

Numerical calculation of EUV emission for LPP scheme with Sn

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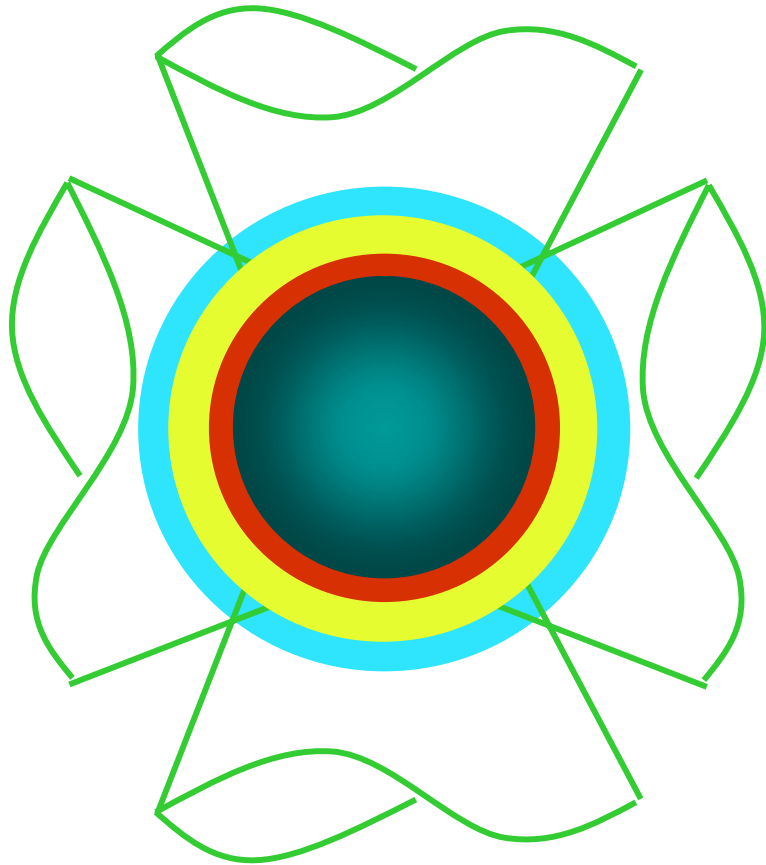
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An ideally “uniform” EUV radiator was produced by GEKKO-XII laser, to obtain laser intensity dependence of the conversion efficiency without lateral energy loss and geometrical effects.



spherically uniform plasmas

Laser :

GEKKOXII, 12 beams
wavelength: ω (1.056 μm), 2ω (0.527 μm)
intensity: $5 \times 10^{10} \sim 1 \times 10^{12} \text{ W/cm}^2$
pulse width: 1.2 ns (FWHM, Gaussian)

Target :

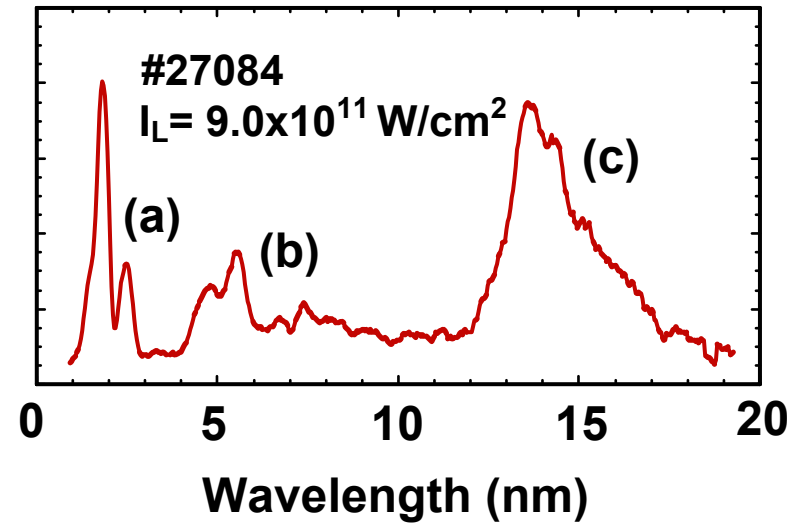
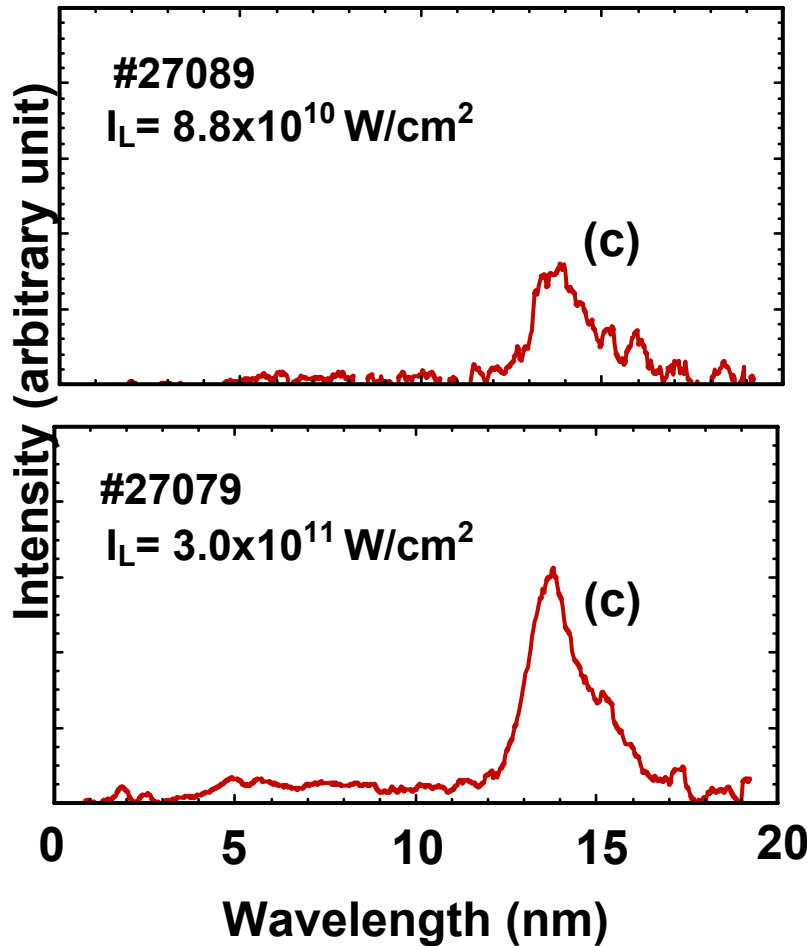
Sn or SnO_2 coated glass ball
300~2000 μm^ϕ (mostly 700 μm)

Diagnostics (XST: time resolved):

transmission grating (TDI) + CCD
grazing incident spectrometers (GIS)
x-ray backlight: density profile



X-ray emission is observed not only from EUV-region but also from short-wavelength region of $< 3\text{nm}$, and/or $\sim 5\text{nm}$.



- (a) $\lambda < \sim 2.5 \text{ nm}$ ($h\nu > \sim 500 \text{ eV}$)
- (b) $\lambda \sim 5.0 \text{ nm}$ ($h\nu \sim 250 \text{ eV}$)
- (c) $\lambda > \sim 10 \text{ nm}$ ($h\nu < \sim 125 \text{ eV}$)



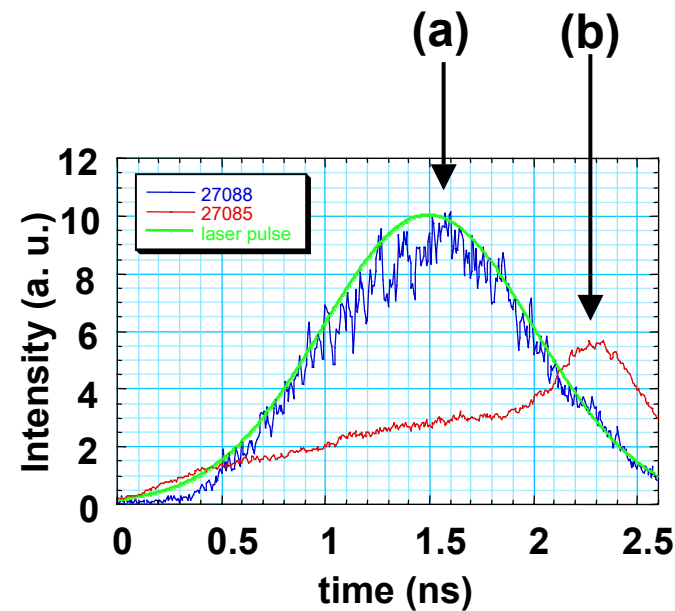
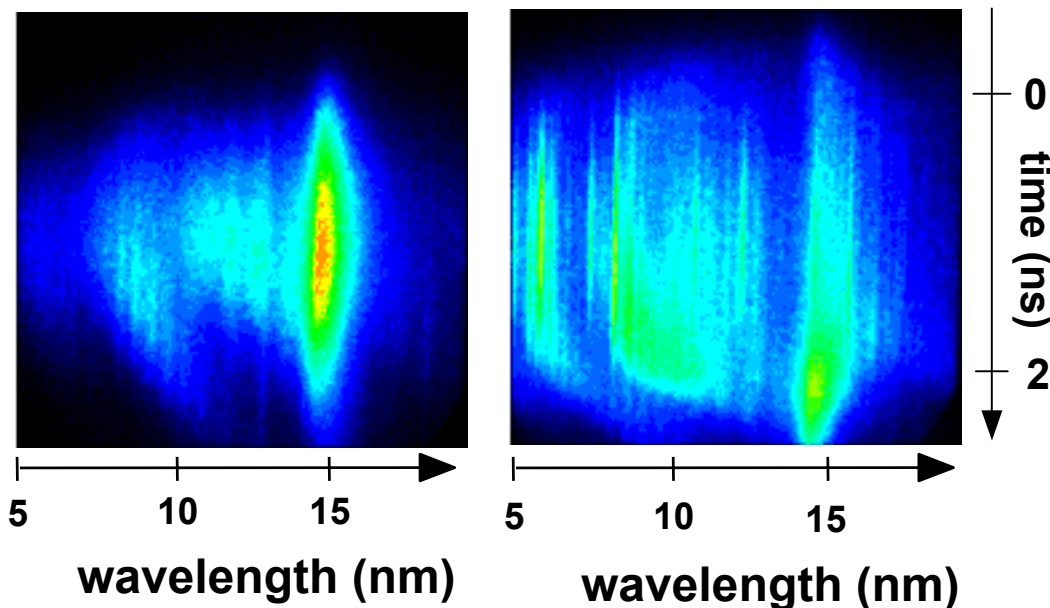
Temporal evolution of the EUV spectra was measured by the GIS coupled with an x-ray streak camera

- Time-evolution of EUV-light at 10^{11} W/cm² synchronizes with a laser-pulse. -

Intensity dependence of the time-resolved spectrum from tin-oxide targets

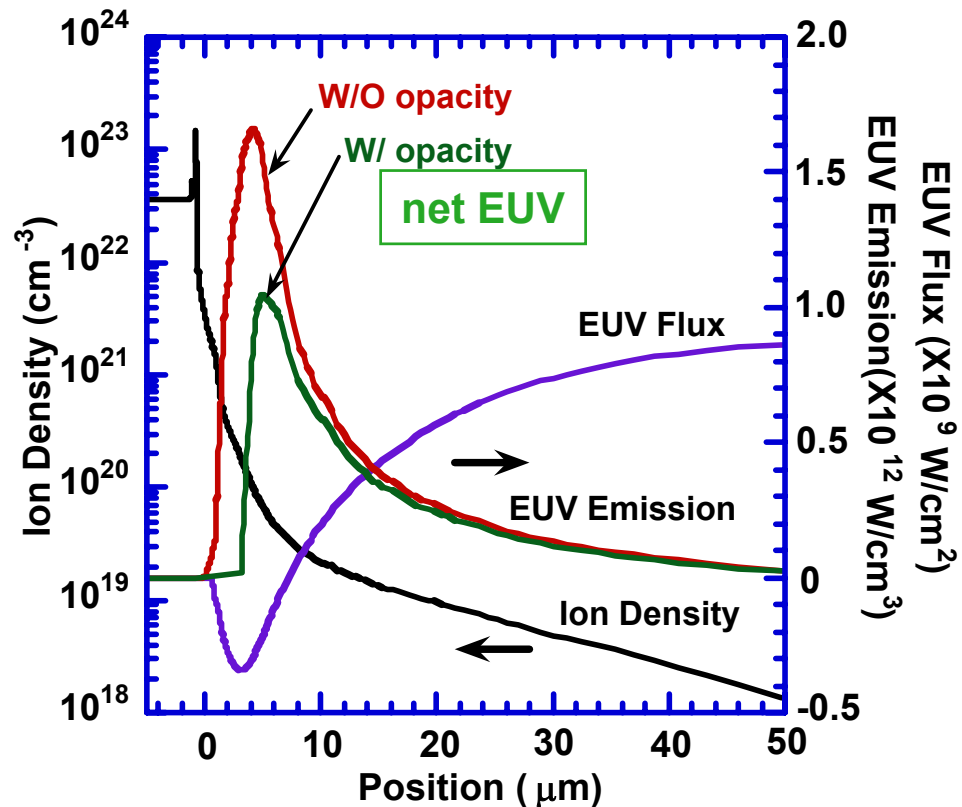
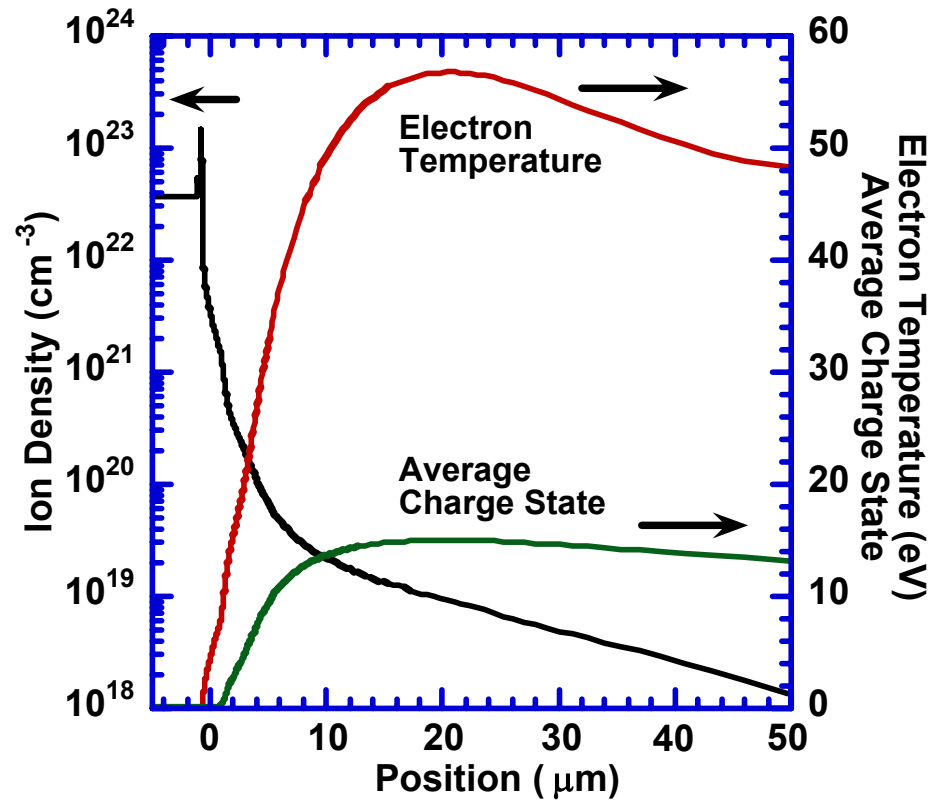
(a) 1.2×10^{11} W/cm²

(b) 9.6×10^{11} W/cm²



With $1 \times 10^{11} \text{ W/cm}^2$, 1.2 ns 1ω pulse, EUV emission is generated at $\sim 10^{19} \text{ cm}^{-3}$ and 30 ~ 50 eV around the electron ablation front from hydrodynamic simulation.

$1 \times 10^{11} \text{ W/cm}^2$, 1.2 ns 1ω



Development of CR-model calculation code.

Atomic configurations: Ground & singly excited states ($n\ell$ -scheme, $n \leq 10$) from neutral to hydrogen atoms.

Atomic energy levels ($n\ell$ -scheme) :

**$Z > 22$: Screening Hydrogenic Model with ℓ -splitting.
Phys. Scr., 39, 332 (1989).**

$Z \leq 22$: Hullac-code (taking an average on jj-atomic levels $\rightarrow n\ell$ -scheme)

Oscillator strengths

$Z > 22$: based on Hydrogenic approximation.

$Z \leq 22$: Hullac-code (taking an average on jj-atomic level transitions)

**Atomic processes (CR-model) : Collisional (de-)excitation, ionization & recombination.
Radiative decay and recombination,
Photo ionization, (de-)excitation.**

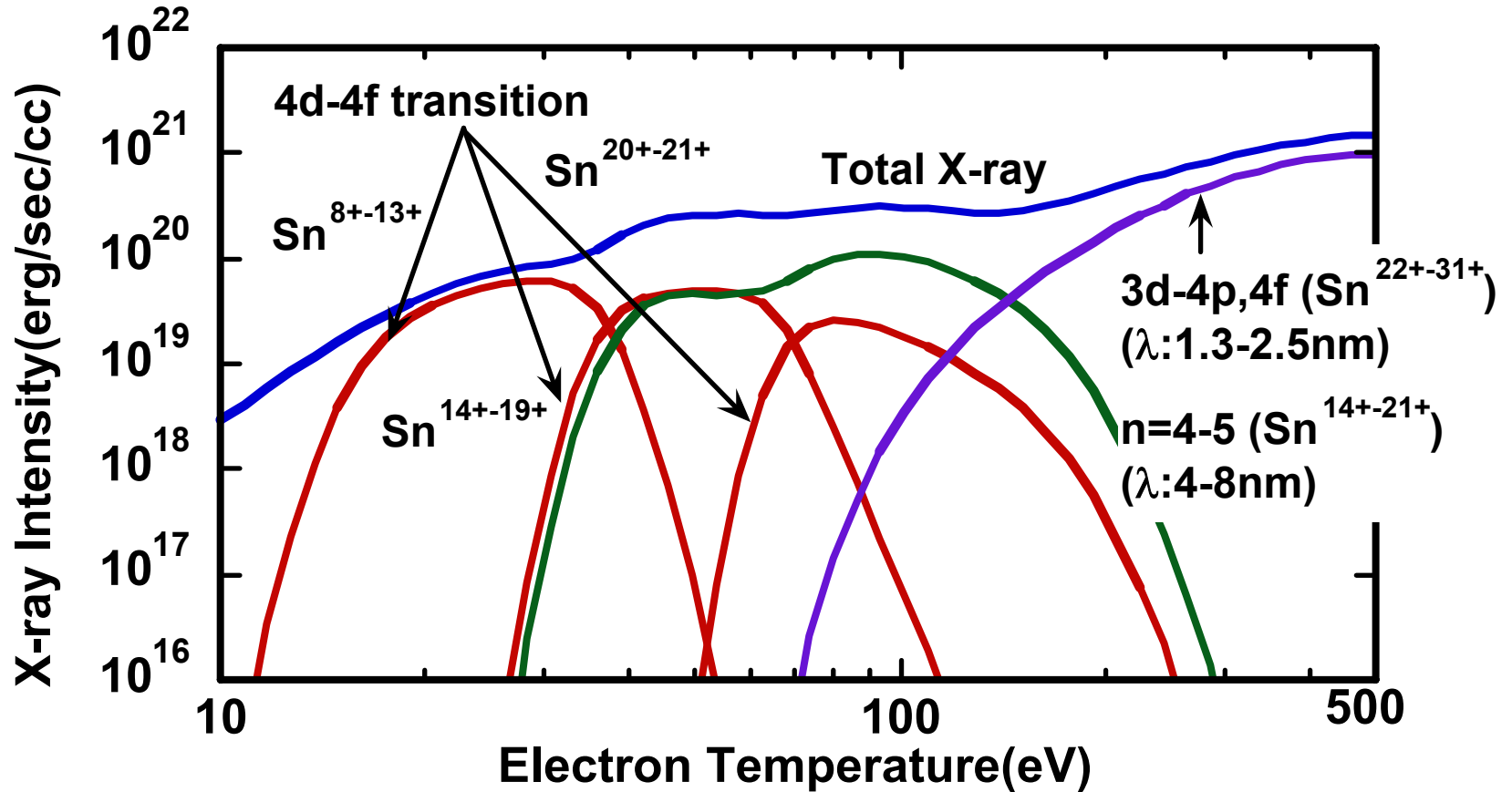
Continuum Lowering : Stewart, Pyatt, Astrophys. J., 144, 1203 (1966)

Pressure ionization : Zimmermann, More, JQSRT, 23, 517 (1980)

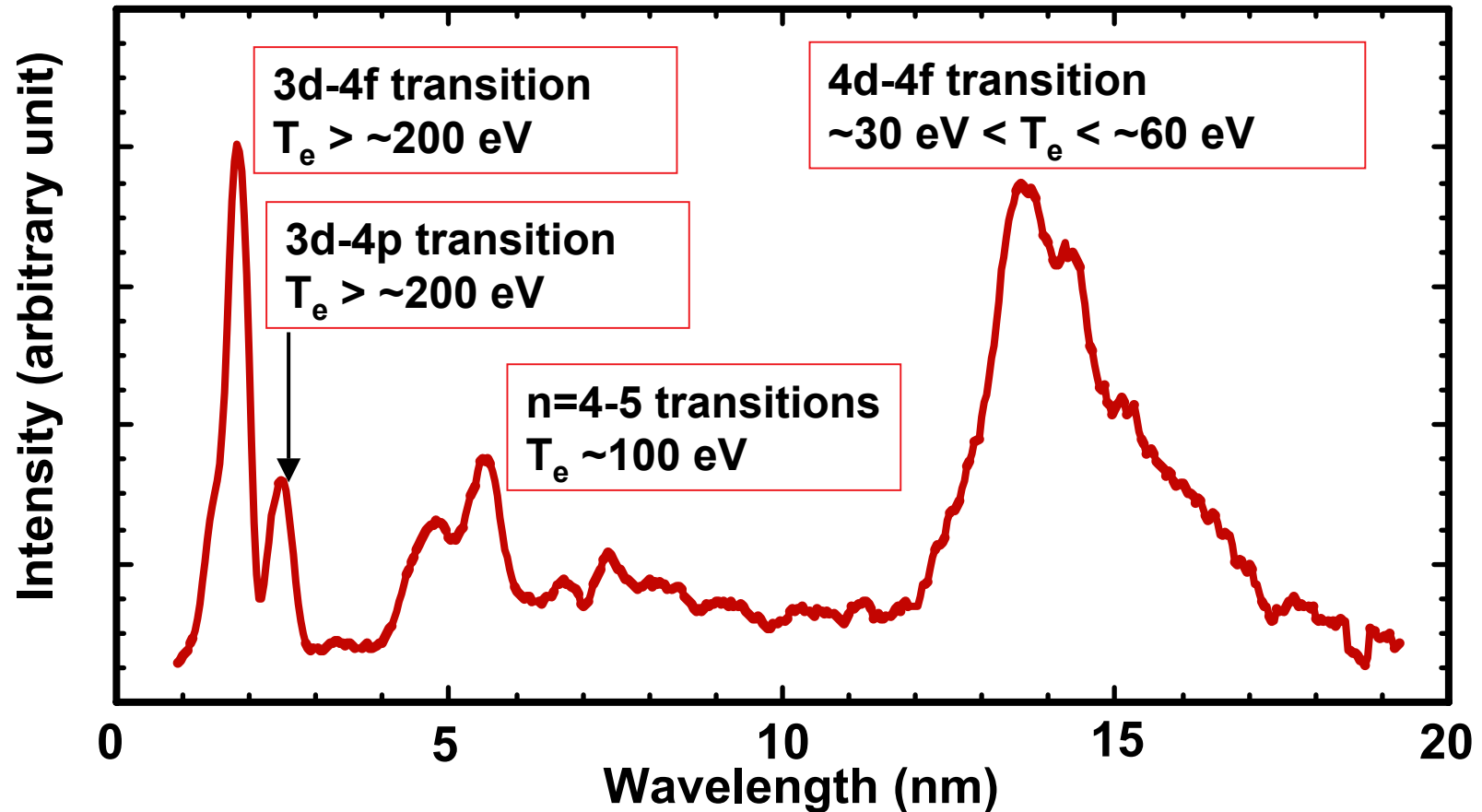


Major atomic transitions relevant to EUV-plasmas(in equilibrium scheme).
The M-band emission dominate at $T_e > \sim 200$ eV, and the N-band at $T_e < \sim 100$ eV.

Sn : 2×10^{19} cm⁻³ External radiation : None

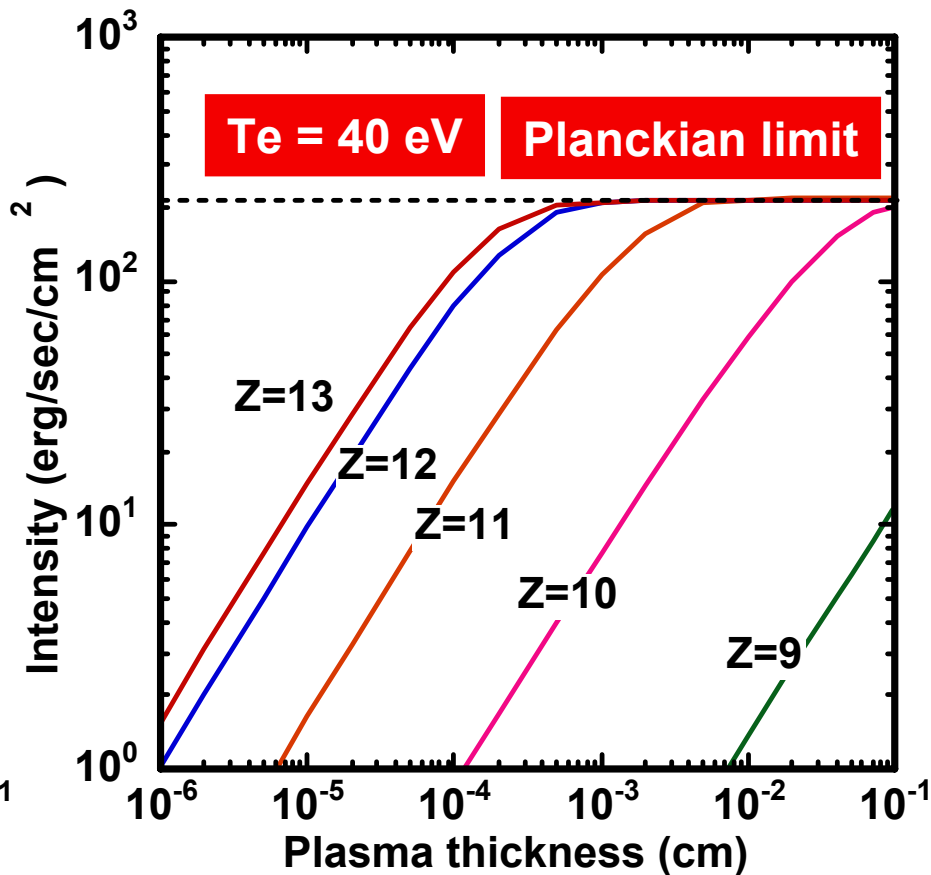
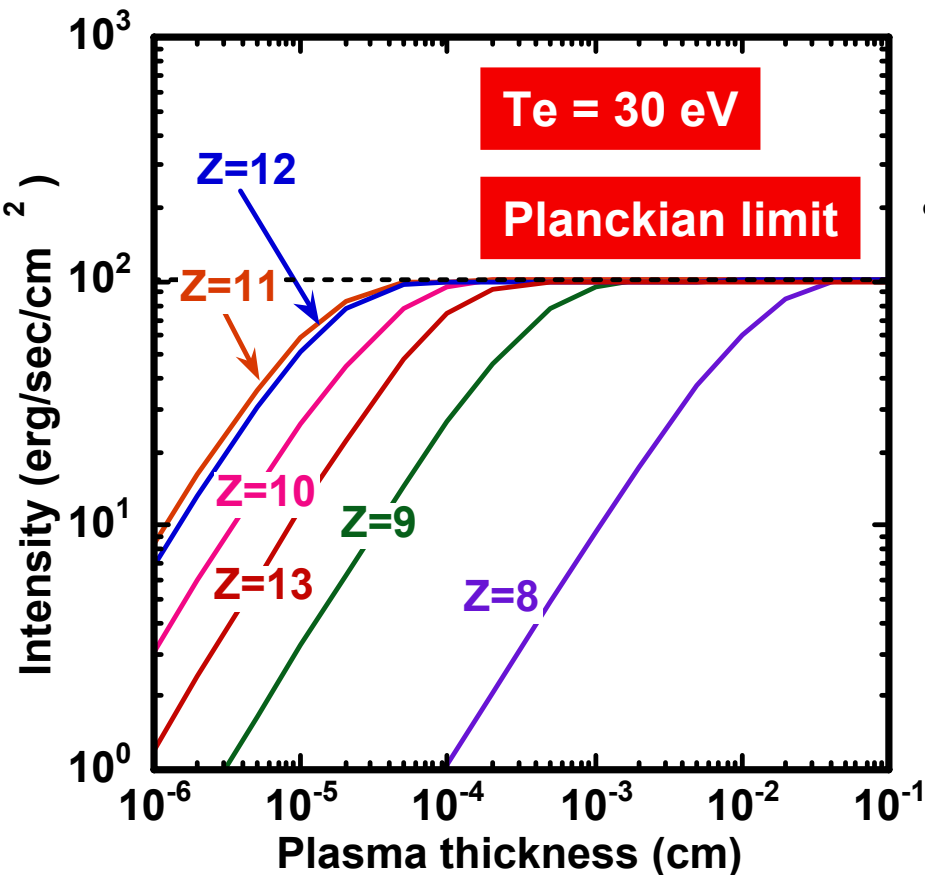


EUV-plasma created by high intensity laser ($\sim 10^{12}$ W/cm²) roughly consists of **three temperature components**.



Desired EUV-light can be obtained at $T_e = 30 \sim 40$ eV (in equilibrium scheme), and is saturated at plasma thickness of $1 \sim 100$ microns according to plasma temperature and charge state, reaching up to the Planckian limit.

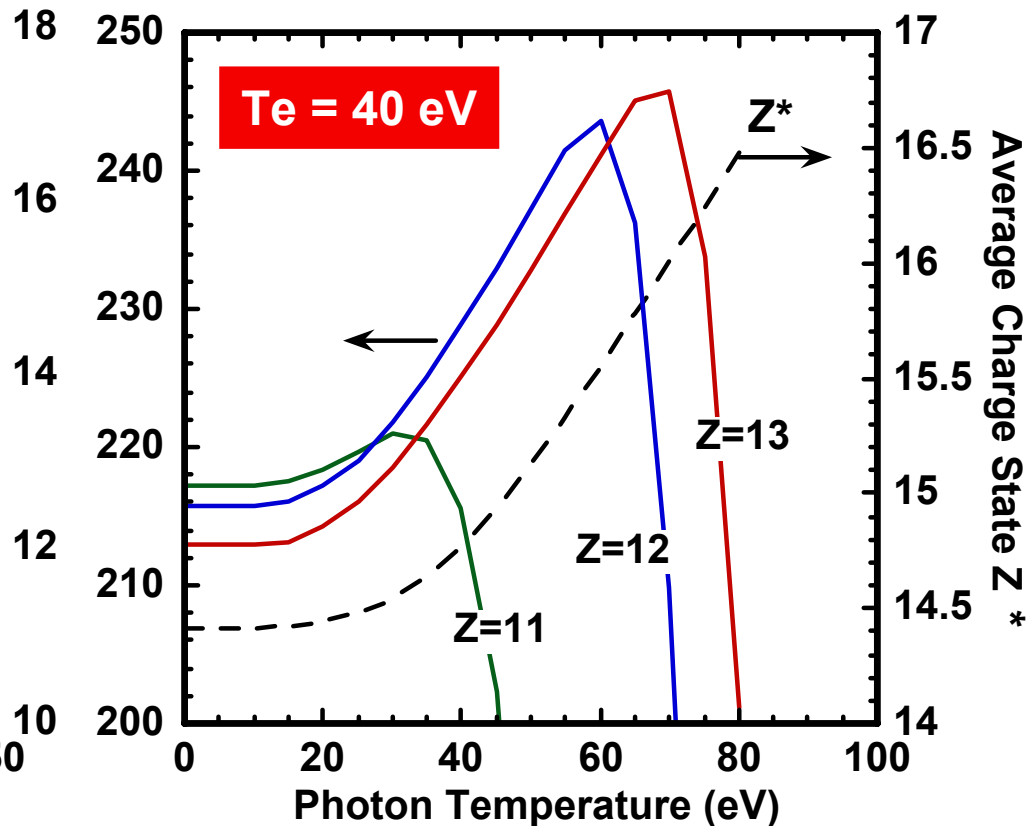
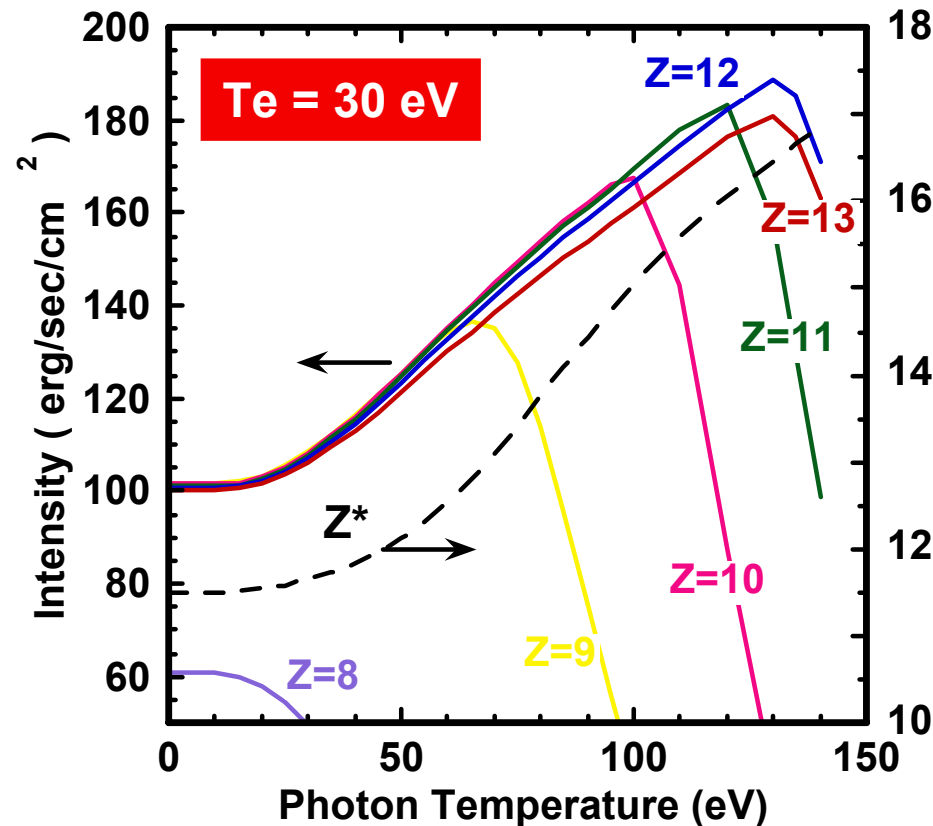
Sn : $2 \times 10^{19} \text{ cm}^{-3}$ External radiation : None



Enhancement of EUV-yield may be expected **with use of external radiation of about 50 eV**. The radiative atomic transitions have effective contribution for generation of EUV-light (in equilibrium scheme).

Sn : $2 \times 10^{19} \text{ cm}^{-3}$

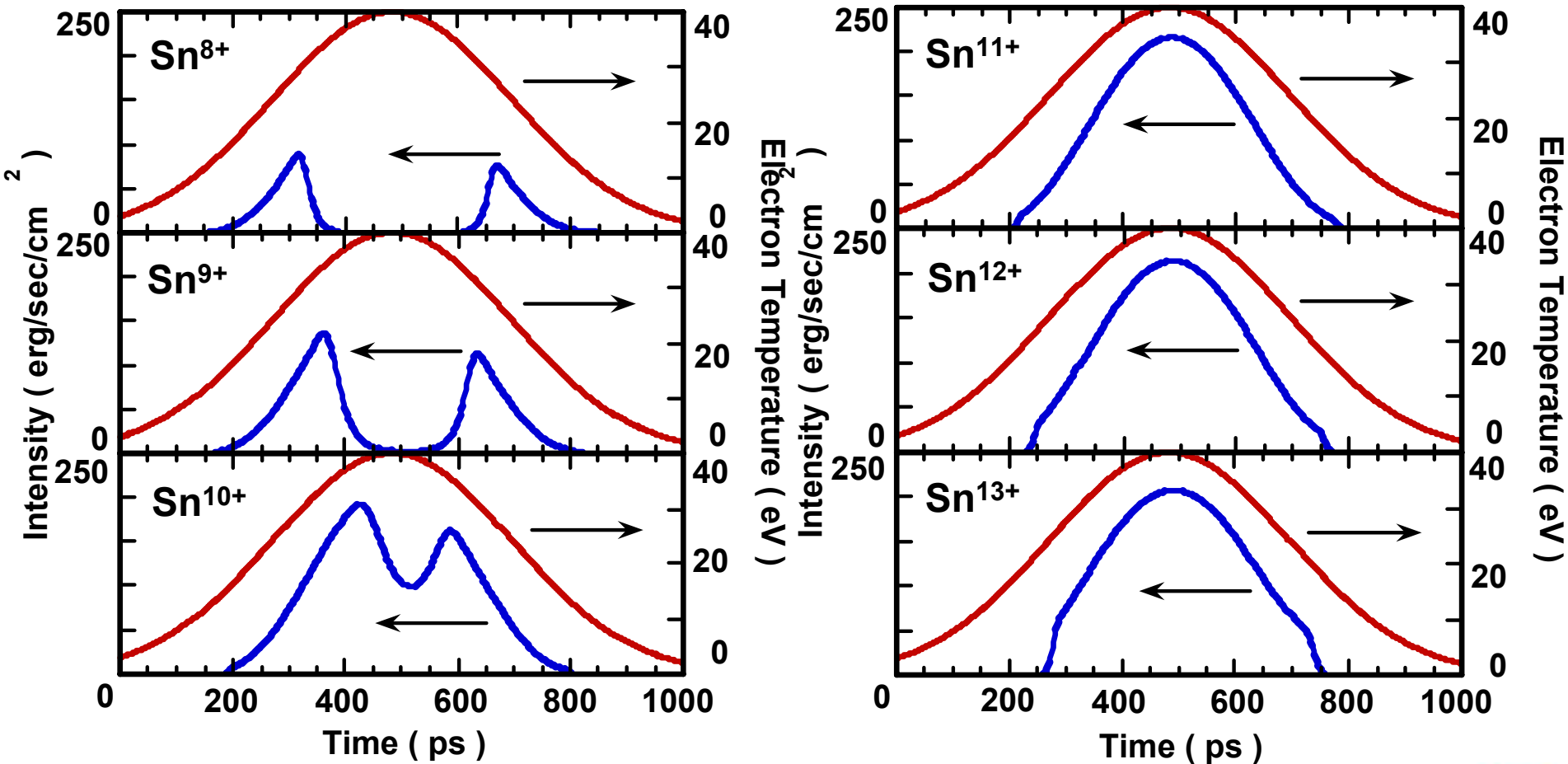
Plasma thickness = 100 μm



Time evolution of EUV-lights of Sn^{8+} - Sn^{13+} under Gaussian temperature profile, of which peak is 40 eV, shows specific features, respectively.

- EUV-lights of $\text{Sn}^{11+ \sim 13+}$ almost reach the Planckian at temperature peak of 40 eV. -

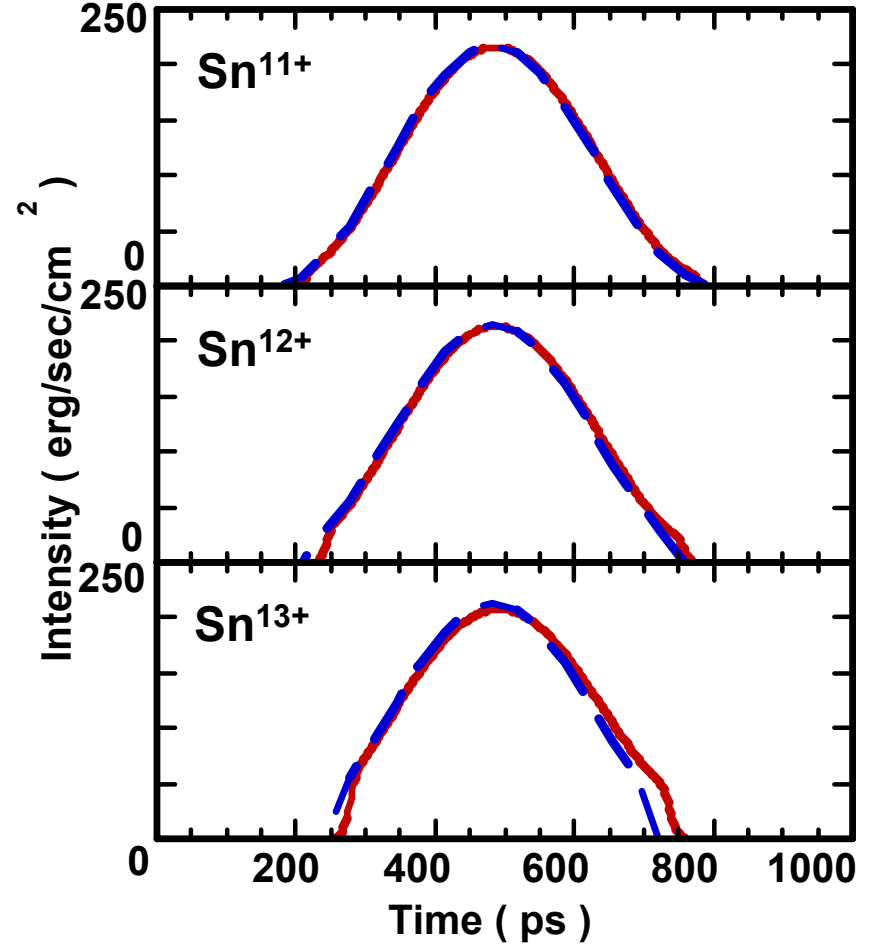
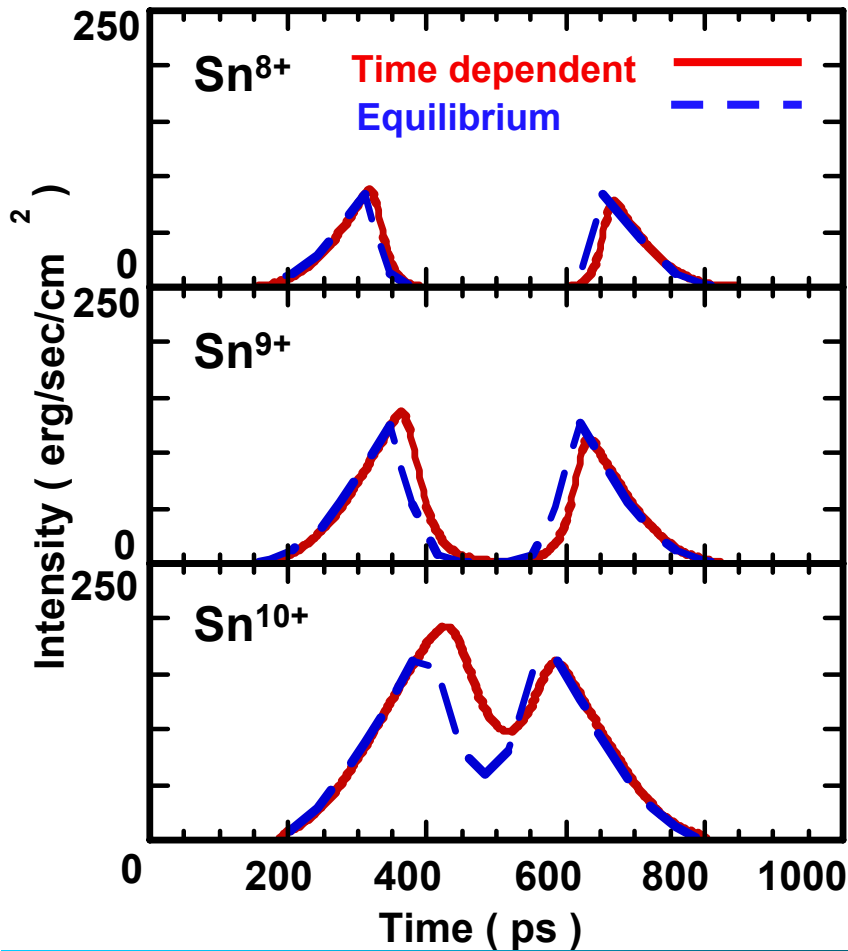
Sn : $2 \times 10^{19} \text{ cm}^{-3}$ Plasma thickness : $100 \mu\text{m}$ FWHM of temperature : 500 ps



Time dependent properties for generation of EUV-light.

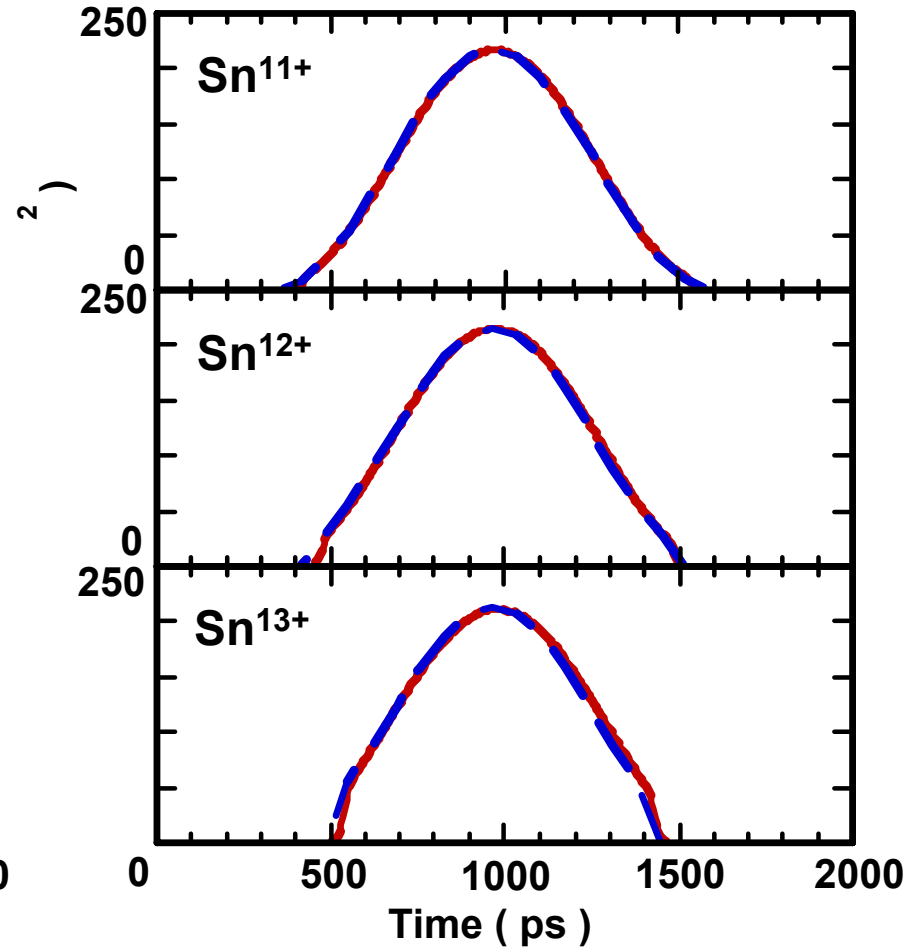
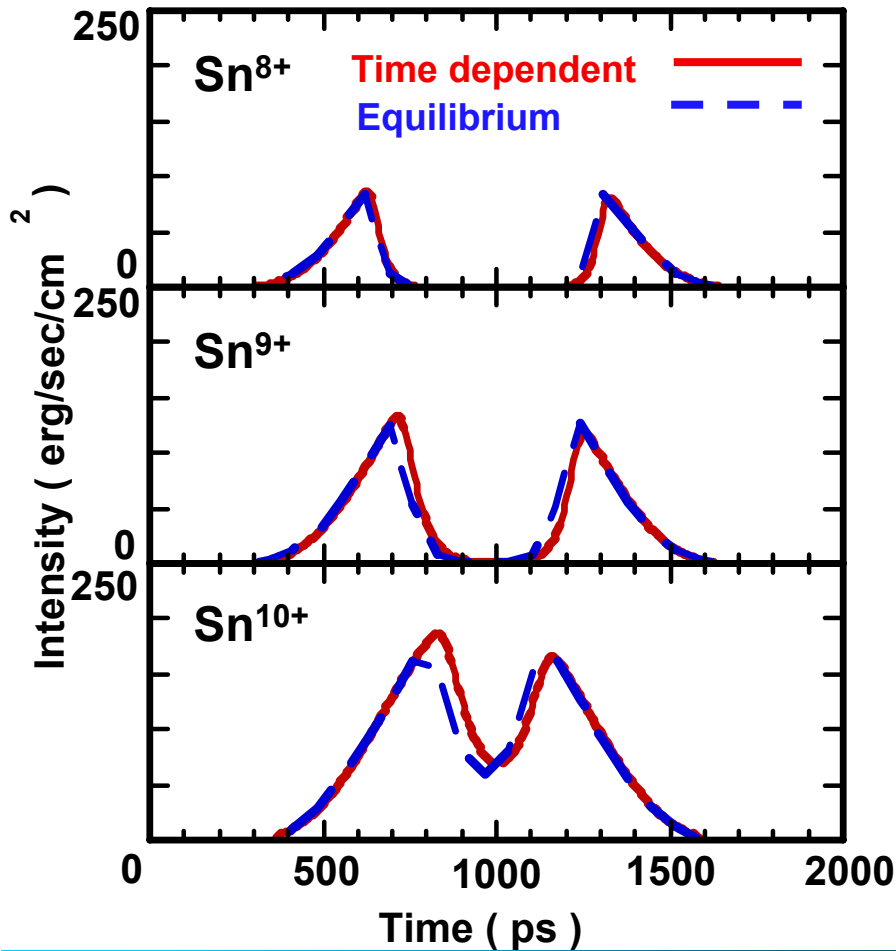
- EUV-lights of Sn^{8+~10+} show small enhancement due to transient effect. -

Sn : $2 \times 10^{19} \text{ cm}^{-3}$ Plasma thickness : $100 \mu\text{m}$ FWHM of temperature : 500 ps



Time dependent properties for generation of EUV-lights of Sn⁸⁺-Sn¹⁰⁺ become very small. **Properties of EUV-lights are almost in equilibrium.**

Sn : 2x10¹⁹ cm⁻³ Plasma thickness : 100 μm FWHM of temperature : 1 ns



Summary

- Desired EUV-emission can be obtained at $T_e = 30 \sim 40 \text{ eV}$, and is saturated at plasma thickness of $1 \sim 100 \text{ microns}$ according to charge state, reaching the Planckian limit.
- Enhancement of EUV-yield may be expected **with use of external radiation of about 50 eV**. The radiative atomic transitions have an effective contribution for generation of EUV-light.
- Peaks of EUV-light from $\text{Sn}^{11+ \sim 13+}$ almost synchronize with that of temperature profile of 40 eV and FWHM=500 ps, **showing the Planckian limit, that is, maximum EUV-generation.**
- **Enhancement of EUV-light from $\text{Sn}^{8+ \sim 10+}$ can be expected due to transient plasma effect of less than 500 ps.**



Acknowledgements

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