In-situ and ex-situ EUV and X-ray reflectivity experiments and modeling of Sn-exposed collector mirrors for EUV lithography Sn-based sources

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Summary

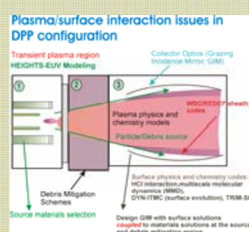
EUV light generated from Sn-based DPP systems are studied in simulated experiments in the IMPACT (Interaction of Materials with charged Particles and Components Testing) experimental facility. The studies focus on the interaction of fast Sn particle interaction with candidate grazing incidence collector mirrors under various device-relevant conditions and, more importantly, the effect on EUV reflectivity.

IMPACT is a particle-beam experiment equipped with a suite of in-situ metrology fully characterizing heterogeneous surfaces under exposure to multiple irradiation and evaporation sources. Experimental results of both photon reflectivity and ion-induced sputtering from fast, energetic Sn particles are used to benchmark surface computational codes to estimate mirror lifetime and performance. Collector mirrors with Ru, Rh and Pd single-layers are used in these studies to simulate grazing incidence mirrors in EUV Sn-DPP source devices. Close collaboration with EUV source suppliers identifies key areas of study and establishes design of experiments. In-situ metrology using ion and electron-based surface spectroscopy track in real time the evolution of the surface during implantation and deposition with energetic and thermal Sn particles, respectively. The exposure conditions include incident singly-charged particles between 500-1000 eV, oblique incidence, and incident fluxes ranging from 10^{11}-10^{14} $Sn^+/cm^2/s$. This paper focuses on describing how simulated experimental results are coupled to computational models to understand collector mirror response under exposure to Sn energetic and thermal particles.

In-situ surface metrology include in-situ sputter yield measurement, Auger electron spectroscopy, X-ray photoelectron spectroscopy, direct recoil spectroscopy, low-energy ion scattering spectroscopy, and a new at-wavelength EUV reflectivity system. Ex-situ measurements include X-ray reflectivity, 13.5-nm absolute reflectivity, scanning electron microscopy, electron dispersion spectroscopy, scanning tunneling microscopy, and atomic force microscopy.

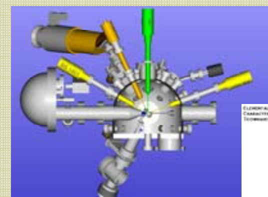
Sn^+ bombardment of EUV light grazing incidence collector mirrors

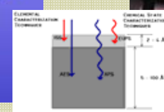
- Energetic particles (ions and neutrals) from Sn plasma-based EUV lamps expose nearby grazing-incidence collector optics
- Understanding the role ultra-shallow heavy-atom implants have on the at-wavelength EUV response of these collector mirrors is leading to designs compatible with metal EUV light 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 in real time by means of in-situ metrology during Sn ion irradiation and deposition of candidate mirror materials (e.g., Pd, Ru, Rh) are thus studied in *simulated, controlled* experiments with in-situ surface metrology
- Results feed back to computational models for both understanding and integrated design



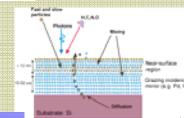
Modeling Sn irradiation of grazing incidence collector mirrors for EUVL

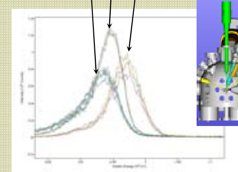
- Argonne's EUVL research strategy is to combine state-of-the art computational codes at different stages of the EUV light source and benchmark with experimental data
- Benchmarks are conducted with experiments on EUV source devices and simulated experiments such as the IMPACT (see above for description) facility at ANL
- Computational codes have been developed for Xe, Sn and Li-based EUV light sources
- This presentation focuses on use of surface codes for modeling of collector optical mirrors:
  - ITMC-DYN and SIBIDET – Dynamic surface codes simulate the surface of a multi-component system as a function of implantation time
  - IMD: computational code by D. Windt include models such as the reflectivity response of materials for a given range of wavelengths and incident angles

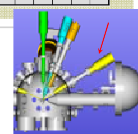




1A	2A	3B	4B	5B	6B	7B	8B			1B	2B	3A	4A	5A	6A	7A	8A
H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ce															





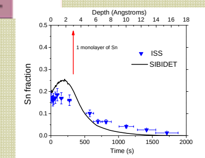


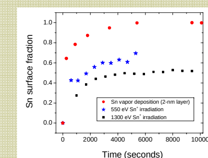
IMPACT Experimental Setup

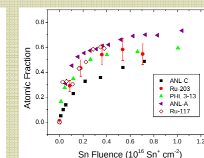
The new IMPACT experimental facility is designed to study multi-component surfaces with in-situ metrology during surface modification by energetic charged and neutral particles at low energies (5-1000 eV)

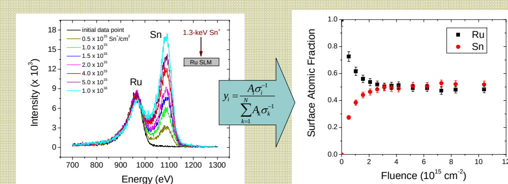
Some of the attributes in the IMPACT experimental facility include:

- 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



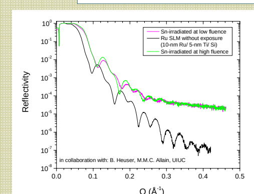




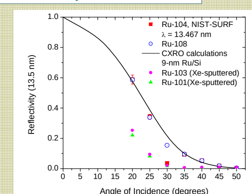


Knowing the scattering cross section of each element for a given incident ion mass, energy and scattering angle allows a transform of peak areas into surface fractions

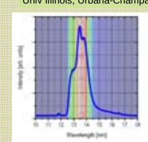
X-ray Reflectivity Studies of grazing incidence mirror response



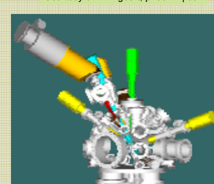
In collaboration with B.J. Heuser, et al., Univ Illinois, Urbana-Champaign



In collaboration with C. Tarrio, et al. NIST

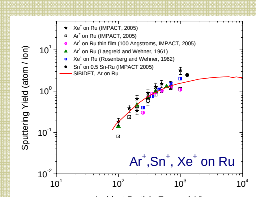


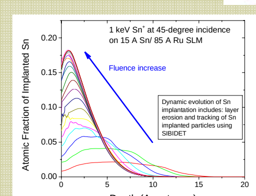
Courtesy of: A. Egbert, phoenix | euv



In-situ EUV Reflectometry

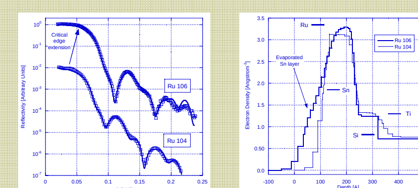
- EUV in-situ reflectometer using 13.5-nm wavelength
- Changes in reflectivity can be measured in real-time as a function of treatment to the sample (bombardment, heating, coating, etc.)
- Grazing (15°) and near normal incidence measurements possible
- For example: Effect of deposited vs implanted Sn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





- As Sn^+ fluence increases, Sn content in the sample increases
- Sn depth distribution changes rapidly at first, but it slows down until it does not change at all
- Maximum Sn content reached is < 20%, lower than found on experiment
- Code does not model any thermodynamic or chemical effects that may affect the Sn content in the surface
- More Sn experiments planned in the future

X-ray Reflectivity and Scattering Length Density



Summary of Results from IMPACT Sn exposures on grazing incidence mirrors

- Energetic, heavy-ion implantation in EUV collector mirrors is deposited at few monolayers from the air/film interface
- Implanted energetic Sn particles reach an equilibrium surface atomic fraction and vary 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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