Dependence of power density and energy fluence on ablation rates and LIBS observation thresholds for laser-irradiated ITER relevant materials

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ABSTRACT

In ablation laser removal of fuel and co-deposits from PFCs, the parameters of removal are commonly expressed in dependence of laser energy flux defined as J/cm^2 and calculated for single laser pulses or series of pulses. Due to variety of recently available laser systems for removal applications, which can provide pulses from broad ranges of energy and time, this approach is no longer sufficient. The limitations of the fluence model are especially clear when comparing removal with the use of short pulse Nd:YAG lasers operating in single nanoseconds and a part of J regime and fiber lasers operating in the regime of one hundred or even few hundreds nanoseconds pulse duration and single mJ energy. To complete the fluence model and make it applicable for assessment of the laser removal efficiency, the information on laser power density and energy flux on the ablation rate for Nd:YAG and Yb-fiber laser systems. The ablation rate in function of fluence is estimated for various power densities from a wide range from 10^9 to 10^10 W/cm^2 by the means of profilometry of laser induced craters. The thresholds for LIBS observation are estimated with the Mechelle 5000 spectrometer.

EXPERIMENTAL SETUP

The recent experimental setup at the IFPLM contains two lasers: the Nd:YAG delivering 1 ns, 0.6 mJ pulses at 1064 nm and up to 10 Hz repetition rate which allows for obtaining high peak power in range of 10^9 W/cm^2 but rather low average power of 6 W Yb-fiber laser with 1 mJ, 100 ns pulses at the repetition rate 2.1 kHz with flexible both energy in the pulse and repetition rate control which offers obtaining the average power of 200 W and peak power in range of 10^9 W/cm^2. In the experiments due to properties of the power amplification and pulse formation in the Nd:YAG laser, the Nd:YAG laser is the main source of triggering in the system. The laser triggers the Mechelle spectrometer, the CCD camera and the pulse generator which is the triggering source for the fiber laser. Mechelle 5000 spectrometer equipped with the listar CCD camera allows for the observation of the optical spectra in 200-1000 nm range with good spectral and time resolution which allows for the observation of the evolution of the spectrum of the expanding laser-plasma cloud.

FIBER LASER ON THE GRAPHITE SUBSTRATE

The obtained results allowed for estimation of the relation between power density and volume of the laser induced crater. The points on the graph were easily fitted by a linear function. The dependence is presented in figures on the right. Estimation of the curve allowed for calculation of the threshold power density for interaction with this type of laser which equals 5.9-6.6 MW/cm^2. The calculated threshold is consistent with profilometry measurements which did not show the presence of a crater for power densities below the threshold.

REPETITION RATE (FLUENCE) DEPENDENCE

The second part of the experiment with the fiber laser included was to measure the craters depth in function of the repetition rate of the pulses of constant power density obtained in previous experiments for the maximum pulse energy. The sample craters obtained for different repetition rates are shown below.

CONCLUSION

Operating in different power density regimes results in quite different phenomena leading to crater formation which can be clearly seen by the means of profilometry. The difference is especially important when the power density is high enough that it produces big amounts of plasma resulted from interaction with the gaseous atmosphere. Results allow for estimation of the power density threshold for the process of the removal of graphite with a fiber laser which may very useful, especially that this threshold is significantly higher than is for a standard deposite.

THE PROFILES FOR VARIABLE POWER DENSITY

The profiles for variable power densities are shown below.

Linear Fit of Data6_volume
Linear Fit of Data8_volume

Nyd-YAG LASER ON THE GRAPHITE AND ALUMINUM SUBSTRATES

The interaction of the Nd:YAG irradiation was tested on carbon and aluminum substrates in vacuum, in 100 Pa and in atmospheric pressure. The pressure had a big impact on the surface area and the depth of the craters. While in vacuum the craters were deep and narrow, in the ambient atmosphere, the burning effect of laser generated plasma led to formation of shallow craters with larger diameters. In vacuum, the craters in the graphite had a diameter of a part of a micrometer and could reach a large depths of a few hundreds of micrometer. The dependence of the power density on the volume for a constant pulse energy is not straightforward as in case of the fiber laser. The dependence taken for the narrow region in vicinity of focal point is shown on the left. The graph shows that there is a optimal focusing regime which allows to obtain the highest crater volume. Such a crater is not extremely deep which takes place when the power density is higher, but the bigger crater diameter makes the volume considerably larger.

The experiments on the aluminum plate shows the morphology of the craters which takes form of the interferometric rings. This surface structure due to its optical properties may introduce errors to the measurements of the profilometer and should be further investigated. A sample crater and the whole plate with craters are shown on the left.