Modeling of the atomic processes in EUVL source plasmas

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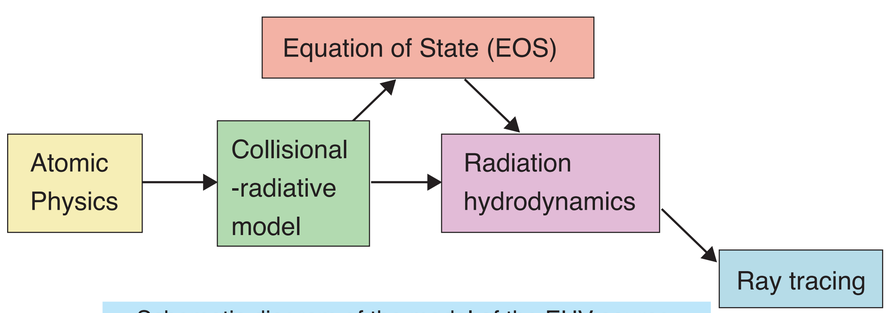
Abstract: We present progresses in the modeling Sn and Xe plasmas. The emission in the 13.5nm wavelength region is attributed to 4d-4f transition arrays of Sn and 4d-5p transition of Xe^{10+} with satellite lines. In the case of Sn, the spectral structure is determined by the detailed structure of the 4d-4f transition, and the width of the array is determined by the distribution of satellite lines. As the opacity of the plasma increases, the absorption through strong resonance lines considerably modifies the spectrum. We improve accuracy of the wavelengths and transition probabilities of 4d-4f and 4d-5p transition arrays of each charge state, after detailed comparisons between calculations and experiments. Emission spectrum from the various EUVL sources are compared with the result from the charge exchange spectroscopy and the opacity measurement. We calculate the emissivity and opacity of the plasma, which are used in the radiation hydrodynamics code to perform optimization of the source power and conversion efficiency, with respect to target and laser conditions.

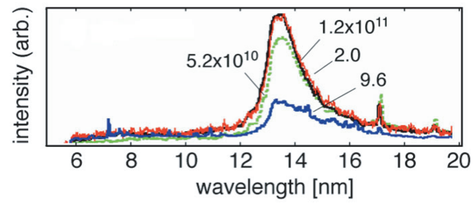
1. Introduction

We develop a radiation hydrodynamics model of laser produced plasma (LPP) source to evaluate EUV spectrum and conversion efficiency (CE). The atomic physics and collisiona-radiative codes provide the emissivity and opacity of the plasma.



Schematic diagram of the model of the EUV source

2. Modeling



Typical EUV spectrum for laser produced Sn plasma

We find from the theoretical investigation of EUV spectra of Xe and Sn, that strong EUV emission from Xe and Sn arises from 4d-4f, 4p-4d, 4d-5p, and 4d-4f resonance and satellite lines from multiply and inner shell excited configurations.

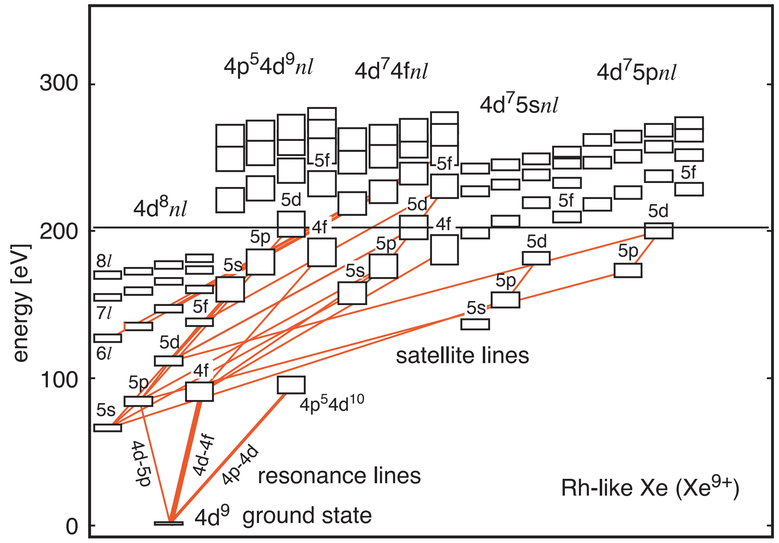
We calculate the population by solving a set of rate equation,

$$\frac{dN_i}{dt} = \sum_j R_{ji} N_j - \sum_k R_{ik} N_i ,$$

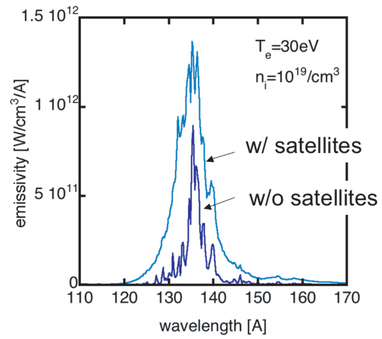
based on the configuration model with energy levels and radiative rates calculated by the HULLAC code.

Emissivity and opacity are calculated including b-b, b-f, f-f transitions, which are calculated from the population and transition probability with detailed line profile.

$$\varepsilon_{bb} = \Sigma\left(const \cdot A_r N \Delta E \cdot \Phi(\nu)\right)$$



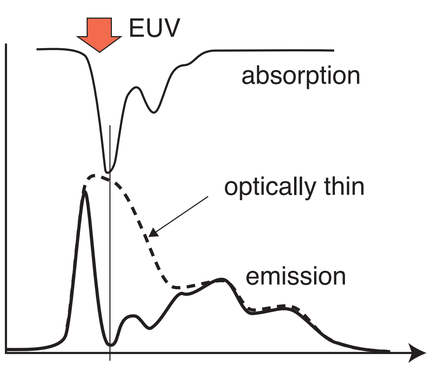
Energy level diagram of Xe^{9+}.

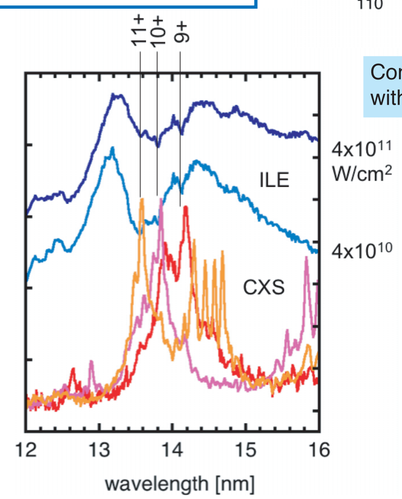


Because Sn and Xe ions have a large number of multiply excited configurations with a large statistical weight, intensity and width of emissivity and opacity increases up to 2x including the satellite lines.

Comparison of calculated emissivity with and without satellite lines.

As optical depth of the plasma increases, absorption of strong resonance lines overlap the emission. Calculated intensity at 13.5nm band and CE depends on the accuracy of the wavelength of the emission lines.

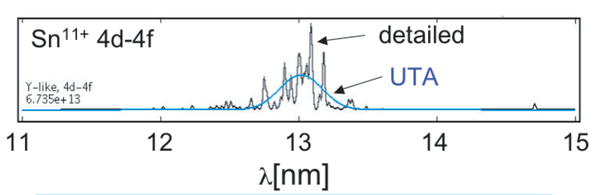




Comparison between spectrum from laser plasma and charge exchange experiment. Effect of the absorption of the resonance lines is shown.

Detailed profile is calculated from distribution of the emission lines, averaged over energy grid (ΔE=0.2eV) of emissivity and opacity. Line separation is assumed to be much smaller than line width.

Calculated spectrum using UTA model assuming Gaussian profile differs significantly from experiment.



Comparison of UTA and detailed spectrum of 4d-4f transition of Sn^{11+} with and without satellite lines.