Research on interaction of pulsed plasma-ion streams of different energy fluxes with SiC and CFC samples

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Abstract

The paper reports on experimental studies of pulsed plasma-ion streams and their interactions with solid targets made of silicon carbide (SiC) or carbon fibre composite (CFC). The deuterium plasma streams were generated by a coaxial accelerator of the RPI (Rod Plasma Injector) type. Interactions of the plasma-ion streams with the chosen targets were investigated by means of optical emission spectroscopy (OES). After the irradiation, targets were analysed by means of a scanning electron microscope (SEM) and energy-dispersive X-ray spectrometer (EDS). The SiC samples showed better performance during irradiation by high-temperature and dense plasma at the energy flux density in a range of 1-6 J/cm^2.

1. Introduction

Research on interactions of intense plasma-ion streams with various solid targets are of great importance for further development and exploitation of various plasma facilities [1-2]. Among different materials used as plasma-facing components there are also carbon fibre composites (CFC) or silicon carbide (SiC). In order to investigate behaviour of such materials one has to use plasma stream of appropriate parameters. For this purpose our team decided to make use of the RPI-IBIS facility which can generate pure deuterium plasma streams of an average energy equal to a few keV. The main aim of the reported research was to measure optical spectra of plasma during its interactions with CFC and SiC samples and to investigate surfaces of the irradiated targets as a function of the total plasma energy flux.

2. Experimental setup

The RPI-IBIS facility was equipped with two coaxial electrodes, each composed of 32 thin (2-mm-diam.) molybdenum rods. These 20-cm-long electrodes were 9 cm and 12 cm in diameter, respectively. The fast-acting gas valve was used to inject some amount of the working gas (usually pure deuterium) in chosen instant before initiation of the discharge. Using various

delay times between discharge and gas injection, the device operated in different modes and produced plasma streams of different parameters [3-4].

During the reported experiments the RPI-IBIS facility was operated at a charging voltage equal to 28-30 kV. In order to obtain plasma streams of various energy fluxes, the device was powered by different number of condenser sections. The energy flux density of plasma streams depended on energy stored in the applied condenser bank and it reached from 1 to 6 J/cm^2. The plasma stream was investigated mainly by means of the OES technique. The optical spectra were recorded with a Mechelle®900-spectrometer coupled through an optical cable with a quartz collimator placed side-on the experimental chamber. The observation field embraced the surface of the SiC or CFC target which was placed at a distance of 20 cm from the electrodes outlets.

3. Experimental results

In order to determine parameters and behaviour of freely propagating plasma, the first series of measurements was performed without any target. The exposition time was set to 15 μs in order to cover the whole period of the most intense plasma radiation. The deuterium Balmer lines recorded during discharges performed at different supply energy are shown in Fig. 1.

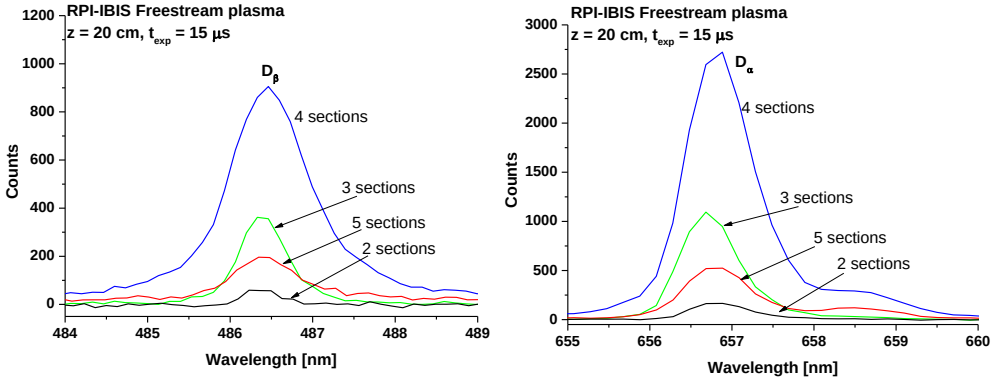

Fig. 1. Deuterium Balmer lines: D_β (left) and D_α (right), as recorded during discharges without targets. Discharges were performed with various numbers of condenser sections, i.e. at different energy flux densities.

On the basis of the recorded lines profiles it was possible to estimate the electron concentration of plasma [5]. The results of such estimations are presented in Table 1.

Table 1. Electron concentration of freely propagating plasma, as calculated on the basis of the Stark broadening of the deuterium Balmer lines

Number of sections	Energy flux density	N_e estimated from D_α profile	N_e estimated from D_β profile
2	1 J/cm^2	2.6×10^{15} cm^{-3}	4.0×10^{15} cm^{-3}
3	3 J/cm^2	2.3×10^{15} cm^{-3}	5.5×10^{15} cm^{-3}
4	4 J/cm^2	3.2×10^{15} cm^{-3}	1.2×10^{16} cm^{-3}
5	6 J/cm^2	3.0×10^{15} cm^{-3}	8.2×10^{15} cm^{-3}

The spectra recorded during interactions of plasma streams with CFC targets are shown in Fig. 2. The spectra were recorded during discharges with various energy flux density, at a chosen times in relation to current peculiarity.

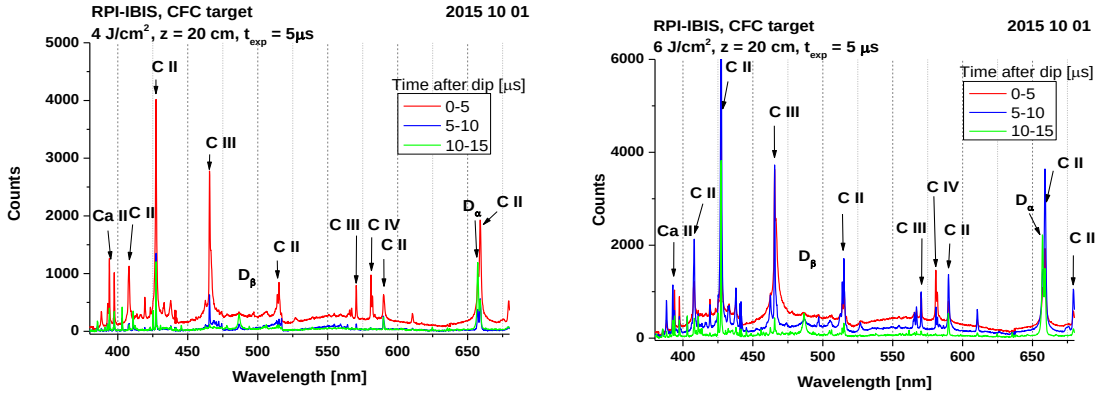

Fig. 2. Optical spectra recorded during interaction of plasma streams with CFC target. Plasma energy flux density was equal to 4 J/cm^2 (left) or 6 J/cm^2 (right). The spectra were recorded at different instants after a current dip, with the exposition time equal to 5 µs.

Another series of measurements was performed with SiC target. Intensities of the line radiation from Si and C ions are presented in Fig. 3, and SEM images of the target surface are shown in Fig. 4.

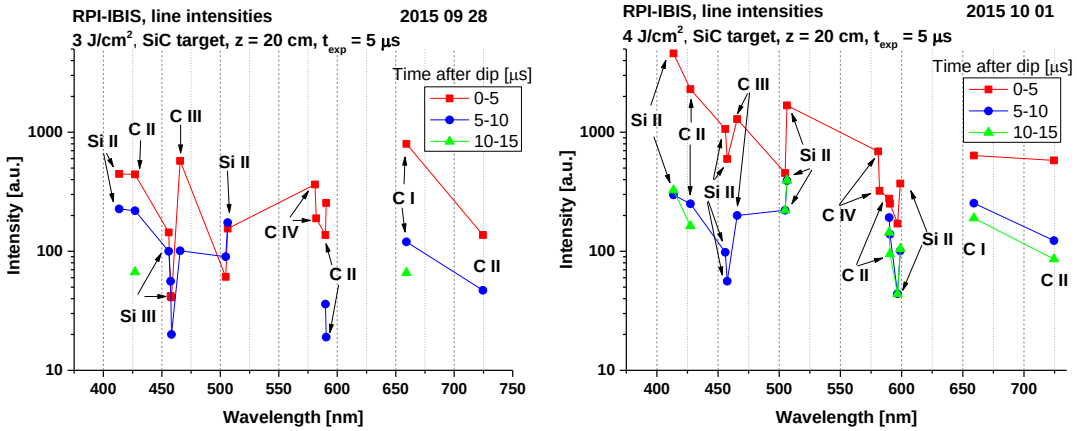

Fig. 3. Comparison of atomic and ion lines intensity during irradiation of SiC target. Plasma energy flux density was equal to 3 J/cm^2 (left) or 4 J/cm^2 (right).

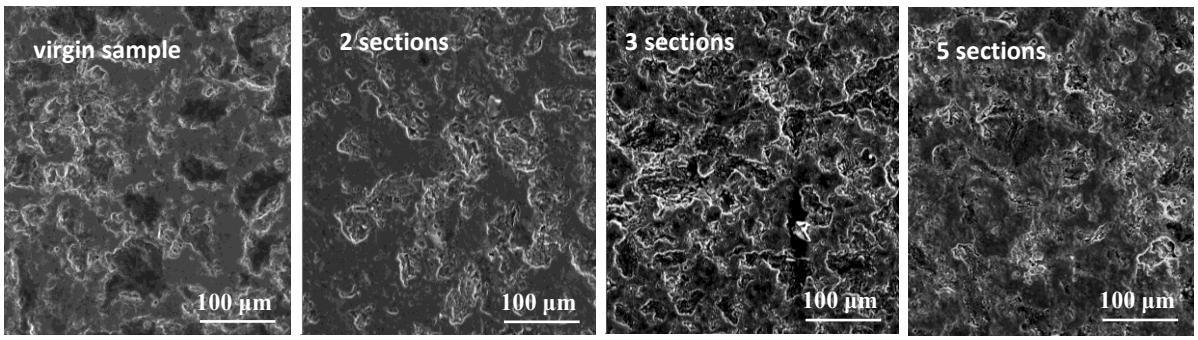

Fig 4. SEM images of a SiC target surface before (a) and after its irradiation by plasma streams of energy flux density equal to 1 (b), 3 (c) and 6 (d) J/cm^2.

Surfaces of the irradiated targets were also investigated with the EDS technique. The results showed mainly elements of the target material and a small amount of impurities from the electrodes of the RPI facility. Exemplary results of such an analysis are presented in Fig. 5.

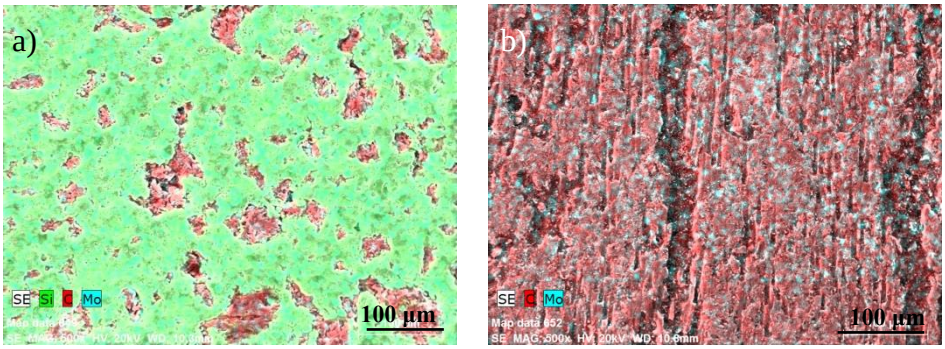

Fig. 5. EDS surface analysis of different targets: a) SiC, b) CFC, after their irradiation by a plasma stream of the energy flux density equal to 3 J/cm^2:

4. Conclusions

The OES measurements allowed ions emitted from target surface to be identified up to the 2nd ionization stage. The intensity and amount of spectral lines increased with an increase in the total energy of the discharge. It indicated that processes of sputtering and ionization of target material are intensified at higher plasma energy flux density. On the basis of the recorded spectra one could observe some threshold of plasma interaction with a SiC target. Interactions with a CFC target showed a similar character for discharges performed with 3-5 sections, but for discharges supplied by 2 sections no Si-lines were recorded. The irradiation by plasma streams of higher energy density lead to sputtering and ionization of Si and C from the surface of the sample. The SEM images showed no distinct changes regardless of the plasma stream energy density. It means that amount of material sputtered during interactions was low and no structural damages were observed up to energy flux density of 6 J/cm^2. The observed differences between CFC and SiC targets proves that SiC material shows better performance during irradiation by high-temperature and dense plasma (in a range of 1-6 J/cm^2).

References

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