LPP EUV Source Development at ETHZ

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Outline

- ETHZ EUV Source Program
  - Aims
  - Experimental Facility

- Computational Results
  - Radiation
  - Debris Load and Collector Lifetime

- Concluding Remarks
Experiment & Computation Applied Synergistically

**Experiment**
- Design of instrumentation
- Radiation: in/off band
- Debris: neutrals/ions
- Angle resolved (mapping)

**Computation**
- Hydrodynamic expansion
- Debris ejection
- Radiation dynamics
- Atomic spectra

**Aims**
- Debris mitigation
- Thermal management
- Reconcile performance with cost of ownership
Experimental Facility at ETHZ

Unique Capabilities in Facility
- 3D Mapping
- Concomitant diagnostics of debris and radiation
- Integration with computational tools
Radiation Diagnostics

Pinhole Transmission Grating Spectrometer

- In/Off-Band Emission: EUV to IR

EUV-meter

- In-Band Time-resolved Emission
Debris Diagnostics

Time and Space Resolved Information

- Time-resolved Debris Load
- Kinetic Energy Distribution

• Time and Space Resolved Information
Multi-scale Computational Tools for LPP EUV Sources

- LPP expands from target (µm, ns) to optics (m, µs) length scales
- 2D/axisymmetric hydrodynamic code coupled to particle code (PIC-DSMC)

![Diagram showing the relationship between target, hydrodynamic code, atomic physics code, and particle code in the context of LPP EUV sources.](image-url)
Radiative Characteristics of LPP

**Baseline:** 40 µm Sn droplet, Nd:YAG, Irradiance 100GW/cm², FWHM 5ns

- CE reaches 2.2% for this laser-target configuration
- Non-uniform EUV and full-band radiation on collection optics
Debris Formation

Spatial distribution of mass density (contours) and velocity (vectors) at 75% pulse duration

- Formation of non-uniform ion and neutral distributions
- Series of simulations conducted to assess debris formation for different laser/target configurations
- Hydrodynamic simulations provide initial conditions for subsequent PIC-DSMC simulations
Debris at Collection Optics

- Sn$^{3+}$ and Sn$^{4+}$ are most energetic ions reach the optics, with elevated number densities at side and back of plume
  - By contrast highly charged ions (Sn$^{8+}$-Sn$^{11+}$) responsible for EUV radiation
- 3D ion distribution measurements in ETH source facility to validate simulations

$t = 1.45 \mu s$
contours: number density
vectors: velocity
Debris Distributions on EUV Collector

- Deposition of fast neutrals highest in central region
- Ion erosion and implantation more pronounced on outer border of EUV collector
- Non-uniformity of ion / neutral distributions must be accounted for in design of debris mitigation techniques
Damage Potential of Tin Ions

- Without debris mitigation, ion kinetic energies are in excess of erosion threshold
- KE distribution use are figure-of-merit to provide benchmark to assess effectiveness of debris mitigation strategies
Assessment of Erosion on EUV Collector

- Erosion times (without debris mitigation) are in range of hours
- Shortest erosion time is on outer border of EUV collector
- Debris mitigation must account for heterogeneity of erosion
Concluding Remarks

- ETH multi-scale code has provided first simulation of debris from plasma generation to collection optics

- Lifetime of EUV mirror has been computed

- Simulations quantify requirements for debris mitigation strategies

- Baseline, provided from simulations, will be used to benchmark relative merits of new debris mitigation strategies developed in ETH LPP facility