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

EXTATIC WELCOME WEEK

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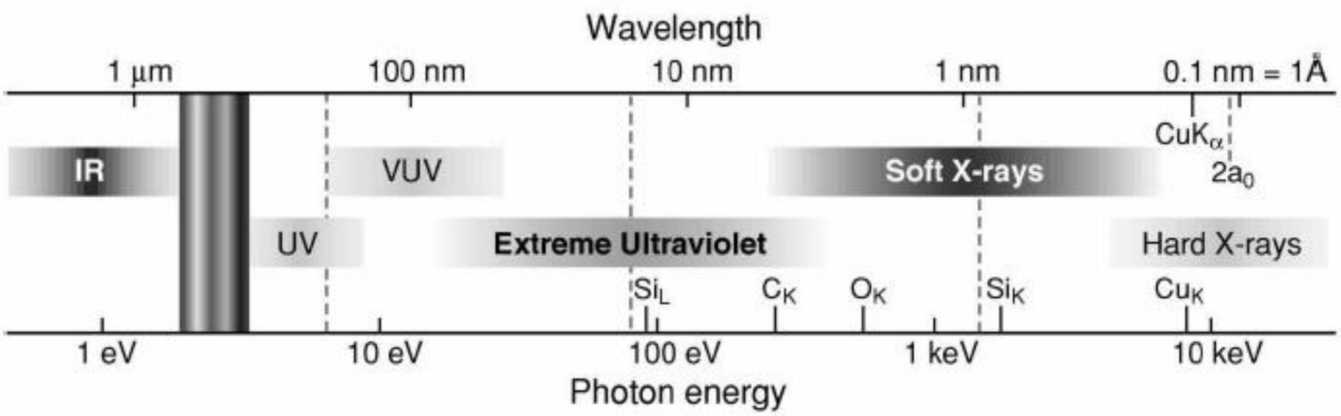
Outline

- 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:

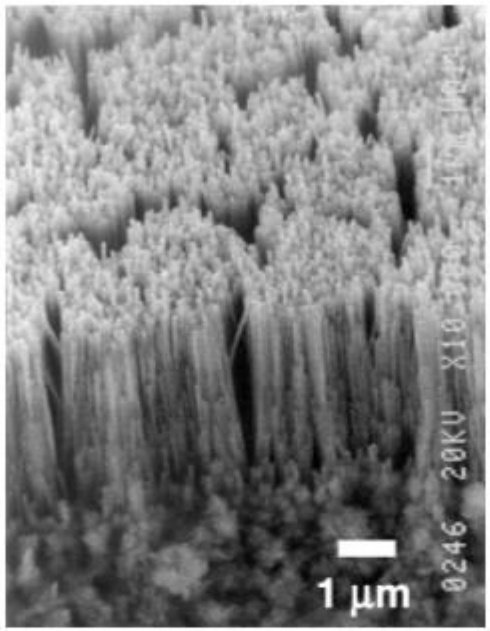
- See smaller features
- Write smaller patterns
- Elemental and chemical sensitivity

Prospective applications of EUV:

- Surface patterning
- Photoelectron spectroscopy
- EUV lithography

Introduction and Motivation

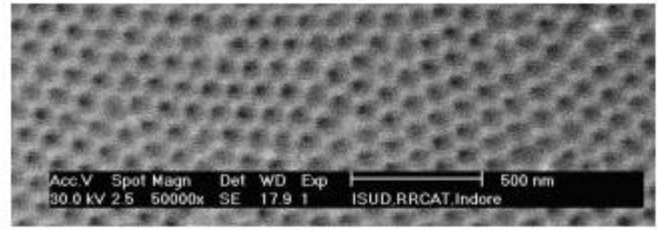
- A high conversion efficiency (CE) of laser energy into the particular spectral band of interest is essential
- Tin plasmas have been identified as the best emitters in the 2% reflection band of multilayer Mo/Si optics at 13.5 nm
- The presence of microstructures at the laser irradiated target surface 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
- 1.4×10^{16} W/cm^2

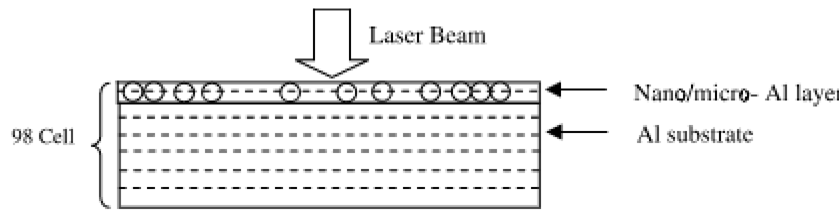
Nishikawa, T., et al. *Applied Physics B: Lasers and Optics* 73.2 (2001): 185-188.



Nanohole alumina (Al_2O_3):

- 4 times x-ray enhancement in the water window region over planar aluminum
- 45-500 fs
- 3×10^{17} W/cm^2

Chakravarty, U., et al. *Journal of Applied Physics* 109.5 (2011): 053301.



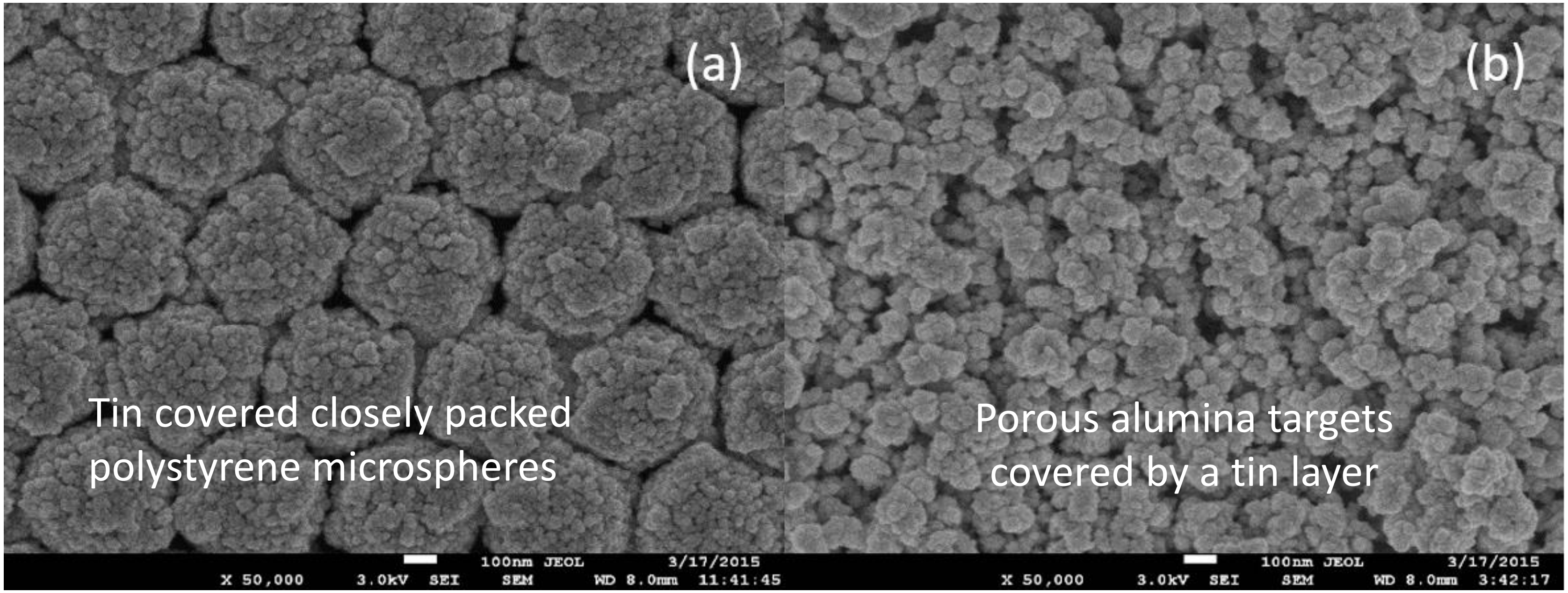
Porous copper nano-layer on a copper target:

- Increased emission at water window wavelengths and at 13.6
- 500 ps /50 ps/5 ns
- 10^{15} W/cm^2

Mahdieh, Mohammad Hossein, and Hossein Mozaffari. *Physics Letters A* 378.16 (2014): 1136-1146.

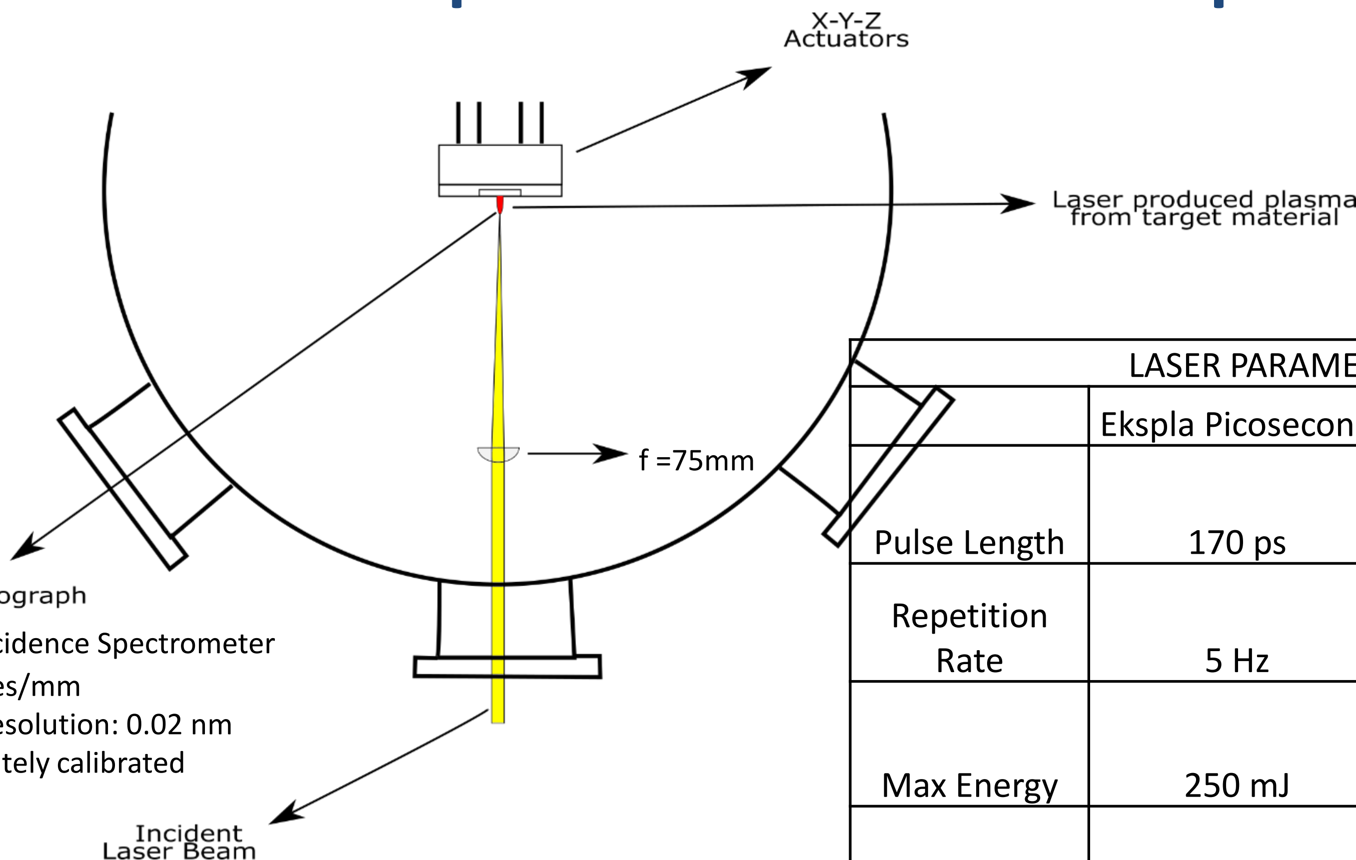
Section 1: Preliminary XUV emission experiments using nanostructured targets

Nanostructured Targets



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

Experimental Setup

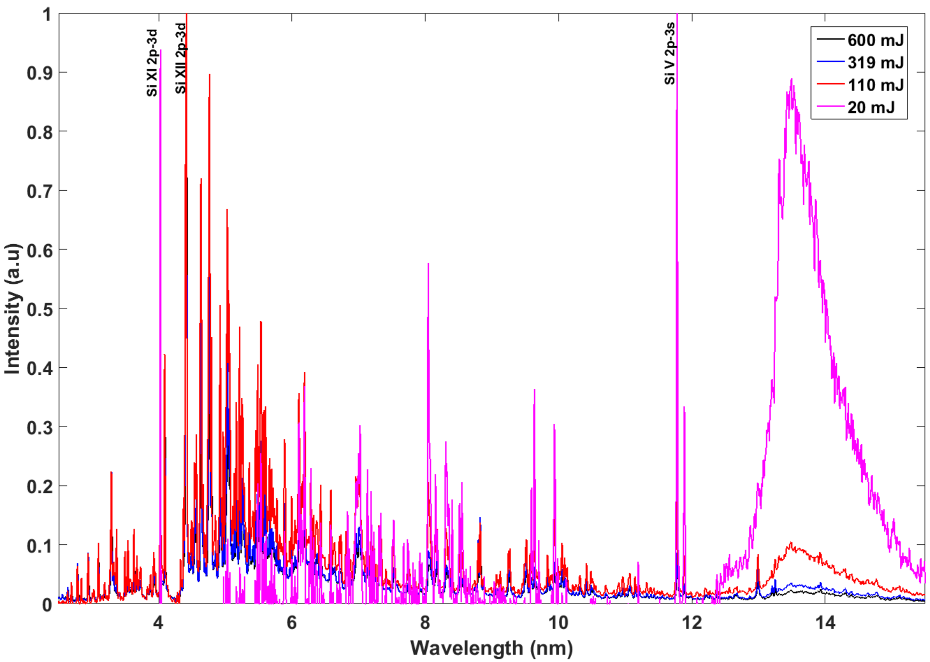


Grazing Incidence Spectrometer
1200 groves/mm
Spectral Resolution: 0.02 nm
Not absolutely calibrated

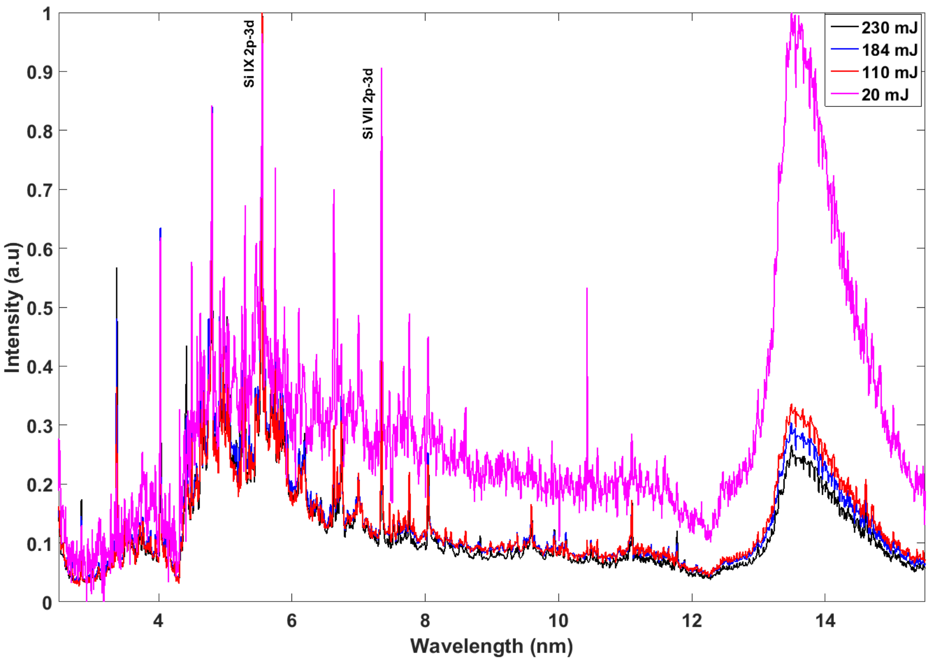
LASER PARAMETERS		
	Ekspla Picosecond	Surelite Nanosecond
Pulse Length	170 ps	7 ns
Repetition Rate	5 Hz	10 Hz
Max Energy	250 mJ	600 – 700 mJ
Laser Intensity	$\simeq 4\times10^{13}$ W/cm^2	$\simeq 2\times10^{12}$ W/cm^2

XUV spectra of microspheres at different laser energies

7 ns laser pulses



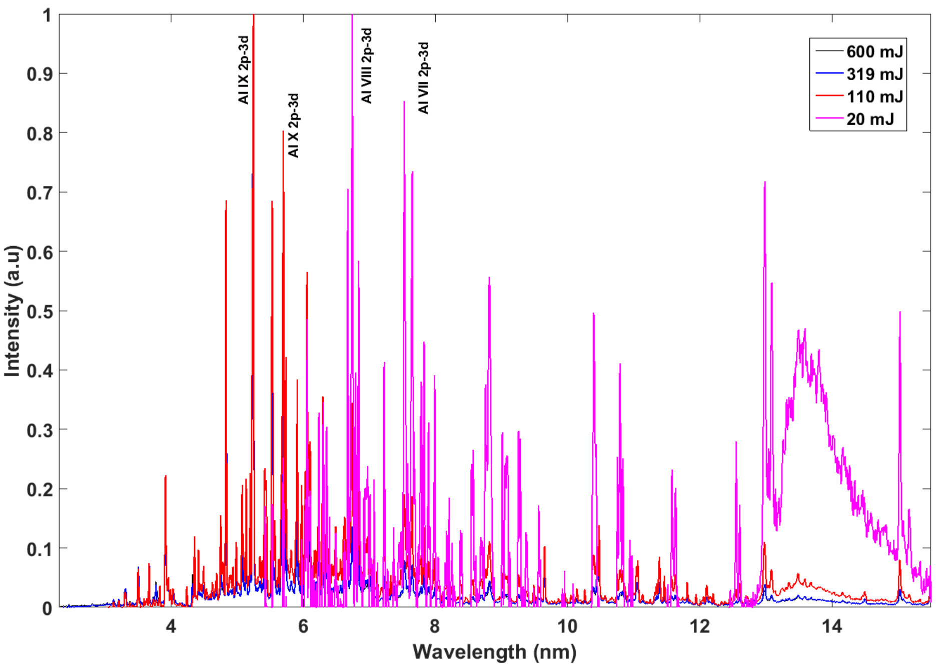
170 ps laser pulses



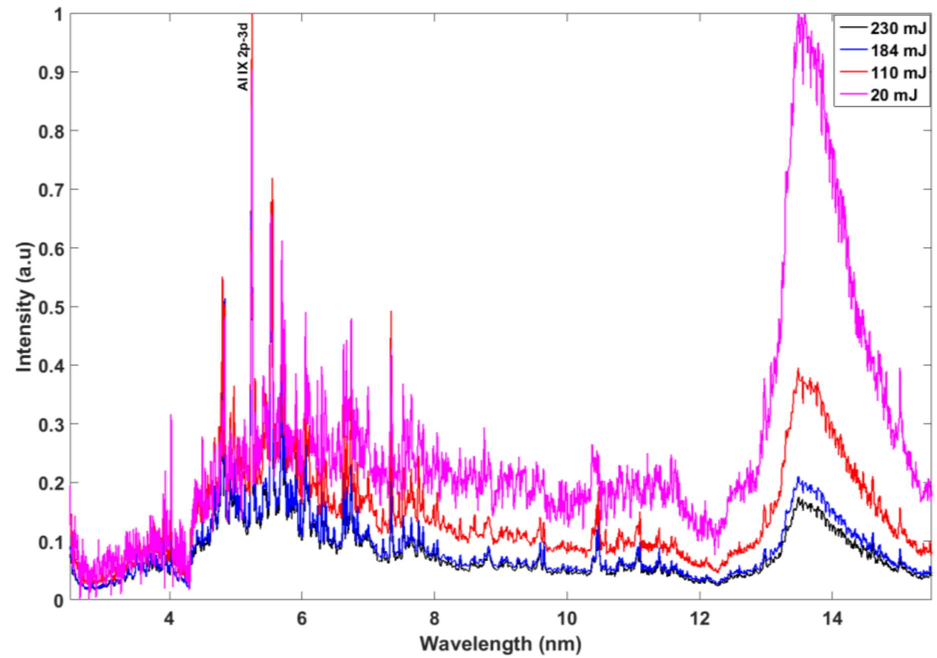
Spectra normalized to the maximum spectral intensity

XUV spectra of porous alumina at different laser energies

7 ns laser pulses



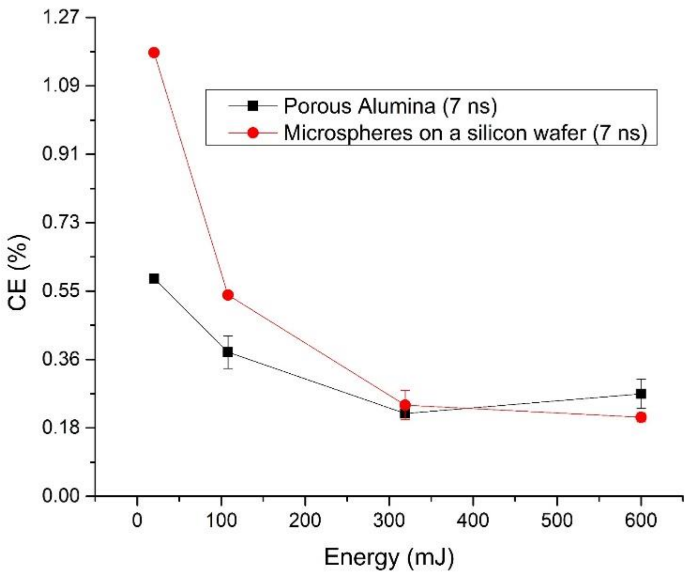
170 ps laser pulses



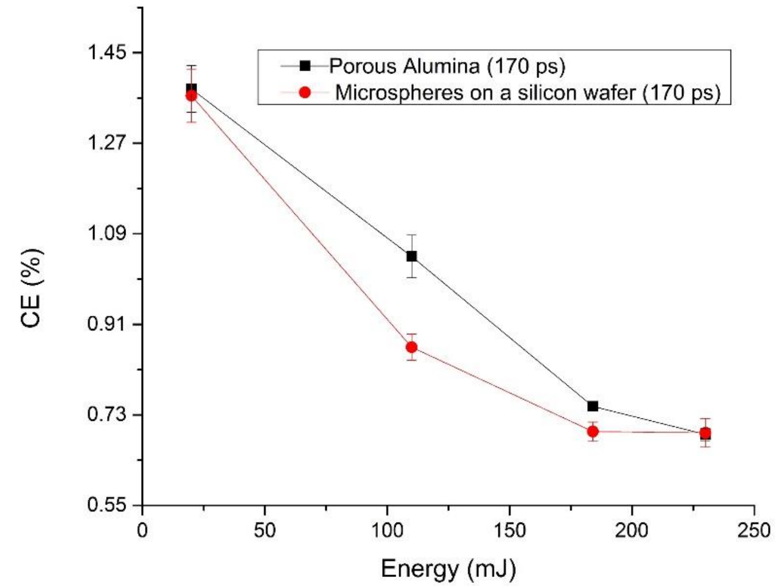
Spectra normalized to the maximum spectral intensity

Estimated CE vs laser energy

7 ns laser pulses



170 ps laser pulses



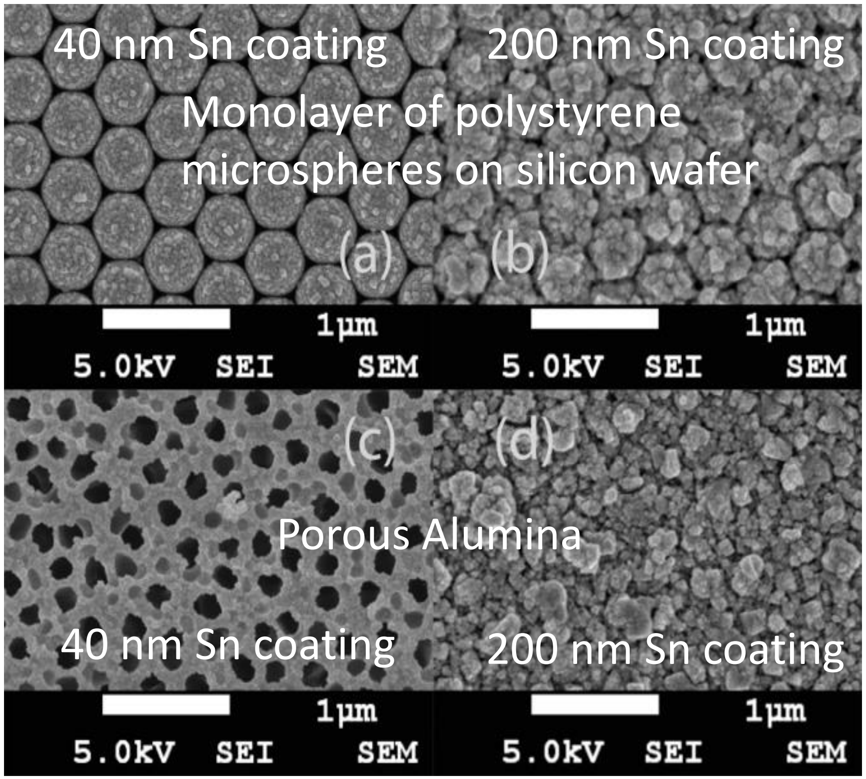
EUV conversion efficiency (integrated at 2% bandwidth centered on 13.5 nm)

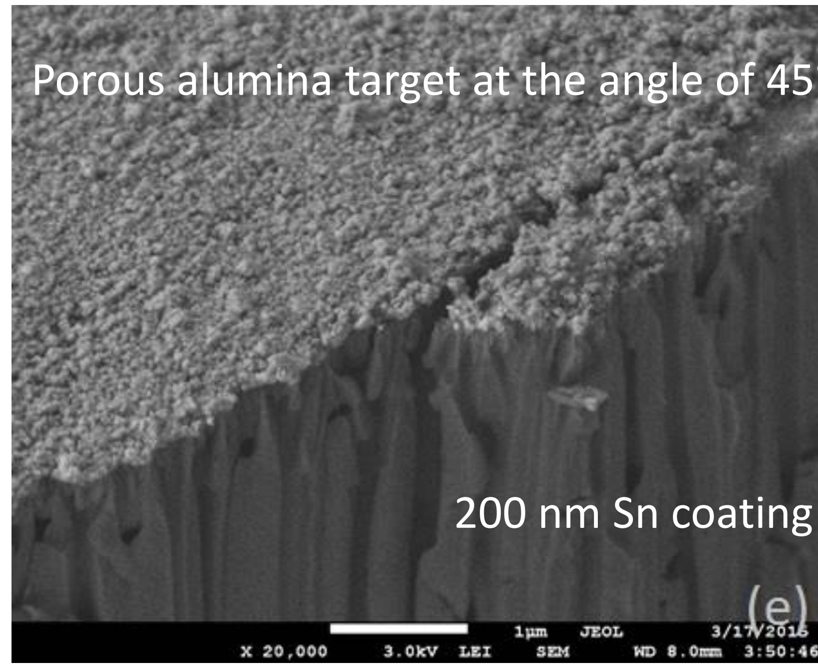
Conclusions

- 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

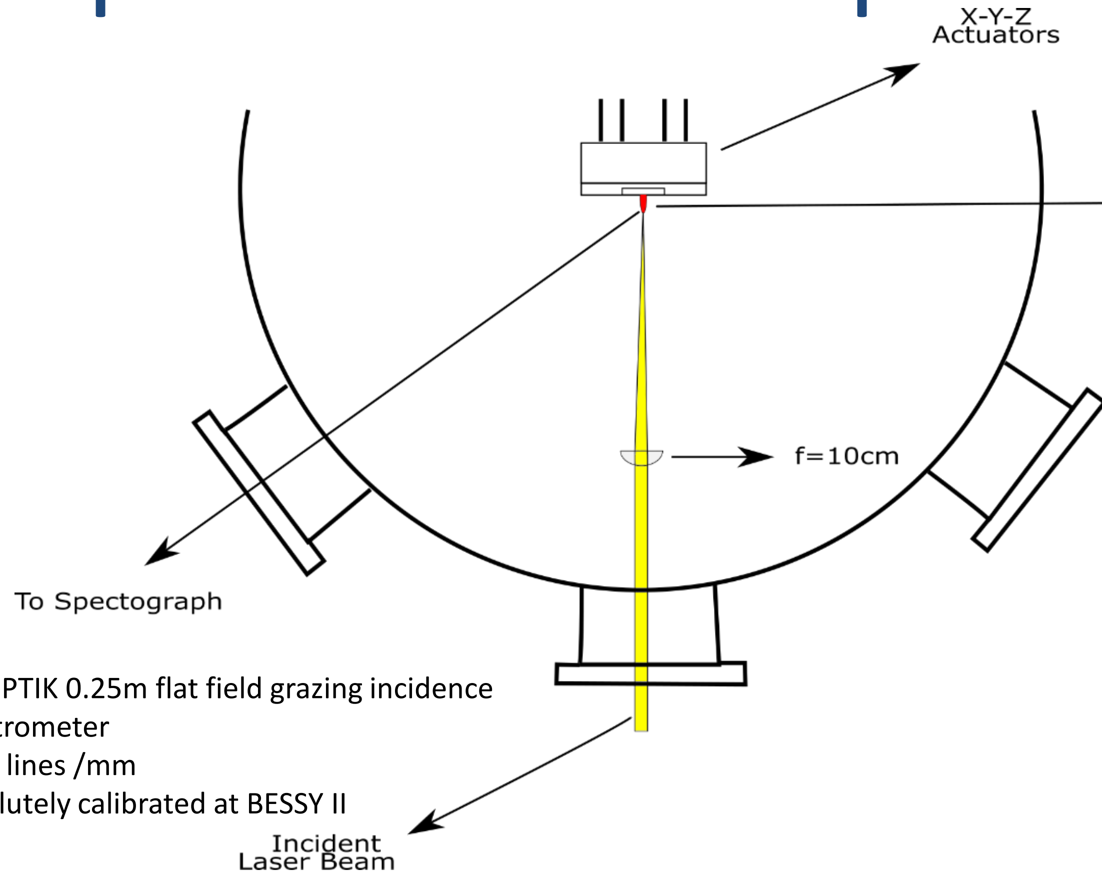
Nanostructured Targets





SEM images of the surfaces of the nanostructured targets.

Experimental Setup

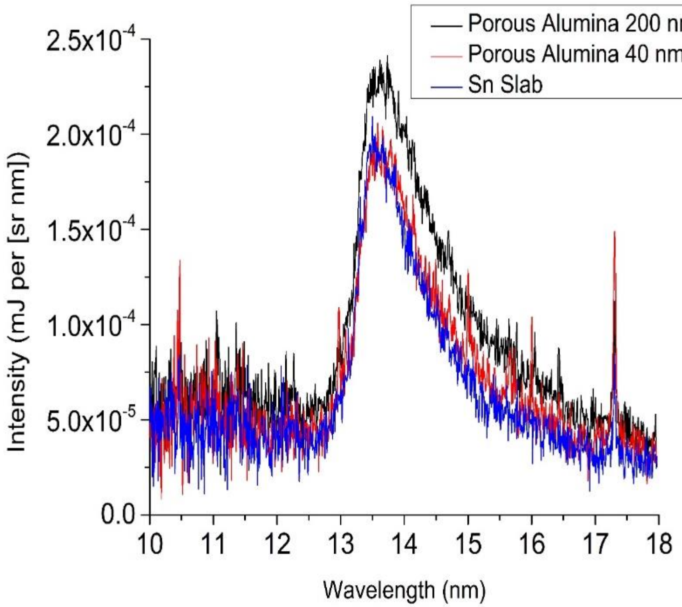


JENOPTIK 0.25m flat field grazing incidence spectrometer
1200 lines /mm
Absolutely calibrated at BESSY II

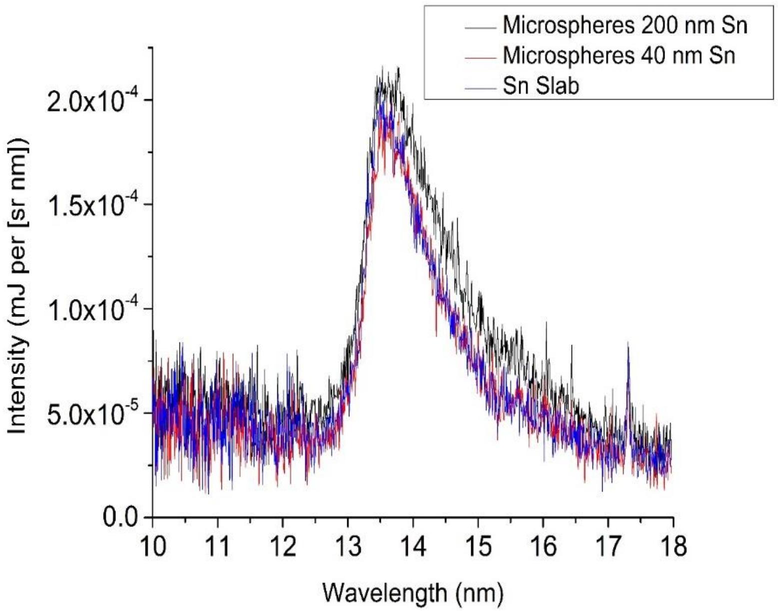
LASER PARAMETERS	
	Ekspla Picosecond
Pulse Length	170 ps
Repetition Rate	5 Hz
Max Energy	240 mJ
Laser Intensity	$\simeq 2\times10^{13}$ W/cm^2

XUV spectra from nanostructured targets under 170 ps laser pulses

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

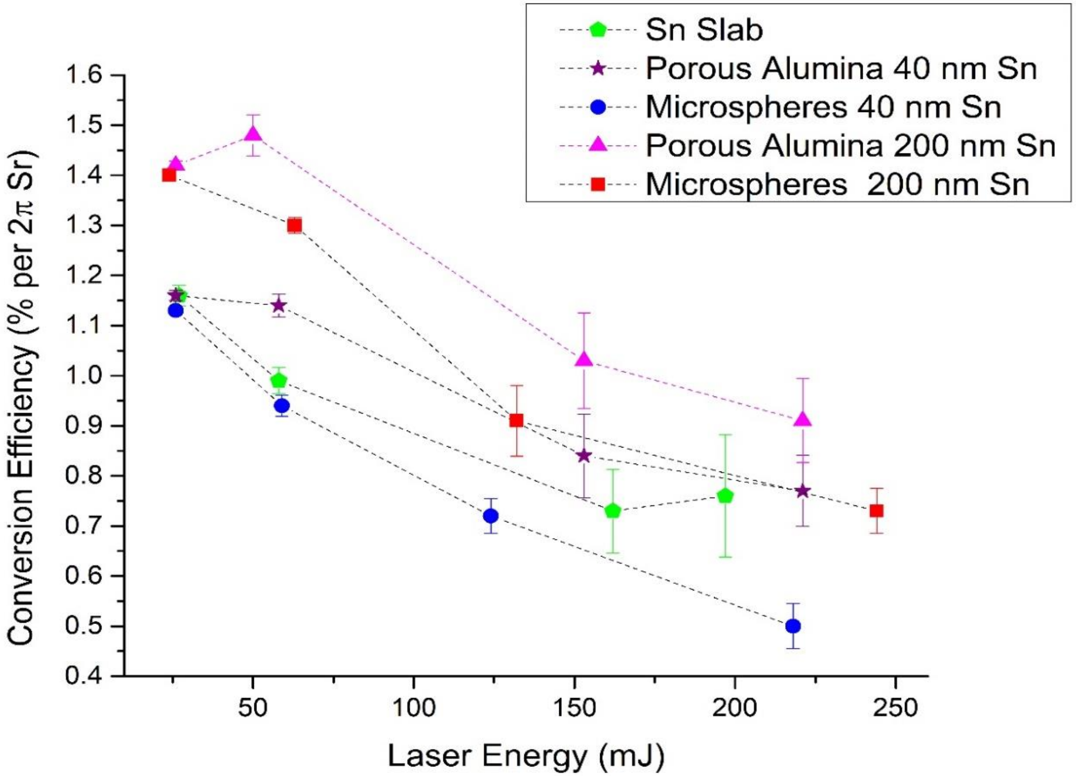


Microspheres at different thicknesses and bulk Sn target at 26 mJ laser energy



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

In-band CE vs Laser Energy

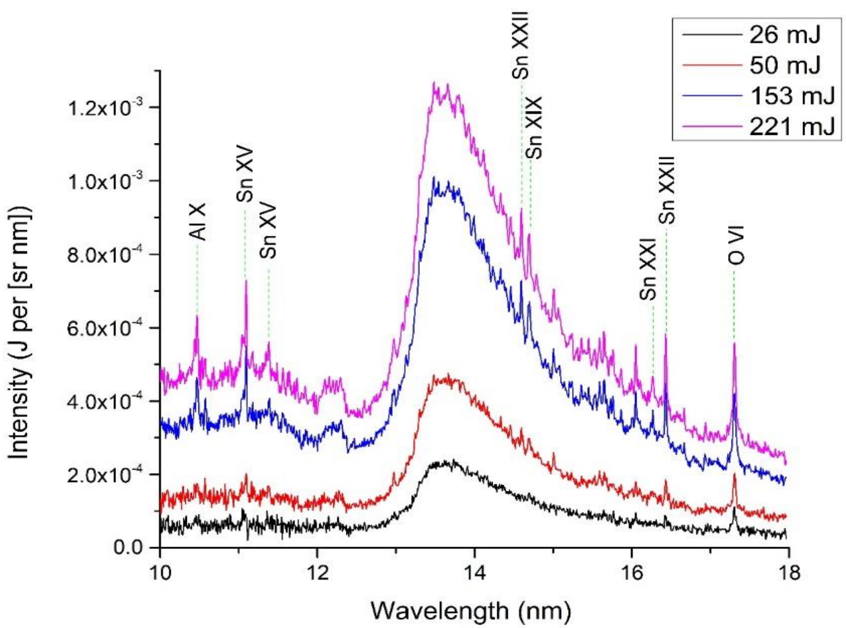


In-band conversion efficiency (CE) of all nanostructured targets compared to a bulk Sn slab.

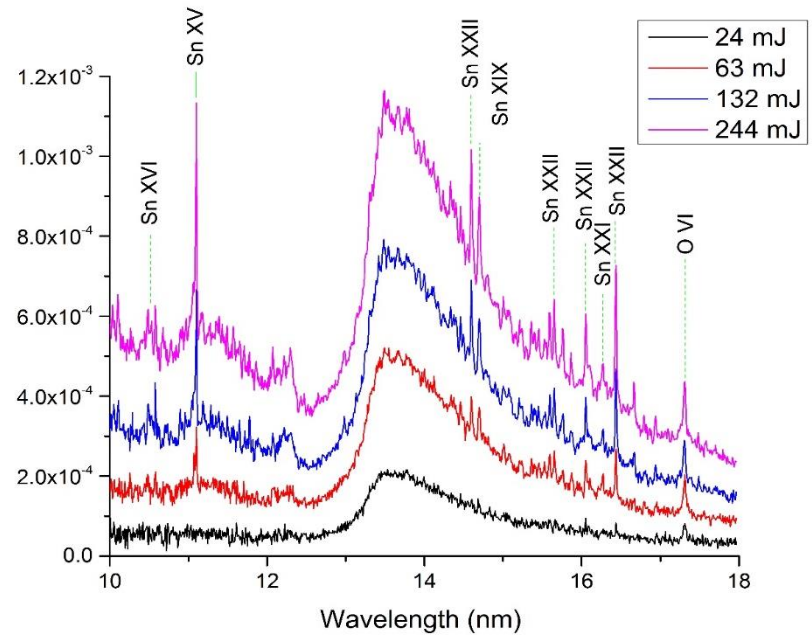
(E.F. Barte, et.al, Laser and Particle Beams (2017), DOI: 10.1017/S0263034617000623)

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 2×10^{12} W/cm^2.
- The maximum in-band conversion efficiency of 1.49 %/(2π Sr), measured for 200-nm-thick Sn layer on a porous alumina substrate at a laser intensity of 4×10^{12} W/cm^2 (laser energy of 50 mJ).
- For laser intensities higher than 4×10^{12} 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!

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