The effect of fast Sn ion bombardment on EUV lithography grazing incidence collector mirror reflectivity

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Summary

EUV metallic light radiators such as Sn or Li used for lithography will limit the lifetime of collector optics in source devices by both contamination and irradiation. Generation of EUV light requires the use of hot, dense plasma. Pinch dynamics generates fast ions and atoms, such as metallic sources (Sn, Li) with energies ranging from 100 eV up to several keV. The expanding Sn plasma will thermalize and condense in nearby components including debris shield and collector optics. The incident distribution of debris onto the collector optics will also consist of Sn fast ions. Sn contamination will lead to two different mechanisms. One is condensation and Sn thin-film buildup on the reflective optics surface (i.e. Ru or Pd mirror) from the thermalized Sn plasma. This mechanism will lead to performance failure after about 1-2 nm build up of a Sn thin film whereby the at-wavelength EUV reflectivity will decrease 10-15% or more in magnitude.

The second mechanism is more complex. Fast Sn ions generated at the pinch will reach the collector optics and induce mixing, sputtering and implant at depths between 3-5 monolayers on the Ru or Pd surface. A steady state Sn surface concentration will be attained after a given fluence. The amount of Sn implanted or deposited will affect EUV reflectivity as a function of ion and/or atom fluence. Debris mitigation systems will be required to operate under high volume manufacturing conditions. These include the use of debris shields and in-situ cleaning techniques using halide etch. However, it is not clear whether these systems are 100% effective, and therefore a given amount of Sn impurities will exist on the collector mirror. An understanding of Sn contamination and its effect on collector mirror performance and associated fluence-dependent thresholds is therefore important in ultimately determining mirror lifetime expectancy and debris mitigation system design.

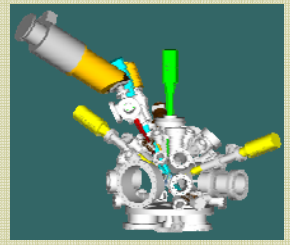
Sn contamination mechanisms are studied in the IMPACT (Interaction of Materials with charged Particles and Components Testing) experiment. IMPACT studies radiation-induced, kinetic and thermodynamic mechanisms affecting the performance of EUV reflective mirror optics. Sn exposure conditions include: incident singly-charged particles between 500-1000 eV, oblique incidence and incident fluxes ranging from 10^{11}-10^{14} ions/cm^2/s. Studies also assess the role of surface temperature on EUV reflectivity performance between 25 and 200 °C. In-situ surface metrology include: real-time sputter yield measurement, Auger electron spectroscopy, X-ray photoelectron spectroscopy, direct recoil spectroscopy and low-energy ion scattering spectroscopy, and at-wavelength EUV reflectivity. Ex-situ measurements include: X-ray reflectivity, X-ray diffraction, scanning electron microscopy, energy-dispersive x-ray analysis and atomic force microscopy.

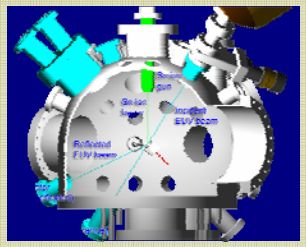
Sn^+ bombardment of EUV light grazing incidence collector mirrors

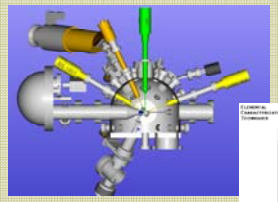
- Energetic particles (ions and neutrals) from Sn plasma-based EUV lamps expose nearby grazing-incidence collector optics
- Understanding the role ultra-shallow heavy-atom implants have on the at-wavelength EUV response of these collector mirrors are leading to designs compatible with metal EUV light fuels (i.e. Sn)
- How the collector mirror surface is modified by the environment of EUV lithography source devices is primarily dictated by synergy of various mechanisms:
  - Debris mitigation system applied
  - Source operational regimes
  - Particle/source interactions and levels of background impurities
- Surface kinetics are measured in real time during Sn ion irradiation and deposition of candidate mirror materials (e.g. Pd, Ru, Rh) under *simulated, controlled* experiments with in-situ surface metrology
- Results feed back to computational models for both understanding and integrated design

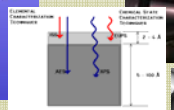
In-situ EUV Reflectometry

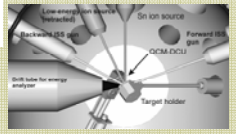
- EUV in-situ reflectometer using 13.5-nm wavelength
- Changes in reflectivity can be measured in real-time as a function of treatment to the sample (bombardment, heating, coating, etc.
- Grazing (15°) and near normal incidence measurements possible
- For example: Effect of deposited vs implanted Sn atoms on Ru surface



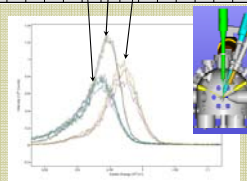


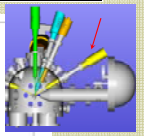




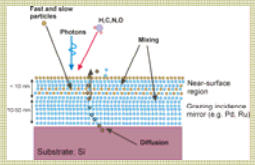


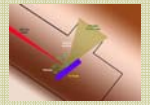
1A	2A	3B	4B	5B	6B	7B	8B				1B	2B	3A	4A	5A	6A	7A	8A
H																		He
Li	Be												B	C	N	O	F	Ne
Na	Mg												Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
Fr	Ra	Ce																

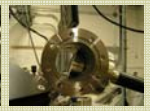


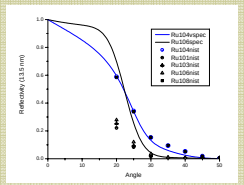


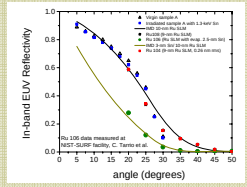
X-ray Reflectivity Studies of grazing incidence mirror response



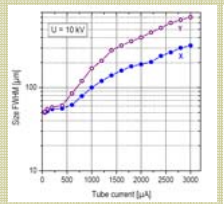


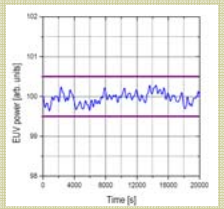


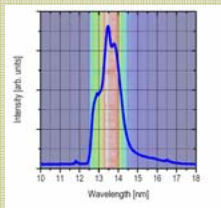




In collaboration with: C. Tarrio, et al. NIST







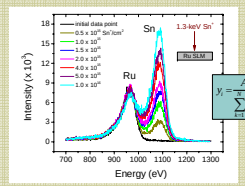
Courtesy of: A. Egbert, phoenix | euv

IMPACT Experimental Setup

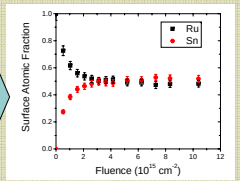
The new IMPACT experimental facility is designed to study multi-component surfaces with in-situ metrology during surface modification by energetic charged and neutral particles at low energies (5-1000 eV)

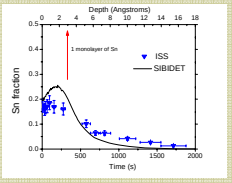
Some of the attributes in the IMPACT experimental facility include:

- LEISS and DRS (direct recoil spectroscopy) are used in conjunction with other techniques: AES, XPS and EUPS for complete elemental and chemical analysis of the surface.
- Absolute in-situ ion or photon-induced desorption is measured during surface treatment.
- Newly installed in-situ EUV reflectometry system to conduct relative reflectivity measurements at a single incident angle of 15 degrees.
- Tunable 193-nm and 248-nm light for in-situ laser post-ionisation for quantitative elemental analysis (e.g. PI-SNMS) coupled to existing IMPACT in-situ metrology (i.e. LEISS, DRS, AES, XPS and EUPS) is used to interrogate desorbed species

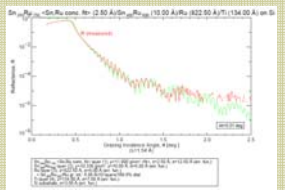


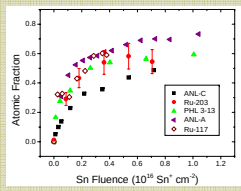
$$y_i = \frac{A_i \sigma_i^{-1}}{\sum_{k=1}^{n} A_k \sigma_k^{-1}}$$

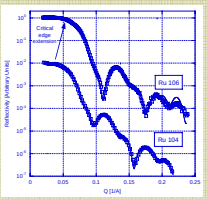


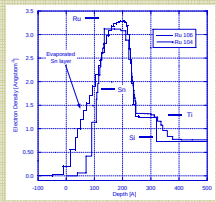


Knowing the scattering cross section of each element for a given incident ion mass, energy and scattering angle allows a transform of peak areas into surface fractions









In collaboration with: B.J. Heuser, et al., Univ Illinois, Urbana-Champaign

Summary and Key Results of IMPACT Sn-irradiation experiments of EUVL grazing incidence mirrors

- Energetic, heavy-ion implantation in EUV collector mirrors are deposited at few monolayers from the air/film interface
- Implanted energetic Sn particles reach an equilibrium surface atomic fraction and varies weakly with incident particle energy
- Temperature can have a significant effect on the surface kinetics of implanted Sn atoms
- Implanted Sn particles as opposed to thermally-deposited Sn have a small effect on the EUV reflectivity for most incident Sn^+ energies studied
- Time domain must also be exploited with pulsed particle excitation sources
- Outstanding Issues:
  - Sn surface diffusion vs bulk diffusion: how do implanted Sn atoms behave with temperature of system?
  - What are the limits of Sn surface contamination with fluence (e.g. for HVM-level contamination?)
  - Can a mixed surface (Ru and Sn or other high-Z component) reflect equally to a virgin SLM?

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