Techniques for directly measuring the absorbance of photoresists at EUV wavelengths

Manish Chandhok,[a] Heidi Cao,[a] Wang Yueh,[a] Eric Gullikson,[b] Robert Brainard,[c] Stewart Robertson[c]

a Intel Corporation, Hillsboro, OR 97124

b Lawrence Berkeley National Laboratory, Berkeley CA

c Shipley Company, Marlborough, MA

1 October, 2003

Acknowledgements: E. Lin (NIST), G. Zhang (Intel)

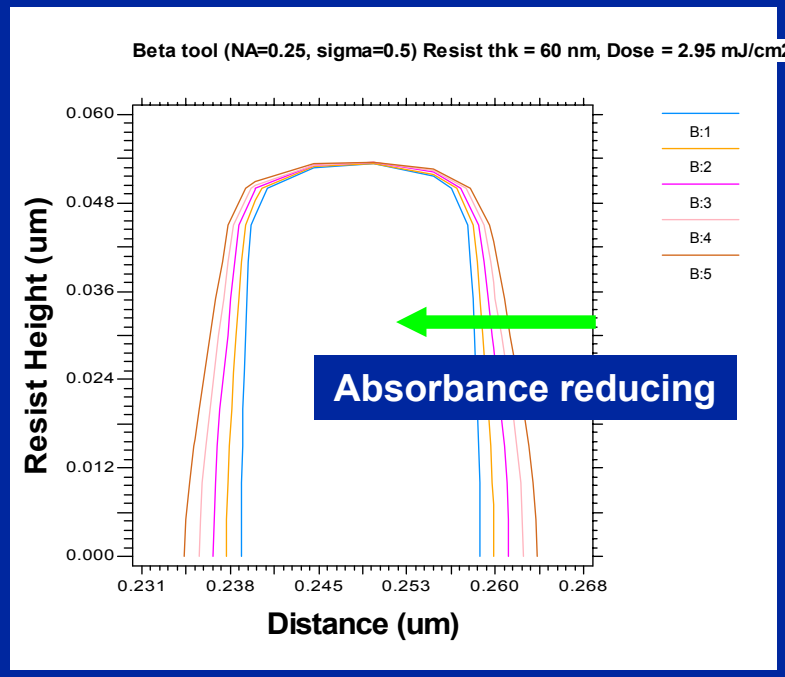
Motivation

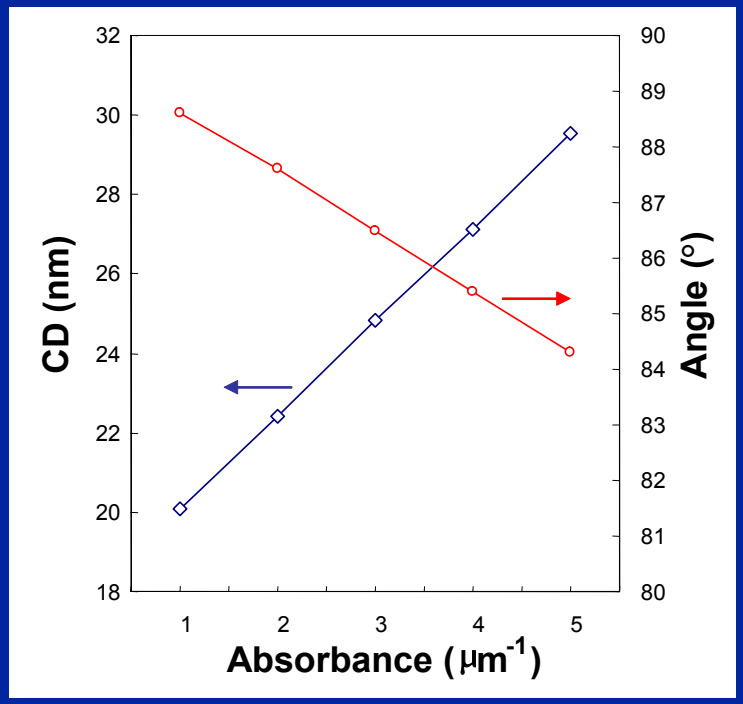
- Resist absorbance is a key parameter that can limit resolution and wall angle
- Calculations such as those by the CXRO website* are typically used for estimating absorbance
  - However, there is limited validation of the calculated absorbance against measurements
- Experimental methods need to be investigated and a technique selected

* http://cxro.lbl.gov/optical_constants

intel®

Simulated effect of reducing photoresist absorbance





- Reducing absorbance increases resolution and wall angle

intel®

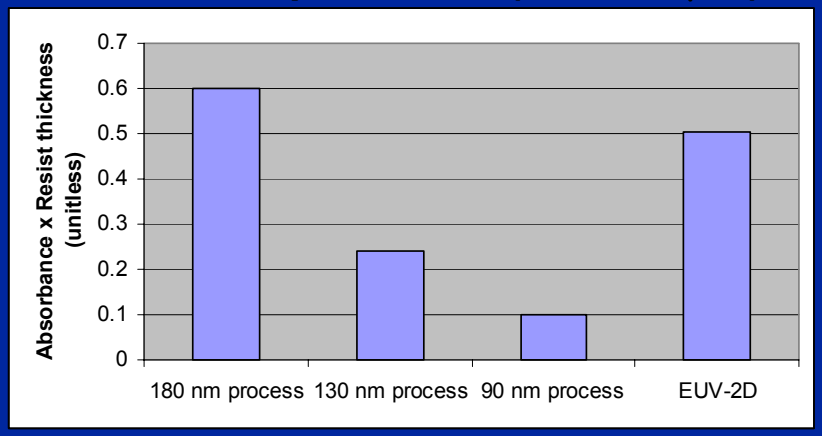
What is the target absorbance for EUVL?

- Beer's law states that intensity of light decreases exponentially with thickness in an absorbing media

$$I(z) = I_0 \exp(-\mathrm{B} \times z)$$

where z = resist thickness, B = Absorbance or "Dill" B parameter (units: 1/μm)

Parameter that matters is (B × z) that's been decreasing with process generation



- For B x z ~ 0.1, with resist thickness of 60 nm target absorbance needs to be ~ 2 1/μm

Calculating the absorbance using the CXRO website

Complex refractive index *n* is given by $$n = 1 - \delta + i\beta$$

where $$\delta \cong \frac{r_0}{2\pi}\lambda^2 n_a \sum_i x_i f_{1i}$$ $$\beta \cong \frac{r_0}{2\pi}\lambda^2 n_a \sum_i x_i f_{2i}$$ $$n_a = \frac{\text{Density} \times N_A}{\text{MW}}$$

r_0 = classical electron radius,

λ= wavelength of the radiation,

n_a = atomic density of the material,

$$\therefore \text{Absorbance} = \frac{4\pi}{\lambda}\beta$$

f_1 and f_2 are the real and imaginary parts of the atomic scattering factor that have been tabulated for various elements

- **Model requires the following to calculate absorbance:**
  - Empirical chemical composition → $$\text{MW} = \sum_i x_i A_i$$
  - Density in gm/cm^3

intel®

Procedure for validating the calculated absorbance of Shipley's EUV-2D resist

- <u>Calculation using CXRO website with:</u>
  - Density obtained by measuring the mass and the film thickness of resist spun on wafers
  - Density obtained by Specular X-ray Reflection (SXR) measurements and elemental composition
- <u>Experiment:</u>
  - Obtain absorbance using normal incidence reflectivity measurements
  - Measure absorbance using grazing incidence reflectivity

intel®

Calculation Method 1: Estimate from CXRO Model using Weighed Density

- The chemical composition of EUV-2D was estimated
- Density was determined by weighing six wafers before and after coat and using knowledge of surface area and thickness.
  - Resulting value was 1.28 g/cm^3
- Using the values for δ and β from the CXRO website to obtain n & absorbance value at 13.5 nm
  - n = 0.9748
  - Absorbance = 4.635 1/μm

intel®

Calculation Method 2: Estimate from CXRO Model using SXR Density

- EUV-2D was characterized with specular x-ray reflectivity (SXR) measurements at NIST to obtain the critical angle (Qc2) and resist thickness
- Density can be determined from knowledge of Qc2 and the materials elemental composition
  - Resulting value was 1.1497 g/cm^3
- Using the values for δ and β from the CXRO website to obtain n & absorbance value at 13.5 nm
  - n = 0.9774
  - Absorbance = 4.160 $1/\mu m$

intel®

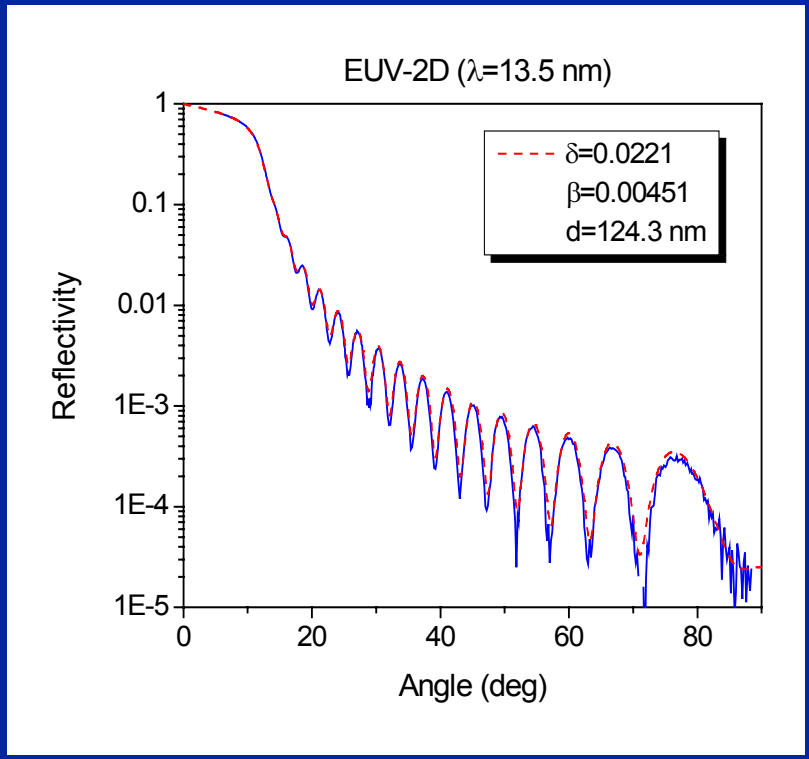
Measurements Method 1: Grazing incidence

- Technique is valid provided $\beta < \delta$
- Fresnel equations for reflectivity

$$R_s(\theta) = \left| \frac{\sin(\theta) - \left[(1-\delta+i\beta)^2 - \cos^2(\theta)\right]^{1/2}}{\sin(\theta) + \left[(1-\delta+i\beta)^2 - \cos^2(\theta)\right]^{1/2}} \right|^2$$

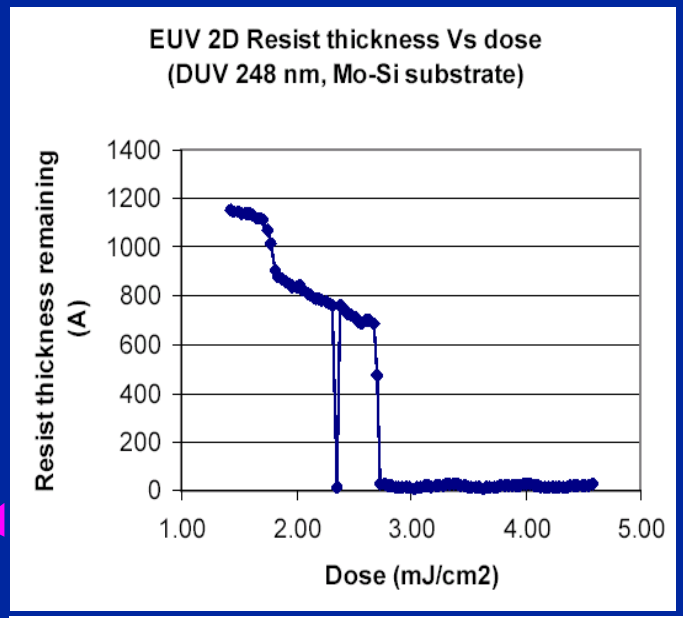
$$R_p(\theta) = \left| \frac{(1-\delta+i\beta)^2 \sin(\theta) - \left[(1-\delta+i\beta)^2 - \cos^2(\theta)\right]^{1/2}}{(1-\delta+i\beta)^2 \sin(\theta) + \left[(1-\delta+i\beta)^2 - \cos^2(\theta)\right]^{1/2}} \right|^2$$

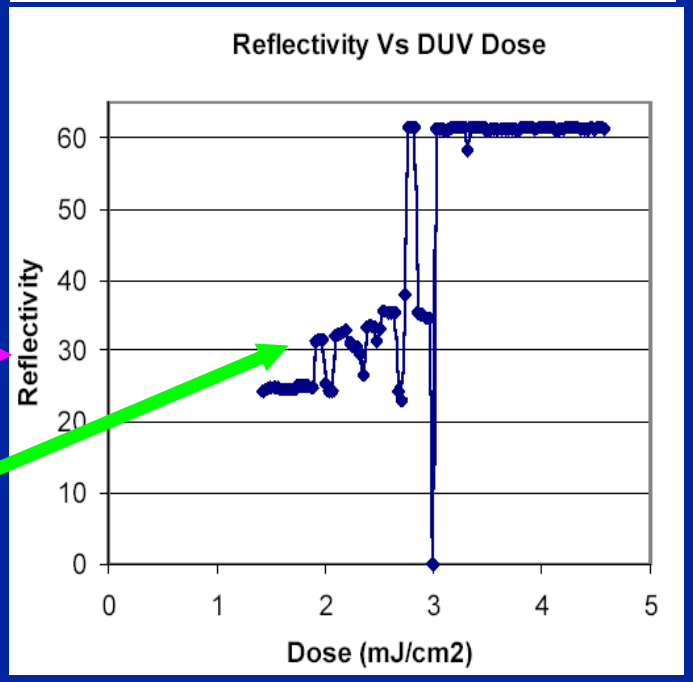
- The grazing incidence reflectivity at 13.5 nm of EUV-2D coated on silicon was measured as a function of angle
- δ and β obtained by fitting experimental data with the Fresnel equations
- The resulting optical parameters were:
  - n = 0.9779
  - Absorbance = 4.198 1/μm



Measurements Method 2: Normal Incidence Reflectivity

- 8” Mo-Si Multi-layer (ML) wafer to get a reflective substrate for normal incidence
- Resist, exposure, and processing by Shipley
  - 1200 A of EUV-2D
  - 10 x 10 array, 1 cm square, Eo exposure pattern using 248 nm
  - PEB, develop
- Thickness remaining at each site measured
- Normal incidence reflectivity measured at each site

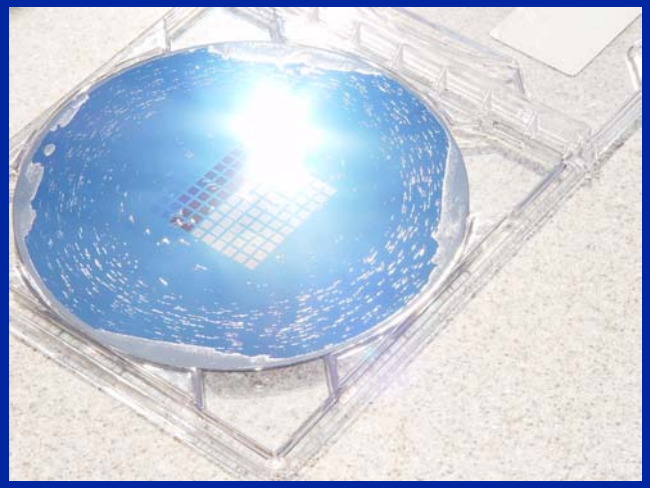




Noise in data due to poor coat quality

intel®

Images of E_0 pattern of EUV-2D resist on Mo/Si ML wafer



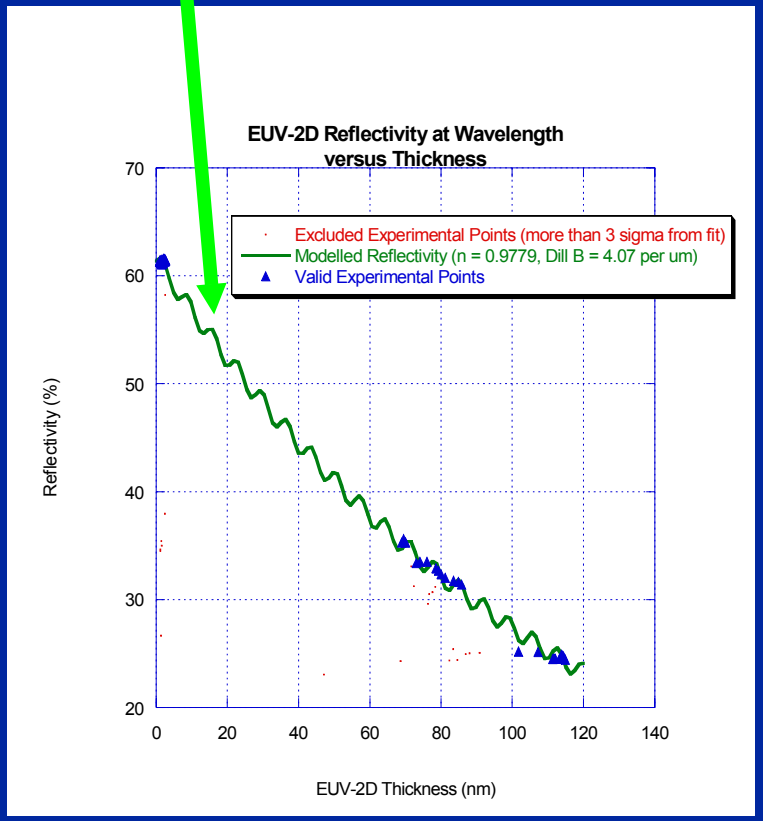
- Multilayer surface yielded poor resist coating quality
- Non-uniform coating increased the noise of reflectivity measurements

intel®

Fitting normal incidence reflectivity Vs resist thickness to obtain the absorbance

- Reflectivity versus thickness data was simulated for various Dill B values (*n* held constant at 0.9779) using lithography simulator
- To reduce the impact of noise in the fit
  - Points lying out with 3 sigma of the model are discarded
  - Sigma value is recalculated and the process iterated until sigma stabilizes.
- Dill B (absorbance) value returning lowest sigma is statistically the best fit
  - Absorbance = 4.07 1/μm

Ripples occur due to standing wave in resist from index of refraction mismatch between resist and reflective substrate



intel®

Data Summary

Calculation	n	Absorbance (1/um)
Weighed method density	0.9748	4.635
SXR method density	0.9774	4.16
Measurements	**n**	**Absorbance (1/um)**
Grazing incidence	0.9779	4.198
Normal incidence	N/A	4.071

Recommended

Recommended

- **The absorbance calculated using the SXR method for the density matches the Grazing Incidence measurements within 1%**

intel®

Discussion

- Density using the Weighed method is prone to error in measurement of the mass of the sample and thickness
  - Hence, density and thus absorbance estimated by Weighed method is 10% higher than that using the SXR method which is more accurate
- The normal incidence measurements require a ML reflective substrate that can be expensive and may have coat quality issues
  - The ripples in the normal incidence reflectivity measurements are modulated by real part of the index of refraction (n). But the noise observed in the experimental data is greater than the ripple amplitude and hence (n) cannot be measured this way
- Grazing incidence measurements are valid provided absorbance is low i.e., $\beta < \delta$
  - Even with $\delta = 0.01$, absorbance values of 10 1/μm and below can be measured using this technique which is the expected range for photoresist materials

intel®

Summary

- Calculations for estimating the absorbance are very sensitive to the assumed density values
- The SXR density produces calculated results very consistent with the experimental measurements made at wavelength, suggesting this is the true density and hence is the recommended density measurement technique
- Despite the noise in the data, the absorbance extracted from normal incidence reflectivity measurements is close (2.2% less) to the theoretical value
- The grazing incidence reflectivity measurements appear to be noise free and is simpler utilizing a bare Si wafer, rather than a Mo-Si ML wafer, and hence is the recommended absorbance measurement technique

intel®