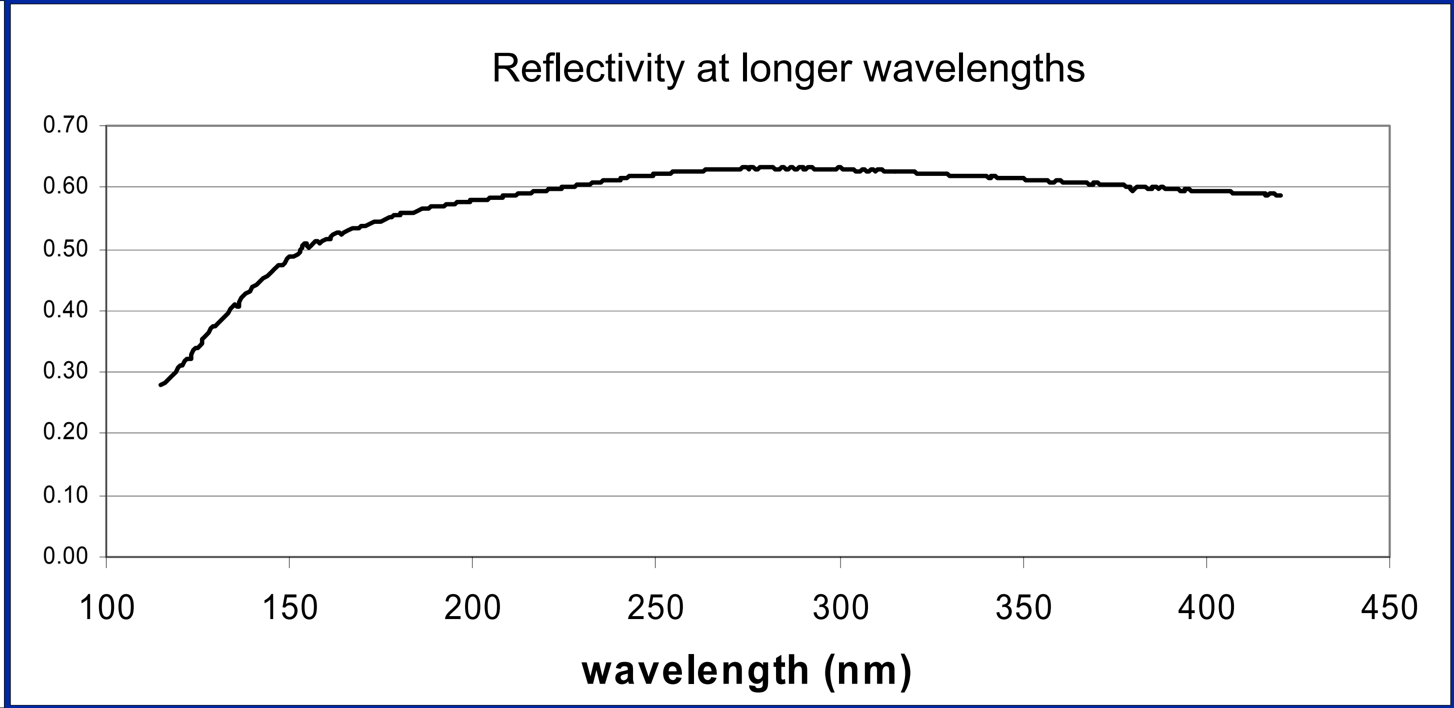


EUV/OOB emission: I(13.5nm+-2%)/I(150-300nm) ~ 24%.
The actual source may have better performance; see source presentations for more details.

Reflectivity of a single EUV optic

Reflectivity from 100-350nm is comparable to EUV.





The EUV reflectivity is based on theoretical predictions with some interdiffusion/roughening. The reflectivity for longer OOB wavelengths is measured on a Ru-capped multi-layer (provided courtesy of NIST).

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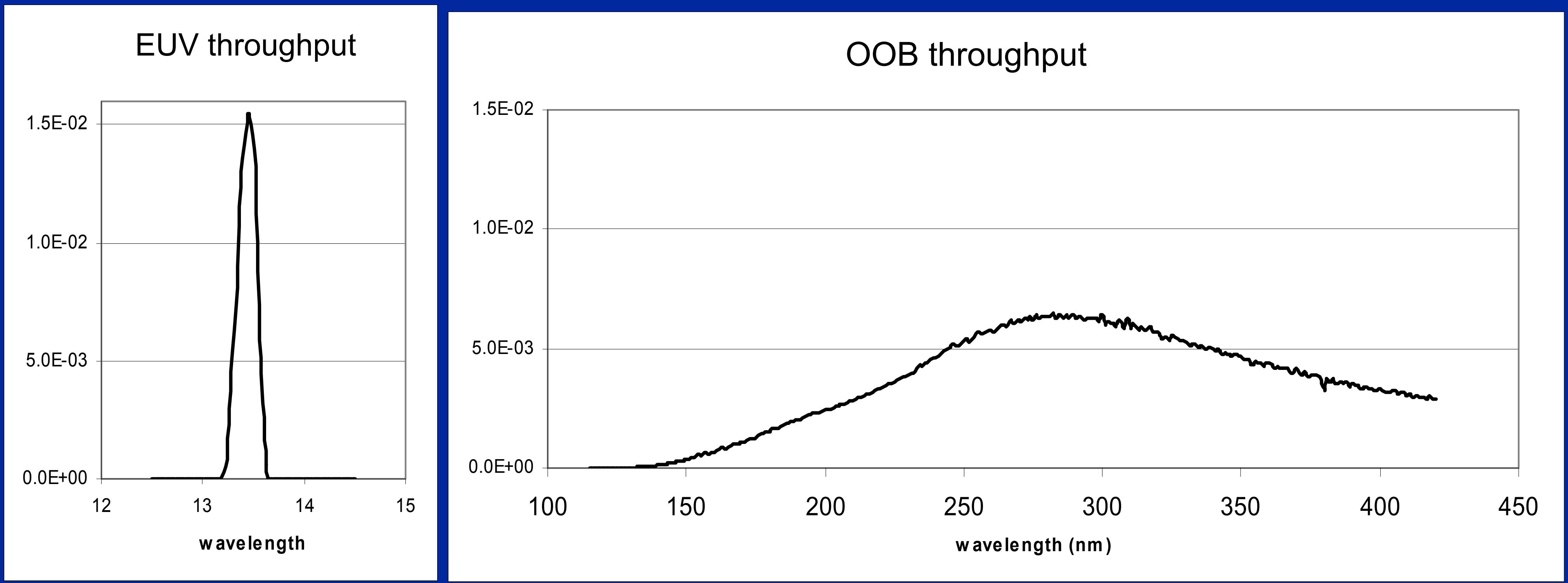
Net reflectivity of optics train.

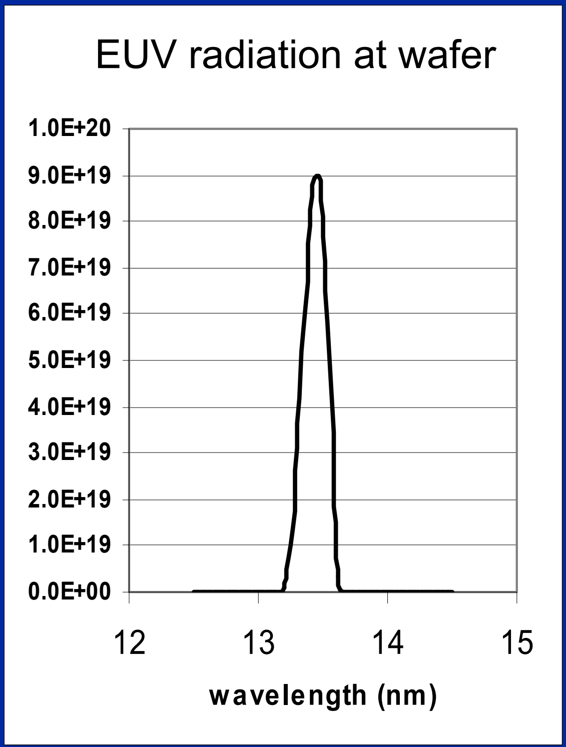
The reflectivity for a single ML mirror is raised to power 11 to predict the throughput for the total optics train. Graphs below shown at same y-scale.

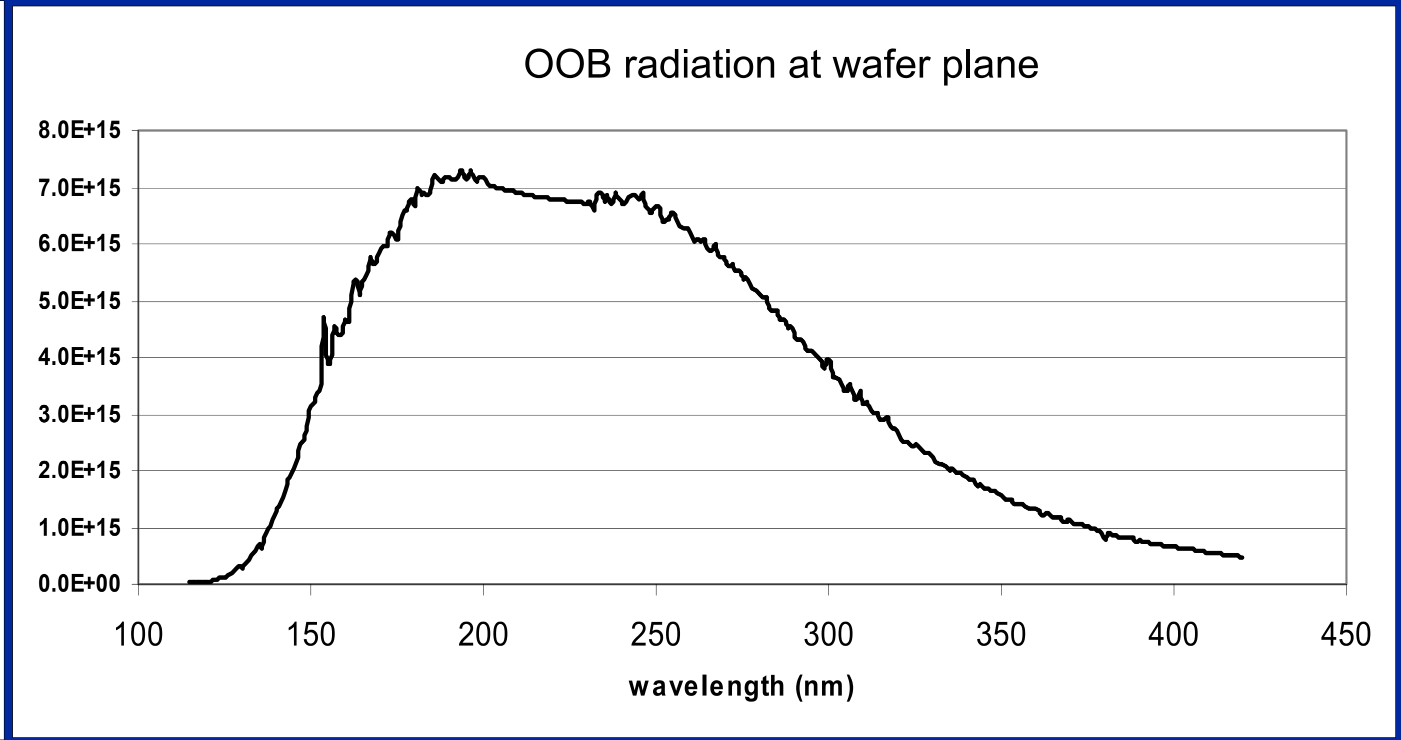


Although the reflectivity of the optics train at EUV wavelengths is higher, the large range of wavelengths that are reflected by the EUV optics may be problematic.

Dose at wafer plane

Radiation at wafer plane = Source emission X net reflectivity.

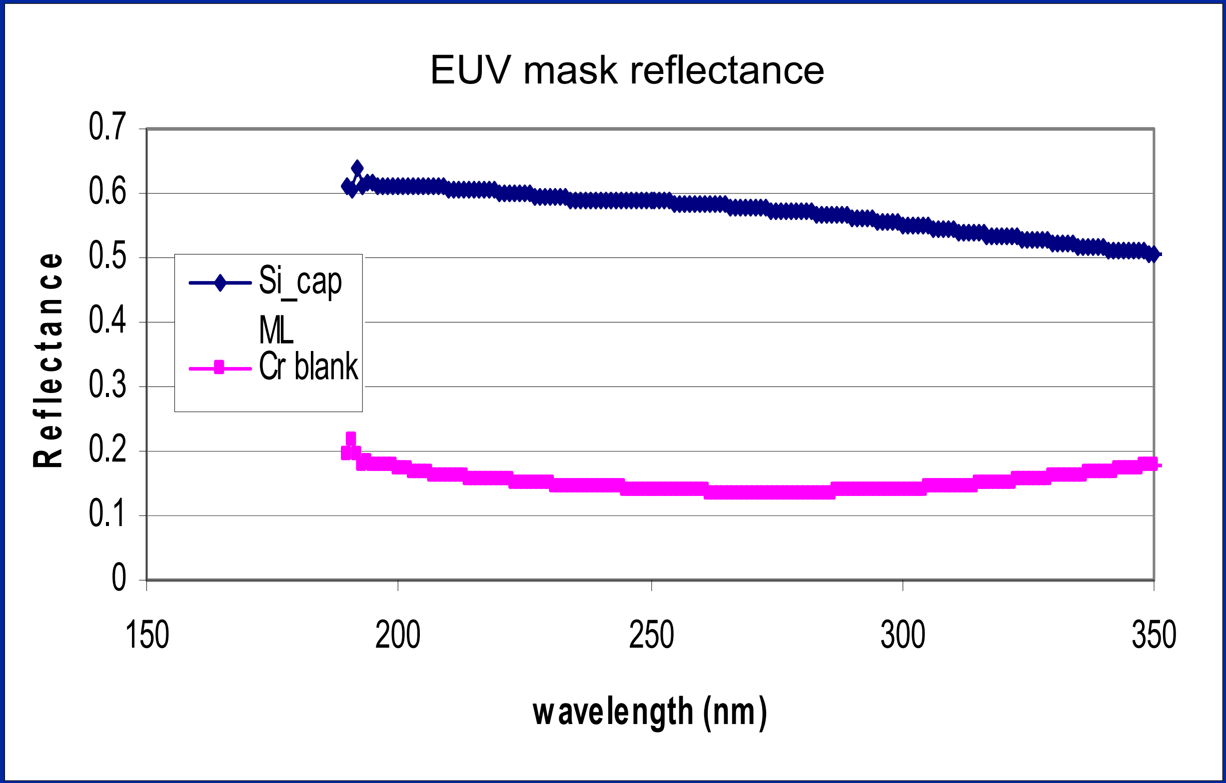




- **The integrated dose from 100nm to 300nm is about 5% of the EUV dose; for an EUV dose of 5mJ/cm^2, the OOB dose would theoretically be 0.25 mJ/cm^2.**
- **The actual case may be better: 1) Realistic sources may have less OOB, 2) Mask absorb and scatter of OOB, 3) Resists will not be equally sensitive to OOB at all wavelengths.**

Reflectance of absorber

Reflectance of chrome absorber is lower than the silicon capped multilayer.

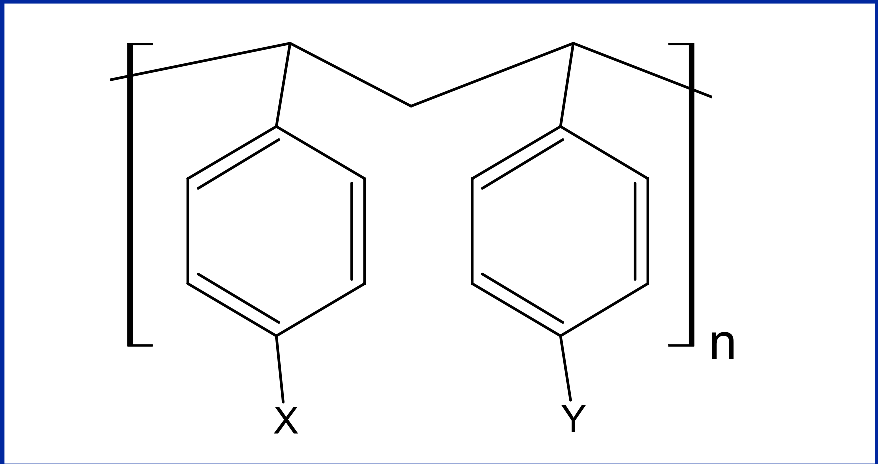


Since much of the OOB radiation will be absorbed by the chrome absorber, the OOB radiation would be expected to cause double exposure flare in the open areas, and pattern density dependant flare in the patterned areas.

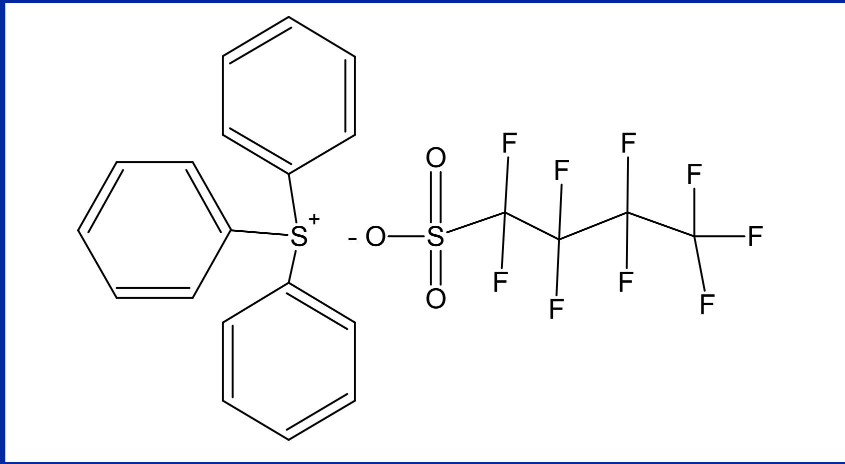
What about photoresist sensitivity to OOB radiation?

The sensitivity of EUV resists to OOB radiation is correlated with the absorbance of the resist at these wavelengths, especially photoacid generator (PAG) absorbance.

Generic chemical structure of some EUV resists.



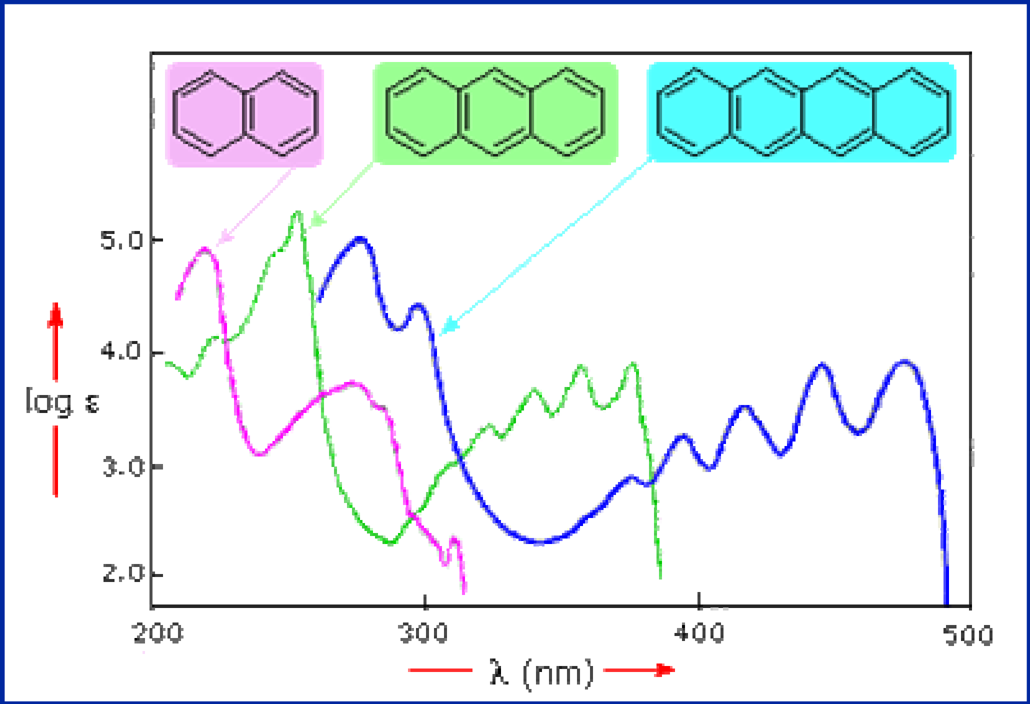
EUV polymers of some resists are based on polystyrene platforms.



EUV PAGs may be aromatic.

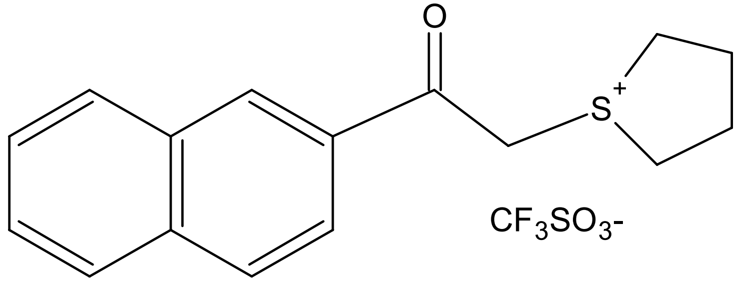
Absorbance of EUV resists at OOB wavelengths

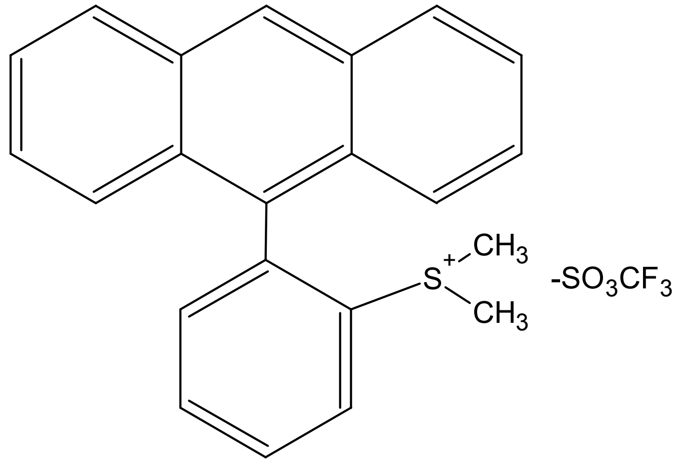
EUV resists (based on styrene) are expected to have high absorbance at ~200 nm, moderate absorbance at ~250 nm, and low absorbance at 350 nm (as seen for ArF, KrF, and i-line lithography). EUV resists may absorb at longer wavelengths if large aromatics are incorporated into the resist.



http://www.cem.msu.edu/~reusch/VirtualText/Spectrpy/UV-Vis/spectrum.htm

PAGs with large aromatics

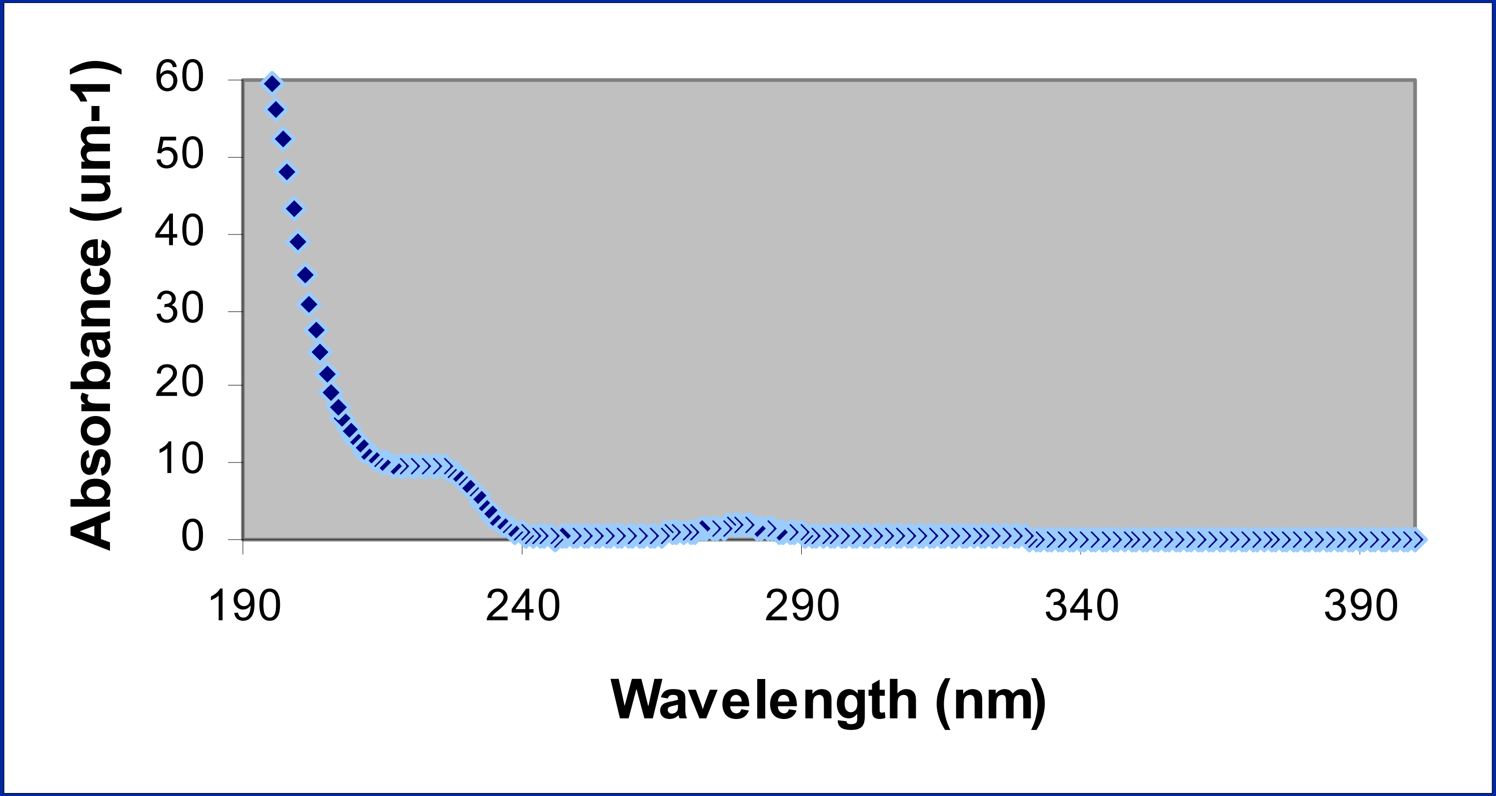




A few PAGs with large aromatics have been designed, and could potentially be used at EUV. If these PAGs were used at EUV, the resists would show more sensitivity to long wavelength OOB radiation.

1) Tsuji, S., et. al., J. Photopolym. Sci. Tech., 13(5), p. 733
2) Zhou, W., et. al., J. Am. Chem. Soc., 124(9), p.1897

Absorbance of EUV Resist "A"



OOB radiation with the following wavelength:

190 – 210 nm – High absorbance

210 – 300 nm – Moderate absorbance

> 300 nm – Absorbance ~ 0

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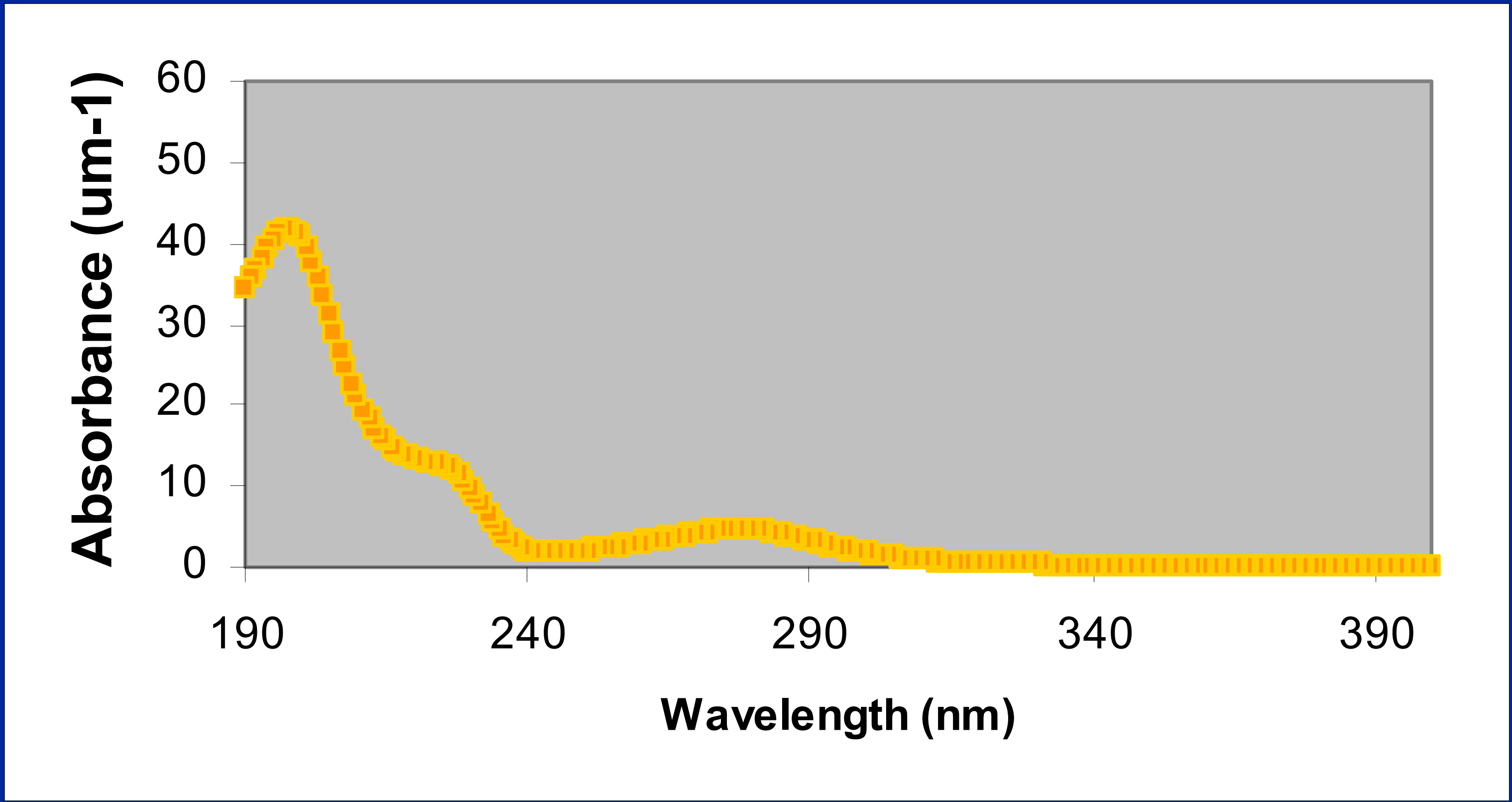
Absorbance of EUV Resist "B"



OOB radiation with the following wavelength:

190 – 210 nm – High absorbance

210 – 300 nm – Moderate absorbance

> 300 nm – Absorbance ~ 0

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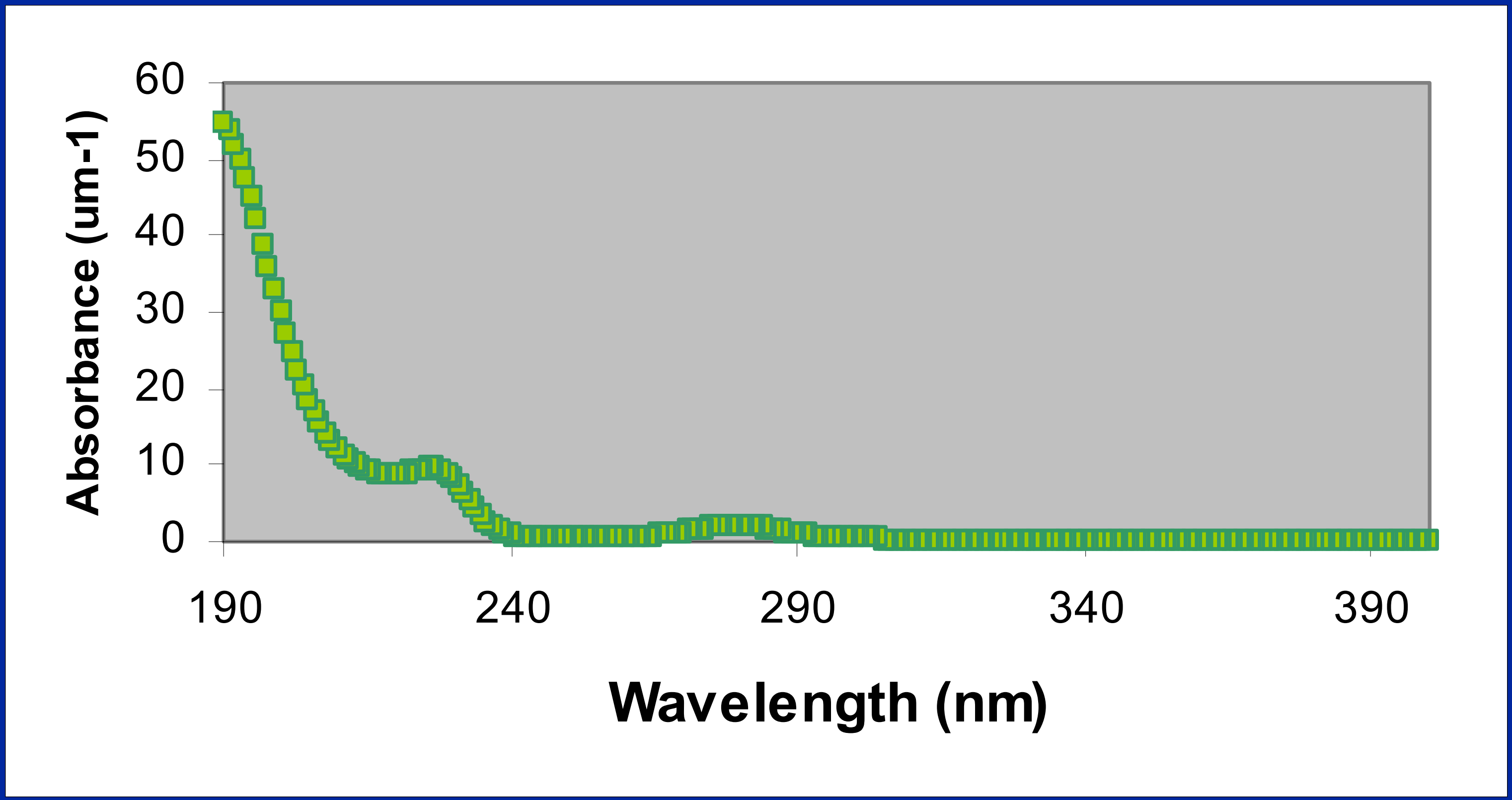
Absorbance of EUV Resist "C"



OOB radiation with the following wavelength:

190 – 210 nm – High absorbance

210 – 300 nm – Moderate absorbance

> 300 nm – Absorbance ~ 0

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Dose to clear (Eo) for various exposure wavelengths

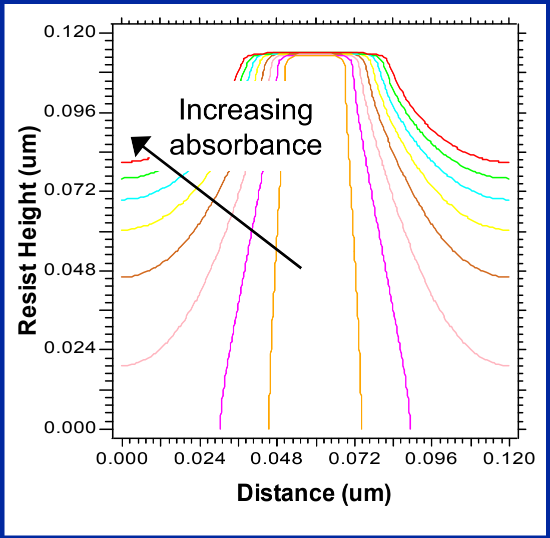
Values of Eo provided by a number of resist suppliers follow the expected trends.

Eo (248 nm) ≈ Eo (EUV)

(Consistent with expectations, since EUV and DUV resists have similar structure.)

Eo (193 nm) > Eo (EUV)

(Top rounding, sloped sidewalls observed, as predicted by resist model for high absorbance High doses needed to clear resist, since most photons will be absorbed at top surface of resist.)



Eo (365 nm) >> Eo (EUV)

(The dose needed for 365 nm radiation to clear an EUV resist is estimated to be 3-4 orders of magnitude higher than the EUV dose.)

Next generation EUV resists

- Novel resists platforms have been proposed for EUV including molecular resists, silicon containing resists, etc. These changes to polymer backbone are not expected to have a significant impact to resist sensitivity to OOB radiation.

- New PAG chemistry is expected to dominate the resist sensitivity to OOB radiation, and novel PAG development could significantly impact the resist sensitivity to OOB radiation.

Conclusions

- Using measured ML reflectivity and modeling the source as a blackbody, the wafer dose from 150-300nm is significant compared to the EUV dose (without a spectral purity filter).
- This OOB radiation delivered to the wafer plane is expected to cause flare, reducing aerial image contrast. Even a 1% gain in effective flare could significantly degrade imaging performance.
- Initial results indicate that the sensitivity of resist to OOB radiation is high for wavelengths from 150 nm – 300 nm.
- Measured data is needed to quantify the impact of OOB radiation on resist performance.

Possible solutions

- Design a resist that is less sensitive to OOB radiation from 150 nm – 300 nm.

  → It is unlikely that a PAG could be designed with low sensitivity to OOB radiation that meets EUV resist sensitivity, outgassing, resolution, and LWR targets.

- Add an DUV absorptive coating to optics and/or spectral purity filter (SPF).

  → Would degrade throughput of EUV tools.

- Design source with lower OOB radiation (better than the 24% OOB/EUV of 18.5 eV blackbody).

  → This may be possible, depending on source elements. In addition to emitting plasma, attention must also be given to neutral gas lines, metastables, etc.

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Acknowledgements

- Resist suppliers
- NIST (multilayer reflectivity data)