Experimental study on basic properties of laser-produced plasma as an EUV source at GEKKO XII laser

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Abstract

One of the world large laser systems for inertial confinement fusion research, GEKKO XII laser system at Osaka University in Japan was utilized to study basic properties of laser produced plasma as the EUV source. EUV emission and its temporal behavior from the uniform spherical plasma were observed. Density structure of the ablation plasma was also investigated experimentally by making use of multi-beams from the GEKKO XII laser.

A part of this work was performed under the auspices of Leading Project promoted by MEXT.

Introduction

Main objectives of the experiment is to provide our computer simulation team with a reliable set of experimental database to improve theoretical models adopted in the simulation code. Therefore,

(1) experimental data must be obtained under well-defined conditions so that direct comparison between experiments and simulations is meaningful, and

(2) major plasma parameters are to be measured.

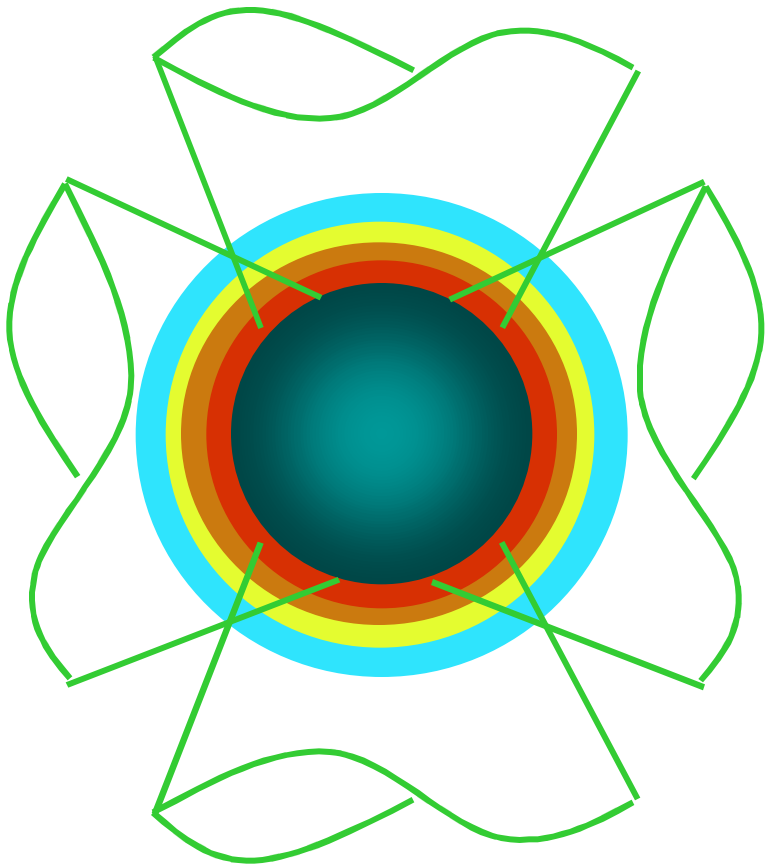
In previous experiments on EUV source development, a single beam illuminated a target from one side. Therefore it was hard to exclude effects arising from lateral flow of energy via plasma expansion and/or thermal conduction. Creation of spherical plasma enables us to compare our experimental result directly with those obtained by one-dimensional hydrodynamic code. We simply illuminated a spherical target

by twelve beams from the GEKKO XII laser system of spherical geometry in order to investigate laser intensity and wavelength dependence of EUV emission (this part or the work will be discussed in another poster " " by M. Yamaura.

To measure density profile or spectroscopic features of the EUV plasma, we make the best use of multi-beams of GEKKO XII to diagnose the laser-produced plasmas. X-ray and EUV backlight techniques were used to investigate density structure of the laser ablation front and opacity of target material. Six of twelve beams are used to heat target plasmas and remaining beams to generate backlight source plasmas. Here,we report preliminary result of on-going experiments at the GEKKO XII laser facility.

Main laser chain of the GEKKO XII laser system at ILE, Osaka University

An Ideally “uniform” EUV radiator was produced by GEKKO-XII fusion laser facility



Laser Conditions:

GEKKO=XII, 12 beams

Wavelength: ω (1.056 μm), 2ω (0.527 μm)

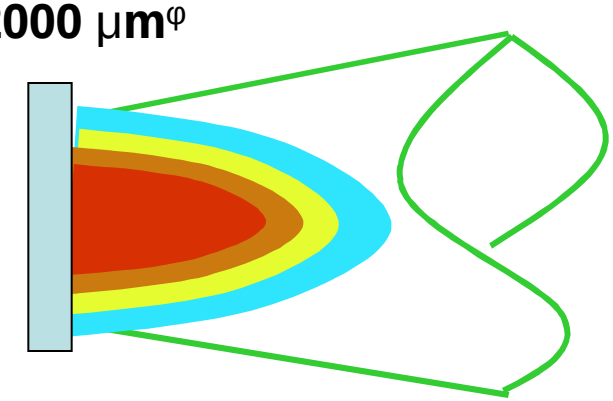
Intensity: 5×10^{10} ~ 1×10^{12} W/cm^2

Pulse width: 1.2 ns (FWHM, Gaussian)

Target Conditions:

Sn or SnO_2 coated glass ball

300~2000 μm$^{\varphi}$



Spherically uniform plasmas

“Non-uniform” plasma

Spherical illumination experiment (1)

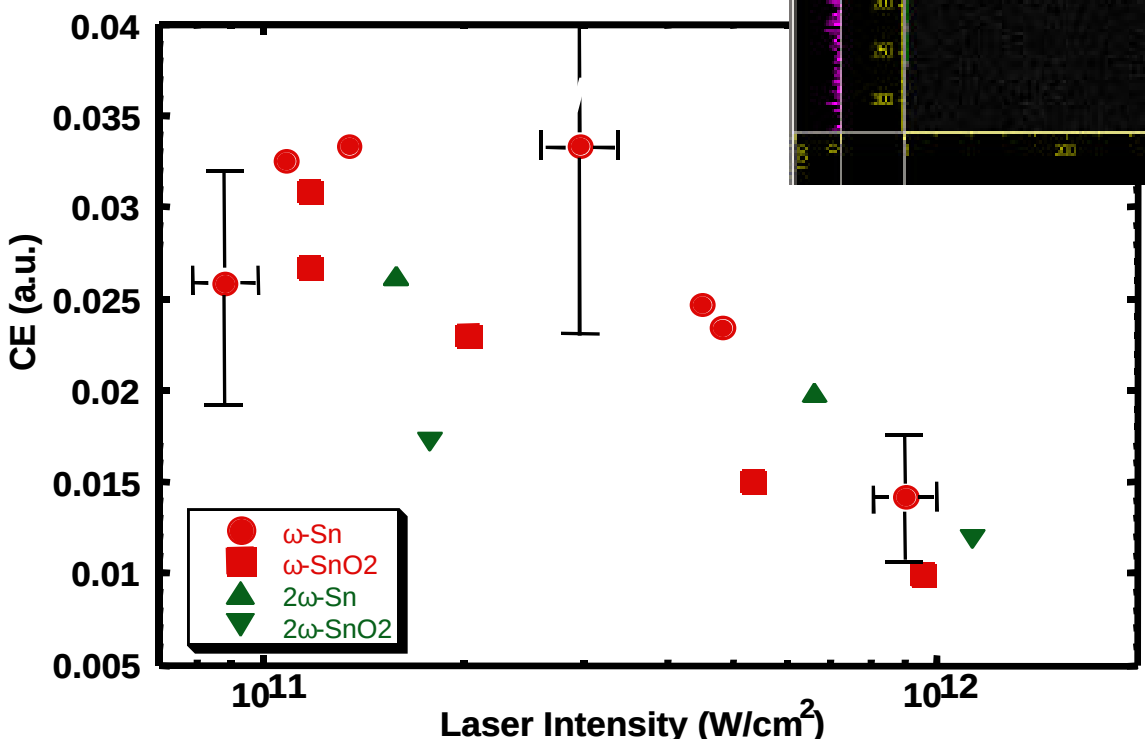
Absolute EUV spectra were measured with a transmission grating spectrometer coupled with a soft x-ray CCD camera.

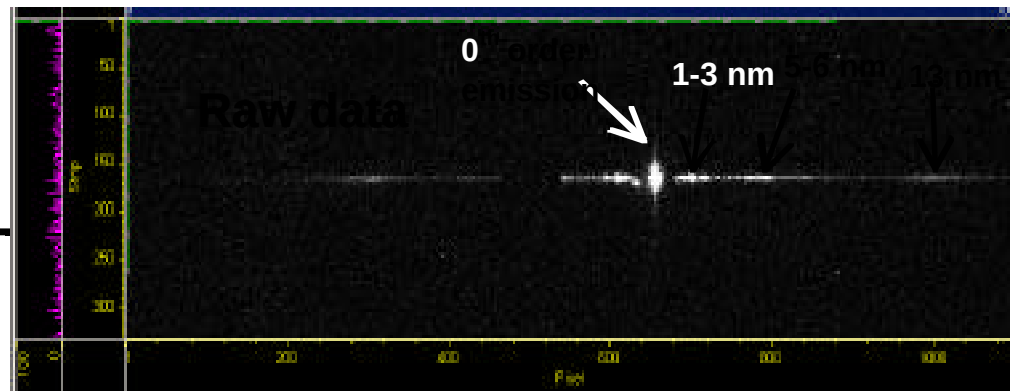
The detector system is not calibrated sufficiently yet.

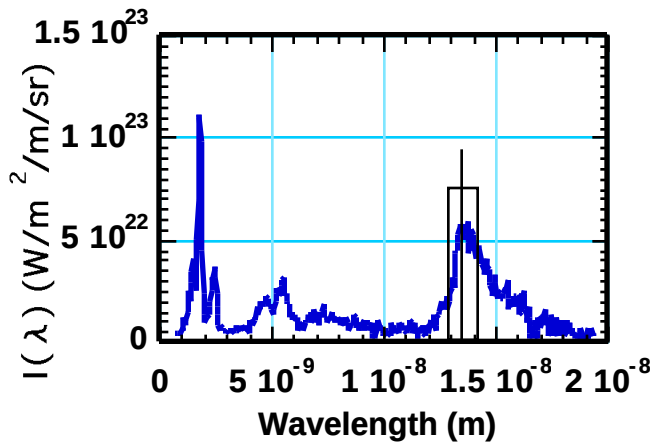
We need precise calibration of the CCD and spectrum reconstruction.

TG: 1000 lp/mm
w/ 50-μm window

Tentative result

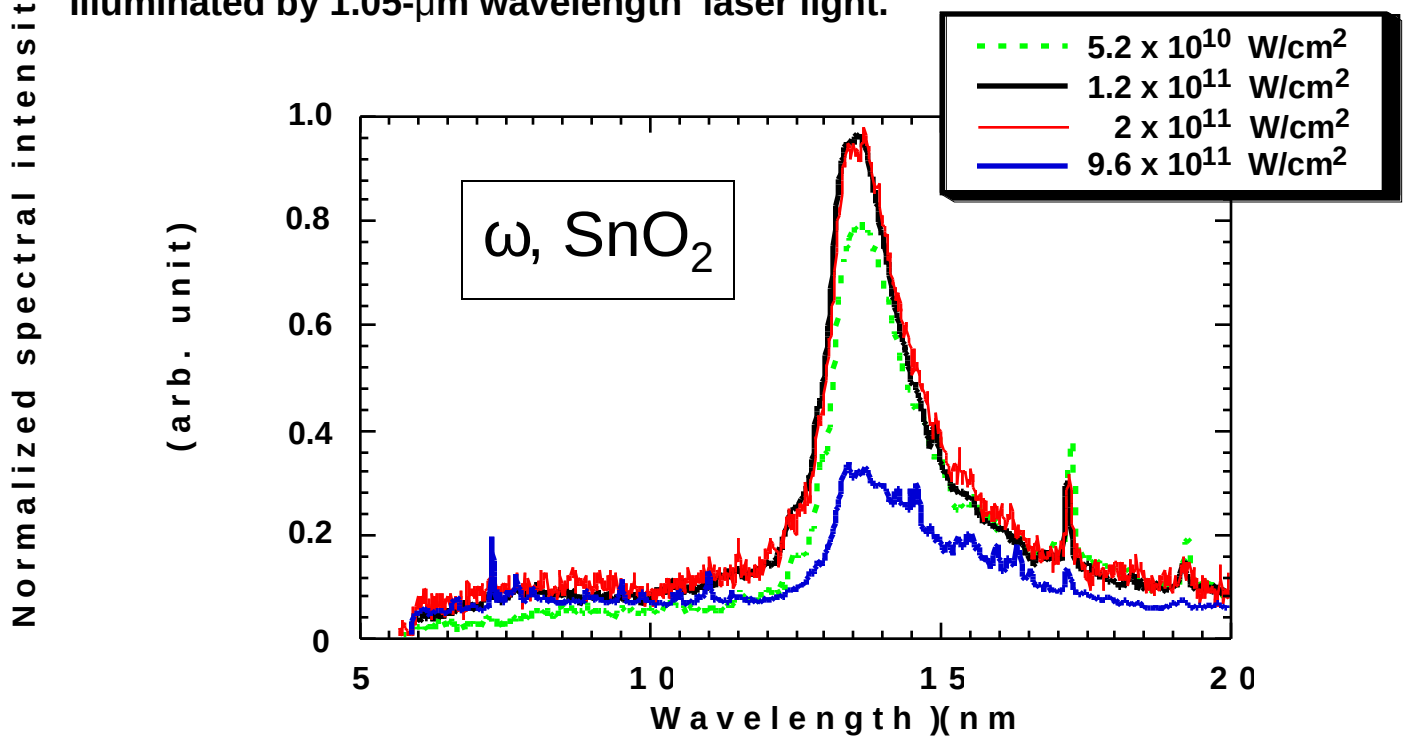






Detailed spectral features are observed by using grazing incident spectrometers (GIS) coupled with a back illumination CCD camera and an x-ray streak camera.

Intensity dependence of EUV spectrum from spherical tin-oxide targets Illuminated by 1.05-μm wavelength laser light.

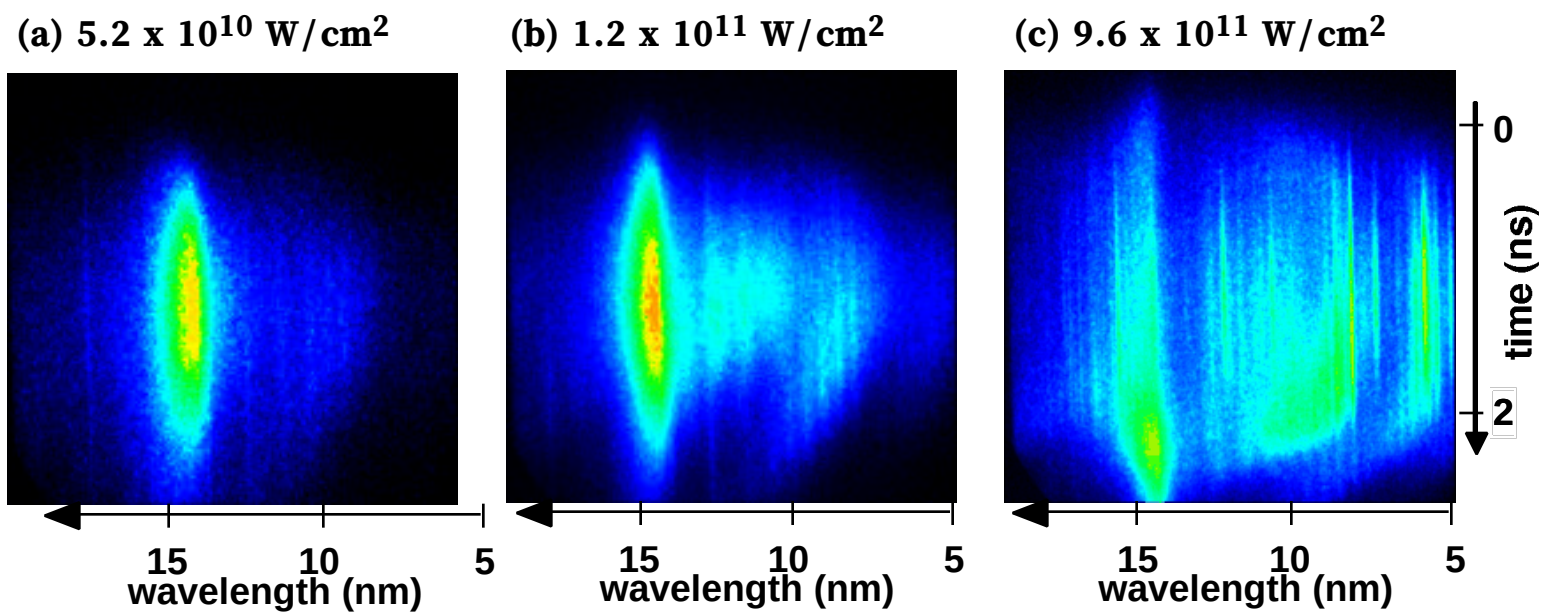


Spectral intensity is normalized by laser illumination intensity.
Thus, conversion efficiency has its maximum around 1- 2 x 10^{11} W/cm^2.

Spherical illumination experiment (2)

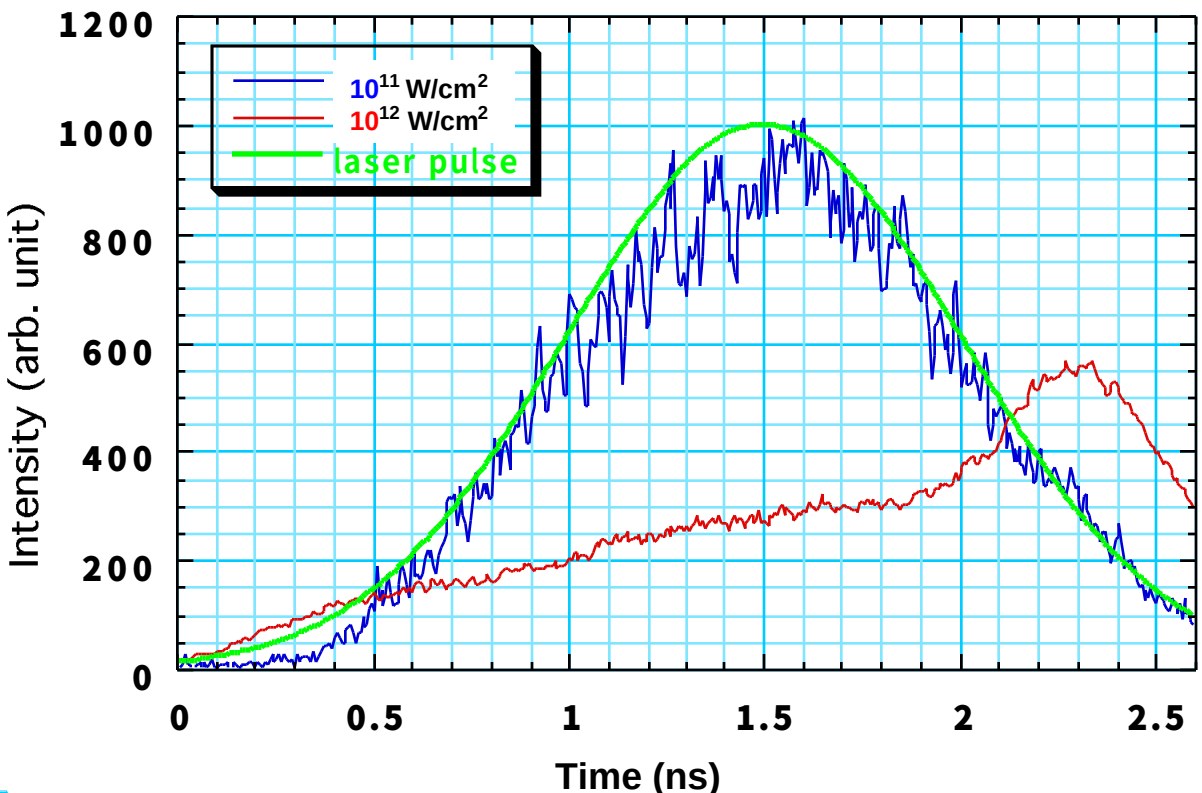
Temporal evolution of the EUV spectra was measured by the GIS coupled with an x-ray streak camera

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



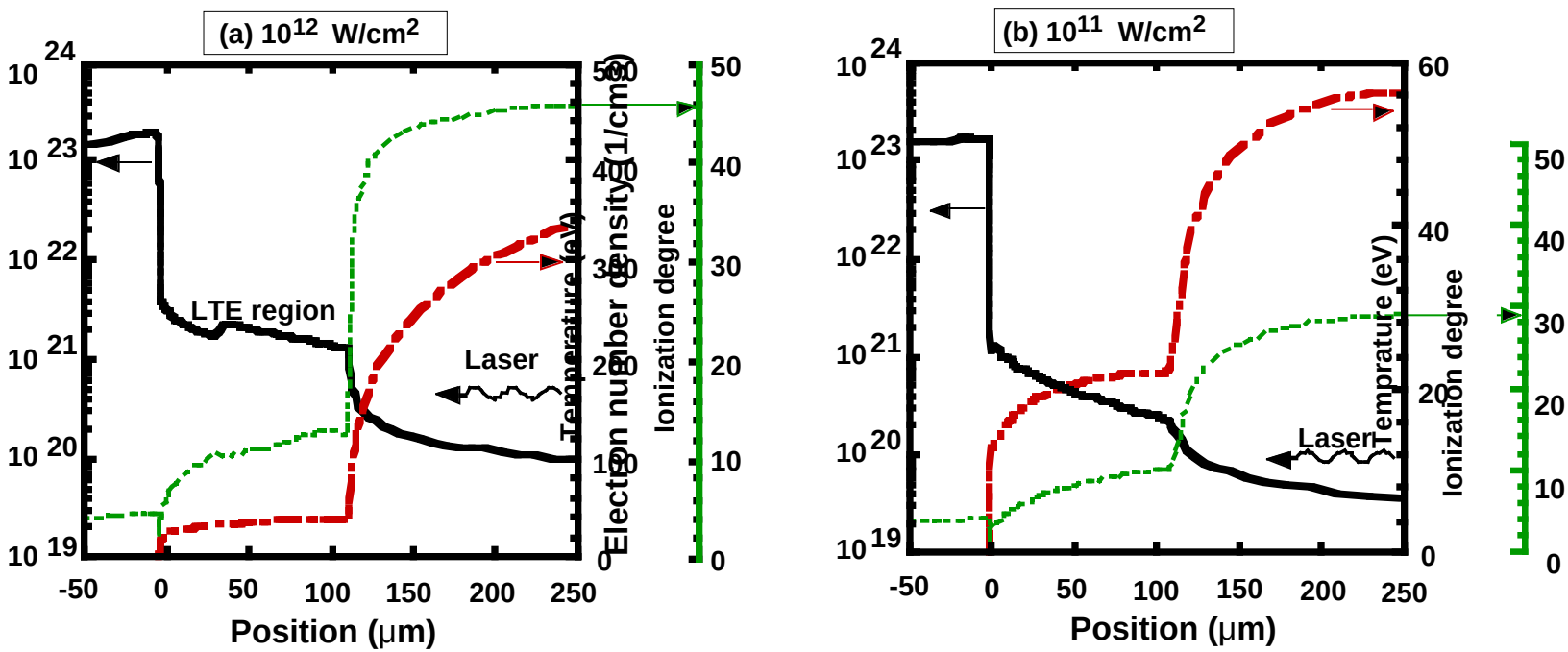
Temporal profile of the 13.5-nm emission from tin-oxide targets irradiated at 10^{11} W/cm^2 and 10^{12} W/cm^2

Spectral integration:12.9-13.7 nm



Laser-irradiated surface of high-Z material has a double ablation structure.

Soft x-ray transport forms the second ablation front in the over-dense region and a density plateau is formed between two ablation fronts.

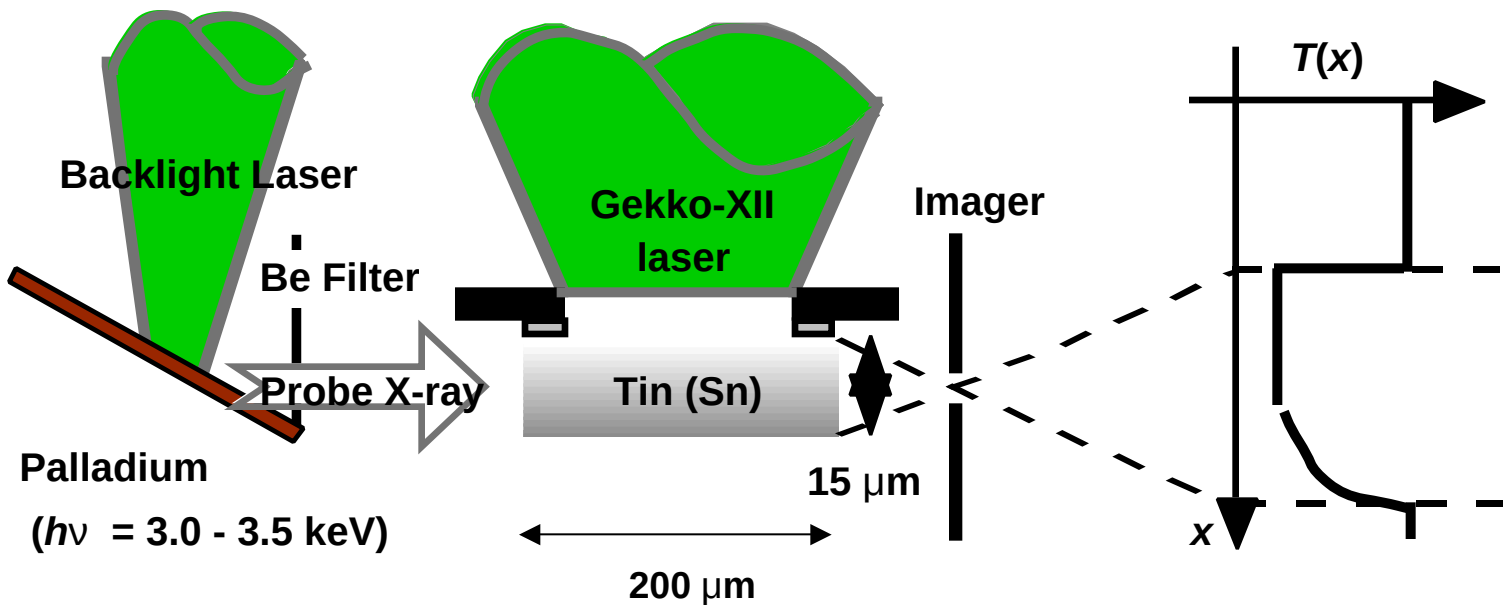


By one-dimensional hydrodynamic code with the screened-hydrogenic averaged ion model.

Density structure of radiative ablation front (2)

Double ablation structure formed inside a laser-irradiated surface of Sn plasma was observed by a side-on x-ray backlight method.

Setup for the experiment

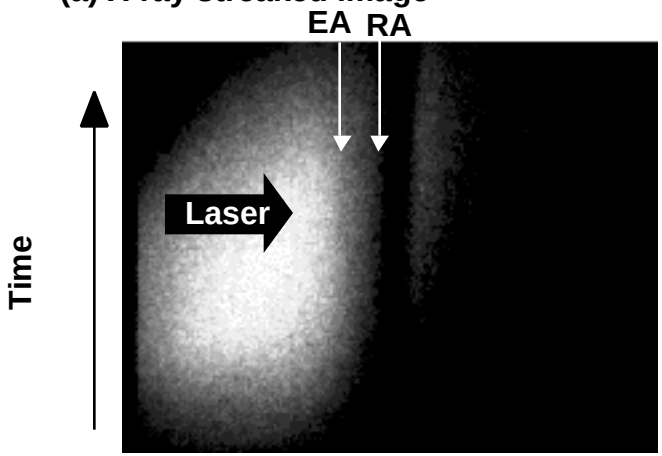


Double ablation structure formed inside a laser-irradiated surface of Sn plasma was observed by a side-on x-ray backlight method.

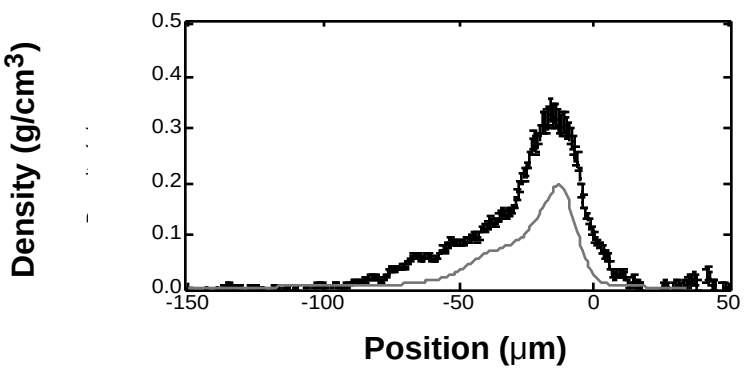
I_L:2.7 x 10^{12} W/cm^2

RA: Radiation driven Ablation front
EA: thermal Electron driven Ablation front

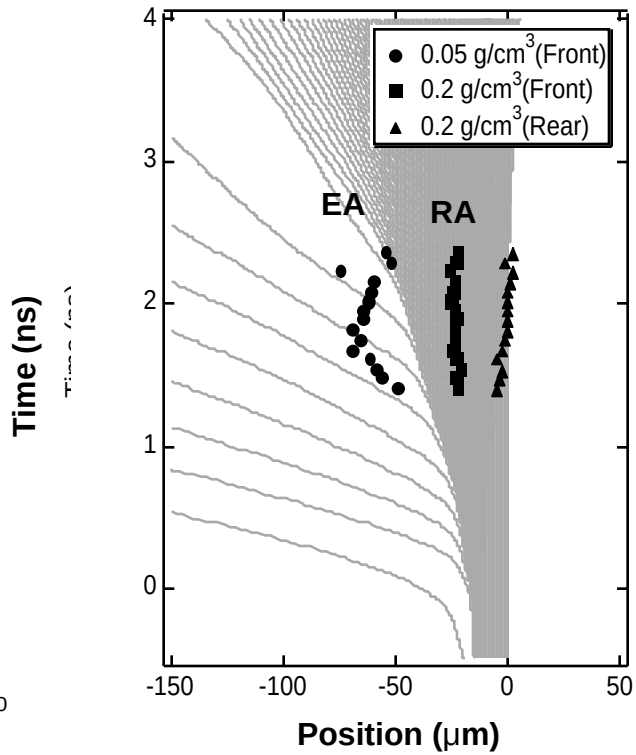
(a) X-ray streaked image



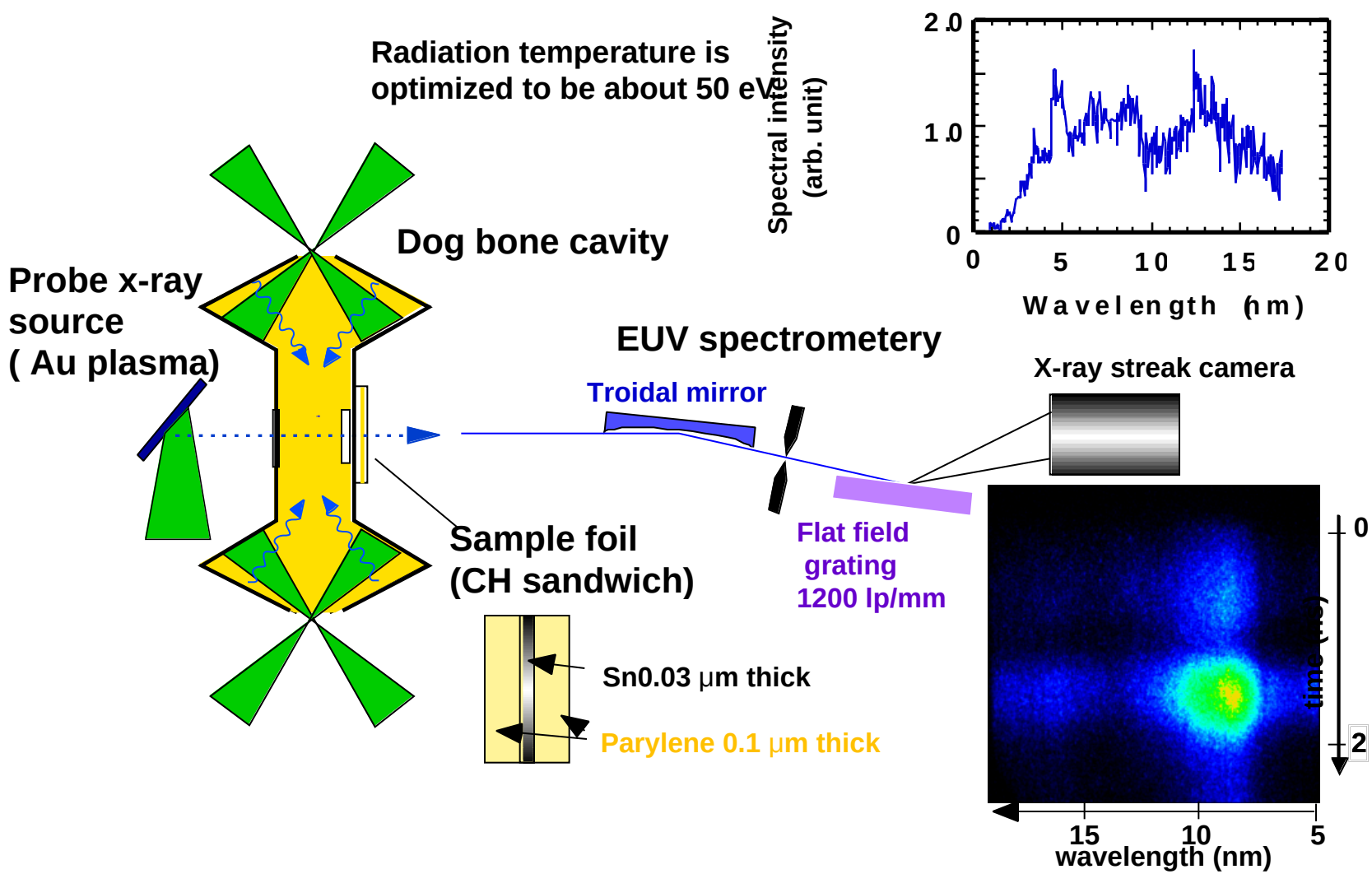
(b) Density profile at 1.74 ns



(c) Flow diagram by ILESTA-1D

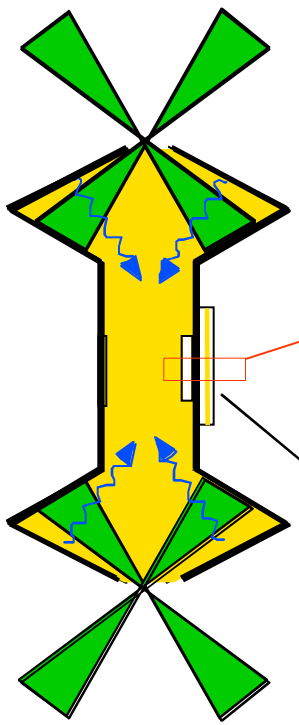


Opacity (absorption) measurements of hot dense plasma have been carried out using “dog-bone” cavity.

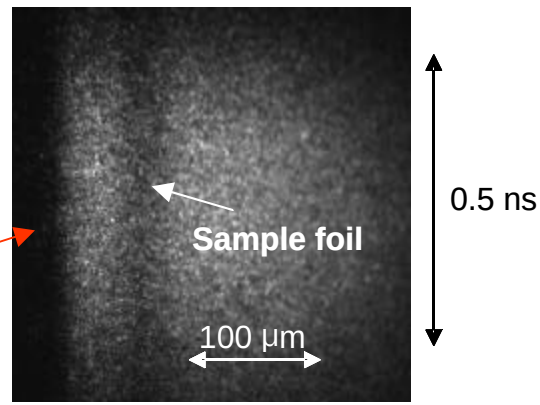


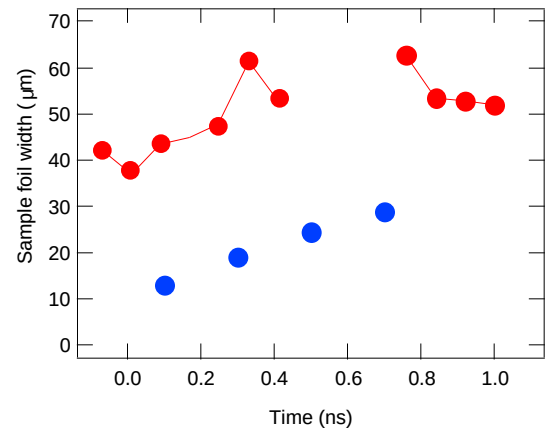
Expansion of the sample foil heated by cavity radiation was observed using side-on x-ray backlight technique.

Dog-bone cavity

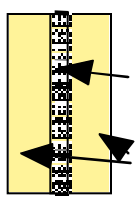


Shadowgraph of expanding foil





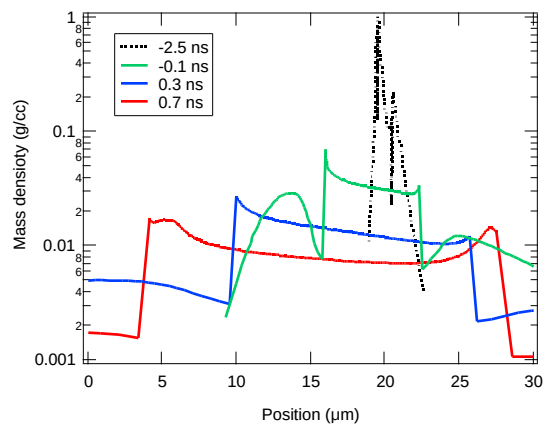
Sample foil (CH sandwich)



Sn0.03 μm thick

Parylene 0.1 μm thick

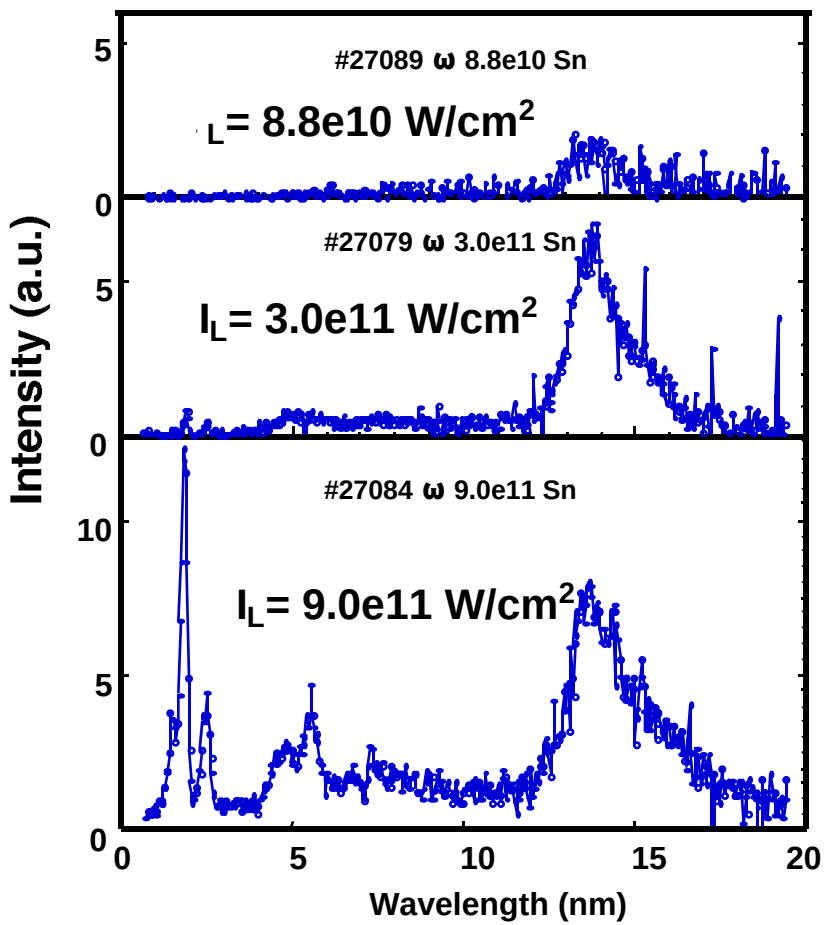
Simulation of expanding foil



BL source : Cu foil

Ref. M. Perry et al., Phys. Rev.E58, 3739(1998).

M-shell emission becomes prominent as the illumination intensity increases.



Target: Sn, Laser: ω
Transmission Grating + CCD

- **Emission at the wavelength of 13-15 nm is mainly due to 4d-4f transition.**

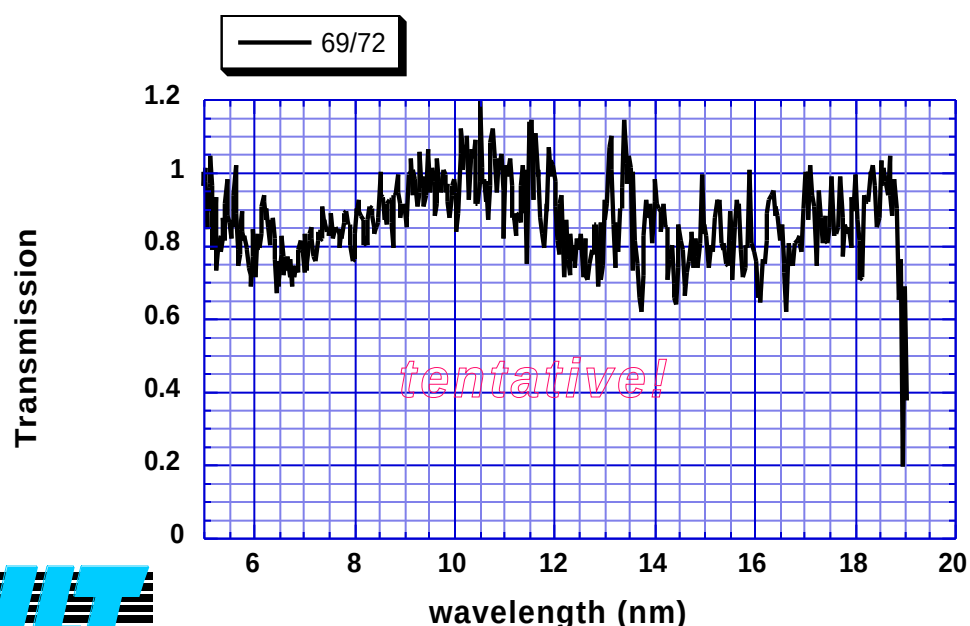
- **M-shell emission causes short wavelength emission <3 nm (1-.5 keV), while N-shell emission does longer wavelength emission >4 nm (<.5 keV)**

Preliminary result of soft x-ray transmission measurement.

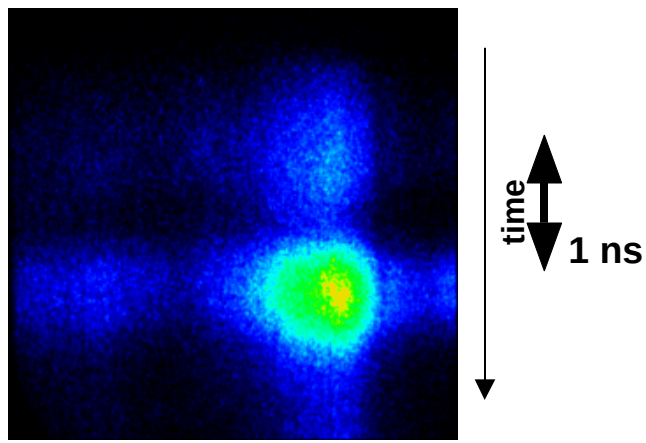
In order to improve the quality of experiment, higher order diffraction by the grazing incident spectrometer must be eliminated and backlight x-ray source is to be optimized.

- **SN27069**
  dog bone shot w/ 300 A Sn and 0.2 μm CH
  low BL beam energy d=-2000, 100 J
  XSC Au 670 μm slit cathode , w/ two Y filter

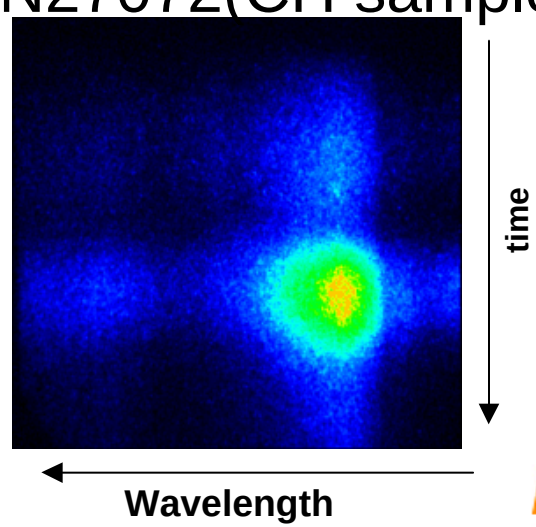
- **SN27072**
  dog bone w/ 0.2 μm CH sample
  XSC Au 670 μm slit cathode , w/o two Y filter



SN27069(Sn sample)



SN27072(CH sample)



Summary (1)

A new project on the LLP EUV source has been initiated at the Institute of Laser Engineering, Osaka University.

1. A set of experimental data is to be provided to develop a detailed atomic model included in the computer code through the experiments. Optimized conditions for efficient EUV generation will be investigated by changing properties of lasers and targets for a wide range.

a). The laser intensity and wavelength dependence of the EUV emission spectra from the laser irradiated tin and tin-oxide has been investigated in spherical geometry using the GEKKO XII laser system. It is confirmed under the ideal experimental condition that conversion efficiency into 13.5 nm band has its maximum at the laser intensity 1-2 x 10^{11} W/cm^2.

(Poster in detail.)

Summary (2)

2. Multi-beam, high power laser system dedicated for the ICF research is utilized for the characterization of the LPP EUV spurce plasmas.

a). Double ablation structure in the laser-irradiation surface was experimentally confirmed by side-on x-ray backlighting method although the measured scale-length of the density plateau was slightly longer than that predicted by present hydrodynamic simulation.

b). We have started to measure the opacity of tin plasma of the temperature and density deeply correlated with the EUV emission. Some preliminary tests have been carried out using “dog-bone” cavity targets.