Spectroscopic measurements of Sn Laser-Produced Plasmas

L. Behnke[1], R. Schupp[1], Z. Bouza[1], J. Scheers[1,2], J. Sheil[1], F. Torretti[1,2], M. Bayraktar[3], C. Shah[4], J. R. Crespo López-Urrutia[4], W. Ubachs[1,2], R. Hoekstra[1,5] and O. O. Versolato[1]

[1]Advanced Research Center for Nanolithography (ARCNL), Science Park 106, 1098 XG Amsterdam, The Netherlands
[2]Department of Physics and Astronomy, LaserLaB, Vrije Universiteit Amsterdam, De Boelelaan 1081, 1081 HV Amsterdam, The Netherlands
[3]Industrial Focus Group XUV Optics, MESA+ Institute for Nanotechnology, University of Twente, Drienerlolaan 5, 7522 NB Enschede, The Netherlands
[4] Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany
[5]Zernike Institute for Advanced Materials, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands

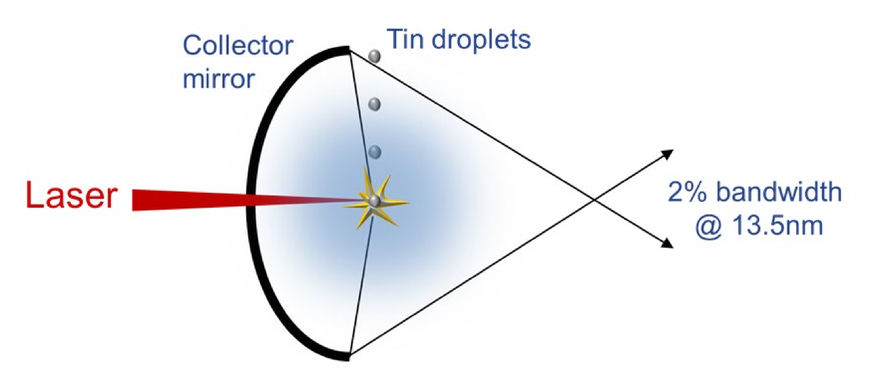
Laser-produced plasma (LPP) and electron beam ion trap (EBIT) Sn plasma emission spectra have been recorded in the extreme ultraviolet (EUV) range. EUV light emission around 13.5 nm wavelength from highly charged Sn ions produced from an LPP, is the light source for state-of-the-art nanolithography. Due to the complex electronic configurations of the relevant ions Sn^{5+}–Sn^{14+}, arising from their open 4*d* and 4*p* subshells, spectroscopic investigation of these plasmas can be quite challenging[1]. In this work, we experimentally investigate the emission of EUV-light from a LPP over a wide parameter range. Finally, we focus on the features at longer wavelength regime between 15 and 20 nm and by using charge-state resolved Sn ion spectra recorded in an EBIT[2], we describe all the features laying in the Sn LPP out-of-band region[3].

Introduction

The strong 13.5 nm emission from this LPP is of relevance for next-generation nanolithography machines

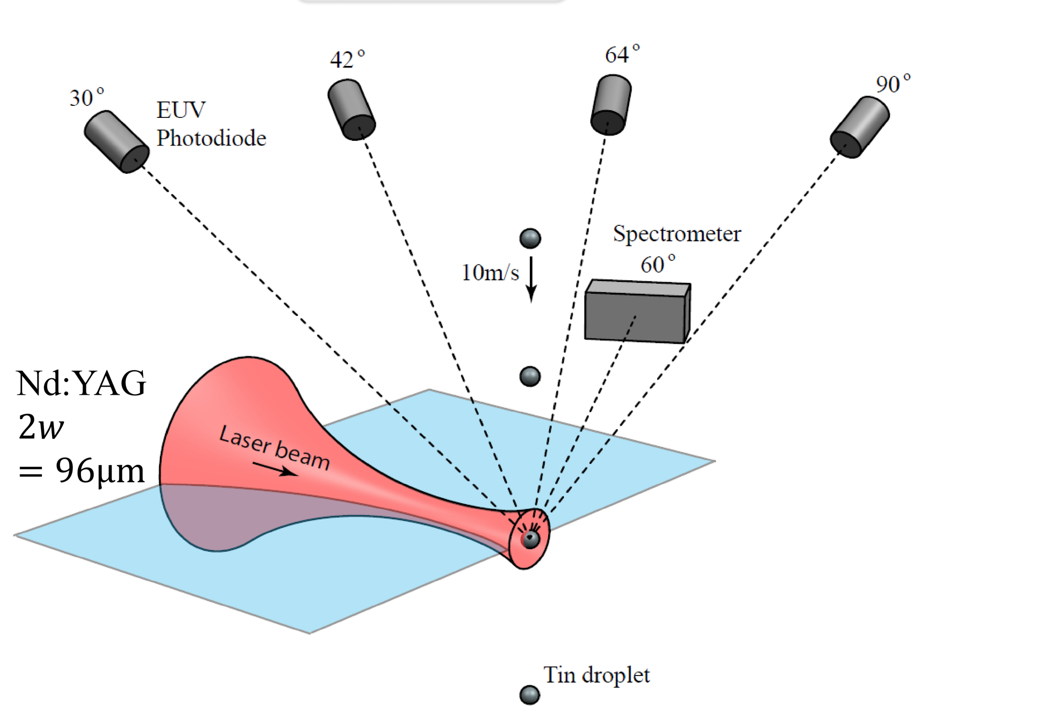
Molten Sn microdroplets are illuminated by high-intensity laser pulses, generating typically hot and high-density plasma

Optics used in the industry are only reflective in a 2% bandwidth around 13.5 nm



Experimental setups

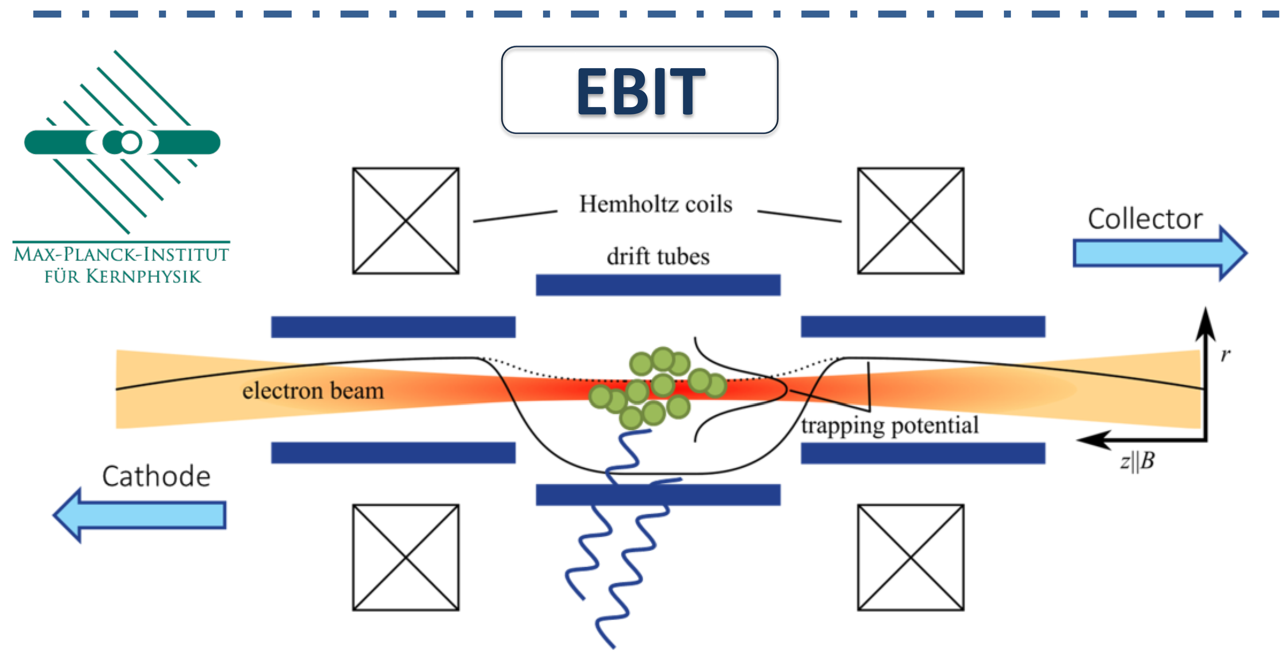
LPP



The tin droplet is irradiated by a linearly polarized, high-intensity laser pulse from an Nd:YAG laser system seeded at 1064 nm

The spectral emission of the produced plasma is observed under an angle of -60° using a wide-range transmission grating spectrometer[4]

EBIT

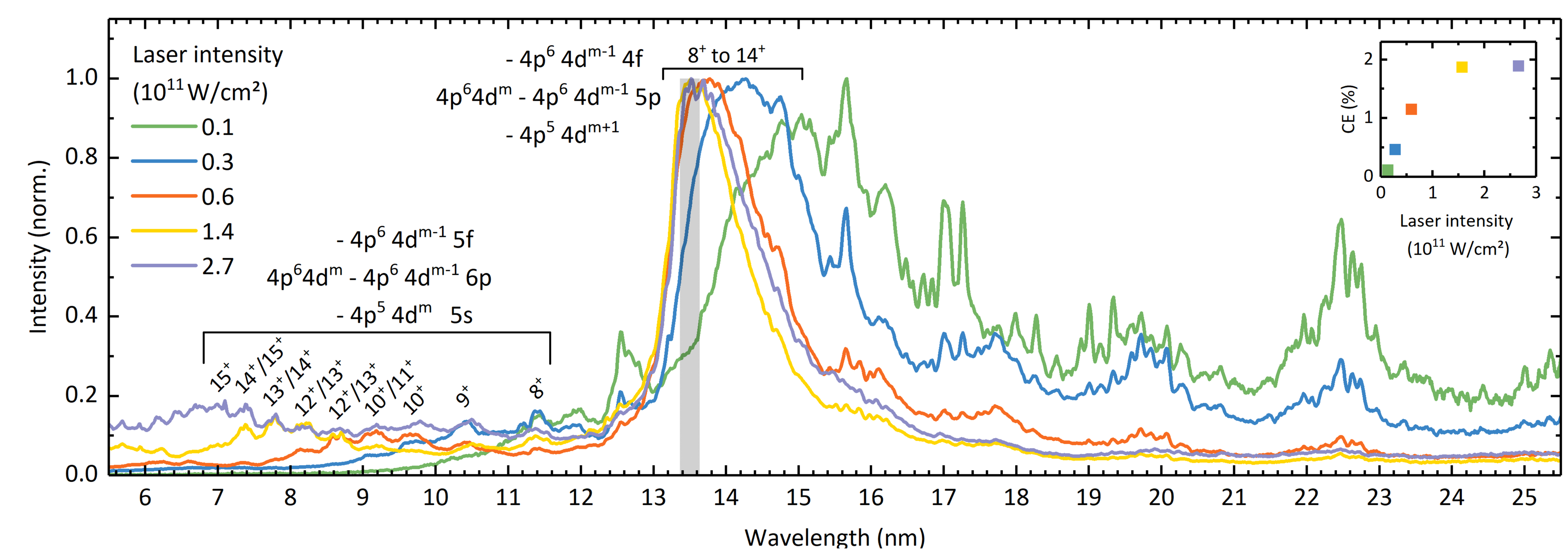


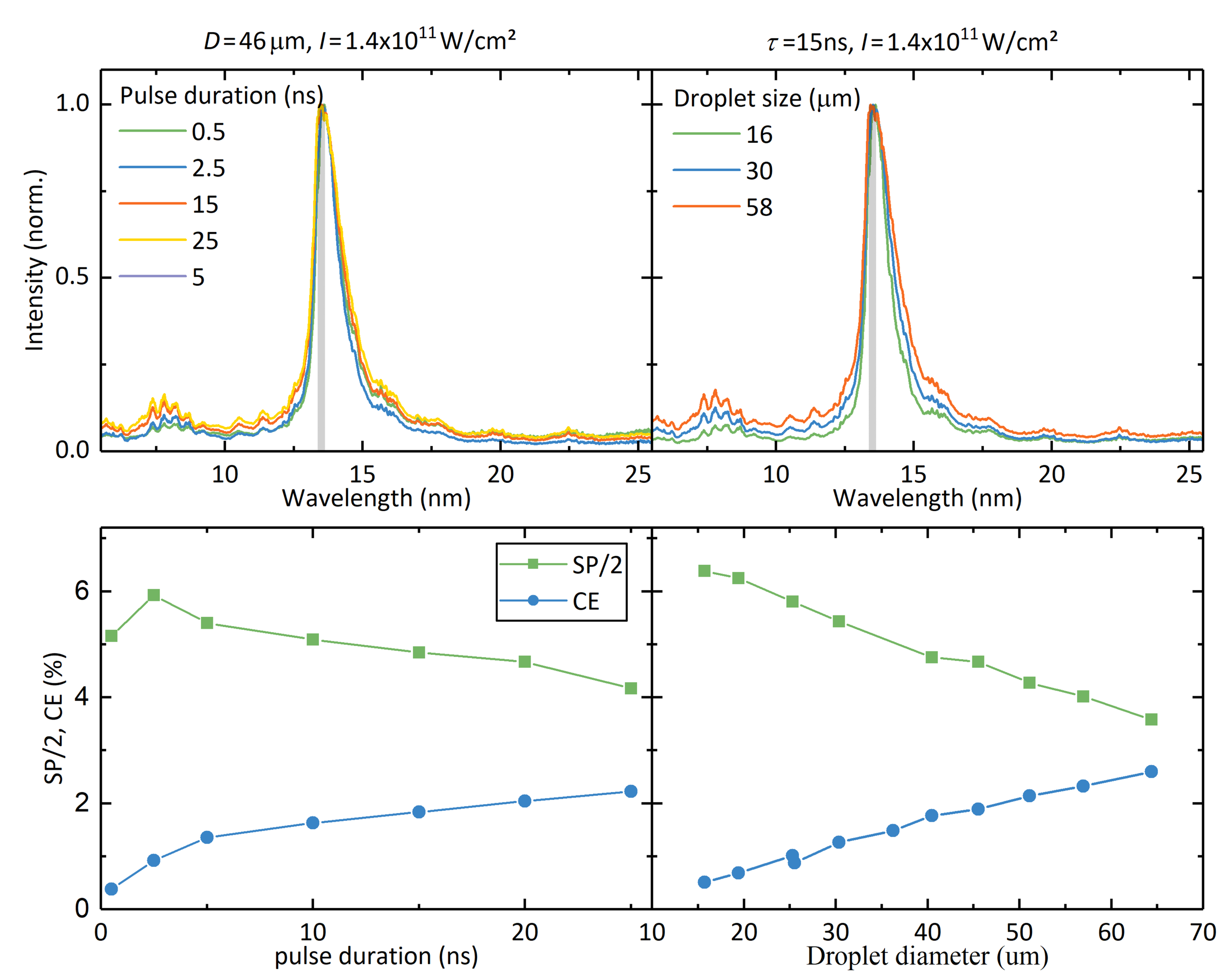
The EBIT delivers an electron beam at various, controlled electron energies

The high magnetic field compresses the electron beam and hence high electron current densities can be reached at the center of the trap

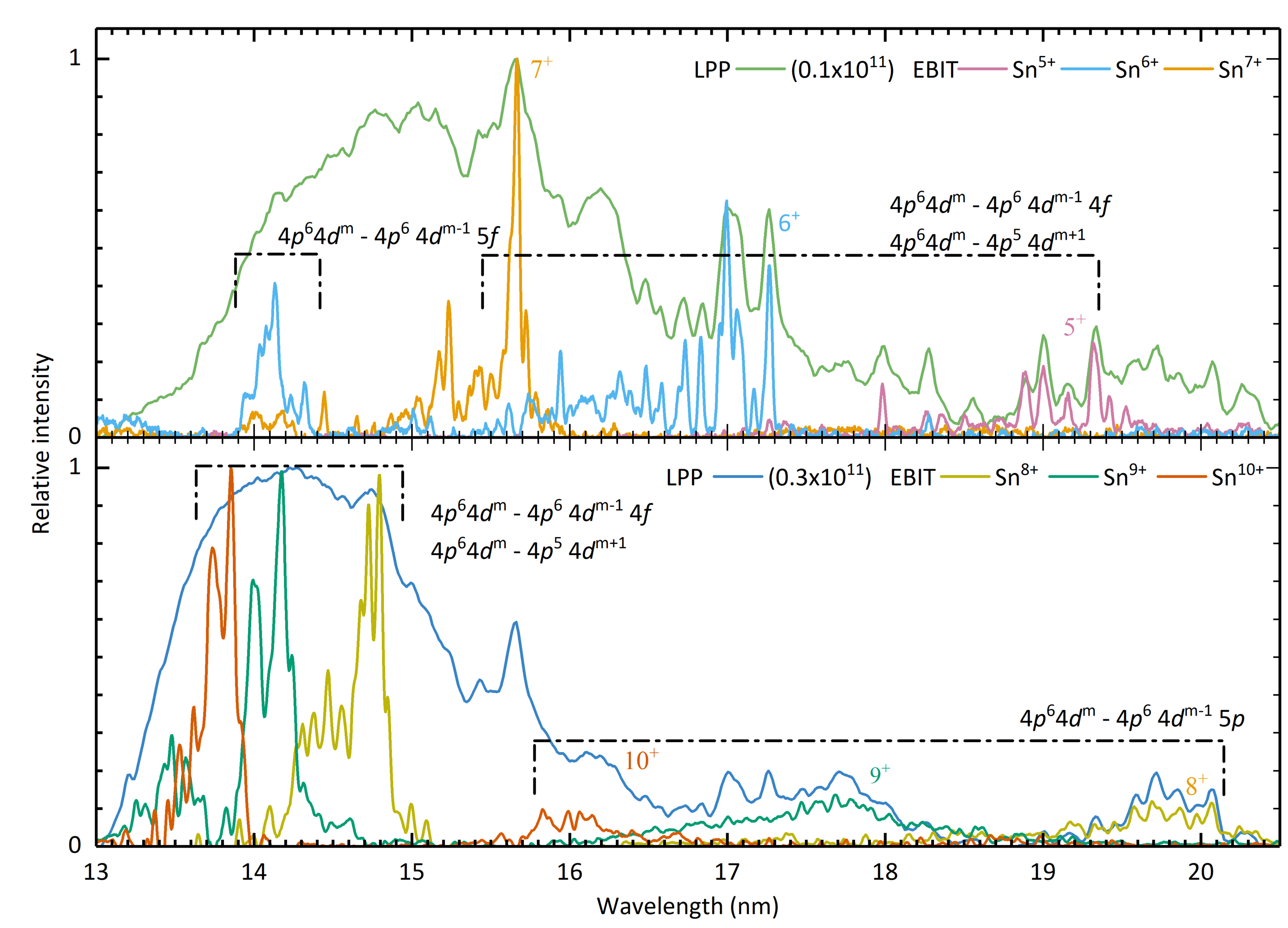
Tin ions are produced and trapped radially by the space charge potential of the dense electron beam as well as by the magnetic field

Results





- The spectral shift toward 13.5 nm with increasing laser intensity is due to creation of tin ions of higher charge states
- The widening of the main emission feature can be attributed to changes in optical depth in plasma
- A relatively high CE of 2.2% is reached at 25 ns
- A CE of 2.8% is reached in case of 15 ns and 65 um droplet size



- Charge states observed in the LPP spectra can be resolved using the EBIT
- Through flexible atomic code calculations (FAC), we have identified features corresponding to transitions in various charge states

Conclusions

- High values for the CE are obtained using a 1-um-laser-pulse-irradiation scheme
- EBIT spectra can explain very well the LPP spectra
- Depending on laser intensity, different Sn ions can be produced and observed at the same wavelength

References

[1] F. Torretti *et al.*, J. Phys. B Plasmas 51, 045005 (2018)
[2] J. Scheers, *et al.*, in preparation
[3] Z. Bouza, J. Scheers *et al.*, in preparation
[4] R. Schupp *et al.*, Phys. Rev. Appl. 12, 014010 (2019)

ARCNL
ADVANCED RESEARCH CENTER FOR NANOLITHOGRAPHY
ASML
VU VRIJE UNIVERSITEIT AMSTERDAM
UNIVERSITEIT VAN AMSTERDAM
NWO
erc