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Atomic Processes in laser produced tin plasmas for application to extreme ultra-violet (EUV) lithography

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Tin plasmas show strong emission in the extreme ultra-violet (EUV) wavelength of λ=13.5 nm, which is applied to the microlithography of the advanced semiconductor devices. In the plasma with electron temperatures between 20-50 eV, around ten times ionized tin emits EUV light through 4d-4f and 4p-4d atomic transitions. Due to the effect of configuration interaction, the 4d-4f and 4p-4d transitions appear as a broad peak called unresolved transition array [1], with the wavelength being constant over charge states. The wavelength is characteristic for the atomic element and emission at shorter wavelength is obtained using heavier elements. The emission spectrum is investigated theoretically using the computational atomic data, and the pumping condition of the plasma is optimized, resulting in more than 500 W of EUV power with a convergence efficiency of 5 %.

Figure 1 shows the energy level diagram of Y-like tin (Sn^{11+}). The Y-like tin ion has a ground configuration of $4d^3$. Fig.1 shows the tin ion has a large number of multiply excited states and emits EUV light not only from singly excited states but from multiply excited states. Emission from multiply increases in high-density plasmas due to enhanced electron collisional excitation causes the broadening of the EUV spectrum toward longer wavelengths (14-16 nm). In addition, 4d-5p, 4d-5f, 4p-5s, and several other transitions appear as side peaks in wavelengths between 5-12 nm [2].

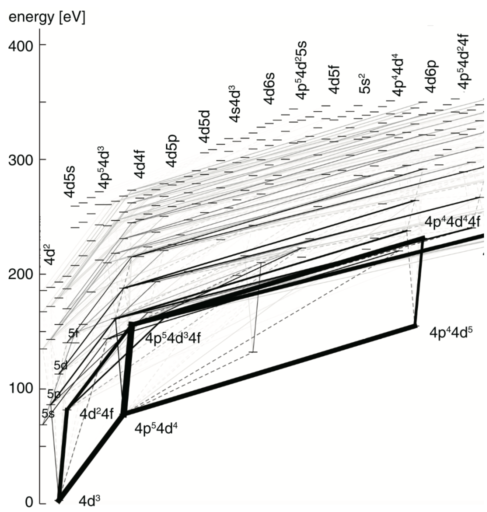

Figure 1: Energy level diagram of Y-like tin [3].

Figure 2 shows the schematic diagram of JATOM2 code. Firstly, energy levels and radiative rates are calculated using the HULLAC code [4]. Secondly, the population of tin ions is calculated using the collisional radiative (CR) model based on the configuration-averaged atomic structure. Thirdly, applying the spectrum of UTA with correction of its wavelength according to the experiment [5], spectral emissivity and opacity are calculated.

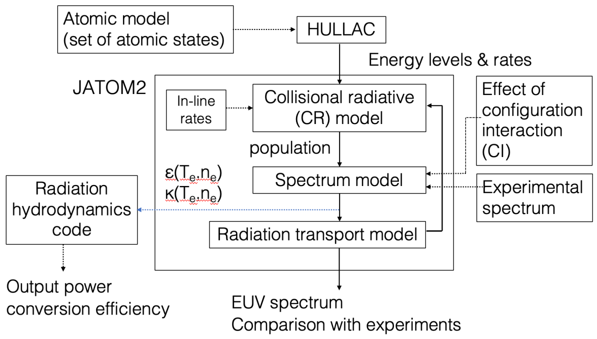

Figure 2: Schematic diagram of JATOM2 code.

Using the opacity table of tin plasmas, the temporal and spatial evolution of laser-produced tin plasmas is investigated using the radiation-hydrodynamics simulation. Optimization of the output power and efficiency using solid-state laser-pumped plasmas will be investigated. The extension of the model to heavier elements is being considered for shorter-wavelength sources in the wavelength region between 2-6 nm, aiming to further miniaturize semiconductor technologies.

References

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