Progress of Opacity Experiment on the Shenguang II Laser Facility

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Abstract. In recent years, a series of opacity diagnostics have been developed at the Research Center of Laser Fusion in China. Two types of cavities (a conical cavity called a type I target, and a cylindrical cavity with foam baffles called a type II target) were designed to convert the eight-beam laser into x-ray radiation to efficiently heat the sample and to prevent the sample from irradiation of the reflected laser and plasmas on the Shenguang II laser facility. Typical opacity experiments have been carried out using the two target designs, respectively. The results show that a sample temperature of about 95 eV has been reached using the type II target which is the highest obtained on the high power laser facility.

1. Introduction

The x-ray opacities of hot, dense plasmas have long been of interest due to their important and urgent need in studies of inertial confinement fusion (ICF), x-ray lasers and astrophysics. Theoretical calculations of opacities are quite complex and usually include numerous approximations. Therefore, experimental measurement of opacity is of importance to verify the theoretical models. In the past two decades, many opacity experiments have been done using high power lasers with the advent of high power lasers [1-7]. However, most of the opacity experiments reached sample temperatures of lower than 60eV. Experimental opacities with much higher sample temperatures are still scarce and challenging on laser facilities [8]. In recent years, a series of opacity diagnostics have been developed at the Research Center of Laser Fusion in China. A ninth laser beam has also been established on the Shenguang II eight-beam high power ns laser facility, which has duration of about 100ps and can be used as a short pulse backlighting beam in the opacity experiment. Two types of cavities have been designed to conduct opacity experiments on the Shenguang II laser facility, one of which has reached a sample temperature of about 95 eV and extended the sample state region of opacity studies.
2. Development of diagnostics for x-ray absorption spectrum

In the opacity experiment one of the crucial diagnostics is the x-ray absorption spectrum measurement. In the soft x-ray and super extra ultraviolet spectral regimes, two sets of flat-field grating spectrometers have been developed with 1200 l/mm and 2400 l/mm gratings, respectively. The 1200 l/mm flat-field grating spectrometer covers the spectral regime of 5 nm to 30 nm with spectral resolution of about 0.02 nm. The 2400 l/mm grating spectrometer can measure the x-ray spectrum from 1 nm to 5 nm with higher spectral resolution of 0.01 nm. Both of the grating spectrometers can be coupled to a gated micro-channel plate (MCP) detector with temporal resolution of about 100 ps, as shown in figure 1. As an application of the flat-field grating spectrometer, the 2400 l/mm grating spectrometer has been used to measure the x-ray absorption lines of low-Z mixture (CHO) [9]. The typical measured results are presented in figure 2. Shown in figure 2(a) are the recorded images of the x-ray source spectrum and the attenuated x-ray spectrum by the radiation-heated CHO sample, in which very clear absorption lines have been observed. The obtained x-ray absorption spectrum is compared with the unresolved-transition array (UTA) simulation [10]. As shown in figure 2(b), the simulated spectrum is in good agreement with the experimental one in general.

![Figure 1. Schematic of time-resolving flat-field spectrometer](image)

![Figure 2. X-ray absorption result for low-Z mixture (CHO) measured with the 2400 l/mm flat-field grating spectrometer. (a) raw x-ray spectrum image; (b) comparison of the measured absorption spectrum with the unresolved-transition array (UTA) calculation.](image)

In the keV x-ray spectral regime, a series of crystal spectrometers have been established which cover the x-ray photon energies from 800 eV to 5000 eV. The crystal-dispersed spectrum can also be recorded with the gated MCP. One of the measured absorption spectra for an Al plasma with the crystal spectrometer is shown in figure 3 and compared with the calculation using the detailed-term
accounting (DTA) model \cite{11,12}. The absorption lines for Li- to F-like Al ions have been observed and reproduced with the simulation \cite{11}.

![Image of X-ray absorption spectrum image for Al plasmas with the crystal spectrometer.]

**Figure 3.** X-ray absorption spectrum image for Al plasmas with the crystal spectrometer.

3. **Opacity experiment on the Shengguang II laser facility**

The Shengguang II laser facility is a Neodymium glass laser facility, which has eight main laser beams and a 9th backlight beam. The main laser can deliver 250J per beam in 1ns with a laser wavelength of 351nm. The 9th laser beam can be operated in pulses of about 100ps or 2000ps. In the opacity experiment, the eight main laser beams are injected into the cavities and converted into intense x-ray radiation to heat the CH-tampered sample. The 9th beam has 2ω laser energy of 100J with pulse duration of 100ps and is delayed by 1ns with respect to the main laser beams. The x rays emitted from the 9th beam-irradiated gold dot are used as a backlighter. The experimental arrangement is shown in figure 4 and the x-ray absorption spectra have been measured with a crystal spectrometer.

![Image of schematic of the opacity experiment arrangement.]

**Figure 4.** Schematic of the opacity experiment arrangement

![Image of schematic of the two target designs. (a) Conical Target; (b) Cylindrical target.]

**Figure 5.** Schematic of the two target designs. (a) Conical Target; (b) Cylindrical target
As shown in figure 5, two types of cavities were designed to convert the eight-beam laser into x-ray radiation to efficiently heat the sample. To prevent the sample from irradiation of the reflected laser and plasmas, a conical cavity, called a type I target, has a conical shape at both ends of the cavity, and a cylindrical cavity, called a type II target, has foam baffles between the sample and the laser-x-ray conversion cavity. As the low density ($40\text{mg/cm}^3$) foam baffle can effectively transport the x-ray radiation, the sample between the two 200 $\mu m$ thick foam baffles can be heated to much higher temperature. The x-ray absorption spectra for Al plasmas using the two target designs are shown in figure 6 (a) and (b), respectively. The experimental results are simulated with a code based on the method given by Abdallah [13]. The results show that a sample temperature of about 95 eV has been reached using the type II target which is much higher than that of 54eV using the type I target [14,15].

![Figure 6. Comparison of experimental absorption x-ray spectra with the simulated ones. (a) using the conical target design; (b) using the cylindrical target design(experiment: solid line, calculation: dotted line).](image)

4. Summary
In recent years, a series of opacity diagnostics have been developed at the Research Center of Laser Fusion. Two types of cavities were designed to convert the eight-beam laser into x-ray radiation to efficiently heat the sample on the Shenguang II laser facility. It was demonstrated that a sample temperature of about 95 eV has been reached using the type II target which is the highest obtained on the high power laser facility. The type II target can be further used in the opacity experiment for high temperature plasmas in the future.

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