Interaction of Intense Pulsed Plasma Streams with CFC Targets

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The paper reports on recent studies of carbon-fiber-composite (CFC) targets exposed to intense plasma streams generated by the PF-360 facility. The main aim was to observe interaction of pure deuterium plasma with surfaces of the investigated material and to estimate parameters of plasma in a near-surface layer. Optical spectroscopy was used to measure the emission spectra in the visible range. Distinct deuterium Balmer-lines were recorded and it was estimated that in a free-propagating plasma stream the maximum electron density was about 2 x 10^{17} cm^{-3}. In experiments with CFC targets it was about one order higher. A dependence of carbon spectral-lines and erossion effects on the crystallographic orientation of the target was observed.

Studies of plasma-surface interactions and associated processes are of primary importance for plasma physics and technology. Experimental studies in this direction have been carried out in many labs with the use of different plasma sources and various materials [1-3]. The main aim of the reported study was to investigate the interaction of intense plasma streams with CFC targets placed inside the PF-360 facility [4]. This facility was equipped with coaxial electrodes made of copper tubes of 120 mm and 170 mm in diameter, respectively. Plasma discharges were powered from a 234-μF condenser bank operated at 30 kV, 105 kJ. The machine generates intense deuterium-plasma streams, containing also powerful beams of fast deuterons [5]. It enables to study plasma-material interactions and material erossion.

In the described experiments all optical observations and measurements were performed side-on, through a quartz window at a distance of 30 cm from the electrode ends, as shown in Fig.1.

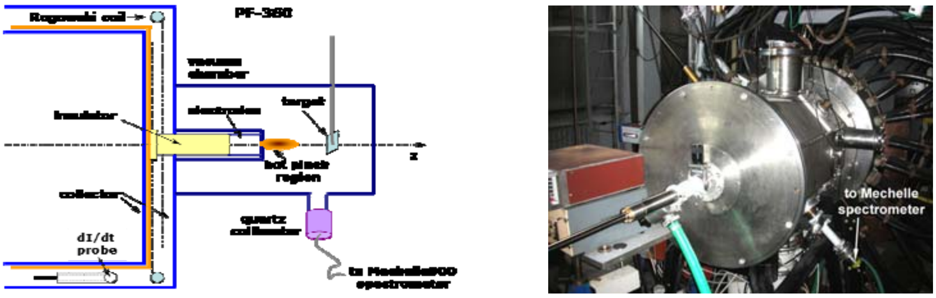

Fig. 1. Scheme (left) and general view of PF-360 experimental chamber (rigth).

The spectroscopic measurements were carried out by means of an optical collimator coupled through the optical fibre-cable with the Mechelle®900 spectrometer equipped with a PCO SensiCam camera, which enabled to record spectra in the wavelength range from 350 nm to 1000 nm, at the chosen time exposition time (e.g. 0.1 or 2 μs) and with a determined delay to the discharge beginning or the current peculiarity (dip). The optical emission spectroscopy has been used first for a free-propagating plasma stream, i.e. without any target. The recorded spectra contained intense Balmer lines of deuterium and a relatively small amount of impurity lines, as shown in Fig.2 (left). Subsequent experiments were performed with the CFC targets of CFC of the Smecta-N11 type (used in the Tore-Supra tokamak). The targets (of 30x35 mm^2 surface and 4-6 mm in thickness) were cut from the CFC cube in such a way that they had different crystallografic orientations. They were fixed successively upon a support placed at the same distance (30 cm) from the electrode outlets, and their surfaces were perpendicular to the plasma stream direction. The recorded optical spectra contained the distinct deuterium and carbon lines, as shown in Fig.2 (right).

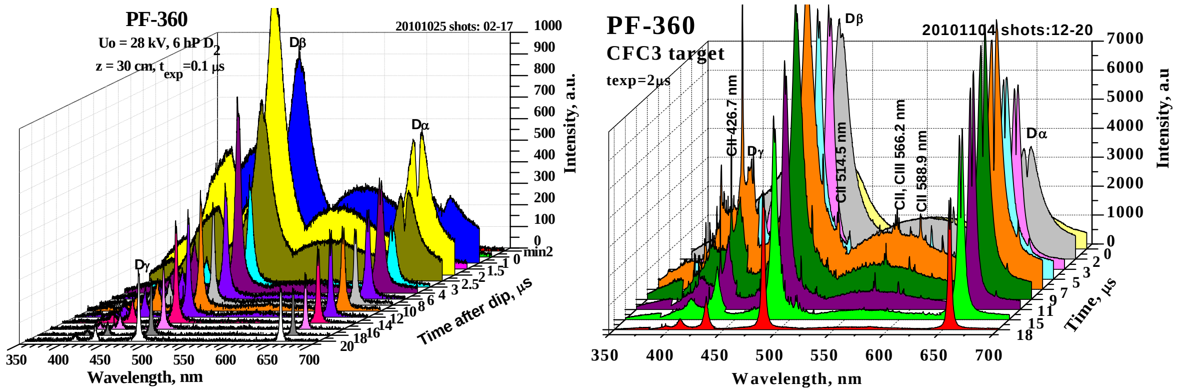

Fig. 2. Optical spectra from a free-propagating deuterium plasma stream (left) and from plasma interacting with the CFC target #3 of a high number of the C-filaments ends (right).

Results of the preliminary spectroscopic measurements have already been reported earlier [6-7]. The detailed analysis of the observed Stark broadening of the recorded deuterium spectral lines showed that the maximum electron density in the free-propagating plasma stream appeared 1-2 µs after the discharge beginning and it amounted to (1-2) × 10^{17} cm^{-3}. In experiments performed with the CFC targets the distinct deuterium lines as well as carbon lines were recorded and analyzed. It was estimated that the average plasma density changed from 10^{18} cm^{-3} to 5×10^{15} cm^{-3} during plasma expansion lasting about 20 µs. The analysis showed that under the described experimental conditions the emission of the carbon-lines started after about 2-4 µs after the discharge-current peculiarity and there was also the high-intensity continuum radiation. The most intense carbon CII lines were analyzed, as shown in Fig.3 (left).

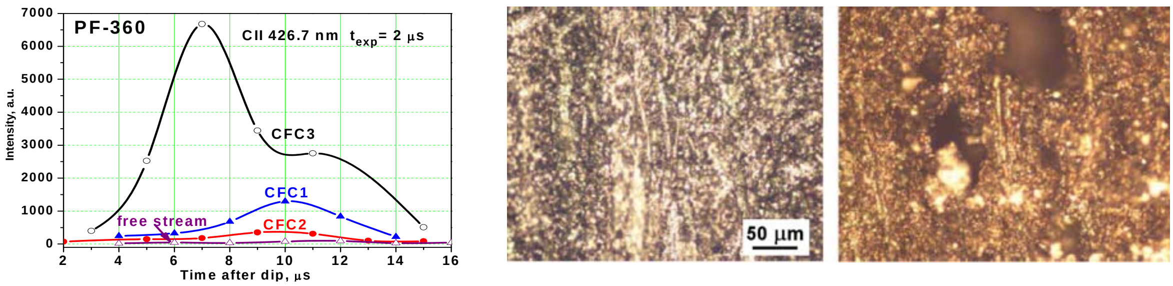

Fig. 3. Intensity of the C II-426.7 nm line for a free plasma stream and during its interaction with the investigated CFC targets (left) and pictures of the CFC-1 target surface before and after its irradiation (right).

It was found that the carbon evaporation and erosion depend strongly on the target crystallographic orientation. To investigate the CFC erosion the irradiated targets were also analyzed with an optical microscope and weighed with an electronic balance. Distinct erosion craters were observed, as shown in Fig.3 (right). It was estimated that one plasma shot causes a loss of 0.4-0.9 mg of the CFC target mass. Since pulsed plasma streams emitted from the PF-360 discharge contain many micro-beams of accelerated primary deuterons (of energy ranging from about 80 keV to several MeV) and high-energy (about 3 MeV) fusion-produced protons, it was impossible to identify which particles caused the observed erosion craters. Nevertheless, it has been shown that such pulsed plasma streams can be used to study materials of interest for future fusion machines.

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