CURRENT STATUS OF THE MAGNETOPLASMA COMPRESSOR DEVICE IN BELGRADE – STUDY OF PLASMA FACING MATERIALS IMPORTANT FOR FUSION REACTORS

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DOI: 10.7906/indecs.13.1.16
Regular article

Received: 8 December 2014. Accepted: 15 January 2015.

ABSTRACT

The magnetoplasma compressor, a quasi stationary plasma accelerator, is a source of supersonic compression plasma flow. High plasma parameters of compression flow, large flow velocity and discharge duration enable their efficient usage for development of new plasma technologies, including material surface modification, creation of sub microstructures and nanostructures. In this paper spatial and temporal distribution of emissivity was studied using inverse Abel transform. This has been realized in LabVIEW environment. The plasma flow generated by quasi stationary plasma accelerators can be used for simulation of high energy plasma interaction with different materials of interest for fusion experiments. Surface phenomena are results of specific conditions during plasma flow interaction with target surface. As the next step in our research, spectral analysis of the plasma area around targets surface, after interaction between target and plasma, generated by magnetoplasma compressor, is planned. The first material which will be subjected to interaction with plasma will be a carbon fiber – material of big importance for divertor region in fusion devices.

KEY WORDS
magnetoplasma compressor, Abel inversion spectroscopy, materials of interest for fusion devices

CLASSIFICATION
JEL: Z19
PACS: 28.52.-s, 52.65.-y

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INTRODUCTION

The magnetoplasma compressor is a source of supersonic compression plasma flow (CPF) [1-4]. It represents a magnetoplasma analog of a Laval nozzle. This is a quasi stationery plasma accelerator with semitransparent electrode system which operates in an ion current transfer regime [3].

There are few advantages of the MPC as compared with the other types of accelerators: high stability of CPF generation, controllability of discharge composition (different gases and their mixtures), size (up to 6 cm in length and 1 cm in diameter) and plasma parameters (electron density up to $4 \cdot 10^{23} \text{m}^{-3}$ and temperature up to 20 000 K), as well as the discharge time duration sufficient for practical applications (up to 80 μs) [4]. It was found that CPF parameters predominantly depend on discharge current. The plasma parameters ‘follow’ the discharge current time evolution. This dependence is a measure of plasma flow stationarity [4]. High plasma parameters of compression flows (electron density and temperature close to $10^{23} \text{m}^{-3}$ and 20 000 K, respectively) together with large flow velocity (close to 100 km s$^{-1}$ in hydrogen and 40 km s$^{-1}$ in nitrogen) and discharge duration (stable CPF close to 50 μs) enable their efficient usage for development of new plasma technologies, including material surface modification [5, 6], creation of sub microstructures and nanostructures, etc. MPC is of great importance for the study of fundamental processes in plasma flows and their behavior in different configurations of electric and magnetic fields. Such systems and their plasma flows are also successfully used in different plasma technologies.

Plasma interaction with materials is important for fusion investigations. In fusion devices, the first wall and divertor plasma-facing components (PFC) must provide adequate protection of in-vessel structures, sufficient heat exhaust capability and be compatible with the requirements of plasma purity [6]. ITER will combine long pulse, high power operation with severe restrictions on permitted core impurity concentrations and, in addition, it will produce transient energy loads on a scale unattainable in today’s devices. Intense thermal loads in ITER and other fusion devices which occur during ELMs (edge localized modes), plasma disruptions and VDEs (vertical displacement events), will result in macroscopic erosion associated with the formation of cracks, melting, droplets, evaporation or sublimation [7]. The main goals of plasma surface interaction investigation are simulation the expected ELM and disruption loads in ITER and other fusion devices. The plasma flow generated by quasi stationary plasma accelerators can be used for simulation of high energy plasma interaction with different materials of interest for fusion experiments.

Generally, our research program is devoted to the construction of two stage quasi-stationary high current plasma accelerator (QHPA), a combination of four MPC – compact geometry units [3]. QHPA will be used to produce fully ionized plasma at the entrance of the acceleration channel of QHPA. Such systems are the new generation quasi-stationary plasma accelerators. These accelerators are sources of quasi stationary compression plasma flows in which the duration of the compression stable state is much longer (∼100-1000 μs) than the flight time of the plasma in the acceleration channel of the one MPC-CG accelerator (1-5 μs).

This article contains an overview of the research activity on the Belgrade MPC device, some of our new experimental data as well as plans for future steps.

EXPERIMENTAL SETUP

The electrode system of the MPC [3] (shown in Figure 1) consists of a conically shaped copper central electrode (cathode) with radius 3 and 0,6 cm, length of 5 cm and with a divertor on
The current status of the Magnetoplasma compressor device in Belgrade – study of plasma ... the top. A cylindrical outer electrode (anode) is made of eight copper rods (0.8 cm in diameter and 14 cm in length), symmetrically positioned along the circle of 5 cm in diameter. A conically shaped cathode of the MPC defines a profile of the acceleration channel. The discharge device of the MPC-CG is situated in a 30×30×150 cm⁻³ vacuum chamber.

It has been found that the current cutoff, which limits the increase in the parameters in the case of classical plasma accelerators operating in the electron current transfer, can be avoided by switching to the ion current transfer [1]. Ion-drift acceleration of the magnetized plasma is realized using specially shaped accelerating channel [1]. The reduction of erosion of the electrodes is important task and because of that cathode of the MPC should not only be specially shaped, but also made of rods to be shielded by the self-magnetic field and therefore protected from the erosion.

Experimental setup consist of vacuum chamber within the MPC is positioned, optical system, Minutmen spectrometer, ICCD camera and PC, as well as of systems for voltage and current measurement. The most important part of experimental setup is schematically shown in Figure 1.

In the inter-electrode region the plasma is accelerated due to the Ampere force $F_A$. Plasma flow is compressed due to the interaction between the longitudinal component of current $I_z$ swept away from the discharge device, and the intrinsic azimuthal magnetic field $B_\phi$ as well as due to the dynamic pressure of the plasma flow converging to the system axis $F_{Ar}$. This is shown in Figure 2a.

There are four phases of the discharge development. In the first phase discharge breakdown takes place and plasma is accelerated along the cathode conical part. Second phase consist of radial plasma compression and relaxation of the accompanied plasma flow oscillations. Third phase is quasi-stationary state of compression plasma flow and in fourth part the compression plasma flow is in decay which is followed by after-glow effects. These four phases are shown in Figure 2b.

Figure 3 shows a part of time evaluation of discharge. These images have been made by using ICCD camera as detector and SpectraSuits software. SpectraSuite is a spectroscopy software program which can be used to capture and analyse spectral data from light sources with the use of a spectrometer. The width of spectral line is largest at the beginning of discharge (~ 10-20 μs) and after that the line width is narrower.

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**Figure 1.** Experimental setup: OPT – optical system, SPE – Minutemen spectrometer, a) magnetoplasma compressor of compact geometry, b) image of plasma on a computer.
Figure 2. a) compression of plasma flow, b) image of plasma flow photographed with camera using the violet filter.

\[ \text{Figure 3. } H_B^\parallel (486.1 \text{ nm}) \text{ recorded by ICCD camera, shown in SpectraSuit program.} \]

**RECENT EXPERIMENTAL RESULTS**

Several papers were devoted to the study of different MPC characteristics. The electric and thermodynamic parameters of the discharge and the plasma flow created in different gases and their mixtures (hydrogen, nitrogen, argon and Ar with 3 % of H\textsubscript{2}) have been measured to optimize the working conditions within the 100-3000 Pa pressure range for input energy up to 6,4 kJ [3, 4, 7].
Recent research activities are related with possibility of MPC usage for investigation of high energy plasma interaction with different materials of interest for fusion experiments.

**RADIAL DISTRIBUTION OF EMISIVITY**

During experimental determination of radial distribution of emissivity, working gas was hydrogen (100 %) at pressure $p = 10$ mbar and temperature $T \approx 40000$ K.

According to well-known correlation between local emissivity and measured intensity,

$$
\varepsilon(r) = \frac{1}{\pi} \int_0^R \frac{dI(y)}{dy} \frac{dy}{\sqrt{y^2 - r^2}}
$$

radiation profile can be found at any position along the radius of plasma if inverse Abel transformation is done. This was performed using a LabVIEW program for determining confidence intervals of Abel-inverted radial emission profiles [8]. This program works with random noise generation. One additional program has been written for data organizing and processing.

For finally analysing of data it is important to know from which point of y-axis the radiation comes. Because of that, it was necessary to calibrate the system. That has been done by using a small source of radiation: PEN-light which is Hg source, heights $h = 3,8$ cm and $\lambda = 435$ nm as line of interests (Figure 4).

Value of one pixel in nm can be found by:

$$
n = \frac{3.8 \text{ cm (y axis)}}{190 \text{ pixel}} = 0.02 \frac{\text{cm (y axis)}}{\text{pixel}}
$$

Figure 5 shows integral profile and radiation profile at one selected position along the radius of plasma.

Time evolution of emissivity at one chosen position is shown in Figure 6.

These radiation profiles have been used for determination of spatial and temporal distribution of electron concentration. One of the obtained profiles, electron concentration dependence on radius at $t = 30$ µs, is shown in Figure 7.

![Figure 4](image-url)

**Figure 4.** PEN – light, Hg I, 435 nm, ICCD camera, a. integral profile - picture from program SpectraSuits, b. Integral profile – after data processing in Origin.
Figure 5. $H_\beta$ ICCD, $t = 50\ \mu s$, a) integral profile, b) radiation profile at one selected position along the radius of plasma $r = 1.43\ cm$.

Figure 6. Radiation profiles at one position along the radius of plasma at different times.
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the ITER experiment. The performance of fusion devices and of a future fusion power plant critically depends on the plasma facing materials and components. Resistances to local heat and particle loads, thermo-mechanical properties, as well as the response to neutron damage of the selected materials are critical parameters which need to be understood and tailored from atomicistic to component levels. Plasma flow generated by MPC is used for investigation of high energy plasma interaction with different materials of interest for fusion experiments and every result is useful for a more complete picture of the plasma facing materials problem in fusion reactors.

REFERENCES

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