Experimental estimation of lithographically-relevant secondary electron blur

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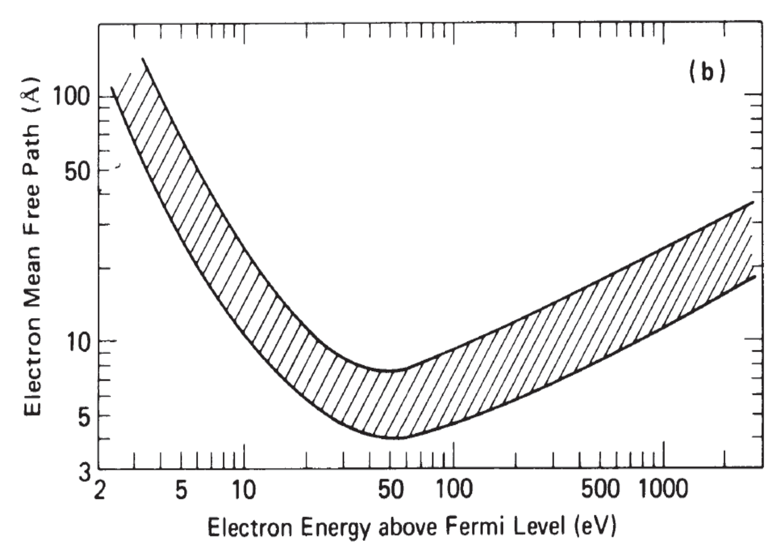
Introduction

The **spatial distribution of secondary electrons** (SE) generated by photons in a photoresist during extreme ultraviolet lithography is of great interest, but still far from understood [1].

Recent works estimated that a cascade of 2-4 electrons is generated, on average, per absorbed EUV photon [2]. Low-energy (i.e. < 10 eV) secondary electrons can travel several nm through the resist from the initial absorption location [3].

Secondary electron blur (SEB) therefore plays an important role in resist sensitivity and is a major limit to achieving ultimate resolution in EUVL.

So far, experimental studies have used low energy electron microscopy (LEES), photoelectron emission spectroscopy (PES), and electron energy loss spectroscopy (EELS) [2][4][5].



Calculated electron inelastic mean free path (IMFP) [6].

IMFP less reliable at E < 100 eV, where Bethe theory is not valid.

This work presents an experimental method to measure SEB from the lithographic point of view:

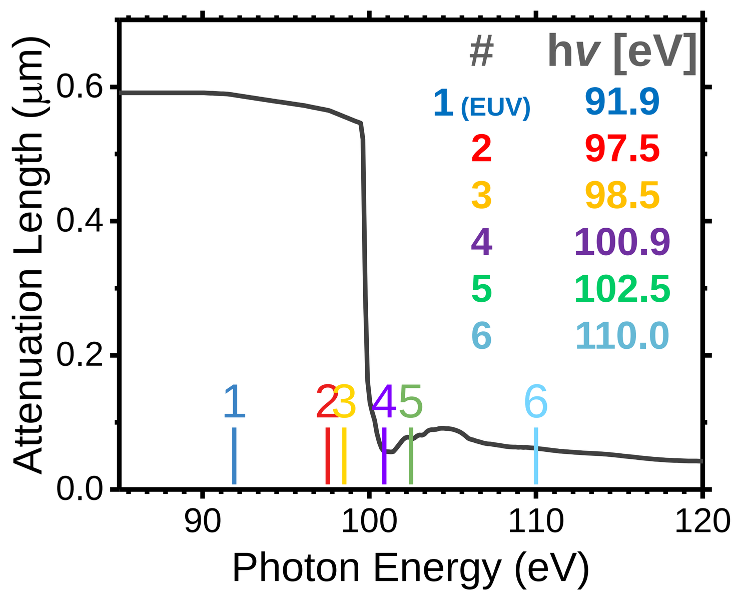
- *Contrast curves on very thin poly(methyl methacrylate)*
- *Exposure wavelength tuned from 91.9 eV (EUV) to 110 eV*
- *Exploiting the discontinuity of optical absorption of silicon*

XIL-II Beamline

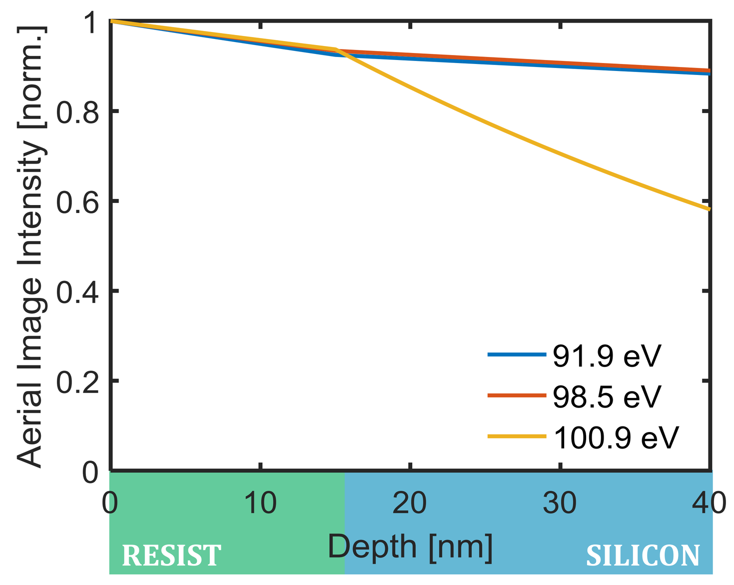
- synchrotron source (SLS)
- flux ≈ 30 mW/cm^2 at EUV
- adjustable wavelength
- flood exposure: 0.5 x 0.5 mm^2

Model

Optical attenuation length in silicon, in the neighborhood of EUV [7], and samples description.



Intensity profile $I(z)$ of light, calculated, in resist + silicon.

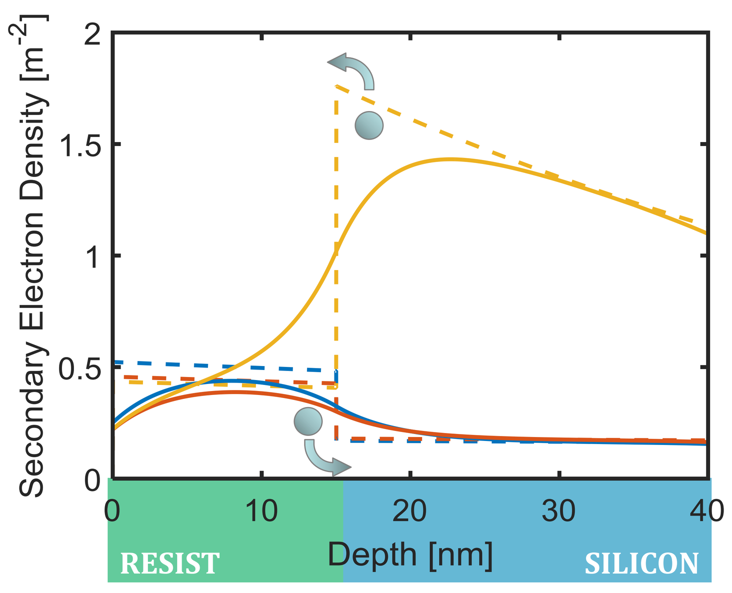


Secondary Electron Density, calculated

without blur: $SED(z) = Dose(z) = \Delta[1\text{-}I(z)]/\Delta z$

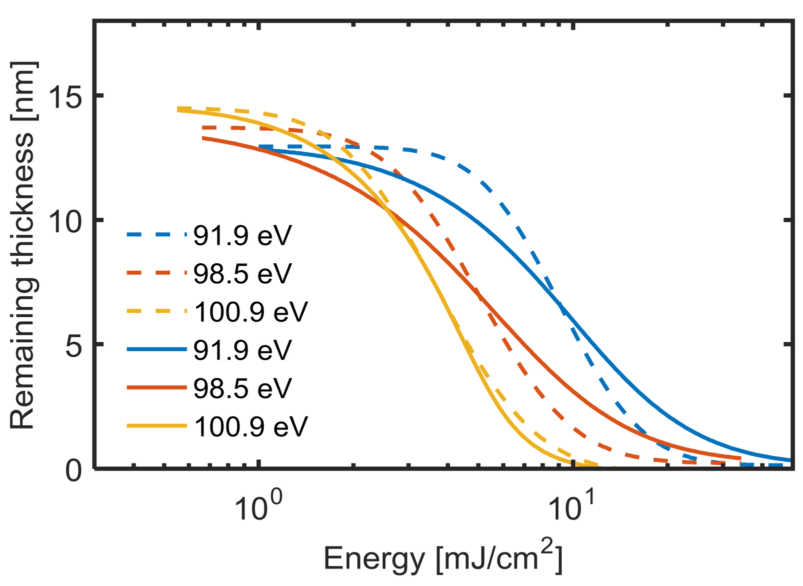
with blur: $SED(z) = Dose(z) * SEBF(z)$

$SEBF(z) = e^{-\lambda_{SEB}|z|}$ (Poisson IMFP). λ_{SEB} = 3 nm [8]



Calculated contrast curves $z(Dose)$

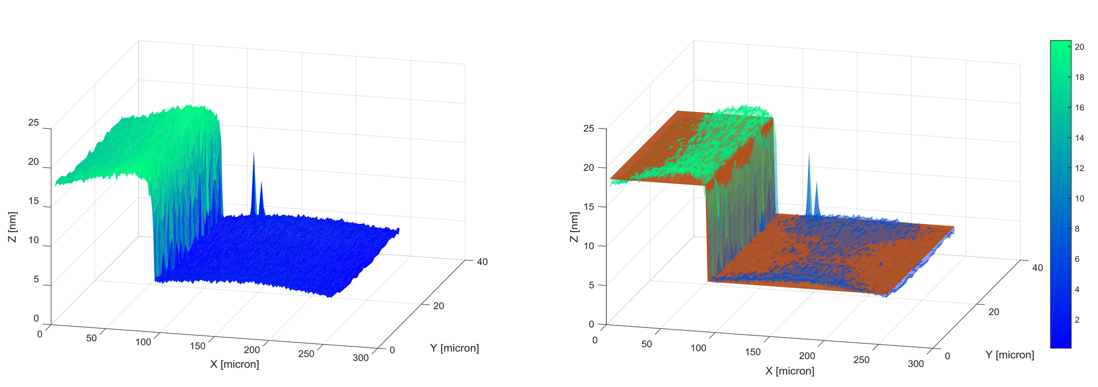
without blur and with blur (5 nm)



Data & Analysis

Experimental

- *PMMA molecular weight 50k, non-CA*
- *Thickness ≈ 15 nm, to enhance the interfacial effect*
- *200 doses x 6 photon energy*
- *All exposures on same wafer, developed at once*



- *Step measured by AFM, fitted to 2D step function*

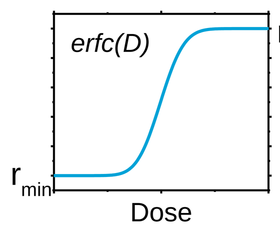
- *Development rate is the Δ thickness per unit time [9]:*

$$r = \frac{dz}{dt} \Rightarrow \int_0^{t_{dev}} dt = \int_0^{z} \frac{1}{r} dz'$$

where the development time is fixed (t_{dev} = 30 s).

- *The development rate depends on both dose and depth:*

$$r = f(z, E) = erfc\big(E \times SED(z)\big)$$

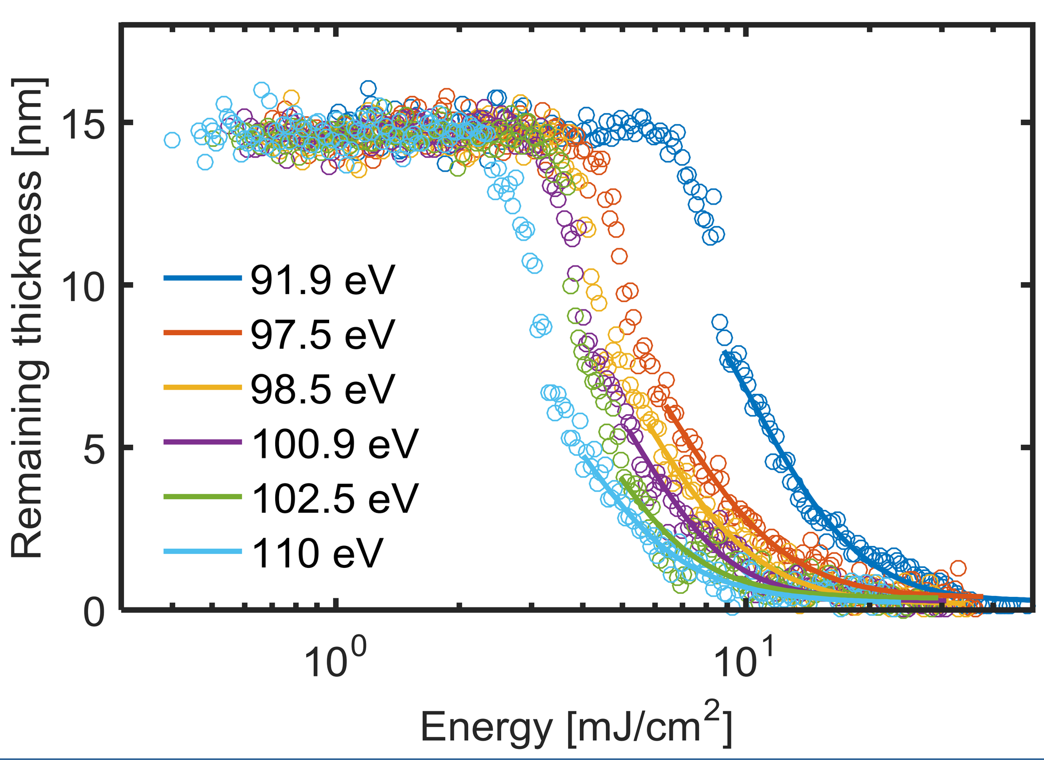


- *Numerical solve of the integral in z (no analytical sol.)*
- *In the approximation of no SEB and linear* r(E), *the developed depth varies as:*

$$z(E) = \alpha^{-1}\ln\big(1 + \alpha t_{dev}(E - E_0)\big)$$

A best fit of the model to the data is run with parameters: r_{min}, r_{max}, erfc slope, E_0, SEB range. All the six sets of dose-to-clear are fit at once

Best fit SEB range = 2.3 nm



Conclusions

A quantitative estimate of secondary electron blur in extreme ultraviolet lithography was extracted by fitting a development rate model to experimental data and exploiting the discontinuity of optical absorption at the photoresist/substrate interface.

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References

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