

EUV-induced carbon contamination of TiO₂-capped multilayer optics: highly non-linear scaling and the effects of water vapor

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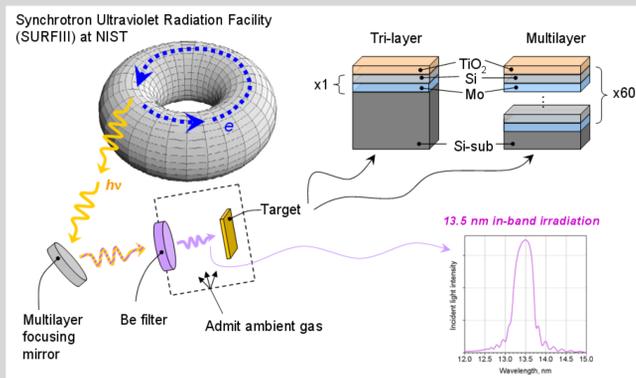
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Abstract

Ongoing studies at the NIST synchrotron facility have demonstrated that the rapid optics degradation observed in pre-production tools for extreme ultra-violet (EUV) lithography is likely due to a highly sub-linear scaling of EUV-induced contamination rates with partial pressure. Here we report contamination rates of TiO₂-capped multilayer samples when exposed to EUV in the presence of controlled partial pressures of several organic species commonly observed as principal resist-outgas products. The contamination rates for all species display an approximately logarithmic scaling with partial pressure over a large range between 1E-10 mbar and 1E-6 mbar. Possible reasons for this behavior and correlation with basic surface science experiments at Rutgers University will be discussed. Since the EUVL tool environment may also contain up to 1E-7 mbar of water vapor, we have investigated the influence of an admixture of water on the C-growth rates of these organics and have found that the effects can vary widely depending on EUV intensity, partial pressures and the intrinsic contamination rate of the organic species. We will also discuss the use of spectroscopic ellipsometry to complement x-ray photo-electron spectroscopy for characterizing the composition and thickness of the contamination deposits.

1. Methods



Tri-layer samples (TiO₂-Si-Mo on Si) replicate surface characteristics and photo-electron production of full Mo/Si multilayer mirrors but avoid modulation of contamination kinetics by resonance effects.

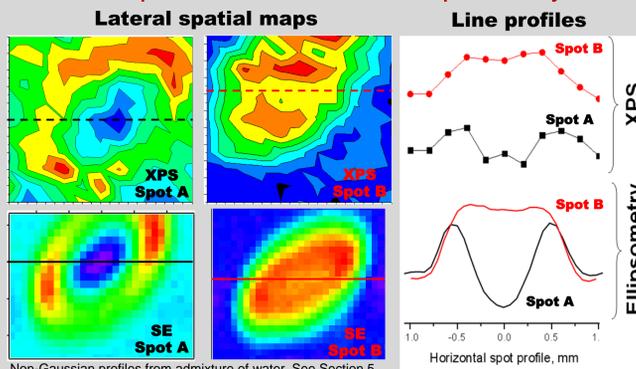
Exposures in fixed partial pressure of admitted ambient gas.

Asymmetric Gaussian EUV intensity distribution

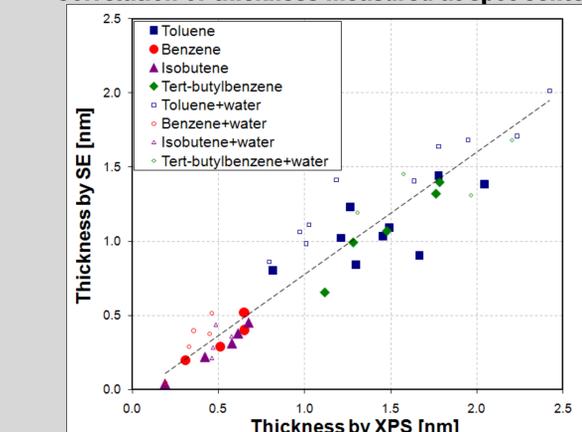
- Full-widths at half-maxima: $\approx(0.6 \times 1.1)$ mm
- Average intensity at center: (3 to 4) mW/mm²
- In-band (13.5 nm \pm 1%) radiation

The thickness of EUV-induced carbon deposits is measured *ex situ* by spectroscopic ellipsometry (SE) and micro X-ray photoelectron spectroscopy (XPS).

Comparison of XPS and ellipsometry



Correlation of thickness measured at spot center



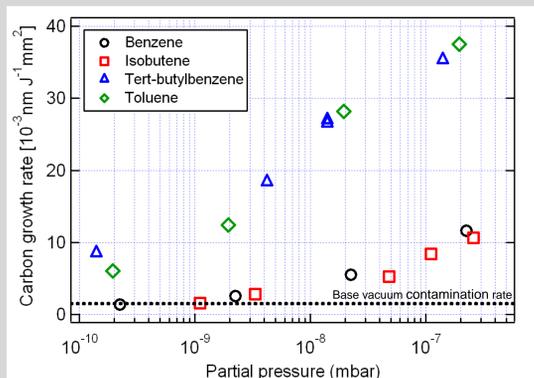
Overall correlation consistent for different gases

Scatter likely due to lower signal/noise of micro-XPS

Slope <1 due to assumptions of material properties (electron scattering lengths, density, dielectric function, etc.)

2. Contamination rates: pressure scaling

Peak contamination rates at spot center*



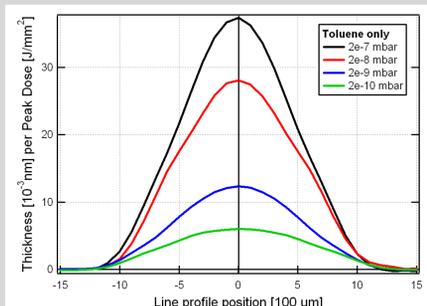
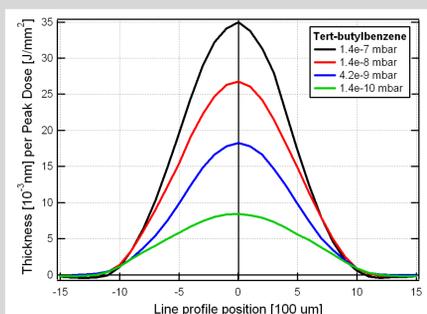
Rates derived from peak thickness measured by SE.

Benzene, isobutene, toluene and tert-butylbenzene (TBB) have been observed in resist-outgas testing.

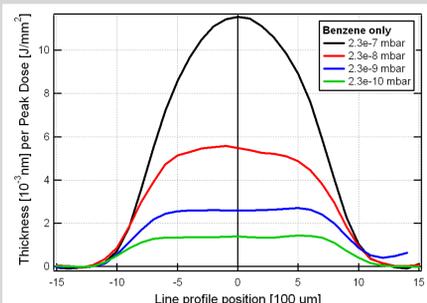
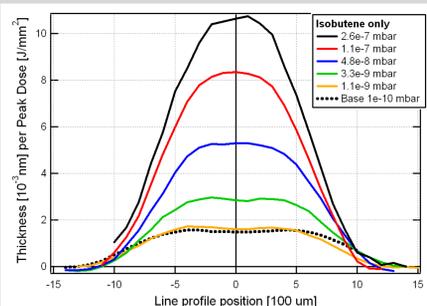
Quasi logarithmic scaling over 2 to 3 decades of pressure implies simple Langmuir adsorption model is not appropriate.

3. Contamination rates: intensity scaling

Dose-normalized line profiles of C distributions*



Spatial distribution of deposited C thickness follows Gaussian EUV intensity distribution for toluene and TBB



Distorted Gaussian and flat-topped distributions for benzene and isobutene suggest that the intensity dependence of the contamination rates saturates in the center of the beam.

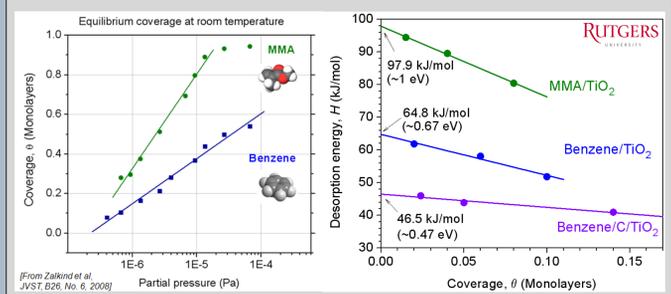
Saturation is more pronounced at lower pressures.

* Absolute partial pressures accurate to within factor of 4 due to uncertainties in ionization gauge sensitivity and calibration for each gas. Relative uncertainties between pressures of given gas is 20%. C growth rates have absolute uncertainty of $\pm 30\%$ and relative uncertainty of $\pm 15\%$ between measurements.

4. Discussion

Pressure scaling is likely driven by fundamental adsorption-desorption processes in absence of EUV.

Coverage & desorption energy measurements

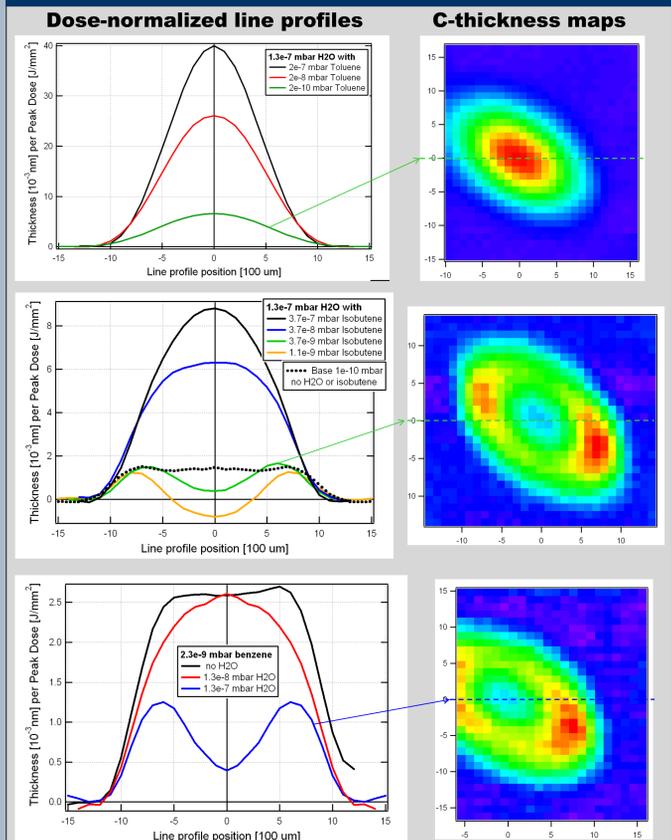


Previous measurements at Rutgers University show logarithmic pressure scaling of coverage and decrease in desorption energy with coverage.

Consistent with a distribution of desorption energies.

Intensity scaling consistent with photon-stimulated desorption rate that varies over distribution of desorption energies.

5. Effect of water admixture



Addition of water mitigates C growth for benzene and isobutene but has little effect on toluene or tert-butylbenzene.

Slower (or even negative) growth rates in high-intensity beam center consistent with linear intensity dependence of H₂O cleaning rate and intensity saturation of contamination rate.

6. Summary

- Spectroscopic ellipsometry correlates well with XPS and measures C thicknesses with few-Angstrom precision.
- Quasi-logarithmic pressure scaling for contamination rates observed over several decades.
- Contamination rates for some species saturate with intensity approaching ≈ 2 mW/mm² at low pressures.
- Behavior consistent with model assuming distribution of desorption energies on surface and desorption-energy-dependent photo-desorption rate.
- Mitigating effect of water admixture appears to scale linearly with intensity for less contaminating species (benzene, isobutene).
- Admixture of H₂O has little effect on contamination rate of more contaminating species (toluene, tert-butylbenzene)