Development of X-ray Source Generated by Laser Plasma for Facilities Diagnosis

Background

Effective nondestructive diagnostic techniques are desired to inspect stress corrosion cracking and plumbing recession in power plants and other facilities. X-ray radiation testing can be used for diagnosis of piping from outside of thermal insulator. Among x-ray sources, generating by laser-plasma can be superior to using an x-ray tube or an isotope in small size and high spatial-resolution (Table 1). In order to put laser-plasma x-ray *[1] to practical use, it is necessary to establish technology to increase x-ray energy and its yield.

Objectives

To increase the yield of high energy x-ray, a method using an x-ray converter *[2] is applied to generation of laser-plasma x-ray.

Principal Results

1. Increase of laser-plasma x-ray in yield and energy

To increase the yield of laser-plasma x-ray, a method using an x-ray converter in which the target was separated from the x-ray conversion section (Fig.1), was proposed and evaluated for validity by experiments.

(1) Tungsten is favorable for the conversion because its atomic number is large. When tungsten was used as a converter, x-ray yield obtained with 0.2mm - 0.5mm thickness was approximately 2.5 times higher than without converter as is shown in Fig.2. These results are good in agreement with the results obtained by a simulation code of Geant4. Since this code can reproduce the behaviors of energetic electrons and x-rays through the converter, this code should be a powerful tool for future theoretical design.

(2) In addition, by making good use of laser pre-pulse *[3], electron temperature was approximately twice higher than that without pre-pulse and electrons with energy of 2-3 MeV were obtained, which indicates that x-ray yield and energy should increase more by the pre-pulse effect.

2. X-ray imaging using laser-plasma x-ray

The above laser-plasma x-ray was applied to x-ray imaging as an x-ray source. As for an image detector, an x-ray image intensifier was used. Figure 3 shows an example of the imaging of IC circuit. The limitation of x-ray penetration for 100 laser shots was 4 mm thickness of cupper plate. By making use of pre-pulse effect and increase of laser shot number, total amount of x-ray yield is expected to be raised ten times, and x-ray imaging of plumbing with thickness of several cm, which is practically used, will be obtained.

Future Developments

We will optimize the laser-plasma condition for x-ray generation and try to obtain x-ray imaging of plumbing with thickness of several cm. In addition, for bringing in narrow spaces, downsizing of laser-plasma equipments and selection of an x-ray imaging detector will be conducted.

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References

Y. Oishi, et al., 2006, “Investigation of x-ray converter in terms of laser plasma x-ray sources”, CRIEPI Report H05014 (in Japanese)

X. Wang, et al., 2006, “Effect of plasma peak density on energetic proton emission in ultra-short high-intensity laser-foil interactions”, Phys. Plasmas 12, 113101 (2005).

*1：Focus irradiation of ultra-short and ultra-high intensity laser on a target generates high-temperature and high-density plasma instantaneously. X-ray generated by electrons in the plasma is called as laser-plasma x-ray.

*2：Normally electron generation and transfer from electrons into x-ray occur in succession within a target. In our method, electron generation occurs within a thin film target, but the transfer mainly occurs within an x-ray converter which is separated from the target. It is advantageous to increase a yield of high energy x-ray because the electron generation and transfer can be optimized separately.

*3：A pre-pulse is determined as a laser-pusle in front of a main-pulse. Usually contrast ratio of pre-pulse to main-pulse is very small and pre-pulse can be ignored. However, in ultra-high intensity laser, pre-pusle effect can not be ignored.

Table 1 X-ray sources for radiographic tests

	Conventional method			Proposed method
	Isotope ^{60}Co	Isotope ^{192}Ir	X-ray tube	Using laser-plasma
Spatial resolution (≦0.1mm)	△	△	○	○
Size of head part (≦～10 cm)	○	○	×	○
Handling (X-ray shield)	×	△	○	○
X-ray energy (MeVclass)	○	×	△	○

Here, for laser-plasma x-ray, future progress in performance is taken into account.

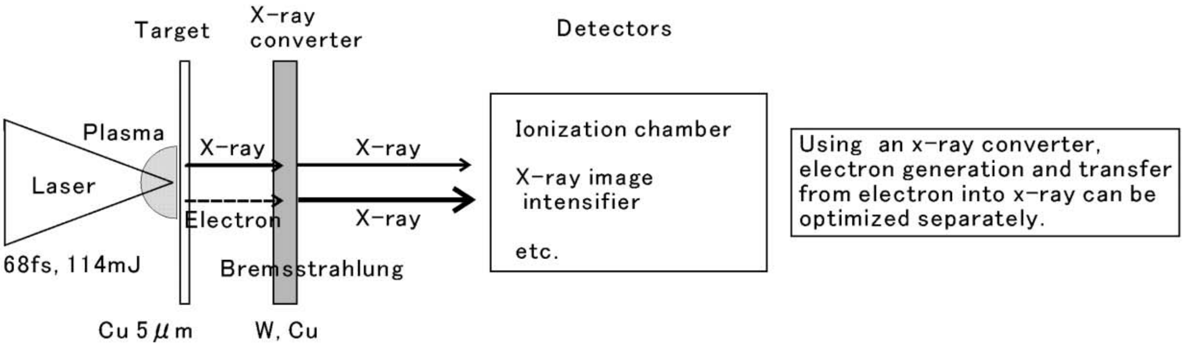

Fig.1 Experimental setup for generation of laser-plasma x-ray using an x-ray converter

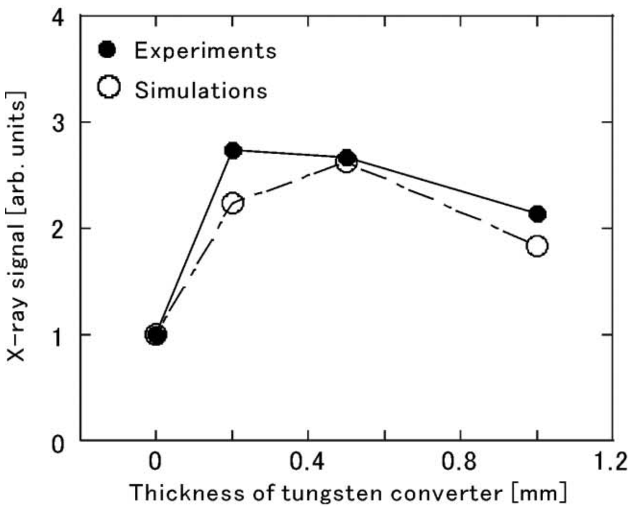

Fig.2 Dependence of x-ray signal on thickness of tungsten converter

Using a tungsten converter, x-ray yield increased approximately 2.5 times higher than without converter.

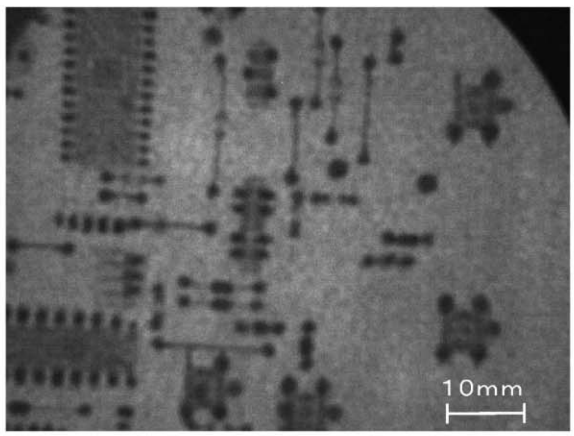

Fig.3 X-ray imaging using the laser-plasma x-ray and x-ray image intensifier

An example image of IC circuit (3mm thick at maximum), which was placed at the rear of 1mm thick alminum.