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LASER-INDUCED PLASMA SPECTROSCOPY OF PLASMA FACING MATERIALS

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Abstract

Qualitative elemental analysis of ASDEX divertor plates' material was performed by laser-induced plasma spectroscopy. The spectra show a decrease in impurity signals and an increase in substrate signal during the layer-by-layer ablation. The selective detection of the plasma light is reasonable for obtaining emission spectra resembling those attained using time-gated detectors.

Introduction

During the operation of fusion devices, plasma-wall interaction is the multitude of the complex processes arising from interaction of plasma facing materials and electromagnetic radiation. Understanding the nature and kinetics of this interaction would facilitate the improvement of materials used for construction of walls for fusion devices [1].

Deposition of carbon layers, retention, co-deposition and diffusion of hydrogen isotopes are the major concerns in fusion devices [2]. Usually this information is gained by means of different methods of analysis including mass spectroscopy, ion beam techniques, the results from deposition or erosion probes etc. An alternative method of rapid elemental analysis technology is laser ablation spectroscopy [3].

The principles of laser spark analysis are similar to those of conventional plasma-based methods of atomic emission spectroscopy (AES) [4]. The advantages of AES-based analysis are the simplicity of the method, the ability of simultaneous monitoring of all elements in plasma, and the possibility of analysis of any material irrespective of its physical state.

Experimental details

A Q-switched Nd:YAG laser (SL-312, EKSPLA) with an emission wavelength of 1064 nm was used as the laser-induced plasma source. Its pulse repetition rate was 10 Hz, pulse width - 135 ps, and pulse energy can be tuned up to 250 mJ.

The samples used in this study were cut from the graphite R6710 divertor plates of an ASDEX Upgrade tokamak.

The laser ablation beam fell normally to the surface of the sample. To avoid formation of excessively deep craters, the beam was slightly defocused. A convex quartz lens focused the beam at a distance of 3 mm inside the sample which was fixed in the vacuum chamber. The experiments were carried out at the pressure of 10^{-5} Torr. A quartz lens projected the plume image onto the entrance of the optical fibre. The collected light was imaged onto the vertical slit of an Andor Shamrock sr-303i spectrograph with a grating of 600 gr/mm. The spectrograph was equipped with an Andor CCD camera.

Results and discussion

Selective detection of the plasma light might give the possibility to enhance detection capabilities, so the strong background continuum occurring at early stages of plasma formation can be successfully reduced even without time-resolved detection [5].

Spectra of laser-induced plasma were recorded by focusing the fibre-optic bundle directly on the ablation spark, then moving the fibre holder along the plasma plume at steps of 0.1 mm (Fig.1). For each case, a series of 10 laser pulses at pulse energy of 20 mJ were applied.

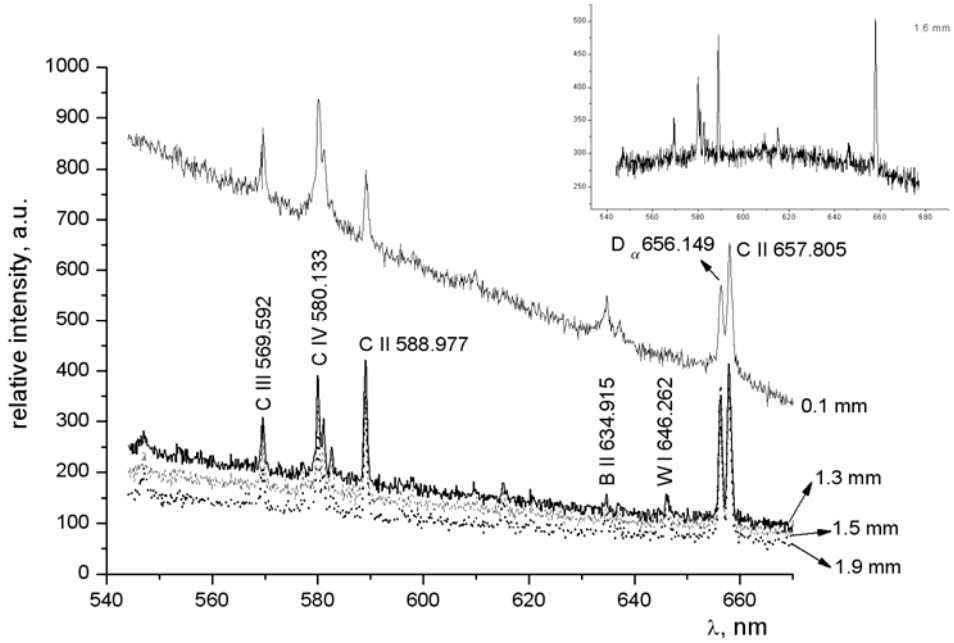

Fig.1. Spectra of laser-induced plasma at different distances from the ablation spark [8]

We observed a clear tendency for the background light to decrease as the distance from the spark was increased. At a distance of about 1 mm from the spark spectra exhibit similar signal-to-background ratio and spectral contents. For these spectra, D_α/C II 657.845 nm signal

ratio equals 0.87, while for the spectra shown in the inset of Fig.1, it is 0.58. This spectrum was obtained at the distance of 1.60 mm with a delay of about 300 ms after starting the sequence of laser pulses. In this case, the intensity of D_α signal is practically at the level of the background, while the signal of the main component of the sample – C II 588.997 nm and C II 657.805 nm – is distinct. To explain this, further investigations related to kinetics of the different elements in the plasma will be made.

To follow the behaviour of spectral lines in spectra, different numbers of laser pulses from 1 to 60 were applied to the surface of the sample (Fig.2a, b). Obtained spectra show the increase of relative intensities of carbon lines. In contrast, the signals of impurities (deuterium and boron) decrease as the number of pulses grows. B II 634.915 nm line is still present in the spectra obtained after 25 consecutive laser pulses, but the signal is equal to the background level in the spectra after 50 laser pulses.

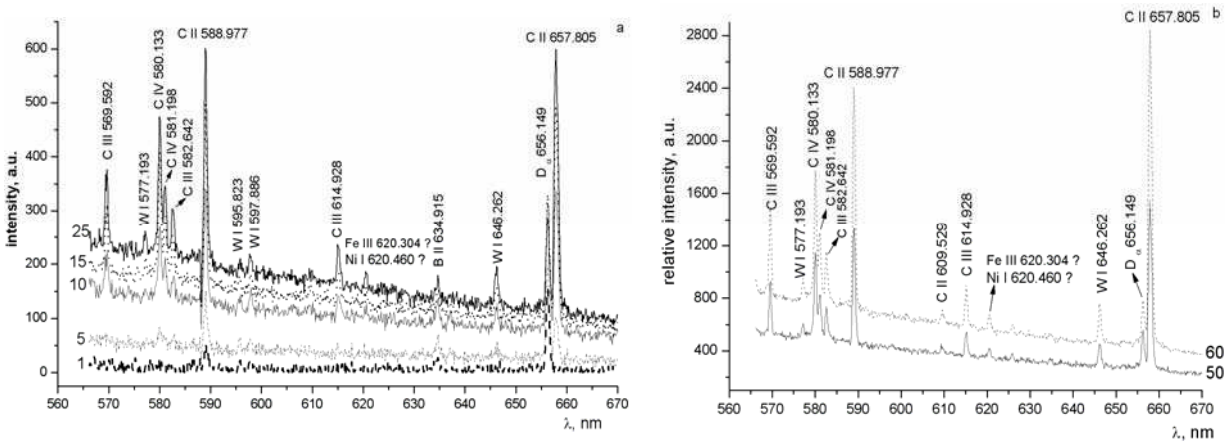

Fig.2a, b. Spectra after applying different numbers of laser pulses to the target. The numbers correspond to the number of the pulse in the sequence [6]

The ratio of D_α/C II 657.845 nm signals is of the highest value of 3.8 in spectrum obtained after the single laser pulse. Relative intensity of C II 657.845 nm line is practically non-detectable in this case. After the 10^{th} pulse, the relative intensity of the C II 657.845 nm line exceeds that of the D_α line. The ratio of these two spectral lines continues decreasing to 0.27 for 60 laser pulses, although D_α line can still be detected in the spectrum.

Apart from carbon, the basic element of the investigated sample, some tungsten lines were also detected. Fe III 620.460 or Ni 620.460 nm might come from the stainless steel components which are not shielded from the plasma [7]. The appearance of the B II 634.927 nm line might be explained by a process of boronization of plasma-facing components [8].

Conclusions

Qualitative elemental analysis of ASDEX divertor plates'material was performed by laser-induced plasma spectroscopy. The spectra show a clear decrease in impurity signals (deuterium and boron) and an increase in substrate signal during the layer-by-layer ablation process. These results show that laser-induced plasma spectroscopy is a potential method of analysis of migrating materials and co-deposited layers of plasma facing materials. Additionally, laser scanning can be used as a procedure of deuterium removal from co-deposited layers [9].

The selective detection of the plasma light is reasonable for obtaining emission spectra resembling those attained by using time-gated detectors. This can sufficiently reduce the expenses related to time-resolved detection.

Acknowledgements

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