Spectroscopic investigation of dense plasma streams and their interactions with CFC targets in PF-360 and RPI-IBIS facilities

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The paper describes spectroscopic measurements of the optical emission from dense plasma streams during their free propagation and interactions with carbon-fiber-composite (CFC) targets within the PF-360 and RPI-IBIS facilities operated at NCBJ in Swierk, Poland. A dependence of the emission of the main CFC-components (i.e., carbon ions) on the crystallographic orientation of carbon filaments in the target was investigated. An influence of plasma parameters on the emission of carbon ions was also analyzed.

1. INTRODUCTION

It is well known that vertical plates of the ITER divertor will be made of a CFC material, and during the initial stage they will work with deuterium (i.e., without tritium filling). Unfortunately, many important questions remain still unsolved, e.g. there is a lack of information about dynamics of the carbon erosion during various plasma-surface interactions. It should be noted that carbon materials are also used in many other systems, e.g., for studies of gas discharges physics and near-electrode processes, as well as for different applications. Therefore, we have undertaken experimental studies of plasma interactions with CFC targets.

The applied dense deuterium-plasma streams of a short duration (1 – 5 μs) were generated by an RPI-IBIS rod plasma injector and PF-360 plasma-focus facility at the NCBJ. Those streams were used for studies and determination of an initial stage of the evaporated impurities, and for investigation of their dynamics during whole plasma-surface interactions.

2. EXPERIMENTS WITHIN THE PF-360 FACILITY

2.1. Experimental arrangement and diagnostics

The PF-360 facility was equipped with Mather-type coaxial electrodes made of copper tubes [1-2]. The initial filling gas (deuterium) pressure was $P_0 = 6$ mbar D_2, the initial

charging voltage was $U_0 = 30$ kV, and the delivered energy amounted to $W_0 = 105$ kJ. The maximum discharge current amounted to about $I_{max} = 1.5$ MA, and the pulsed plasma streams were emitted mainly during a characteristic current peculiarity (dip) occurring about 5 μs after the discharge initiation. The emitted radiation was recorded behind a quartz window, through an optical collimator and a fiber cable. The spectroscopic measurements were carried out mostly side-on, at a distance of 30 cm from electrode outlets. The exposition time of a Mechelle®900 optical spectrometer was chosen to be $t_{exp} = 2$ μs. The same optical spectrometer was used for measurements in both investigated devices. It could record optical spectra in the wavelength range from about 300 nm to 1100 nm, with the exposition time varied from 100 ns up to 50 ms. A cooled CCD camera of the spectrometer was coupled with a PC equipped with a GRAMS/32 V6.0 spectroscopic software [3].

Three different side-slices of the investigated CFC cube were used as samples (targets) of different crystallographic orientation. The surfaces of the samples #1 and #2 were parallel to carbon filaments, and sample #3 contained a higher number of filament ends.

2.2. Experimental results

After irradiation of the investigated targets with the pulsed deuterium-plasma streams, two the most intense carbon lines (C II 426.7 nm and 588.9 nm) from the recorded optical spectra were subjects to a detailed analysis, as shown in Fig. 1. The C II line emission appeared at about 3 μs and it existed until 15 - 17 μs. It was observed that the carbon lines from the CFC#3 sample were more intense and they reached the maximum in about 7 μs after the discharge initiation.

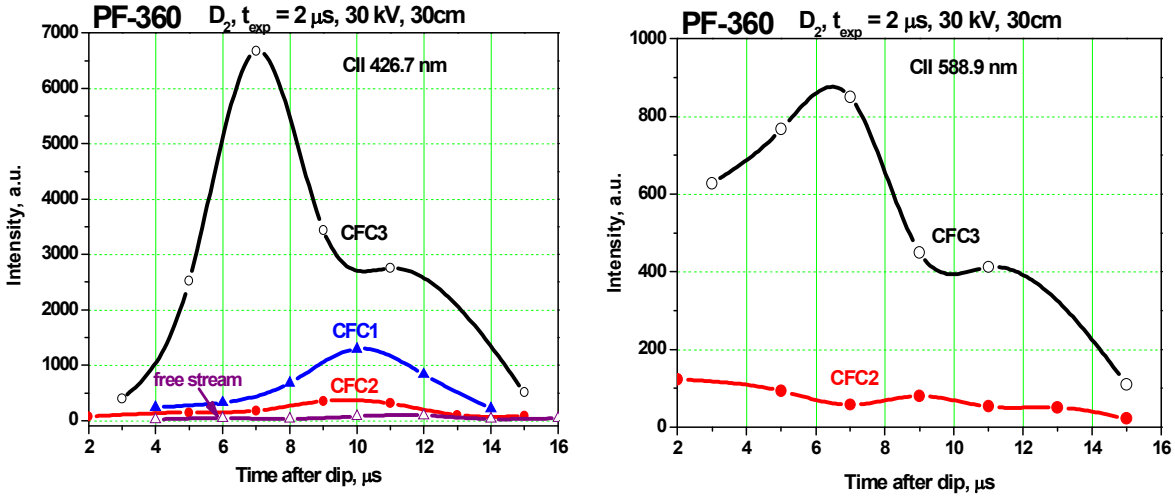

Fig.1. Temporal behavior of CII-spectral lines (426.7 nm and 588.9 nm) during interactions of deuterium plasma streams with the investigated CFC targets within the PF-360 experiment.

For experiments performed within both facilities plasma electron densities were estimated on the basis of the observed Stark broadening of the recorded deuterium spectral lines (from the Balmer series), and for the PF-360 experiment they amounted to 10^{18} cm^{-3}.

3. EXPERIMENTS WITHIN THE RPI-IBIS FACILITY

3.1. Experimental arrangement

The experiments with the same CFC targets were continued within the RPI-IBIS device. In that case plasma discharges were initiated between two coaxial electrodes, each consisting of 32 thin molybdenum rods. The working gas was also pure deuterium [4]. The initial charging voltage of the condenser bank was $U_0 = 30$ kV and energy stored in this bank was $W_0 = 33$ kJ. The discharge was initiated after injection of pure deuterium, and the peak current amounted to $I_{max} = 500$ kA. The plasma-ion pulse duration lasted 1-3 μs, but the emission of carbon lines was not so intense as in the previous experiment. The CFC targets were prepared as previously, but they were placed at a distance of 10 cm from the electrode ends.

3.2. Experimental results

Behavior of the most intense carbon CII 246.7 nm spectral line is presented in Fig. 2. The maximum emission of this carbon line was observed in the period lasting from 5 to 10 μs after the current peculiarity (dip). Therefore, for detailed measurements within the RPI-IBIS device the exposition time of the optical spectrometer was chosen to be 5 μs.

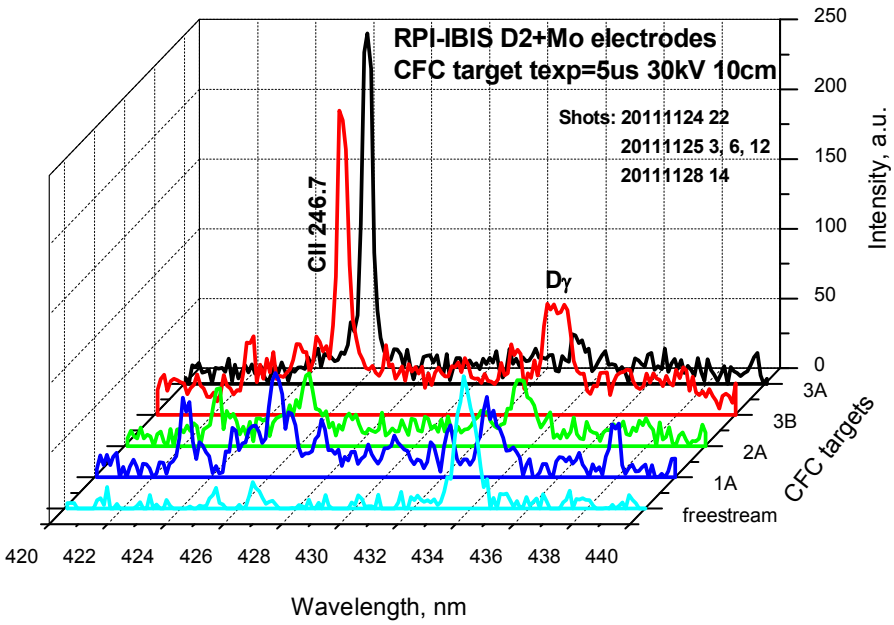

Fig.2. Part of the recorded optical spectrum with the distinct CII 426.7 nm and Dγ lines, as observed for the CFC targets of different crystallographic orientation.

The most intense emission of carbon spectral lines was observed also for the CFC#3A target (with a higher number of filament ends). To check it once again the experiment was repeated with the identical CFC#3B target. The emission from other targets (i.e., CFC#1A and CFC#2A) was considerably weaker.

An averaged plasma electron density achieved in these experiments was estimated to be equal to about 10^{15} cm^{-3}.

4. CONCLUSIONS

The dependence of the emission of carbon ions from the irradiated CFC targets on the crystallographic orientation of the carbon filaments was confirmed in the both described experiments, i.e., with the use of intense plasma streams from the PF-360 plasma-focus device and those from the RPI-IBIS facility. The most intense erosion was observed for the CFC targets #3, which had the highest number of filament ends upon the surface. This observation was confirmed by additional analysis of the irradiated samples (targets), which included a comparison of target mass losses (after the irradiation) and a microscope analysis of targets surfaces [5-6].

Hence, one can conclude that in order to reduce the erosion of the CFC material the samples (to be exposed to plasma streams) should be cut parallel to the filamentary layers.

Plasma electron density values have also been estimated, and an influence of plasma parameters on the emission of carbon ions was analyzed. In the PF-360 experiment the maximum plasma density was observed about 1 - 2 μs after the current dip and it amounted to (1 - 2) × 10^{18} cm^{-3}. The plasma density in the RPI-IBIS experiment was about 3 orders lower. Hence, one can explain why the intensity of the carbon emission in the PF-360 experiment was several orders of magnitude higher, due to the higher plasma concentration and energy flux density. It confirms that the erosion of the CFC material depends considerably on plasma parameters.

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