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Effects of repetitive ELM-like heat pulses on tungsten surface morphology

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Abstract

The effects of ELM-like heat pulses on tungsten surface morphology were studied by using a fundamental wave (wavelength of 1.06 μm) of a YAG laser, which was operated in a multi-pulsed mode with an effective pulse length of about 100 μm, typical pulse length of ELMs. Tungsten base temperature was 640 °C, heated by a sheath heater and laser pulse heating. The energy absorption rate of the laser light was about 30% for mirror finished surface. Under non-melting conditions (laser pulse energy fluence: ≤0.1 kJ/cm^2), roughening and cracking formation within the laser spot appeared. As the energy fluence decreased, the larger shot number was necessary for the surface morphology change to appear. Even at the highest temperature of around 1240 °C, surface roughening and fine cracking appeared at the large shot number (200,000 shots).
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Keywords: ELM; Repetitive heat pulse; Tungsten; YAG laser

1. Introduction

In magnetic confinement systems like ITER and DEMO, Type I ELMs are one of the major concerns for plasma facing materials (PFMs) [1]. For ITER, a pulse length and a heat load of Type I ELMs were predicted to be ~0.2 ms and 0.5–1.2 MJ/cm^2, respectively. The effects of intense heat load on tungsten and graphite were estimated by Federici et al. [2]. They showed that lifetime of tungsten PFMs significantly decreased due to melting and evaporation when the ELM energy exceeds 0.4 MJ/m^2 assuming the pulse length of 0.1 ms.

The severe damage caused by ELM's could be avoided by using recently developed ELM mitigation techniques (e.g. ELM pace making by pellet injection [3]). Even under the mitigated conditions, however, a change in surface temperature with a frequency of several Hz causes alternate expansion and contraction, leading to metal fatigue and surface cracking. This phenomena could further reduce a tolerable limit of ELM pulse energy.

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Renk et al. [4] showed that the surface roughness was produced on tungsten materials by repetitive pulsed load by high energy ion beam irradiation. This surface morphology could be caused by a thermal fatigue effect. Their experiments were done by very short pulsed ion beam (pulse length of ∼100 ns). Since the heat diffusion length is roughly proportional to square root of pulse length, the heat diffusion length as well as total deposited energy for ELM-like heat load (>0.1 ms) is much more than those for Ref. [4] (∼100 ns). Therefore, it can be considered that the effects of repetitive heat load would be strongly dependent on the pulse length and the studies under the conditions of the pulse length of an order of 0.1 ms need to be done. However, comprehensive studies on this issue are far from sufficient so far. Transient heat pulse effects are also studied by using a plasma gun [5].

In this study, the effects of repetitive laser pulses on tungsten surface morphology were investigated by using a YAG laser with an effective pulse length of about 100 μs. We will show that the repetitive pulsed heat load with much less energy than that causing melting gives significant cracking on tungsten materials.

2. Experimental

A fundamental wave (wavelength of 1.06 μm) of a YAG laser (Spectra Physics Co.) was used to irradiate tungsten samples with repetitive heat load. Experimental system is shown in Fig. 1. Laser beam with the beam diameter of about 10 mm was introduced to tungsten samples located in a vacuum chamber with several dielectric mirrors. The vacuum chamber was evacuated by a turbo-molecular pump to the pressure of about 10^{-7} Torr. The laser beam was focused onto the tungsten samples by a convex lens with a focal length of 511 mm. By moving the lens position along a beam path, the spot size and the fluence (J/cm^2) to the tungsten samples were changed from 0.017 to 1.7 J/cm^2. An alignment of YAG laser beam was done by using He–Ne laser and two pinholes. He–Ne laser beam was aligned so that the beam passed through the two pinholes and focused onto the sample. Then the YAG laser beam was aligned to pass through the pinholes. The laser beam was aimed at the samples at an angle of 45°.

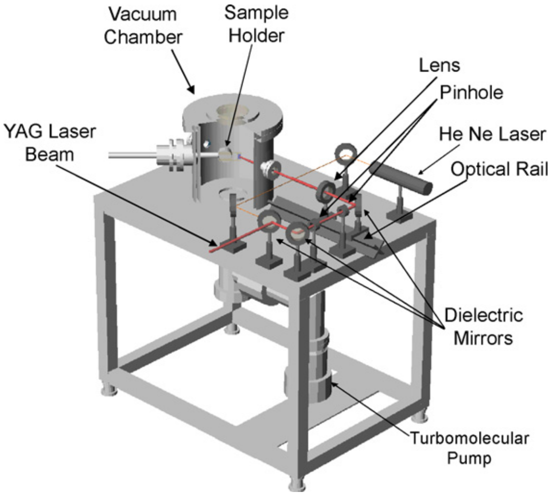

Fig. 1. Schematic of laser irradiation setup. YAG laser device itself is not shown.

The YAG laser was operated without a Q-switch. The pulse waveform measured by a pin diode was shown in Fig. 2. The operation mode was a multi-pulsed one with an effective pulse length of about 100 μs, close to typical pulse length of ELMs. Pulse energy and a repetition rate are 1.25 J/pulse and 10 Hz, where pulse energy was measured by a calorimeter. Sudden increase in the sample temperature by one laser pulse irradiation was decreased rapidly and the temperature became a steady-state value before the next laser pulse. The irradiation area was limited within a small spot and the power deposition profile was not uniform. These

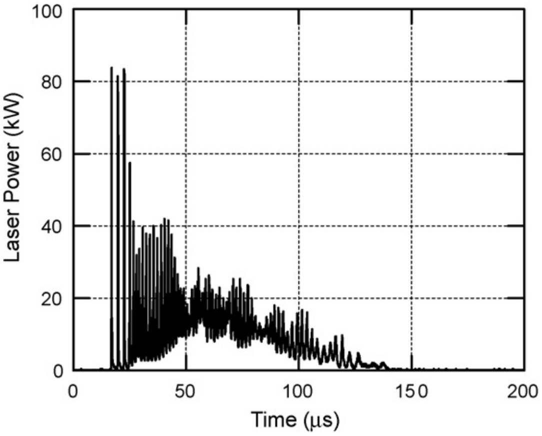

Fig. 2. Laser pulse waveform for the experiments.

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