S-P6-2

Advanced Plasma Diagnostics Using Lasers
レーザーを用いた先進プラズマ診断

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Various diagnosing techniques have been developed to investigate plasma characteristics and its behaviors for studies of high energy density science and fusion science, and fusion reactor engineering. Developments of high power and high intensity lasers have opened new approaches to diagnose plasmas using laser-generated high energy particles as a probe. Advanced plasma diagnosing techniques using the laser-generated particles are introduced and their applications are discussed.

1. Introduction

Diagnosing plasma is essential in most experimental researches on plasma science and engineering. A variety of diagnostics have been developed to study the plasma characteristics and its behaviors. For example, the electrostatic probe and the spectroscopy of plasma emission are commonly used to measure the temperature and density of plasma. Diagnosing techniques using laser light is also widely used; such as the laser interferometry or the absorption in plasmas to determine the plasma density. Laser scattering, the Thomson scattering for example, is also common for the characterization purpose. In addition to the plasma characterization, laser light has been also used to monitor fields around the plasma. Magnetic field measurement with Faraday rotation of laser light is a good example.

Laser development in recent years opens the way for new approaches to diagnose the plasma and the fields around plasmas. Examples of such advanced techniques are introduced in the presentation and also expected applications in the fusion reactor engineering are discussed.

2. Plasma Diagnostics Using Lasers

2.1 *Diagnostics for plasma characterization*

The plasma characterization using a laser optical probe cannot be used when the transmittance is not enough in the plasma. X ray is another option as a backlighter to investigate such plasmas. Particularly, K-shell x rays can be a strong solution[1]. Because the characteristic x ray is monochromatic, it has great advantages compared to broadband x rays as similar to the comparison between a monochromatic laser light and a white light. Characteristic x ray can be generated by the irradiation of an intense laser light on a solid target. Due to the short pulse duration of the laser light (< ps), the backlight using laser-induced K-shell x ray can have a good temporal resolution.

Laser-generated broadband x ray is also useful to characterize plasma in some techniques. One of them is the x-ray line absorption spectroscopy[2]. Plasma (more appropriately, component ion in plasma) absorbs x rays at specific energies depending on the material and its ionization level, which is a function of the plasma temperature and density. Figure 1 shows sample spectra (shown with dots) of shock-heated aluminum doled CH foam. In the experiment, the Al-doped CH plasma was backlit with broadband x rays emitted from samarium dot target, which was irradiated with nanosecond laser pulses. X-ray streaked spectrometer was employed to observe temporal evolution of the absorption lines of Al. As shown in the figure, the fittings of the spectra using atomic physics code (solid curves) provide the inferred temperature and density of plasma in each time window.

When sample is opaque for low energy x rays so that the above techniques cannot be used, the sample may be characterized with the neutron

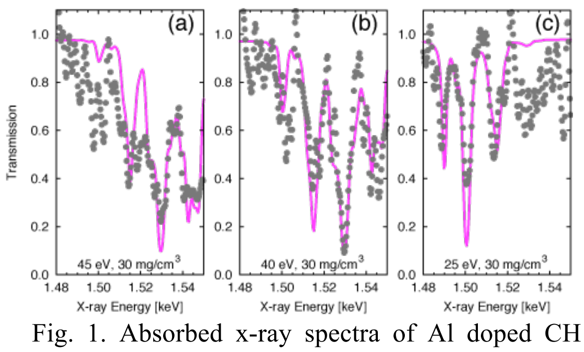

Fig. 1. Absorbed x-ray spectra of Al doped CH plasma observed at various timings; (a) 6 ns, (b) 7 ns, (c) 8 ns after the laser pulse irradiation.

resonance spectroscopy[3]. For the technique, neutron absorbers are doped in the sample in advance. The absorbed spectra due to the dopant reflect the sample temperature. Recent study indicates that 10^9 neutrons can be generated with ~100 J class ultra-intense laser pulses[4].

2.2 *Diagnostics for field measurements*

Backlight with laser-generated charged particles is useful scheme to study electrostatic or magnetic fields around plasmas. Field information is important to understand the plasma dynamics. Backlight technique with protons (~MeV) has been well established for the studies of laser-plasma interactions[5]. Typically, multi-layered film-type detectors are used in experiments. The detectors allow observing multiple images of protons with different energies at once. Because of the differences in the velocity of protons, the images can show the spatially and temporally resolved field information. The temporal resolution can be in the order of ps.

We have observed proton radiographs of a wire attached cone target after an intense laser light (10 ps duration) was focused into the cone[6]. Proton beam was generated by interactions between 1 ps laser pulse and a solid foil. Observed image is shown in Fig. 2. The proton distribution was perturbed by electrostatic fields around the target, which was excited by fast electron pulse. The proton radiographs can be used to understand the fast electron beam propagation in the target, which is important for the high energy density science.

Laser-generated fast electron beam is also a candidate as a backlight source[7]. Comparing to the proton backlight, the fast electron backlight has some advantages; 1) better spatial resolution due to its smaller divergence, 2) better temporal resolution due to its short pulse duration, and 3) high transmission in matter.

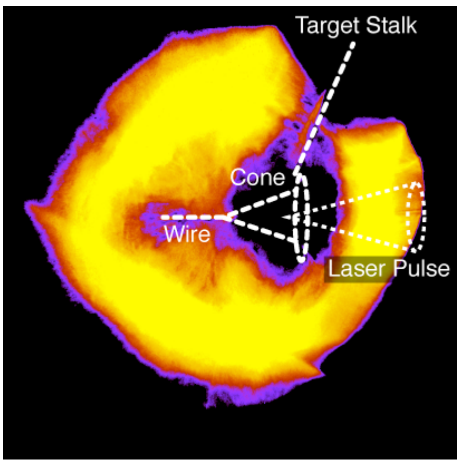

Fig. 2. Proton radiograph of laser-irradiated cone-wire target. Protons (5 MeV) are deflected around the target due to electrostatic fields, which is estimated to be 30 kV/μm around the wire tip.

3. Application for Fusion Reactor Engineering

The plasma diagnostics with lasers can be a good tool for the research of fusion reactors, particularly plasma-wall interactions. The diagnosing technique of temperature and density described above can be applied to investigate the condition of ablated plasma from the wall and the heated wall itself. The backlight techniques using laser-generated charged particles are also useful to monitor the dynamics of ablated plasmas, for example. As similar to the application in high energy density science, the advantages of laser-based techniques, such as good temporal resolutions, are still valid for the reactor study.

4. Summary

Laser-based plasma diagnostics are introduced and discussed their advantages for the usage in the high energy density science. Development of high power, high intensity lasers has provided many advanced techniques to characterize plasma and investigate fields surrounding plasma. Those laser-based diagnosing techniques are expected to help to further understanding of underlying physics in researches of fusion reactor engineering.

Acknowledgments

Part of this work was supported by NNSA/US DOE under Contracts DE-FG52-09NA29033 (NLUF), DE-FC02-04ER54789 (FSC), and DE-FG02-05ER54834 (ACE). Author gratefully acknowledges useful discussion with Profs. F. N. Beg (UC San Diego), S. P. Regan (LLE, Univ. Rochester), and K. A. Tanaka (Osaka Univ.), and also Drs. H. Sawada (UC San Diego), K. Anderson (LLE, Univ. Rochester), M. S. Wei, R. B. Stephens (General Atomics), and P. K. Patel (LLNL).

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