Enhancement of extreme ultraviolet emission from laser irradiated targets by surface nanostructures

EXTATIC WELCOME WEEK
Ellie Floyd Barte, M.Sc
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Outline

• Introduction and Motivation
• Experiments
  – Section 1: Preliminary XUV emission experiments using nanostructured targets
  – Section 2: 13.5 nm emission from nanostructured targets using absolutely calibrated spectrometer
• Future Work
• Acknowledgements
Introduction

Advantages of EUV:
- See smaller features
- Write smaller patterns
- Elemental and chemical sensitivity

Prospective applications of EUV:
- Surface patterning
- Photoelectron spectroscopy
- EUV lithography
Introduction and Motivation

- A high conversion efficiency (CE) of laser energy into the particular spectral band of interest is essential.
- Tin plasmas have been identified as the best emitters in the 2% reflection band of multilayer Mo/Si optics at 13.5 nm.
- The presence of microstructures at the laser irradiated target surface can enhance laser absorption and influence the dynamics of the plasma plume.
Au nanocylinder array:
• 20 fold x-ray enhancement (7-20 nm region) vs flat Au foil
• 90 fs
• $1.4 \times 10^{16}$ W/cm²

Nanohole alumina (Al₂O₃):
• 4 times x-ray enhancement in the water window region over planar aluminum
• 45-500 fs
• $3 \times 10^{17}$ W/cm²


Porous copper nano-layer on a copper target:
• Increased emission at water window wavelengths and at 13.6
• 500 ps /50 ps/5 ns
• $10^{15}$ W/cm²


Section 1: Preliminary XUV emission experiments using nanostructured targets
Nanostructured Targets

- Preparation: Magnetron sputter deposition
  - Anodic oxidation
- Sn Thickness: 120 nm
- ČVUT-KFE (Proška et al.)

Tin covered closely packed polystyrene microspheres

Porous alumina targets covered by a tin layer
**Experimental Setup**

**LASER PARAMETERS**

<table>
<thead>
<tr>
<th></th>
<th>Ekspla Picosecond</th>
<th>Surelite Nanosecond</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse Length</td>
<td>170 ps</td>
<td>7 ns</td>
</tr>
<tr>
<td>Repetition Rate</td>
<td>5 Hz</td>
<td>10 Hz</td>
</tr>
<tr>
<td>Max Energy</td>
<td>250 mJ</td>
<td>600 – 700 mJ</td>
</tr>
<tr>
<td>Laser Intensity</td>
<td>$\approx 4 \times 10^{13}$ W/cm²</td>
<td>$\approx 2 \times 10^{12}$ W/cm²</td>
</tr>
</tbody>
</table>

**Notes:**
- Grazing Incidence Spectrometer
  - 1200 groves/mm
  - Spectral Resolution: 0.02 nm
  - Not absolutely calibrated
- Incident Laser Beam
- Laser produced plasma from target material
- X-Y-Z Actuators
- To Spectograph
- f = 75 mm
XUV spectra of microspheres at different laser energies

7 ns laser pulses

170 ps laser pulses

Spectra normalized to the maximum spectral intensity
XUV spectra of porous alumina at different laser energies

7 ns laser pulses

170 ps laser pulses

Spectra normalized to the maximum spectral intensity
Estimated CE vs laser energy

EUV conversion efficiency (integrated at 2% bandwidth centered on 13.5 nm)
Conclusions

• We observed higher conversion efficiency and emission under picosecond laser for all structured targets compared to nanosecond laser

• Porous Alumina plus tin target has higher conversion efficiency than others specifically for 170 ps laser
Section 2: 13.5 nm emission from nanostructured targets using absolutely calibrated spectrometer
Nanostructured Targets

SEM images of the surfaces of the nanostructured targets.

- 40 nm Sn coating
- 200 nm Sn coating
- Monolayer of polystyrene microspheres on silicon wafer
- Porous Alumina
- Porous alumina target at the angle of 45°
Experimental Setup

**LASER PARAMETERS**

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<tr>
<th>Parameter</th>
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<tbody>
<tr>
<td>Pulse Length</td>
<td>170 ps</td>
</tr>
<tr>
<td>Repetition Rate</td>
<td>5 Hz</td>
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<tr>
<td>Max Energy</td>
<td>240 mJ</td>
</tr>
<tr>
<td>Laser Intensity</td>
<td>$\approx 2 \times 10^{13}$ W/cm$^2$</td>
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**JENOPTIK 0.25m flat field grazing incidence spectrometer**

1200 lines /mm

Absolutely calibrated at BESSY II

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**Diagram Details**

- **To Spectograph**
- **Incident Laser Beam**
- **X-Y-Z Actuators**
- **f=10cm**
- **Laser produced plasma from target material**
XUV spectra from nanostructured targets under 170 ps laser pulses

Porous alumina at different thicknesses and bulk Sn target at 26 mJ laser energy

Microspheres at different thicknesses and bulk Sn target at 26 mJ laser energy

(E.F. Barte, et.al, Laser and Particle Beams (2017), DOI: 10.1017/S0263034617000623)
In-band CE vs Laser Energy

In-band conversion efficiency (CE) of all nanostructured targets compared to a bulk Sn slab.

(E.F. Barte, et.al, Laser and Particle Beams (2017), DOI: 10.1017/S0263034617000623)
XUV spectra of nanostructured targets at different laser energies

Porous alumina with 200 nm Sn coating

Microspheres with 200 nm Sn coating

(E.F. Barte, et.al, Laser and Particle Beams (2017), DOI: 10.1017/S0263034617000623)
Conclusion

• Targets comprising a tin layer on a porous alumina substrate are superior to those based on a monolayer of polystyrene microspheres on a silicon wafer.
• 40-nm-thick Sn layer is too thin for efficient energy conversion to XUV emission at 13.5 nm for laser intensities higher than $2 \times 10^{12} \text{ W/cm}^2$.
• The maximum in-band conversion efficiency of 1.49 %/(2$$\pi$$ Sr), measured for 200-nm-thick Sn layer on a porous alumina substrate at a laser intensity of $4 \times 10^{12} \text{ W/cm}^2$ (laser energy of 50 mJ).
• For laser intensities higher than $4 \times 10^{12} \text{ W/cm}^2$ the CE decreases mainly due to excessive heating and ionization of the Sn layer that is documented by the presence of lines belonging to high ionization states up to 21+ in the observed XUV spectra.
Future Work

• Nanostructured Sn targets under the action of femtosecond lasers (EUV range).
• Rh nanostructured targets under femtosecond lasers (water-window region).
Acknowledgement

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THANK YOU FOR YOUR ATTENTION!