Interaction of a high-energy plasma flow with a gas jet in the laboratory

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1. Introduction

Experimental results concerning the interaction dynamics of the high-energy plasma flow with gas jet are presented and discussed. Earlier in [1-4], the results of experiments on the collision of high-energy (up to 100 kJ) plasma flows have been reported. The experiments are aimed at studying the possibilities of creating powerful sources of soft X-ray radiation. Similar experiments were carried out in other laboratories [5]. The purpose of the research is to develop a source of powerful soft X-ray radiation due to the thermalization of plasma flows generated by pulsed plasma accelerators. On this path, the following tasks are solving:

- studying the dynamics of the soft X-ray source formation;
- measuring spectral characteristics of soft x-ray radiation and determining the created plasma electron temperature.

2. Experimental facility MKT

The experiments were carried out at the MKT facility of TRINITI (Fig. 1).

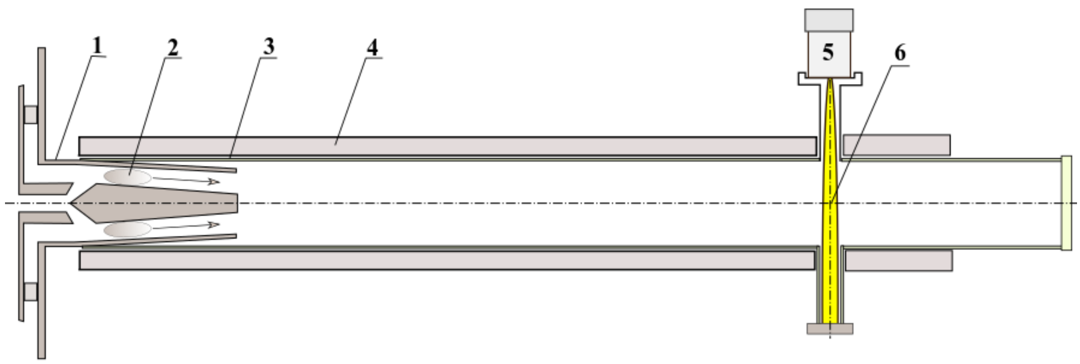

Figure 1. MKT facility scheme: 1 - pulsed plasma accelerator; 2 - accelerated plasma; 3 - vacuum chamber; 4 - longitudinal magnetic field solenoids; 5 - supersonic gas jet former; 6 - supersonic flat gas jet.

Hydrogen plasma flow with velocity (4÷6)×10^{7} cm/s, ion density (2÷4)×10^{15} cm^{-3}, flow duration of 10÷15 μs, and energy content of ≤ 30 kJ was produced by coaxial pulse accelerator. A longitudinal magnetic field with an induction of up to 2 T was created in the interaction chamber.

The hydrogen plasma flow interacted with supersonic nitrogen or neon gas jet, which was formed using a pulse gas valve and flat Laval nozzle. The maximum density in the gas jet reached 10^{17} cm^{-3} with a jet thickness of ≈ 5 cm and a width of ≈ 15 cm.

2D images of the plasma-gas interaction region were obtained by a framing MCP camera with four pinholes. Radiation spectra in the range of 1÷70 nm with the spatial and temporal resolution were registered by a TGS spectrometer with a transmission grating of 500 nm period and the same framing MCP camera.

2. Experimental results

Figure 2 illustrates the collision dynamics of a hydrogen plasma flow with a nitrogen jet. There are the frames through the 4-pinholes camera. The width of the emitting zone is ≈ 3÷5 cm. The displacement velocity in the direction of the plasma flow is ≈ 3×10^6 cm/s.

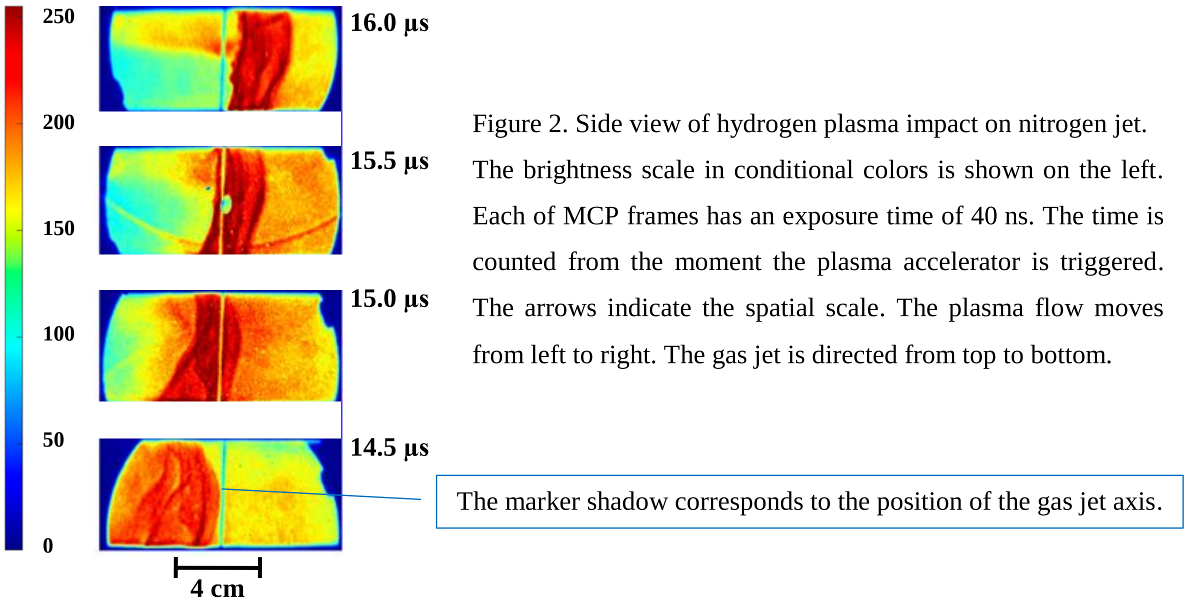

Figure 2. Side view of hydrogen plasma impact on nitrogen jet. The brightness scale in conditional colors is shown on the left. Each of MCP frames has an exposure time of 40 ns. The time is counted from the moment the plasma accelerator is triggered. The arrows indicate the spatial scale. The plasma flow moves from left to right. The gas jet is directed from top to bottom.

For the planned experiments on the collision of counter-propagating plasma flows on the central gas jet, this means that the synchronicity of the beginning of the collision should be within ≈ 1 μs.

Obtained by TGS spectra were analyzed to determine the plasma electron temperature T_e using the collisional-radiative code PrismSPECT [6] for the wide range of ion densities (10^{15} cm^{-3} to 10^{17} cm^{-3}) and temperatures from 10 eV to 100 eV. The diagnostic approach based on the fact that both nitrogen and neon spectra contain spectral lines, which intensity ratios depend weakly on the ion/electron density, but significant changes with T_e within a quite wide range of values. For the nitrogen plasma, such condition is fulfilled for the ratio determined as the summarized intensity of three lines **1**, **2**, **3** (corresponding transitions are shown and labeled in Figure 3a) emitted by Li-like N V ions divided by the intensity of He-like N VI ion resonance line. Concerning the neon plasma, this condition is fulfilled for the ratio of the line "**B**" (see Figure 3b) formed by unresolved lines of B-like Ne corresponding to transition $1s^2 2s2p^2 \rightarrow 1s^2 2s^2 2p$ and "**C**" associated with transitions between different states of configurations $1s^2 2s2p \rightarrow 1s^2 2s^2$.

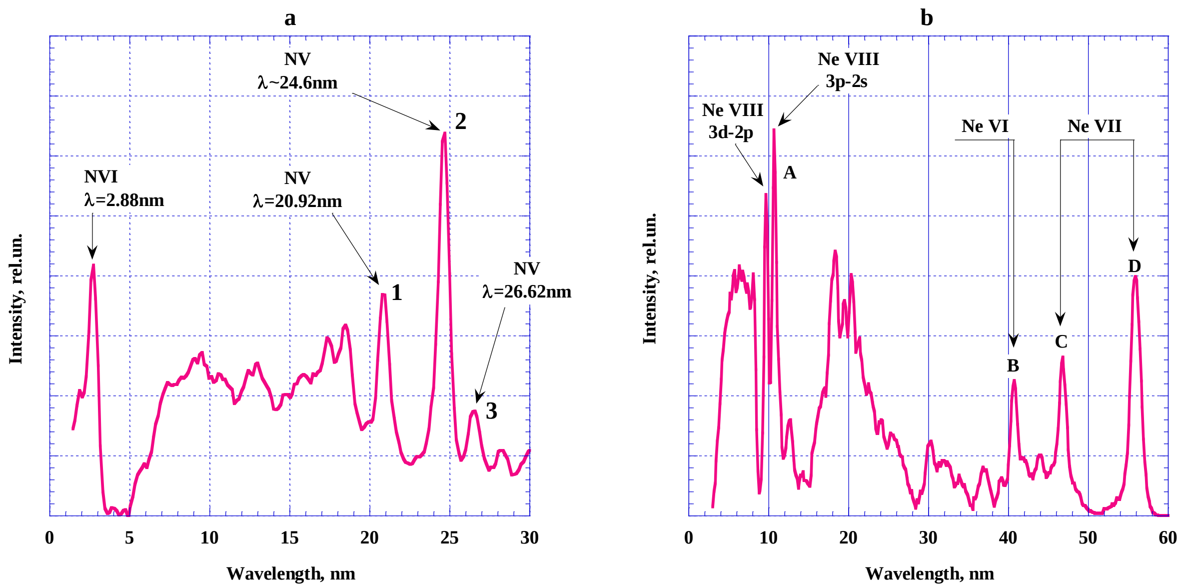

Figure 3. Plasma soft X-ray radiation spectra registered for the case of using nitrogen **(a)** and neon (**b)** jet as gaseous targets.

Comparison of the calculation results with the experimentally observed ratios values showed that for the both gaseous target types the plasma with $T_e = 40 \pm 10$ eV was formed in the flow-jet interaction region. Average over all the experimental shots values obtained for the nitrogen are slightly lower than for the neon jets. However, it should be noted that theoretical spectra of neon plasma simulated for the indicated temperature range does not reproduce the presence of two intense lines near 10 nm (resonance transitions in Li-like Ne ions labeled as "A" on Figure 2b) for any physically reasonable values of ion density. Such intense lines can be emitted by a plasma consisting of Ne ions only at a temperature of 70÷100 eV. The most probable reason of the observed discrepancy is existing in plasma two separated in space and/or time regions with different parameters contributing in the spatially and temporally integrated spectra registered during the experiments.

3. Summary

The main results of the work are as follows:

- When a hydrogen plasma flow interacts with a supersonic gas jet of nitrogen or neon (the maximum density in the gas jet reached 10^{17} cm^{-3}), a plasma layer ≈ 3÷4 cm thick for ≈ 2÷3 μs is formed, which emits soft X-ray radiation. The displacement velocity in the direction of the plasma flow is ≈ 3×10^{6} cm/s. Such a high speed of the radiation source movement under one-sided action on a gas jet puts forward certain requirements for the synchronization of counter-propagating plasma flows in the current experiments on two-sided action on a gas jet.
- Line emission spectra of multiply charged ions recorded during the interaction of hydrogen plasma flows with jets of nitrogen or neon made it possible to estimate the electron temperature of the plasma formed in these experiments, which in both cases turned out to be at the level of 40 ± 10 eV. However, it should be noted that observed intense resonance Ne VIII lines can be emitted by a plasma only at a temperature of 70÷100 eV.

This work was supported by the Russian Foundation for Basic Research (Projects No. 18-29-21013 and No. 20-21-00153).

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