Substrate Effects in EUV Photoresist Patterning

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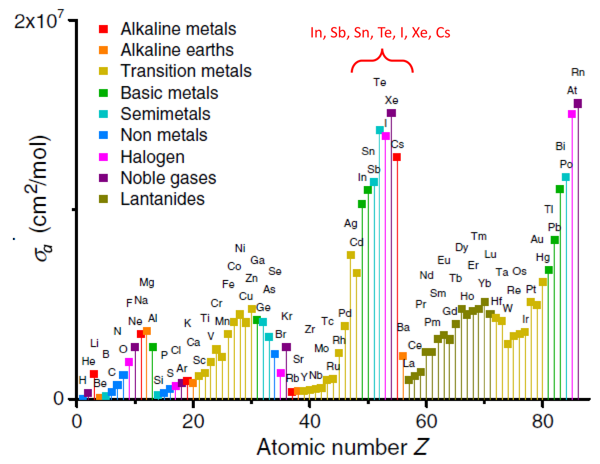
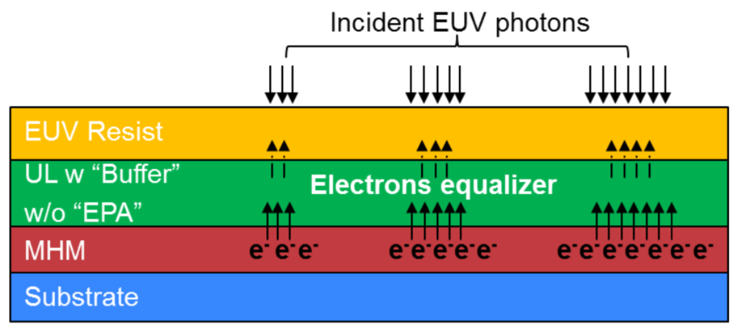
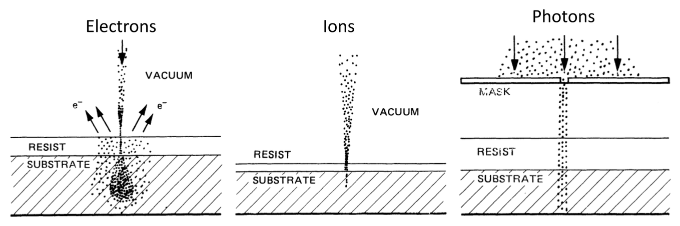
Underlayer Engineering for EUV resists

EUV light sources with current resists require longer exposure time than existing ArF photon sources. Metal containing photoresists have attracted considerable attention recently due to their high absorption cross section, as well as their small cluster size which improves both sensitivity and resolution. Understanding how the underlayer affects the triggering of chemical changes in the photoresist and the bonding at interfaces, will allow a design of an optimal underlayer. Helium ion beam lithography can be used as an efficient proxy for photons or electrons in lab studies to evaluate new resists and patterning properties.







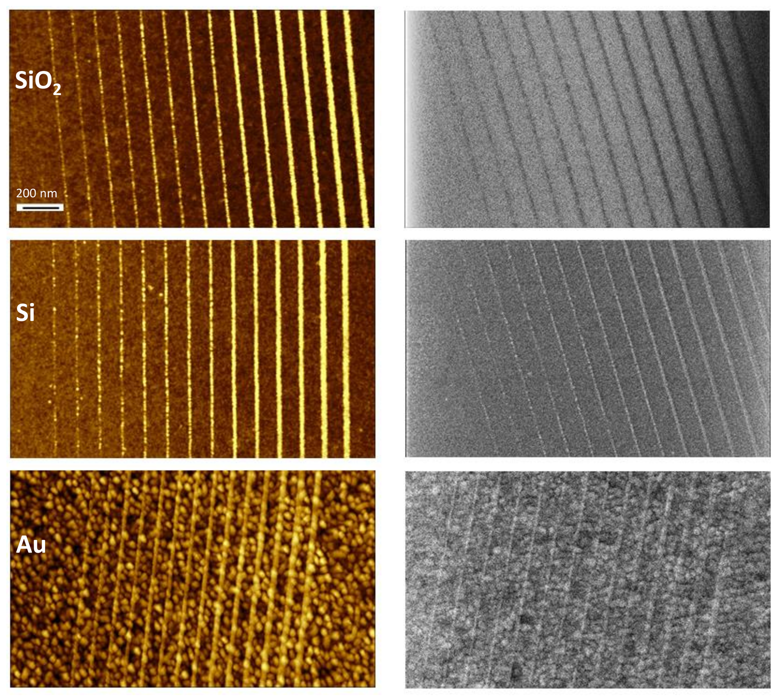
Fallica, Roberto, et al. *Journal of Micro/Nanolithography, MEMS, and MOEMS* 15.3 (2016): 033506-033506.
Li, Jin, Ide Yasuaki, et al. In *Advances in Patterning Materials and Processes XXXI*, vol. 9051, p. 905117. SPIE, 2014.

Goals

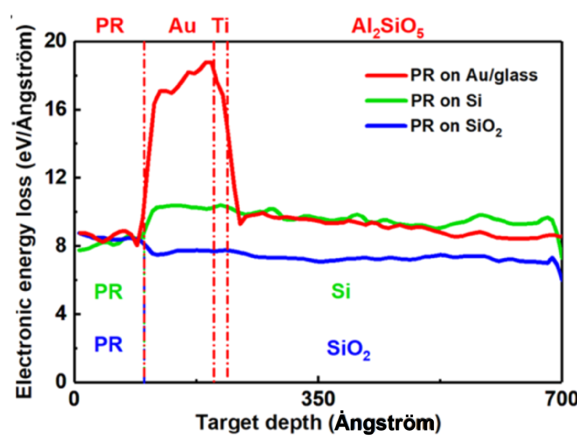
- Explore the effect of substrates with different electron emission cross section by *in situ* chemical analysis.
- Determine optimal resist-underlayer interactions.
- Detail a non-destructive analytical protocol to prescreen novel EUVL resists.

Substrate – Extra Electron Emission

Line-Space pattern evaluation on different substrates.



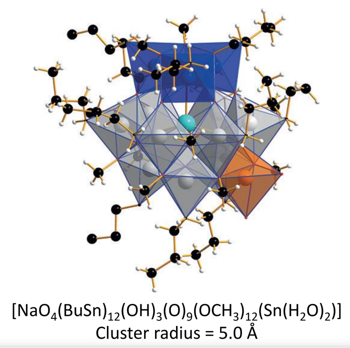
AFM and HIM images. The nominal line widths are 2, 3, 4, 5, 10, 15, and 20 nm from left to right.

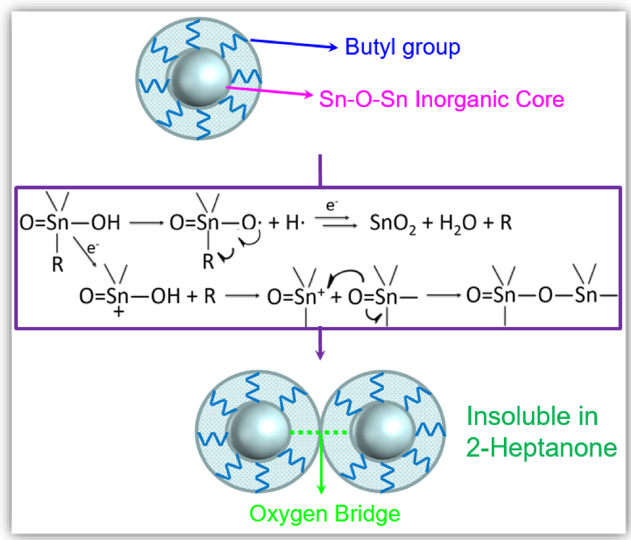


Incident Ion	Helium (40 keV)	iSE Yield	R_p (nm)	Backscattered Ion Yield (%)
Solid	Si	1.24	560	0.10
	Au	7.93	160	2.80

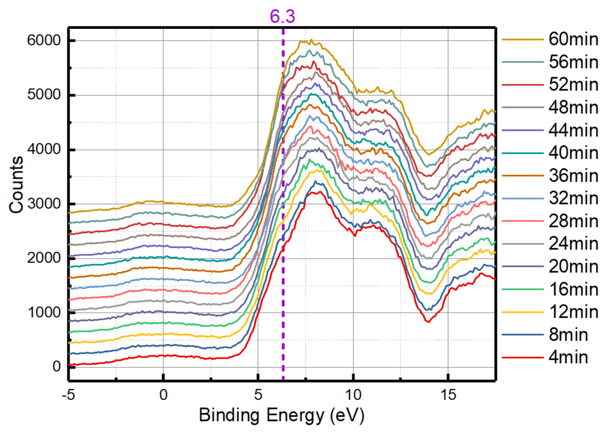
High ion-induced secondary electron yield from gold
→ Enhance the chemical changes of the photoresist near the interface region.

In situ monitoring of valence band changes upon UV exposure (He1α at 21.2 eV & He2α at 40.8 eV)

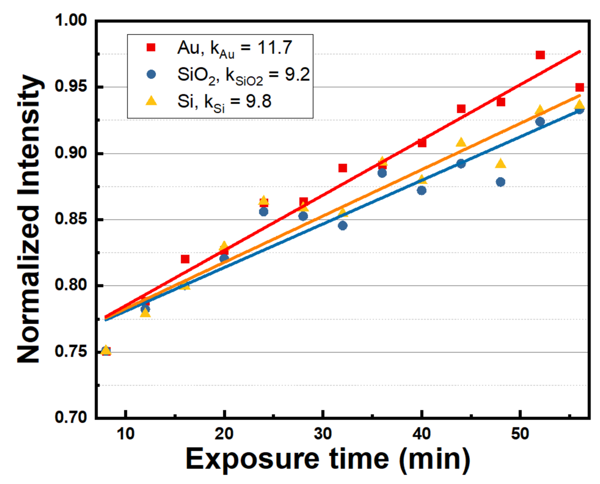




β-$NaSn_{13}$ resist exposure mechanism



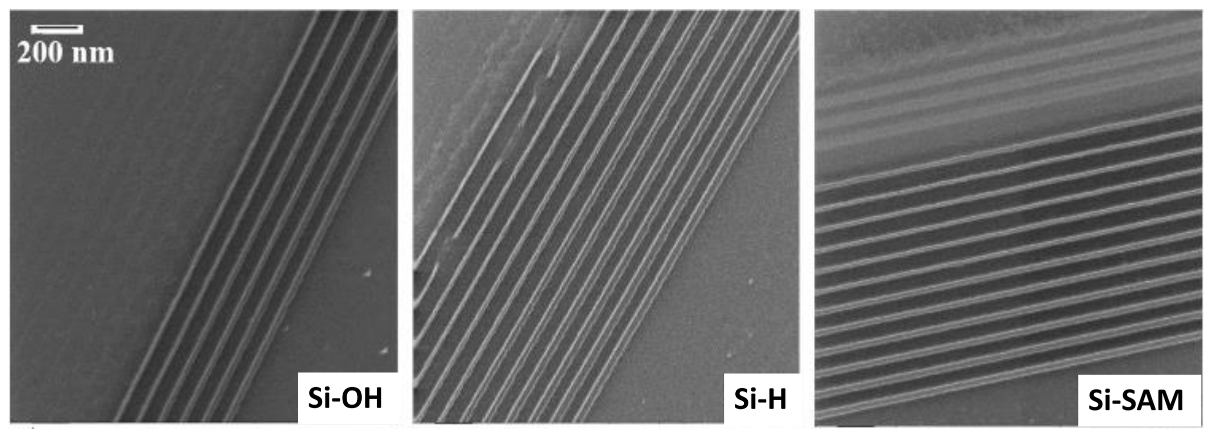
A significant shoulder at 6.3 eV;
The major peak at 8 eV broadens.
→ **Sn-O-Sn bonds are formed with a more metal oxide-like environment**.
(M. Batzill, Sensors, 6(10), 1345, 2006)



- We use the normalized intensity of the increasing shoulder at 6.3 eV to evaluate the effective sensitivity and reaction rate of the resist on the three different substrates.
- The Au substrate increases the effective resist sensitivity in comparison to SiO_2 and Si.

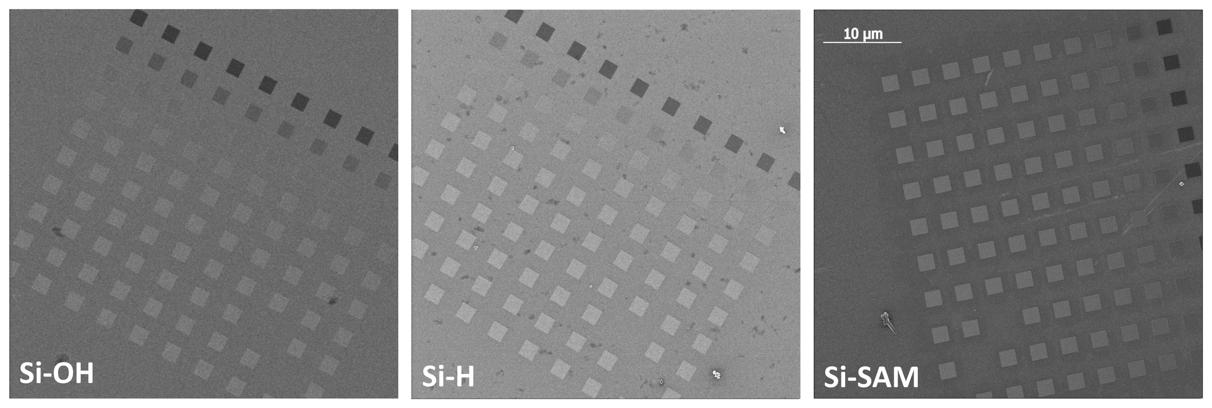
Interface – Adding Benefits with Controlled Interaction

Line-Space and square patterns evaluation on modified interface.



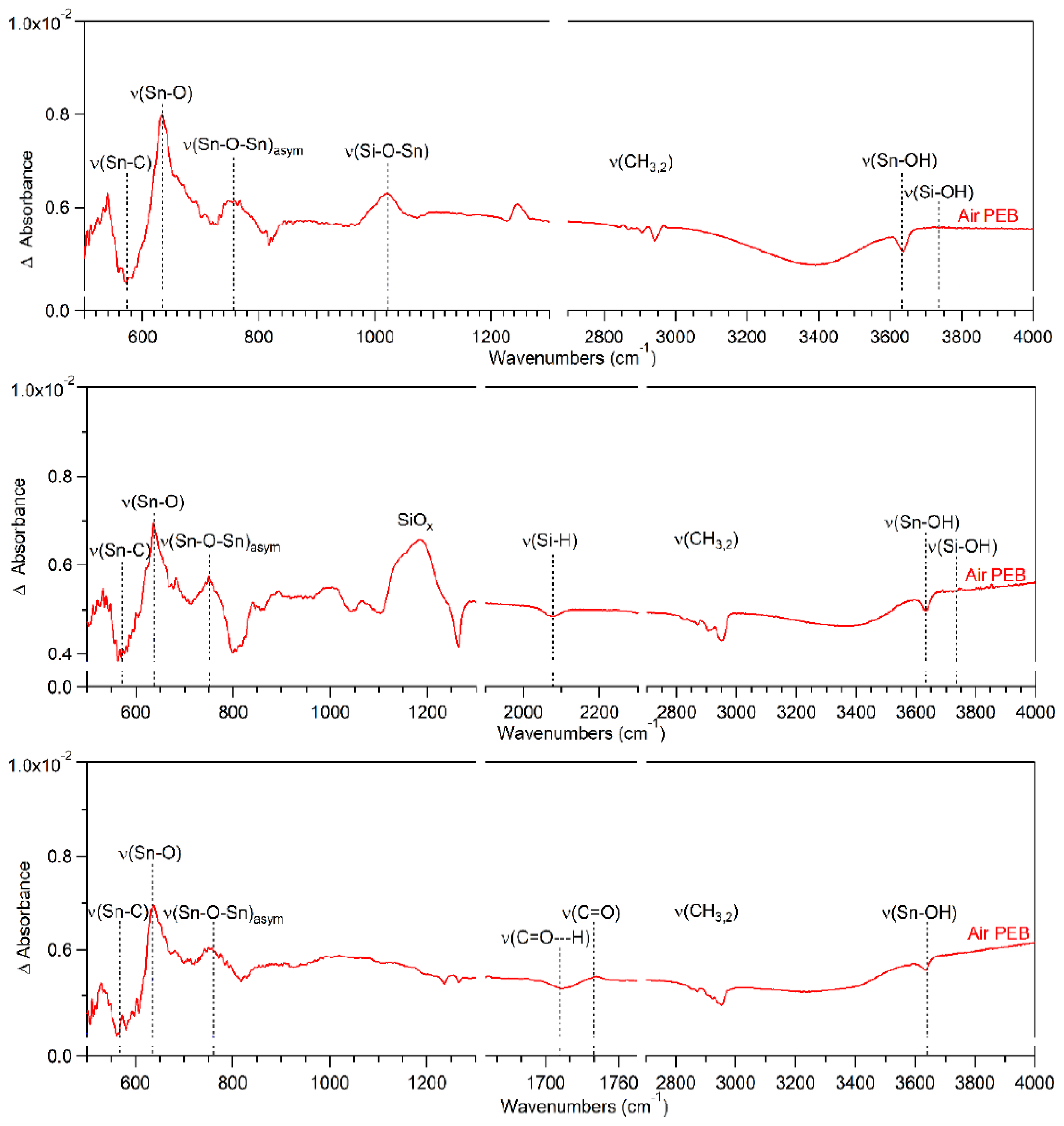
	Si-OH	Si-H	Si-SAM
Finest Line Width (nm)	28.9	20	20
Line Edge Roughness (nm)	13.1	8.1	6.8

With a self-assembled monolayer (ethyl undecylenate) terminated substrate, our resist shows the best line pattern performance.



Arrays of squares with dose variation on modified interfaces show similar contrast.

FT-IR analysis for bonds at interface.



-OH terminated surface: react with the tin-oxo group forming a strong Si-O-Sn bond → insufficient crosslinking within the resist film itself.

-H terminated surface: 23% loss of hydrogen at the interface after exposure → inhomogeneous interface with Si-H, Si-O and Si-O-Sn bonds.

SAM terminated surface: still not sufficient to completely passivate the interface bonding under irradiation; only Van de Waals forces will remain to hold the resist after the hydrogen donor is consumed.
→ Winner: uniformly moderate bonding such as hydrogen bonds.

Sn-OH < Forming Sn-O linkages → Resist condensation
Sn-OH < React with C=O bonds in the SAM

Summary

- **Resist underlayers with high secondary electron yield can improve sensitivity.**
- **Careful resist-substrate bonding control can minimize resist condensation and post-exposure resist residue.**
- **Helium ion beam (HIM) lithography is a good lab-based EUV substitute for resist exposure.**
- **UPS and FTIR provide critical chemical information for novel EUVL resist development.**

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