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Hard X-Ray and Electromagnetic Pulse Harsh Environment in Fast Ignition Experiments
高速点火実験における硬X線および電磁パルス過酷環境

Hiroyuki Shiraga, Mayuko Koga, Yoshinori Ishii, Takehiro Sogo, Osamu Maegawa, Yasunobu Arikawa, Hirokazu Hosoda, Takahiro Nagai, Mitsuo Nakai, Shinsuke Fujioka, Hiroshi Azechi
白神宏之，古賀麻由子，石井圭憲，十河雄大，前川修，有川信安，細田裕 計，長井隆浩，中井光男，藤岡慎介，疇地宏

Institute of Laser Engineering, Osaka University
2-6 Yamada-Oka, Suita, Osaka 565-0871 Japan
大阪大学レーザーエネルギー学研究センター　〒565-0871　大阪府吹田市山田丘2-6

In Fast Ignition experiments, targets are irradiated with ultra-intense short-pulse laser for heating of the compressed fuel plasma. Intense hard x rays (γ rays) and electromagnetic pulse (EMP) are generated in such experiments from hot electrons generated by the heating laser. Those bring serious background problems to x-ray imaging diagnostics and neutron diagnostics as well as malfunctioning of electronic devices. Furthermore, intense γ rays causes some nuclear reactions producing neutrons which are obstacles to the measurement of fusion neutrons. Plasma diagnostic instruments for Gekko-XII/LFEX laser facility have been improved to be compatible with such hard x-ray and EMP harsh environment.

1. Introduction

FIREX project has been carried out for Fast Ignition (FI) research at the Institute of Laser Engineering, Osaka University [1]. In FI experiments, targets are irradiated with ultra-intense short-pulse laser for heating of the compressed fuel plasma. A new laser system, LFEX, has been constructed and activated for this purpose as a fast heating laser. Its final output will be 10 kJ in a 0.5 – 20 ps pulse. In such experiments, intense hard x rays (γ rays) and electromagnetic pulses (EMP) are generated from hot electrons created by the heating laser. Those bring serious background problems to x-ray imaging diagnostics and neutron diagnostics as well as malfunctioning of electronic devices. Furthermore, intense γ rays causes some other nuclear reactions producing neutrons which are obstacles to the measurement of fusion neutrons. Plasma diagnostic instruments for the experiments with Gekko-XII/LFEX laser facility must be compatible with such hard x-ray and EMP harsh environment.

The first campaign of the integrated experiments of FI was performed in 2009, and the second one in 2010. In 2009 experiment, we found that the plasma diagnostics were in a very serious situation of γ-ray background and EMP as descrived above, and it was very difficult to find the real signals in the data covered with intense backgrounds or noises. Then, we have much improved the diagnostic instruments including shielding and collimation as well as redesigning of the instruments.

2. Fast Ignition Experiment on Gekko-XII and LFEX lasers

Implosion and heating experiments of FI targets for FIREX-1 have been performed by operating both Gekko-XII and LFEX lasers. Typical laser and target parameters were as follows. Gekko-XII laser for implosion: 0.53-μm light with an energy of 1.5-4.5 kJ in total in a 1.5 ns nearly Gaussian pulse in 2009, and a nearly flat-top pulse in 2010 experiment, nine beams among twelve. LFEX laser for heating: 1.053-μm light with an energy up to 1-2 kJ in 1-5 ps. The beam(s) were focused and injected into a cone attached to a shell target. Shell targets (CD: deuterated polystyrene): 500 μm in diameter and 7 μm in thickness. A 10-20 μm wall-thickness Au cone with an opening angle of 30 or 45 degrees. Outer surface of the Au cone was coated with 10- μm-thick CH layer. Distance from the center of the shell to the cone tip was 50 μm.

Characteristics of the imploded and heated fuel plasmas were observed by using a variety of plasma diagnostics. Dynamics of the imploded fuel plasma was observed with ultrafast x-ray spectroscopic imaging utilizing x-ray streak cameras [2-4] and x-ray framing cameras [5]. Fusion products were observed with detectors including a multi-channel single-hit neutron spectrometer, ultrafast liquid scintillator neutron detectors [6], filtered CR-39 detectors, and so forth.

3. X-ray Imaging Diagnostics

3.1 *X-ray framing cameras*

Intense non-imaged hard x-ray signals were observed on gated-MCP based x-ray framing cameras coupled with x-ray pinhole cameras. Although this signal can be used as the heating time indicator [5], it buries the thermal x-ray images of the target at around the time of the heating beam injection, the most important frames. We have developed x-ray framing cameras coupled with total reflection x-ray mirrors, which reflect only thermal x-ray images below 5 keV. Those worked very well in observation of the imploded core plasmas at the time of the heating.

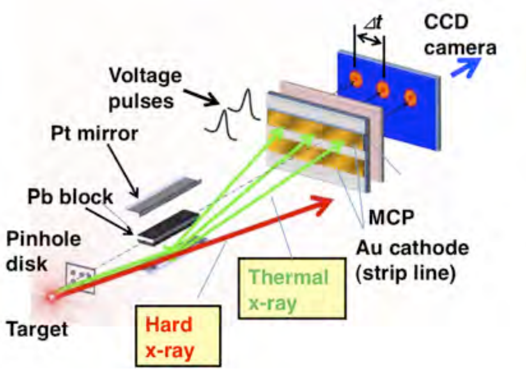

Fig.1. X-ray framing cameras coupled with total reflection x-ray mirrors.

3.2 *X-ray streak cameras*

Time-resolved two-dimensional x-ray images of the imploded core plasma was observed with Multi-Imaging X-ray Streak Camera [2]. The streak tube has a cathode disk made of 1-mm-thick stainless steel with slits for choosing the image. However, the disk material is almost transparent to hard x-rays of > 20 keV, and the whole surface worked as cathode for such hard x-rays, resulting in discharges between the cathode disk and the acceleration mesh due to large amount of the photoelectrons generated by intense hard x-rays. In 2010 experiment, the streak camera was equipped with a hard-x-ray shielded photo cathode disk, and the discharge was successfully extinguished. Furthermore, injection time of the heating beam relative to the implosion was measured with this x-ray streak camera with an accuracy better than +/-10 ps by using non-imaged hard x-ray signals.

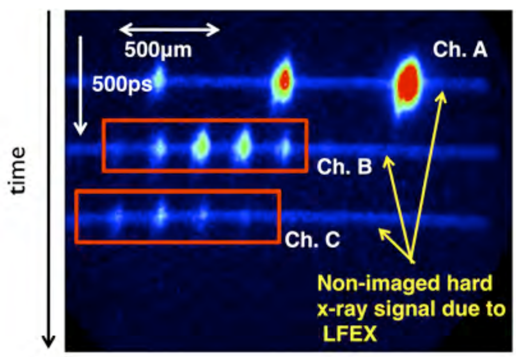

Fig.2. X-ray streak camera data .

4. Neutron Diagnostics

Neutron time-of flight detectors are the most important diagnostic instruments for determining the enhanced neutron yield and ion temperature in FI experiments. Large hard x-ray signal and its decay are obstacle to the fusion neutron diagnostics. An ultrafast-decay liquid scintillator was developed to solve the problem [6]. Also we found that not only the DD fusion neutrons from the imploded and heated core but also neutrons due to (γ, n) reactions and scattered γ rays were detected by time-of-flight neutron detectors. Signals of (γ,n) neutrons and scattered γ rays were analyzed by using Monte-Carlo simulations. Such obstacle signals were carefully eliminated and the net DD neutron signals were extracted to determine the enhanced DD neutron yield.

5. Electronic Devices and EMP

High-intensity laser-irradiated plasma emits intense EMP in GHz-THz spectral regions. A high performance electromagnetic shielding box was introduced to keep electronics and PC's. Noise amplitude was significantly reduced by a factor more than 20, although further reduction is needed.

6. Conclusions

Various improvements in plasma diagnostics worked well, and the plasma data were successfully obtained in FI experiment with Gekko-XII/LFEX.

Acknowledgments

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