Estimations on Generation of High Energy Particles from LPP EUV Light Sources

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It is very important to characterize the high energy particles from LPP EUV light sources and to understand their effect on the Mo/Si multilayer in order to develop the necessary long-lifetime mirror technology.

We estimate energy spectra of high energy particles from LPP EUV light sources by some analytical models.

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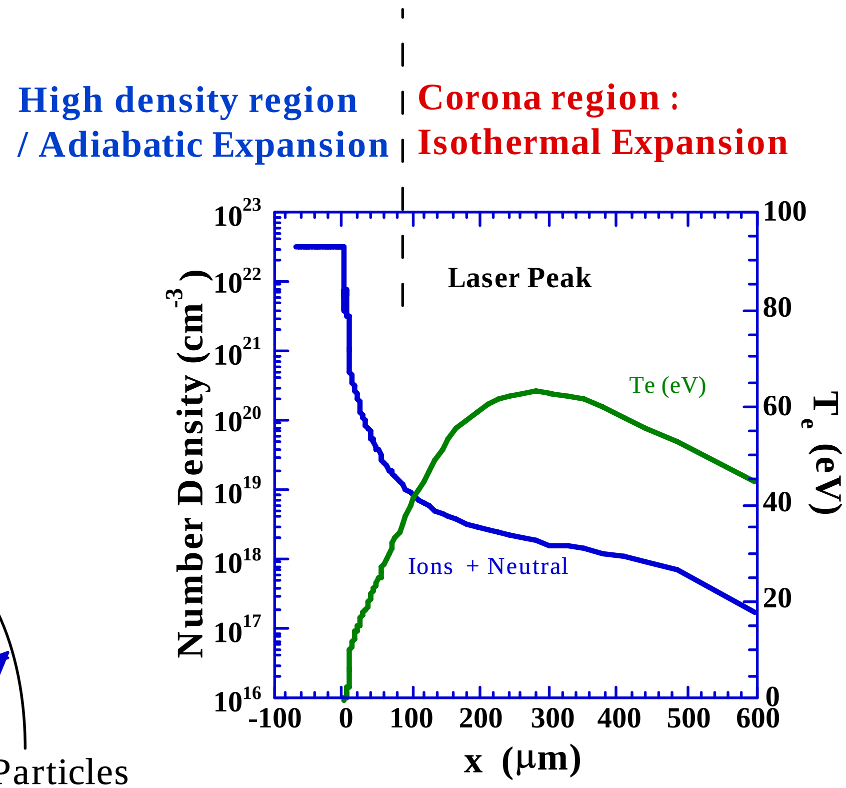
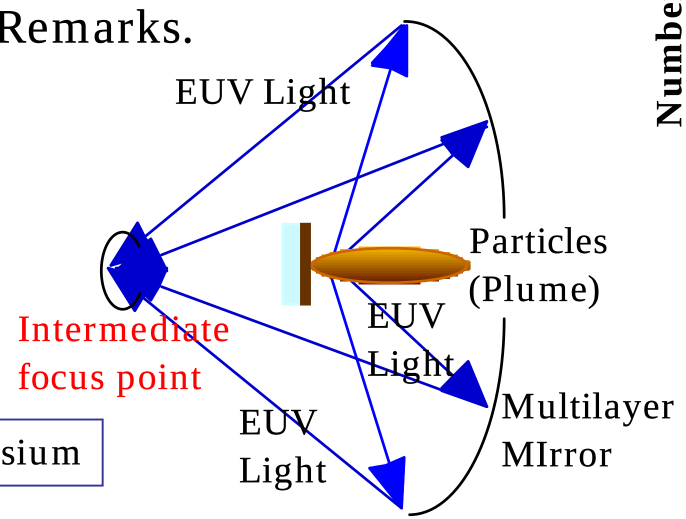


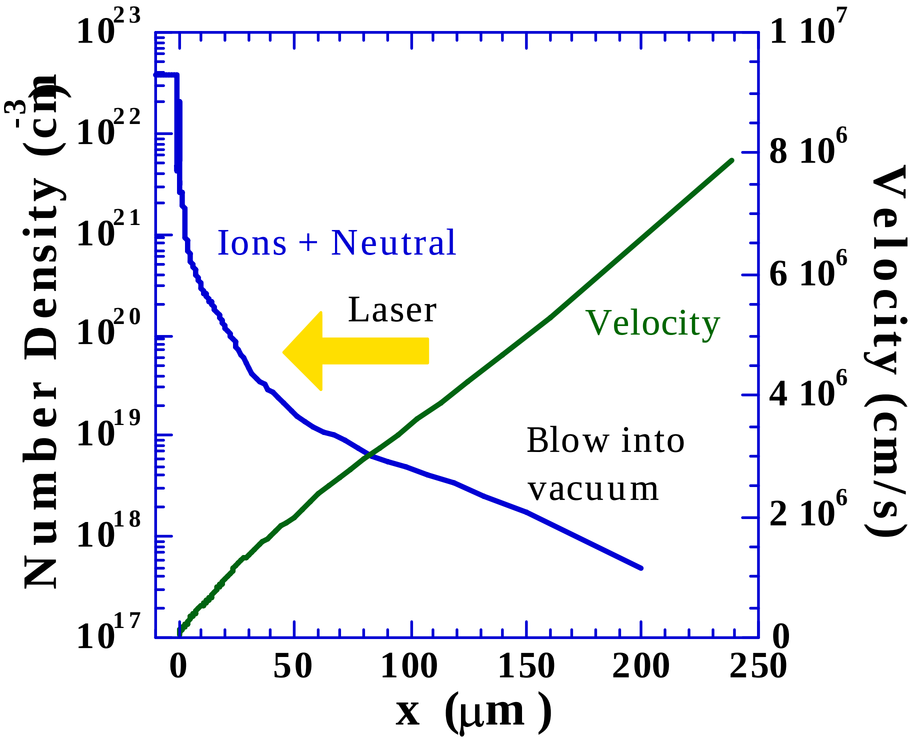


2004 EUVL Symposium

Considerations on Mechanisms of Generation of High Energy Particles from LPP EUV Light Sources

We consider following effects as mechanisms of generation of high energy particles.

1. Initial number density is high for the case using solid or liquid target.
2. Particles blow into vacuum.
3. Plume is heated by laser irradiation during particles blow into vacuum.
4. At the top of plasma, charge separation occurs.
5. After laser irradiation finishes, plume expands adiabatic with radiation cooling.



Isothermal Expansion Model on Energy Spectra of High Energy Particles

Solutions of 1d Fluid Equations assumed isothermal expansion are as follows.

$$n_i(x,\tau_L) = n_0 \; exp\left(-\frac{x}{c_s \tau_L}\right) \qquad v(x,\tau_L) = c_s + \frac{x}{\tau_L}$$

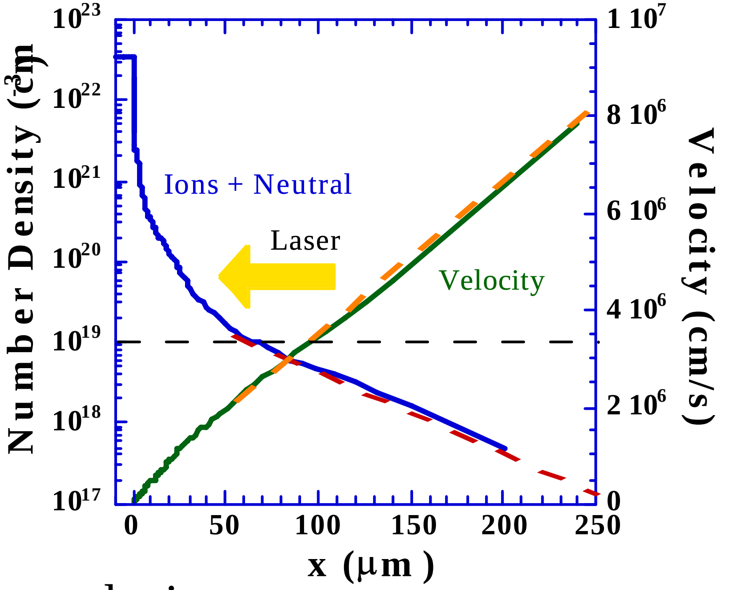
c_s : Sound velocity ~ 10^6 cm / s , τ_L : Laser pulse duration ~ 10 ns
n_0 ~ 10^{19} cm^{-3}

Energy Spectra of High Energy Particles

$$\frac{dN(\varepsilon)}{d\varepsilon} = \frac{n_0 c_s \tau_L S}{\sqrt{2 Z^* T_e}} \frac{1}{\sqrt{\varepsilon}} \; exp\left(-\sqrt{\frac{2\varepsilon}{Z^* T_e}}\right)$$

Ref. P. Mora, Phys. Rev. Lett. 90 (2003) 185002-1.

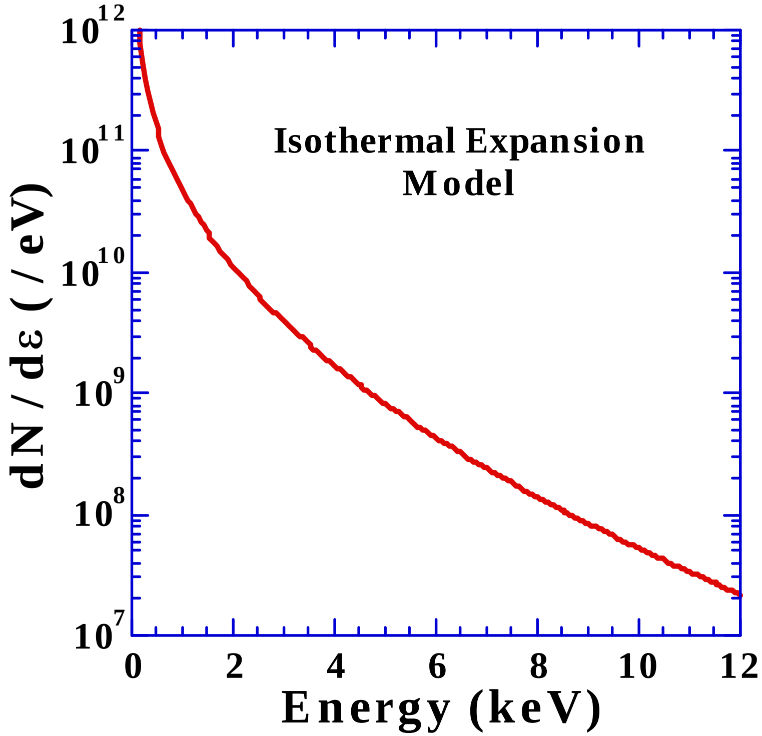
T_e ~ 30eV , Z*~10 , S : laser spot area

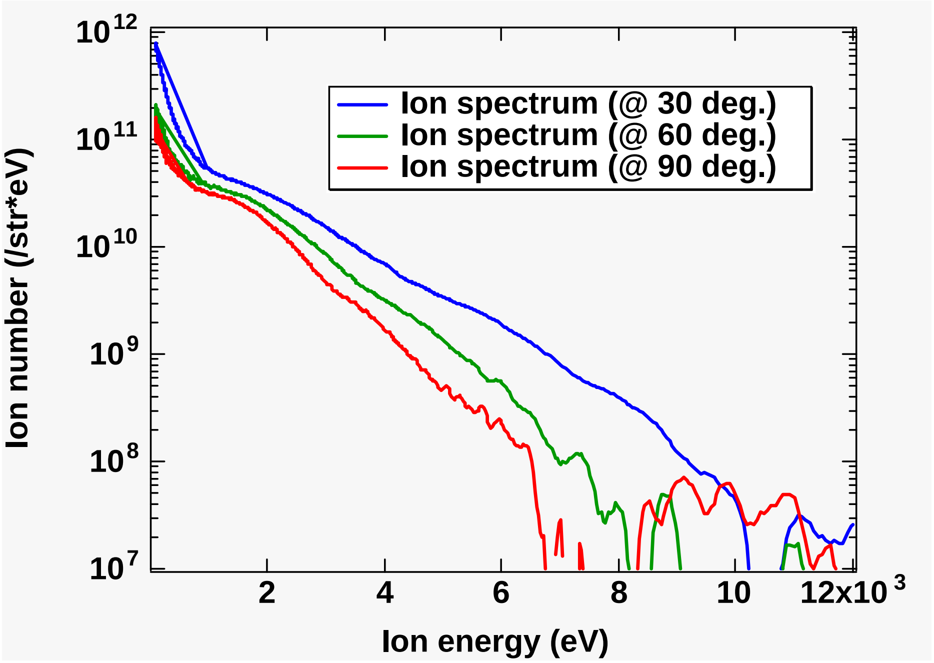


This model is often used in laser fusion plasma analysis.

Comparison of Result by Isothermal Expansion Model with Experimental Result at ILE

Laser Intensity 10^{11} W / cm^2 , pulse duration 10 ns , tin target





Please look at posters CoP12 (Kang et. al.) and CoP15 (Fujioka et. al.) in detail.

Adiabatic Expansion Initially Isentropic Profile Model on Energy Spectra of High Energy Particles

1. In the time a target is irradiated by laser (0 ns < time < roughly 30 ns)
   Detail Laser Ablation Fluid RAdiation simulation

2. After laser irradiation finishes (roughly 30 ns < time < roughly 10~100 μs)
   Adiabatic Expansion (Initially Isentropic Profile)

Using a couple of models mentioned above, we estimate energy spectra of particles from LPP EUV light sources.

$$\frac{dN_{plane}(\varepsilon)}{d\varepsilon} \propto \frac{1}{\sqrt{\tilde{\varepsilon}}}\left(1-\tilde{\varepsilon}\right)^{3/2}$$

plane geometry expansion

$$\frac{dN_{spherical}(\varepsilon)}{d\varepsilon} \propto \sqrt{\tilde{\varepsilon}}\left(1-\tilde{\varepsilon}\right)^{3/2}$$

spherically expansion

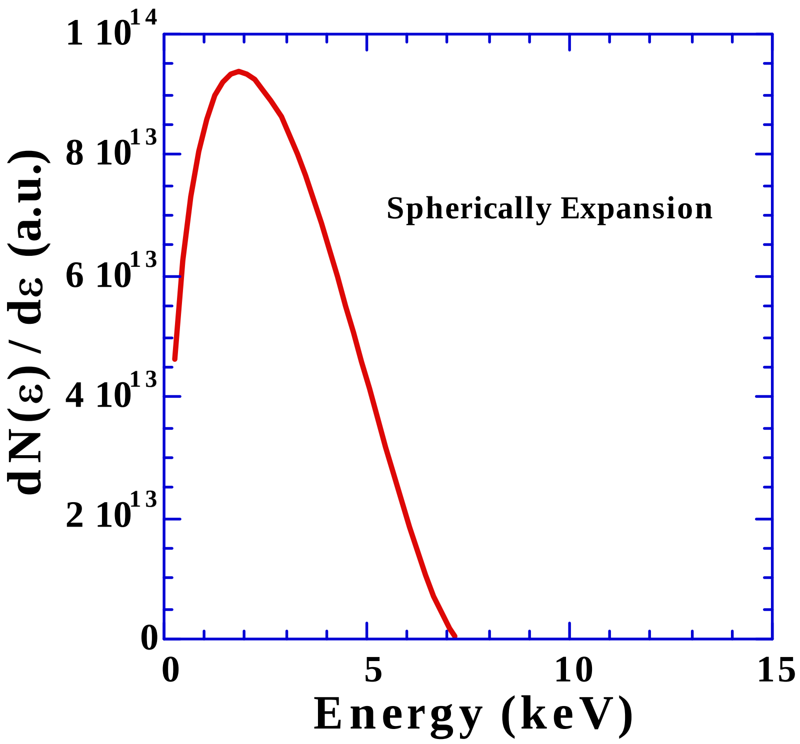
This model is often used in high power laser ablation analysis.

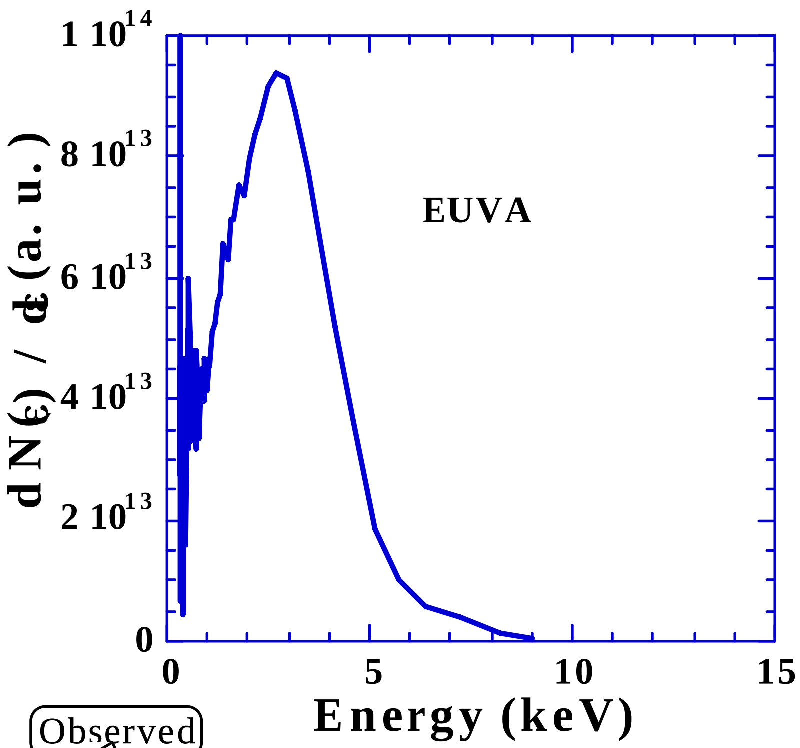
References

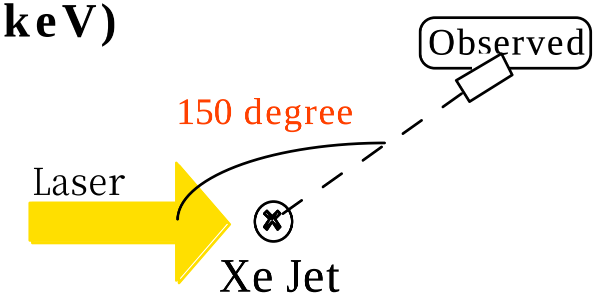
S. I. Anisimov, B. S. Luk'yanchuk, and A. Luches, Appl. Surf. Science **96-98** (1996) 24-32.

B. S. Luk'yanchuk, S. I. Anisimov et. al., SPIE **3618** (1999) 434-452.

Adiabatic Expansion Initially Isentropic Profile Model

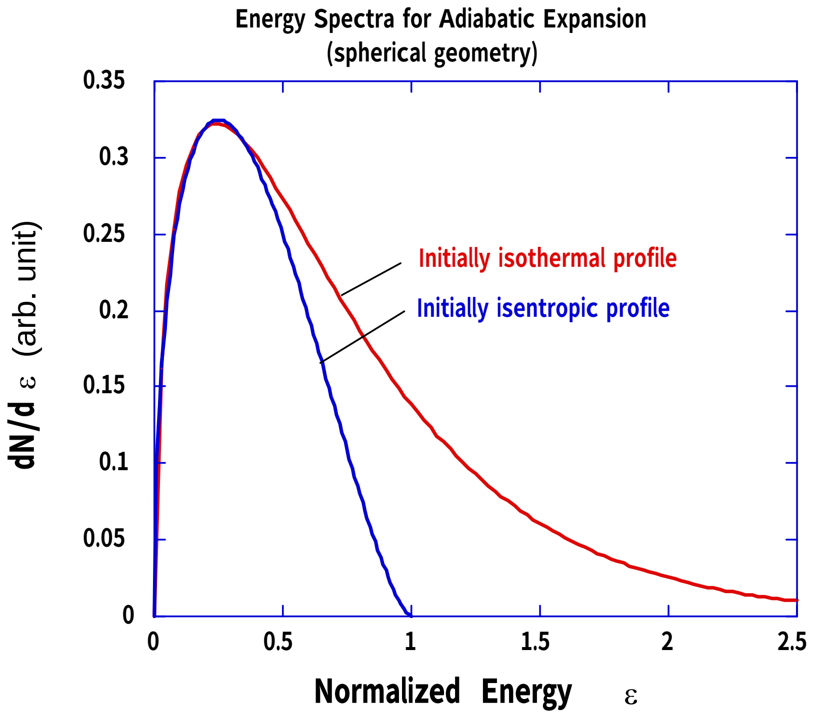


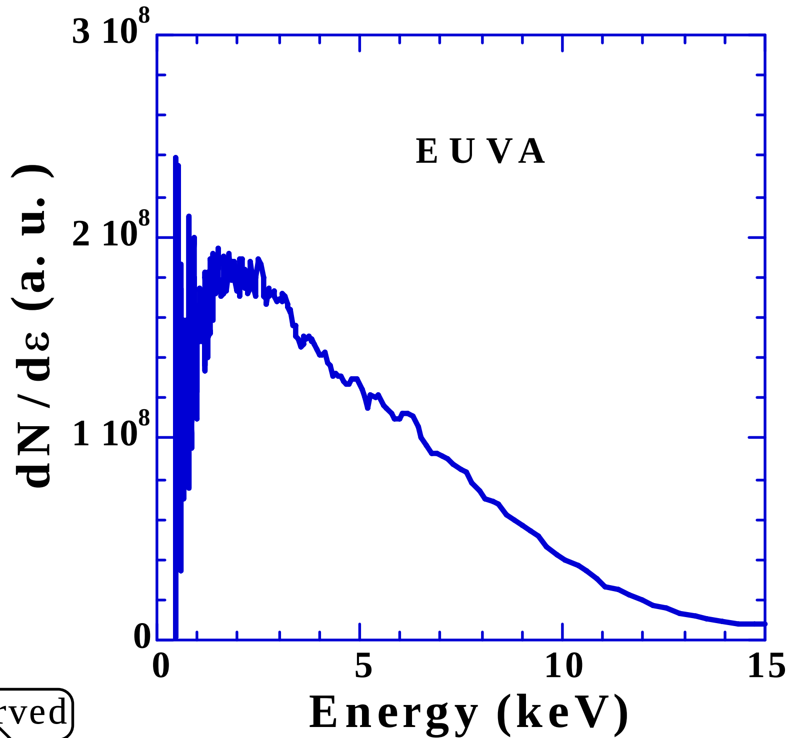


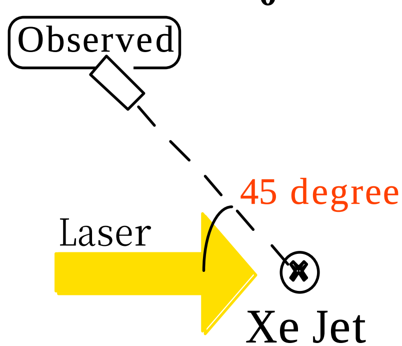


Observed angle is
150 degree.
(backward)

Adiabatic Expansion Initially Isothermal Profile Model





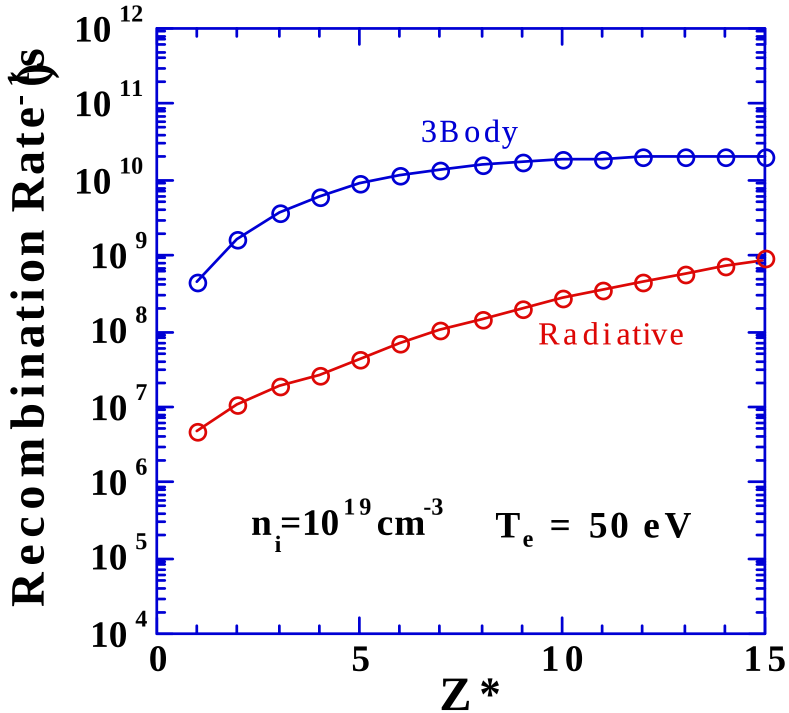


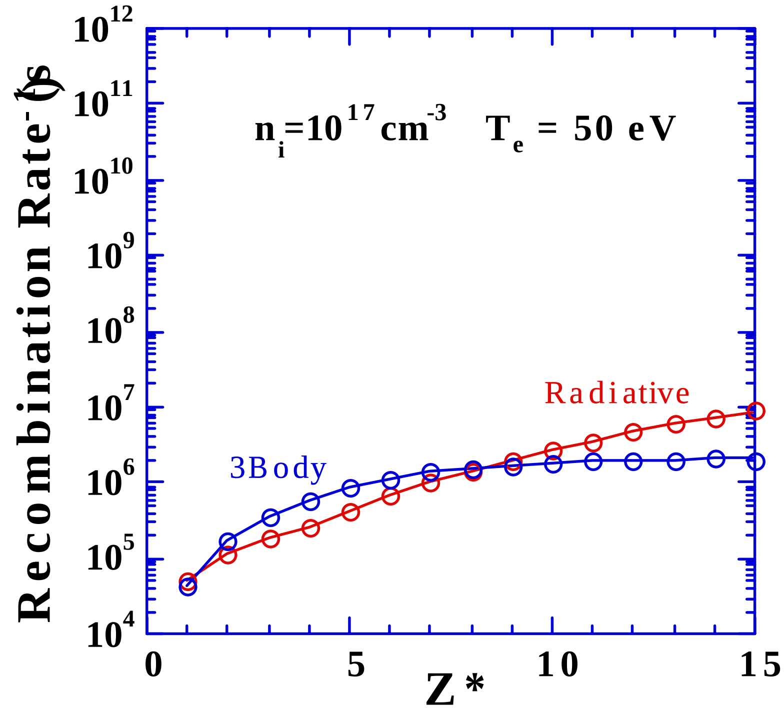
Please hear the talk of
Co05 (H. Komori)
on experiments of
EUVA in detail.

Observed angle is
45 degree.
(forward)

Recombination Rate obtained by Hydrogenic Ion Approximation

Typical parameters for EUV light are
$n_i \sim 10^{19}\ cm^{-3}$, $T_e \sim 20\sim50$ eV,
for the cases using 1.06 μm wavelength lasers and solid tin.





Recombination rate is order of 10^{10} /s ($n_i=10^{19}\ cm^{-3}$, T_e=50 eV, Z*=10) .
We have to estimate time dependent recombination processes coupled with radiation transport.

Modeling on Recombination and Ionization Processes with Radiation Cooling

1. Populations are determined solving time dependent rate equations.

2. Emissivity and Opacity data used analysis of radiation transport are obtained at every time and all of space using population data.

3. Electron temperature is determined by energy equation.

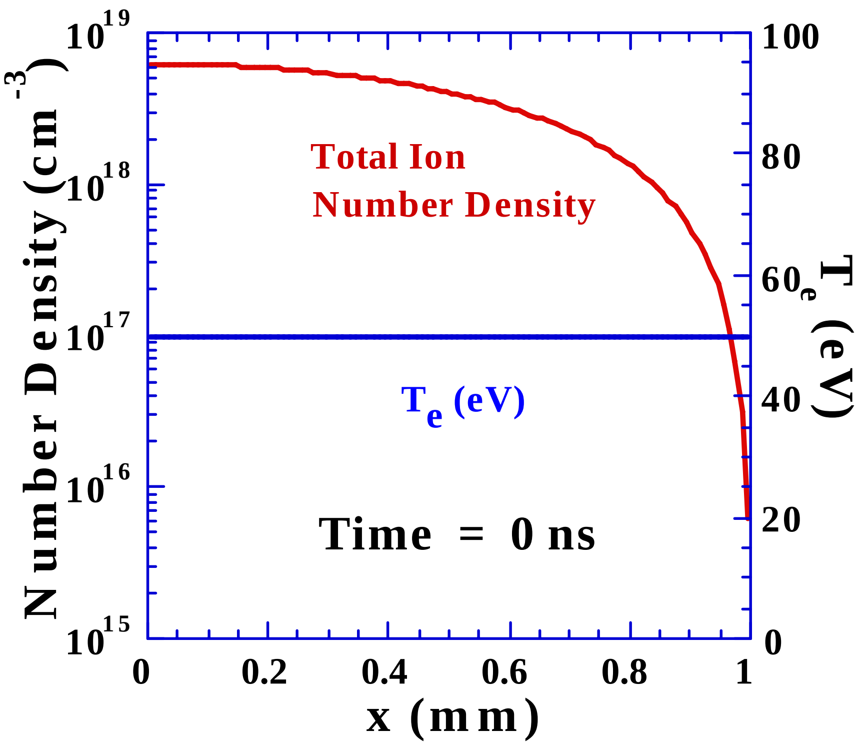
$$\rho(x,t)\, c_{ve}(x,t) \frac{d\,T_e(x,t)}{dt} = Q_x(x,t)$$

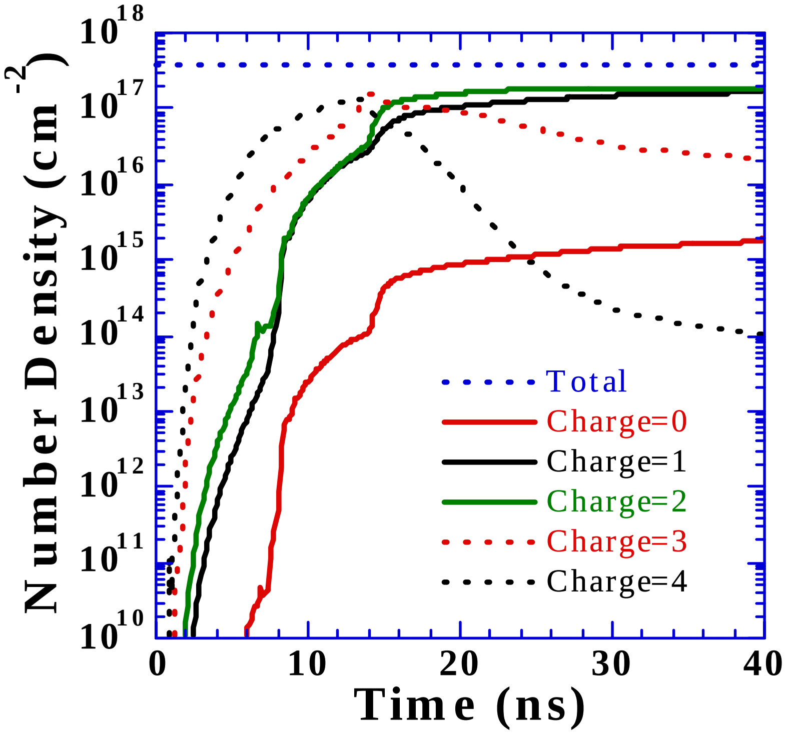
$Q_x(x,t)$ is determined by radiation transport.
Specific heat $c_{ve}(x,t)$ is obtained by equation of state.

Time Evolutions of Number Densities of Neutral Particles and Charged Particles

We suppose 100 nm thickness tin target.

And we assume the profile at the time laser irradiation finishes as follows.





Concluding Remarks

- We estimate energy spectra of high energy particles from LPP EUV Light sources.

1.1 Isothermal Expansion Model.

Those by isothermal expansion model are compared with experimental results at ILE.

1.2 Adiabatic Expansion Initially Isentropic profile Model.

Those by analytical model 1.2 are compared with an experimental result by EUVA.

1.3 Adiabatic Expansion Initially Isothermal profile Model.

Those by analytical model 1.3 are compared with those by model 1.2 and an experimental result by EUVA.

2. We have developed a model on recombination and ionization processes with radiation cooling.

We estimate time evolutions of number densities of neutral particles and charged particles.