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Enhancement of resistance against high energy laser pulse injection with chevron beam dump

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HIGHLIGHTS

- The laser irradiation tests onto flat-mirror-molybdenum sample were carried out.
- The absorbed energy density is the correct figure of the laser-induced damage.
- Experiments validated the design of a new beam dump called chevron beam dump.
- The chevron beam dump would have much longer lifetime than conventional beam dumps.

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ABSTRACT

The laser beam dump of the Edge Thomson scattering (ETS) in ITER is being developed and a new type of beam dump called the chevron beam dump was proposed recently. The laser-induced damage on the surface is one of the most severe issues to be overcome. The key concept of the chevron beam dump is to reduce the laser energy absorption per unit area and to absorb the laser beam gradually. The laser irradiation tests onto flat-mirror-molybdenum sample were carried out. It was clarified that the absorbed (rather than incident) energy density of the laser pulses should be the correct figure of merit for the laser-induced damage. Therefore, the concept of the chevron beam dump design, that minimizes the absorbed laser energy density per unit area, was validated experimentally. The chevron beam dump enables us to extend its lifetime drastically relative to conventional beam dumps. Potential methods to improve the laser-induced damage threshold (LIDT) are also discussed in this paper.

1. Introduction

The Edge Thomson scattering (ETS) is the primary diagnostic system for measuring the electron temperature and density profiles of edge plasma in ITER [1]. The energy and the repetition rate of the incident laser beam are 5 J and 100 Hz, respectively [2]. In the ITER ETS, the pulsed laser beam is radially injected into plasma and the scattered light is collected through the equatorial port [3]. The beam dump for absorbing the incident laser pulse is integrated in the central I-beam of the blanket module [4]. Since the beam dump is located in the vicinity of fusion plasma, harsh electromagnetic and thermal loads are applied to the beam dump. Because of the high melting point, high thermal conductivity, relatively low mass density combined characteristics compared to other high-melting-point metal, molybdenum is one of the most promising materials for the beam dump in ITER. When the intense laser pulse hits the metallic surface, the laser-induced damage is the main issue to be overcome. The order of 10^9 laser pulses will be injected throughout 20-year operation of the ITER.

In order to overcome the laser-induced damage issue, a new type of beam dump called chevron beam dump was designed for ITER [4–7]. The multiple-pulse laser-induced damage is understood as the fatigue due to the thermal expansion-contraction cycles during laser pulses injection [8,9]. The laser energy absorption which is the cause of thermal expansion should be the most important factor for damage onset. Therefore, the chevron beam dump was designed so as to reduce laser energy absorption per unit area and to absorb the laser beam gradually inside the beam dump. The incident laser beam is polarized horizontally for the Thomson scattering measurements in the ITER geometry. The chevron beam dump has multiple bent sheets aligned in parallel, so that the incident laser electric field is s-polarized. The angle of incidence

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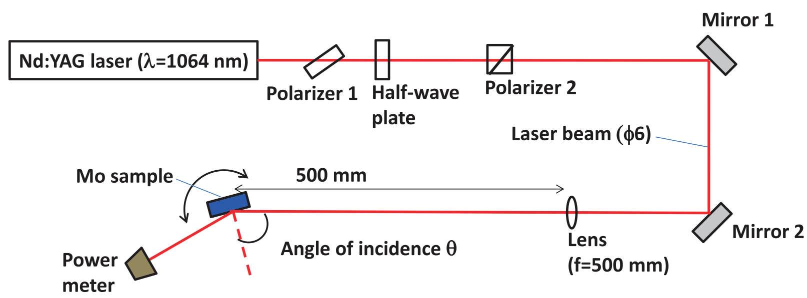

Fig. 1. Layout for the laser irradiation onto the molybdenum sample (flat mirror). Polarizer 2 is replaceable for selecting polarization of the incident laser beam.

for the first section of the sheet was designed to be 80 degrees. Considering 1064-nm wavelength, absorption of s-polarized light with 80-degree angle of incidence on molybdenum is 6% while with 0-degree angle of incidence it is 30%. It is expected that the lifetime of the beam dump extends drastically due to not only increasing the laser irradiated area but also reducing the absorbed energy density. Multiple-pulses-laser-induced damage threshold (LIDT) for the molybdenum was investigated with small angle of incidence [10]. In this study, laser irradiation tests were carried out not only with small (5 degrees) angle of incidence but also with large (75 degrees) angle of incidence to show the effect of absorbed laser beam energy against the LIDT.

This paper aims to validate the key concept of the chevron beam dump design, which is reducing the absorbed pulse energy density to extend the beam dump lifetime. Experimental setups are explained in Section 2. The results of the LIDT measurements are shown in Section 3. Observations of damaged surface by microscopes are summarized in Section 4. Comparison of performances between the chevron beam dump and the conventional beam dump are discussed in Section 5. Potential methods to increase the LIDT are also discussed in Section 5. Finally, conclusions are summarized in Section 6.

2. Experimental setups

Laser irradiation tests were performed using a flat mirror sample for simplicity. In this paper, the sample was installed in air at atmospheric pressure. Fig. 1 shows the layout for measuring the LIDT. A Nd:YAG laser (LOTIS LS-2134U: 270-mJ maximum pulse energy, 15-Hz maximum repetition rate, 6-ns minimum pulse duration and 1064-nm wavelength) is used as the incident laser. Since the output beam from the incident laser is polarized elliptically, the polarizer 1 is installed after the incident laser to make the laser beam be polarized horizontally. The incident laser pulse energy is adjusted using the half-wave-plate and the polarizer 2. In the case of configuration shown in Fig. 1, the incident laser beams is polarized horizontally. By replacing the polarizer 2, the vertically polarized beams can also be injected. Laser beam diameter is focused onto the molybdenum sample by the lens with 500-mm focal length. Since the normal line of the sample is horizontal, vertical and horizontal polarization of the incident laser beam corresponds to s-polarization and p-polarization, respectively. Fig. 2 shows the beam profile on the sample with 15-Hz repetition rate and 6-ns full-width-half-maximum (FWHM) pulse duration. The beam profile is hollow and smoother than the Gaussian. Hereafter, the incident and absorbed beam energy density are characterized by their peak values.

The sample used in this study was a molybdenum poly-crystal mirror with 11-nm root mean square (RMS) roughness. Fig. 3 shows the specular reflectivity of Molybdenum as functions of angle of incidence; closed squares and circles are measured data for s-polarization and p-polarization injections, respectively. Curves in

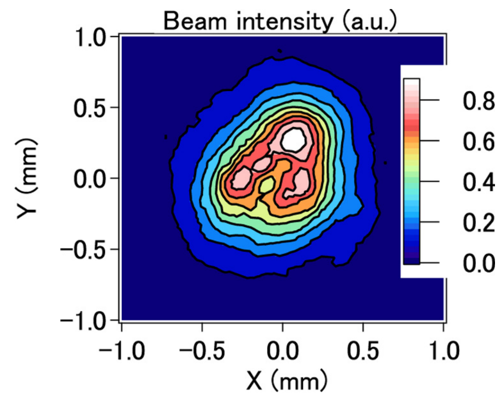

Fig. 2. Beam profile of the incident laser on the sample surface with 15-Hz repetition rate, 6-ns pulse duration and 0-degree angle of incidence. In this figure, right and left of the profile measured by a profiler were reversed for comparing with photographs and height profiles of damaged surface measured by the scanning electron microscope (SEM) and laser microscope, respectively.

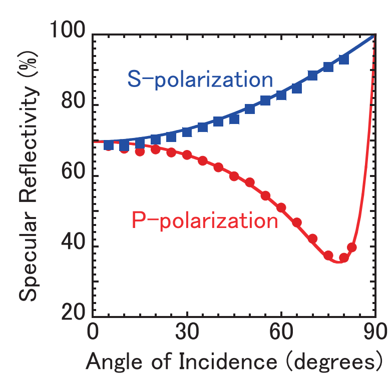

Fig. 3. Reflectivity of molybdenum as a function of the angle of incidence for the wavelength of 1064 nm. The closed squares and circles denote the reflectivity at the s-polarization and p-polarization incidence, respectively. Lines denote the theoretical reflectivity curves of molybdenum reflectivity.

Fig. 3 are reflectivity calculated from the complex refractive index of the molybdenum which is 2.3–4.4i for 1064-nm wavelength (interpolation of values shown in [11]). Reflectivity of s-polarization and p-polarization light as a function of the complex refractive index ($\tilde{n} = n - \kappa i$) are written as follows:

$$R_s = \left| \frac{\cos\theta - \sqrt{\tilde{n}^2 - \sin^2\theta}}{\cos\theta + \sqrt{\tilde{n}^2 - \sin^2\theta}} \right|^2, \quad (1)$$

$$R_p = \left| \frac{\tilde{n}^2\cos\theta - \sqrt{\tilde{n}^2 - \sin^2\theta}}{\tilde{n}^2\cos\theta + \sqrt{\tilde{n}^2 - \sin^2\theta}} \right|^2, \quad (2)$$