In-situ EUV reflectivity of Ru, Pd and Rh single-layer mirrors exposed to energetic and thermal Sn

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Abstract

EUV (extreme ultraviolet) metallic light radiators such as Sn used for 13.5-nm lithography will limit the lifetime of collector optics in EUVL source devices by both contamination and irradiation[1,2]. Generation of EUV light requires the use of hot, dense plasma. Pinch dynamics generates fast ions and neutrals, such as metallic sources (Sn) with energies ranging from 10's of eV up to several keV. The expanding Sn plasma will thermalize and condense in nearby components, including the debris shield and collector optics. Although there are additional types of debris that reach the mirror, Sn will be the dominant contaminant to the mirror when operating under high EUV power conditions.

Experiments in the IMPACT facility study thermal and energetic Sn interactions with candidate mirror materials (Ru, Pd and Rh). Sn contamination studies show that collector mirror performance is affected by two mechanisms. One is condensation and Sn buildup on the reflective optics surface (i.e., Ru or Pd mirror) from thermal Sn particles. This mechanism leads to performance failure after formation of Sn islands that coalesce during deposition. Degradation of mirror reflectivity at 13.5-nm measured in-situ results in 30-40% reflectivity loss. The second mechanism is more complex. Energetic Sn ions are found to induce mixing, sputtering, and implantation at depths between 3 and 5 monolayers on the mirror surface. Moreover, in-situ 13.5-nm reflectivity show that the optical properties of the mirror surface are not substantially changed after implantation therefore resulting in small reflectivity losses.

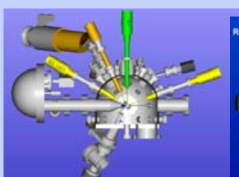
This paper identifies Sn fluence thresholds for damage from both thermal and energetic Sn using a novel In-situ EUV reflectometer during mirror exposure to Sn. In addition to EUV reflectivity, measurements of surface Sn concentration and mirror erosion are presented.

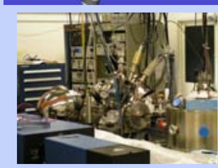
1. J.P. Allain, A. Hassanein, et al., Proc. SPIE Int. Soc. Opt. Eng. 6151 (2006) 31.
2. M. Nieto, J.P. Allain, A. Hassanein, et al., J. Appl. Phys. 100 (2006) 053510.

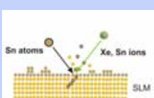
IMPACT Experimental Setup

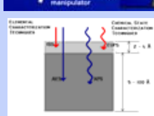
Designed to study heterogeneous surfaces at the nanoscale with in-situ metrology during surface modification by energetic charged and neutral particles at low energies (5-1000 eV) and thermal metal atoms (e.g., Sn, Li).

- IMPACT is equipped with various excitation sources including: EGN4 e-beam evaporation source (thermal Sn), several ion sources including an NTI 14MS Sn energetic source, electron source and several X-ray sources (see below).
- Surface concentration is probed by low-energy ion scattering spectroscopy and XPS.
- Sputtering induced by energetic ions is measured in-situ with a rotating quartz crystal microbalance dual-control unit (QCM-DCU).





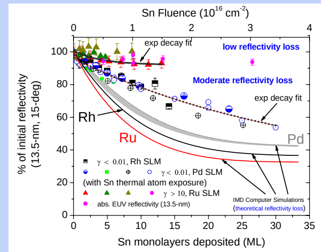


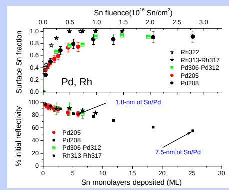


Results

In-situ reflectivity in IMPACT on candidate SLM materials (Ru,Pd and Rh) show low to moderate 13.5-nm reflectivity regimes. Simulated experiments in IMPACT focus on two characteristic debris types: fast and thermal Sn particles. Their interaction with mirror surfaces are studied for various ratios of ion to thermal fluxes, $\gamma = R_i/R_{th}$. Results are compared to IMD computations of the theoretical Fresnel reflectivity response of the mirror surface as a function of Sn fluence or Sn ML deposition (implantation for the case of energetic Sn). Other debris types and conditions are being integrated in these studies.

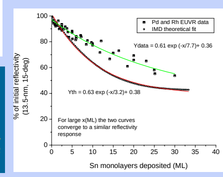
- For γ ratios, where energetic Sn atom implantation is dominant, the exponential decay of the 13.5-nm reflectivity is slow and asymptotically approaches reflectivities between 90-93%
- In-situ EUV reflectivity results in IMPACT are confirmed by absolute at-wavelength (13.5 nm) reflectivity measurements ex-situ
- For γ ratios, where thermal atoms are dominant, the exponential decay is faster but slower than theoretical predictions
- For γ ratios between 0.1 and 1.0, the decay is between the two cases above
- A strong correlation is found between deposition conditions (ion flux, thermal flux) and surface morphology (what appears as Sn island growth)

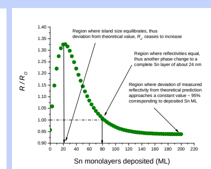


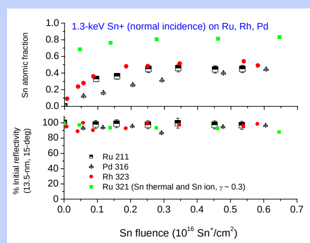


- Incident 13.5-nm light is absorbed in first 3-5-nm (exponential decay in material surface): this is critical region for performance
- In-situ EUV reflectivity on various mirror materials (Pd, Ru, Rh) reveal critical surface kinetic processes
- Deviation from theoretical reflectivity can reach 30-35% for some cases, indicating performance dictated by surface growth processes

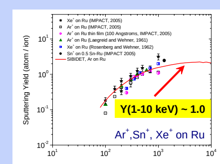
- LEISS measures first 1-2 ML evolution of Sn on SLM mirror surfaces
- Growth of Sn structures faster on Rh, Ru substrates compared to Pd
- With sufficient ML deposition (large fluence), EUV reflectivity approaches theoretical prediction within 2-5%



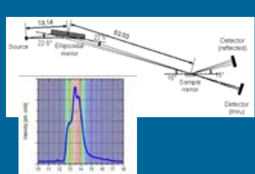


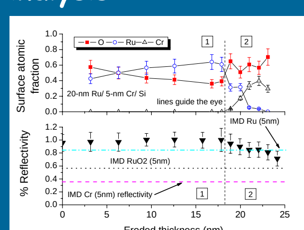


What about surface sputtering?

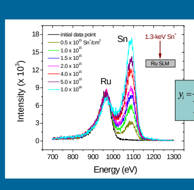


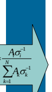
Surface Tools and Analysis

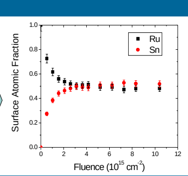




- Surface Sn concentration is monitored in real time during exposures (LEISS) *simultaneously* with EUV reflectivity (13.5-nm), chemical state of Sn (XPS) and surface impurity evolution (QMS).
- Losses in reflectivity can be correlated to mirror surface erosion, metal impurity concentration and surface morphology.
- Results are compared to IMD modeling of EUV at-wavelength reflectivity response







- ❑ EUV in-situ reflectometer uses a Phoenix sem|20 EUV 13.5-nm source
- ❑ Relative EUV reflectivity changes can be measured in real-time, in-situ during exposure to thermal and energetic Sn under variety of environmental conditions
- ❑ Grazing angle = 15° measured with filtered EUV photodiodes (non-dispersive source)
- ❑ Example of experiments: Effect of deposited vs. implanted Sn atoms on EUV reflectivity from a Ru single-layer mirror (SLM) surface (i.e., What is the chemical state of Sn while being implanted?)

Summary and Future Work

- ❑ Energetic (100-1000 eV) Sn atoms are implanted in the first few (2-4) monolayers of EUV collector mirror candidate materials (i.e., Ru, Pd, and Rh)
- ❑ Implanted energetic Sn particles reach an equilibrium surface atomic fraction and varies weakly with incident particle energy and strongly with incident impact angle and mirror material
- ❑ Thermal Sn atoms when condensed on mirror surfaces lead to growth by diffusion-mediated aggregation of deposited atoms
- ❑ Ratio of ion-to-thermal particle debris dictate EUV (13.5-nm) reflectivity performance with up to 30-35% deviation from theoretical predictions
- ❑ Deviations are believed to be correlated to surface morphology structure, the subject of future work

❑ **Outstanding Issues and Future Work:**

- ➢ What is the effect of ion/atom flux ratio on surface morphology and ultimately 13.5-nm EUV reflectivity?
- ➢ Sn surface diffusion vs bulk diffusion: how do implanted Sn atoms behave with temperature of system? Thermodynamics vs Kinetics
- ➢ What are the limits of Sn surface contamination with fluence (e.g. for HVM-level contamination?)
- ➢ What is the role of Sn-ion energy on growth mechanisms and EUV reflectivity performance?
- ➢ Other debris concerns: EUV-induced molecular contamination, debris mitigation material, low-density localized EUV-induced plasma and detrimental etching processes. All or some will be coupled to current ion/atom mirror surface interaction studies in IMPACT

Acknowledgements

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