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INVESTIGATIONS OF COMPRESSION PLASMA FLOWS IN QUASISTATIONARY PLASMA ACCELERATORS BY INTERFERENCE-SHADOWGRAFY METHODS

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Results of shadowgraphic and interferometric studies of physical processes in both a magnetoplasma compressor (MPC) and a two-stage quasistationary high-current plasma accelerator (QHPA) of P-50M type are presented. Use of these methods has enabled definition of basic gas- and thermodynamic parameters of plasma flows in such accelerators.

INTRODUCTION

Among the most informative and yet extremely complicated techniques for diagnostics of plasma accelerators are interferometric and shadowgraphic methods based on visualization of optical inhomogeneities in objects under study. Due to unique features inherent in such methods, these latter provide a possibility to obtain an extensive and reliable information without adverse effects to parameters of plasma being investigated.

However, practical implementation of shadow and interference methods is involved with certain difficulties resulting primarily from complexity of conventional devices. The additional problems arise when it comes to studying objects in vacuum chambers. These drawbacks may be minimized by the use of a two-mirror autocollimation interferometer with visualization of field of view [1], developed specially for diagnostics of physical processes in plasma accelerators. Due to the implementation of autocollimation concept coupled with monoaxial arrangement of optical elements the device with the 200-mm field of view has desk-top dimensions and can easily be installed practically at any experimental setup.

This paper presents results of shadowgraphic and interferometric studies of plasma flows generated by both a magnetoplasma compressor (MPC) [2] and a two-stage quasistationary high-current plasma accelerator (QHPA) of P-50M type [3].

EXPERIMENTAL

The operation of electrodynamic valves delivering a working gas into MPC and QHPA, was monitored using the developed shadow-interferometric device (Fig. 1). The radiation of the He-Ne laser 4 reflected by a wedge-

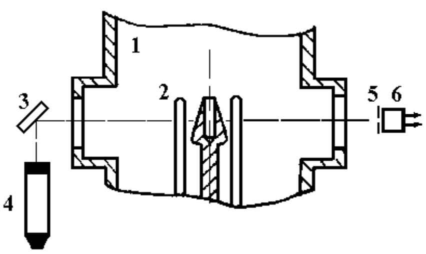

Fig. 1. Diagram of shadow-interferometric device 1— vacuum chamber, 2 — accelerator, 3 — wedge-shaped plate, 4 — laser, 5— diaphragm, 6 — PM

shaped quartz plate 3 with 50 % and 99 % reflecting coatings on front and rear surfaces accordingly, is split into two coherent beams. Spatial frequency of interference fringes formed on a diaphragm 5 with narrow slot mounted in front of a photo multiplier 6 (PM), depends on a wedge angle and a distance between the wedged plate and the diaphragm. Development of optical nonuniformity in the path of beams causes the fringe pattern to shift relative to the slot, resulting in the PM signal modulation recorded by a storage oscillograph. The typical oscillogram of the gas pulse shape obtained by the above method, is shown in Fig. 2.

The device sensitivity at the specified fringe width is determined by both a distance from the nonuniformity

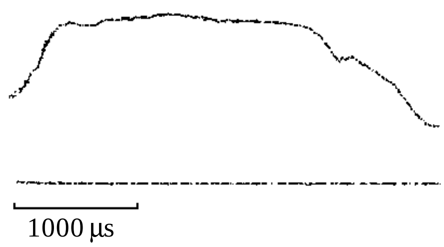

Fig 2.

to the diaphragm and the slot width. Among advantages of the technique as compared to available shadow methods are low sensitivity to vibrations and ability to conduct measurements without resorting to complicated procedure of preliminary calibration.

The electron concentration of plasma formations in channels of both MPC and QHPA was determined using the laser interferometer. To that end the diagram in Fig. 1 was changed as follows: PM was placed behind a rear mirror of the laser, a retroreflecting mirror was mounted in place of PM, and a wedge-shaped plate was faced by highly reflecting surface towards a laser beam. A typical interferogram obtained in such a way upon probing the P-50M type QHPA accelerating channel, and corresponding changes in the electron concentration are shown in Fig. 3.

The measurements of electron concentrations in both MPC and QHPA compression plasma flows were conducted with the spatio-temporal resolution using various

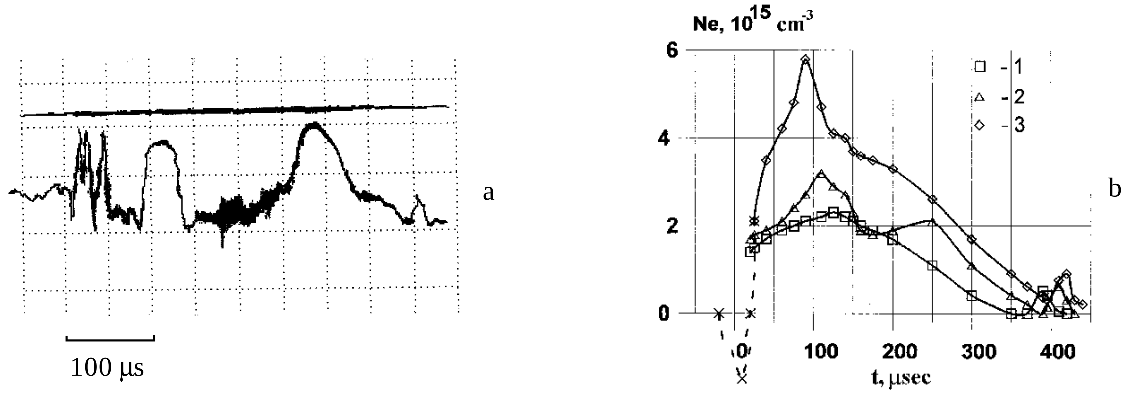

Fig. 3. a — interferogram;
b — electron concentration in QHPA accelerating channel

versions of the two-mirror autocollimation interferometer with fields of view in range from 50 up to 200 mm, depending on experimental conditions. Interference patterns were recorded with a high-speed photorecorder VFU in frame mode enabling in a single experiment a series of interferograms, and thus temporal variations in a phase refractive index of a plasma formation throughout the field of view, to be obtained. The use of a ruby laser operating in a free-running mode with mode selection as a probing light source, ensures the temporal resolution not worse than100 ns at a photorecorder frame rate about 250000 fps.

Shown in Fig. 4 is a diagram of the 200 mm interferometer mounted on the P50-M QHPA experimental

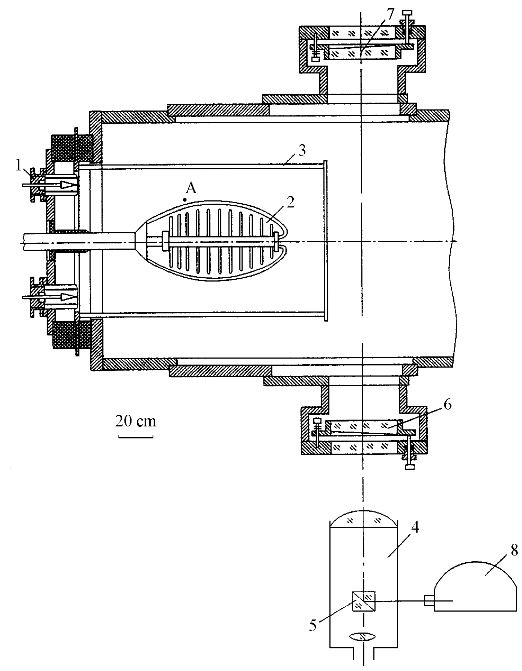

Fig. 4. Diagram of the interferometer mounted on the QHPA: 1 — input ionization chamber, 2 — cathode transformer, 3 — anode transformer, 4 — telescope, 5 — beam splitter, 6 and 7 — interferometer mirrors, and 8 — high speed photographic camera.

setup. The collimating optics transforms a laser radiation into a parallel beam 200 mm in diameter. The front and rear interferometric semitransparent mirrors retroreflect reference and object beams respectively. Upon passing through the collimating optics, both beams are directed by a deflecting mirror at the photorecorder VFU. To process the obtained interferograms, an automated system with software support providing a way of obtaining the electron density radial distributions via Tikhonov's regularization, was developed.

Interferometric studies of both MPC and P50-M QHPA were carried out at a single wavelength of a probing ruby laser, since the plasma refraction in a range of parameters ($Ò_e$ ~ 1÷15 eV, $N_e \sim 10^{15} \div 10^{17}$ ñì$^{-3}$) characteristic of MPC and QHPA, according to the preliminary analysis is determined mainly by free electrons. Thus, concentration of electrons in plasma is determined by the expression:

$$N_e = -3,21 \cdot 10^{17} \, \frac{k}{2} \cdot \frac{1}{l},$$

where N_e — concentration of electrons in plasma, k — shift of interference fringes relative to their initial positions in absence of plasma, l — thickness of plasma formation in direction of probing. The relative error in measurements of electron density determined by an uncertainty in definition of both fringe shift and linear size of plasma, does not exceed 10 %. Typical interferogram of a QHPA compression flow and corresponding spatial

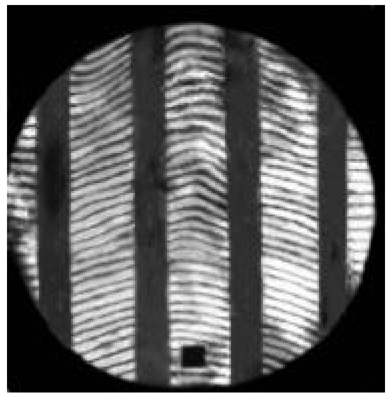

Fig. 5

and temporal distributions of electron concentration in plasma are shown in Fig. 5 and Fig. 6, respectively.

Plasma temperature was determined from results of experiments on a supersonic compression flow incidence on a thin wedge with an acute leading edge. Lines of perturbations emerging on the leading edge were visualized by a shadow instrument with double passage of a probing laser beam through an area under study. In

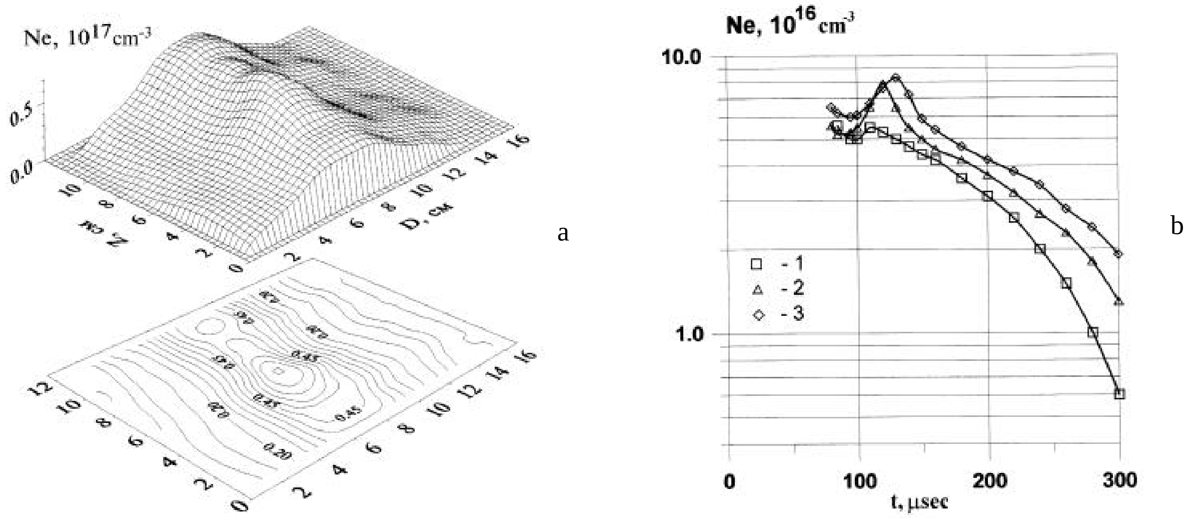

Fig. 6. a — temporal evolution of the electron density in the plasma flow of the QHPA;
b — spatial electron density distribution in the plasma flow in the QHPA

this case interferometer diagram shown on the Fig. 4 was changed as follows. The front mirror 6 of interfer-

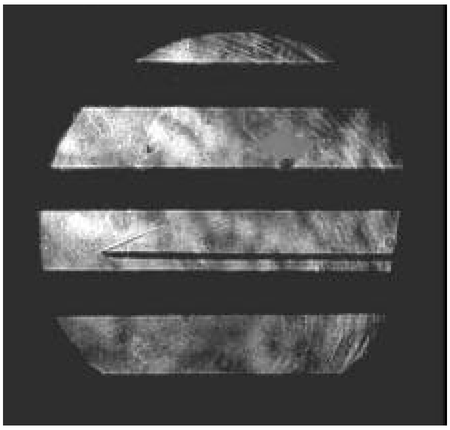

Fig. 7

ometer was removed and the rear mirror 7 was replaced by a plate with 99 % reflecting coating. Fig. 7 presents a typical shadow picture of a flowfield originating in the course of the QHPA plasma flow incidence on the wedge. Knowing a velocity of a compression plasma flow and inclination of a perturbation line with respect to a wedge (Mach angle), it is possible to find the plasma temperature:

$$T_{pl} \approx \frac{(V_{pl} \cdot \sin a)^2 \cdot M_i}{gk(1+z)},$$

where V_{pl} —velocity of a compression plasma flow, a — Mach angle, M_i — a mass of an ion, z — a charge of an ion, k — a Boltzmann constant, g — Poisson isentropic exponent. Under experimental conditions typical in P-50M QHPA, the plasma temperature determined by the above method, makes 10-15 eV.

The measured values of temperature and concentration of electrons in the P-50M QHPA plasma have enabled the gas-kinetic pressure of compression plasma flow to be defined: under conditions of experiments it attained ~ $(2 \div 3) \cdot 10^5$ Pa.

Thus, due to the use of shadow-interferometric methods in studies of physical processes in quasistationary plasma accelerators the spatio-temporal distributions of main thermodynamic parameters of plasma in such systems were obtained.

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