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 Sn⁵⁺–Sn¹⁴⁺ arising from their open ⁴d and ⁴p subshells, spectroscopic investigation of these plasmas can be quite challenging. 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, we describe all the features laying in the Sn LPP out-of-band region.

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

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.

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 µm droplet size.

Conclusions

- 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.
- 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