INVESTIGATIONS OF PULSED PLASMA STREAMS GENERATED BY "PROSVET" DEVICE OPERATED WITH DIFFERENT GASES

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The paper presents the investigations of plasma streams generated by pulsed plasma gun "Prosvet" operated with different gases: krypton (m = 84), nitrogen (m = 14) and helium (m = 4). Contour parameters of working gas spectral lines (full intensities and half-widths) are used for determination of spatial distributions of the electron density and temperature. Temporal distributions of the spectral lines intensities (both neutrals and ions of working gas), impurity spectral lines and continuum intensities are analyzed. Plasma stream velocity was estimated by time-of-flight method between two monochromators (MUM) connected with photo-multiplier. Longitudinal distributions of the plasma pressure for different time moments and varied distances from the accelerator output have been used for investigation of the plasma stream dynamics and study the plasma compression in the focus region for different operational regimes of plasma accelerator. Experiments show that operation regime of the accelerator and plasma stream parameters strongly depend on the gas atomic mass.

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1. INTRODUCTION

Plasma accelerators of different types are used at present as powerful sources of dense plasma streams for basic studies, fusion-oriented experiments and for technological applications [1,2]. Pulsed plasma processing of the constructional materials and alloys results in improved physical and mechanical properties of surface layers, and, in particular, increases the microhardness and wear resistance. Reliable information about plasma stream parameters is necessary for achievement of optimal conditions of materials processing with plasma streams. Dense plasma of heavy noble gases is also considered as prospective source of intense radiation in different spectral ranges.

Optical spectroscopy is one of the most precise methods of the plasma characteristics measurements. It allows estimation of the electron density and temperature, plasma stream velocity, emission duration, temporal distributions of neutrals, ions and continuum intensities during the plasma pulse. In this paper spectroscopy studies were applied in combination with the measurements of plasma pressure distributions and energy characteristics of the plasma streams for comparative analysis of operation regimes of pulsed plasma gun with gases of different atomic mass.

2. EXPERIMENTAL SETUP

The experiments were carried out with "Prosvet" facility [1], which consists of the coaxial plasma gun (anode Ø=14 cm, cathode Ø = 4 cm) and vacuum chamber (length – 120 cm and Ø = 100cm). Scheme of experimental device and the diagnostics used in described experiments are presented in *fig.1*. Power supply of plasma gun comes from the capacitor battery with maximal voltage up to 25 kV. Discharge current is ~500 kA, typical discharge duration is 3…5 μs. Accelerator generates plasma streams with following parameters: ions energy – from 0.4 to 2.5 keV, average electron density – 10^{16} cm^{-3}, energy density – 25…30 J/cm^2. Initial experimental conditions for operation with different gases (krypton, nitrogen, helium) are indicated in *Table 1.*

Table 1

	He (m=4)	N (m=14)	Kr (m=84)
Filled gas quantity, cm^3/particles per pulse	3.2/ 8.6×10^{19}	2.9/ 7.8×10^{19}	2.7/ 7.3×10^{19}
Pressure under the valve, atm	22…23	22…23	22…23
Time delay τ, μs	850	1100	1400

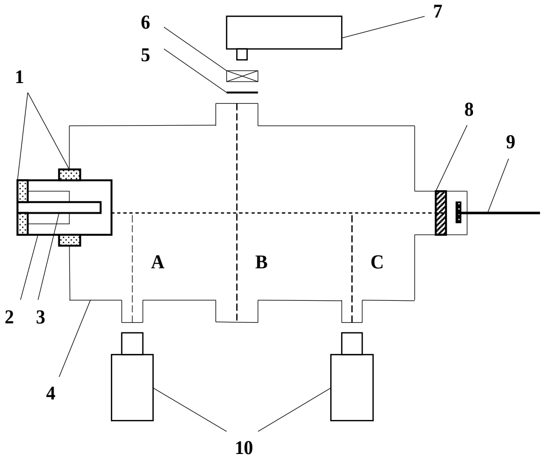

Fig.1. Scheme of experiment: 1 – insulator, 2 – anode, 3 – cathode, 4 – vacuum chamber, 5 – lens, 6 – rotary prism, 7 – spectrograph DFS-452, 8 – vacuum valve, 9 – target/piezodetector, 10 – monochromators MUM+PEM. Lines of the measurements: A – 15 cm, B – 35 cm, C – 75 cm from accelerator output

3. EXPERIMENTAL RESULTS

Grating spectrograph DFS-452 was used for plasma emission registration in section B (35 cm from electrodes outlet) and near the target surface (target material – copper, Ø – 5 cm). Plasma stream velocity was estimated by time-of-flight method between two MUMs connected with PEM and located on the distance 60 cm from each other. Velocity distributions of krypton plasma stream versus the discharge voltage are presented in *fig.2.* These data have been compared with the velocity obtained using piezodetectors (peaks and fronts of signals for different spatial regions of 10…75 cm from accelerator output). The velocity values estimated by two independent methods are in good agreement. Plasma stream velocity increased from 4 to 8×10^6 cm/s with the discharge voltage increase up to 20 kV. Helium plasma stream velocity is determined similarly and its value is higher in one order of magnitude – $(1.5…2)\times10^7$ cm/s for U = 20 kV. This difference in the velocity magnitude is explained by the significant atomic masses difference He (m = 4) and Kr (m = 84).

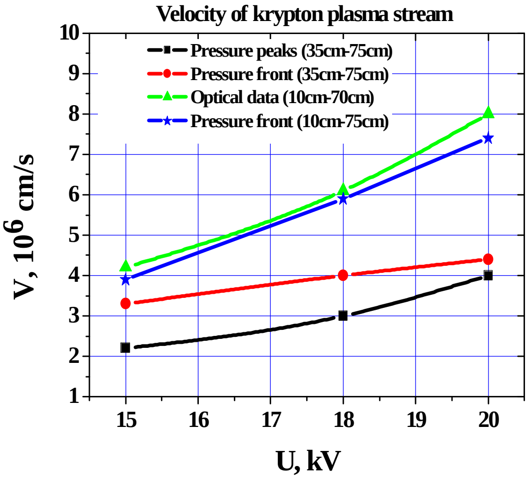

Fig.2. Krypton plasma stream velocity versus the discharge voltage

Temporal evaluations of the separate spectral lines of a neutrals, ions and continuum intensity have been performed using monochromator (MDR-23) device. Registration conditions for all gases were the same – in section A (15 cm from the electrode outlets) at U=18 kV. Such information allows to reconstruct the whole temporal evolution of neutrals, different species of ions, impurities and continuum which quantitatively characterized the plasma density behavior ($I \sim N_e^2$).

Intensive luminescence of the singly ionized helium atoms is observed on 10 μs after discharge ignition and continues during 5 μs (*fig.3*). Helium neutrals luminescence has minimum at the same time and then during 10 μs its intensity increasing. So the most compressed and dense helium plasma formation is obtained on 10 μs after discharge beginning with total duration ~ 10 μs. After that plasma is extended in the vacuum camera space and the second peak of continuum intensity (on 40…45 μs) corresponds to the impurity appearance (CII).

KrII and continuum luminescence for krypton plasma are practically corresponded in time (*fig.4*). Maximal intensity is observed on 8…9 μs after discharge beginning, but its total duration is less than HeII and continuum intensity for helium plasma, and equal to 7…8 μs. However in this case impurities are appeared considerably earlier – CuI-12 μs and CII-19 μs. It can be explained that working gas mass Kr (84) and impurity elements C (12), especially Cu (64), are more closed to each other that for He plasma.

Electron density measurements were carried out using Stark broadening of working gas spectral lines KrII (4739, 4355, 4292, 4355). Stark widths for these lines are available in [3]. Usually the linear Stark effect is obtained for neutral atoms and quadratic one – for different species of ions. Helium Stark theory is an exception as the neutral He atoms are exposed to the quadratic effect and ions – to the linear one [4]. Electron density and temperature calculations for helium plasma interacted with copper target are performed in detail in [5].

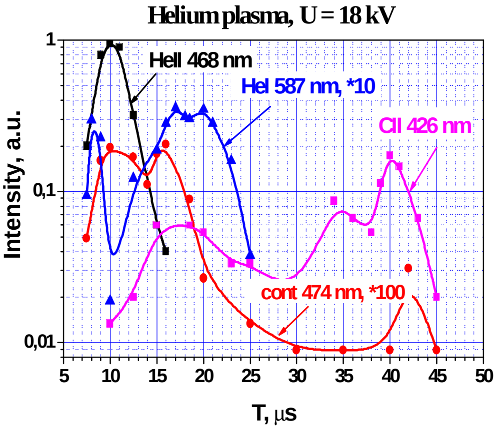

Fig.3. Temporal evolutions of HeI, HeII, CII spectral lines and continuum intensity

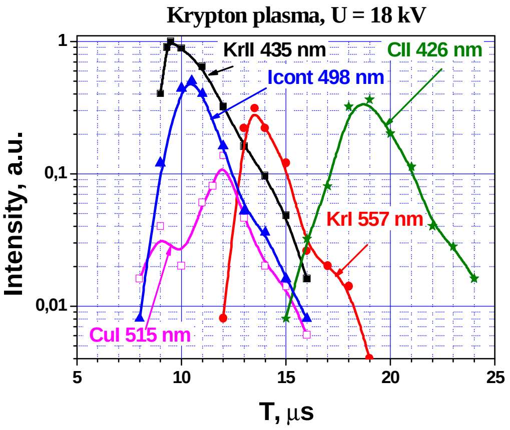

Fig.4. Temporal distributions of KrI, KrII, CII, CuI spectral lines and continuum intensity

Measurements of the plasma pressure spatial distributions have been used for analysis of the plasma stream dynamics and study the plasma compression in the focus region for different operational regimes and working gases *(fig.5).* Plasma parameters measured for different working gases are summarized in *Table 2.*

Table 2

Plasma parameters	He (m=4)	N (m=14)	Kr (m=84)
V, cm/s	2×10^7	1×10^7	0.7×10^7
τ, μs	6-8	5	3.5
N_e, cm^{-3}	7×10^{16}	0.8×10^{16}	0.07×10^{16}
T_e, eV	5…5.3		3.5…4
P, atm 10 cm/35 cm	29/13	27/11	7/6.5
E_{ion}, keV	0.48	0.75	1.5…2.5
J, J/cm^2 10 cm/35 cm	42/30	40/24	16/10

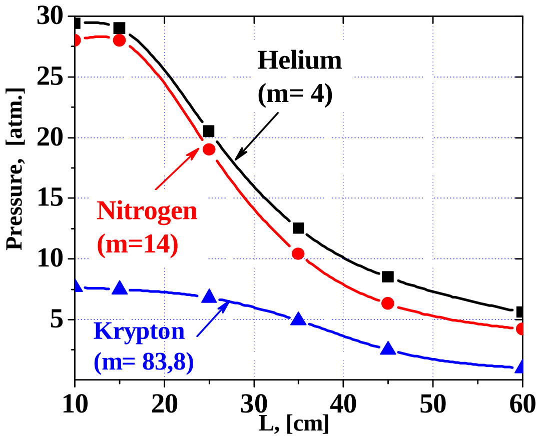

Fig.5. Spatial distributions of the plasma pressure

4. CONCLUSIONS

Basic plasma characteristics have been investigated for pulsed plasma gun operation with different working gases (He, N, Kr). Electron density and plasma stream velocity were estimated by two independent methods (optical spectroscopy and piezodetectors). These data are in a good agreement.

Plasma pressure and energy density are decreased with atomic mass increasing. At the same time the average energy of ions has higher value.

Spectral lines of working gas ions and impurities were analyzed for all gases. At first, pure plasma of working gas ions is formed and the impurities are coming later on.

Spatial distributions of the pressure and energy density in plasma stream were measured. Obtained results show the possibility of effective variation of plasma stream parameters which is necessary for technological applications of dense plasma streams.

ACKNOWLEDGEMENTS

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ИССЛЕДОВАНИЕ ИМПУЛЬСНЫХ ПЛАЗМЕННЫХ ПОТОКОВ, ГЕНЕРИРУЕМЫХ ИПУ «ПРОСВЕТ» ПРИ РАБОТЕ НА РАЗЛИЧНЫХ ГАЗАХ

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Исследованы параметры плазменных потоков, генерируемых импульсным ускорителем плазмы «Просвет» при работе с различными газами: криптон (m = 84), азот (m = 14) и гелий (m = 4). Контуры спектральных линий рабочего газа (полная интенсивность и полуширина) использовались для определения пространственного распределения электронной плотности и температуры. Проведен анализ временных распределений интенсивности спектральных линий (нейтралов и ионов рабочего газа), спектральных линий примесей и интенсивности континуума. Скорость плазменного потока оценивалась время-пролетным методом между двумя монохроматорами (МУМ), соединенными с фотоумножителем. Пространственно-временные распределения давления плазмы использовались для исследования динамики плазменного потока и зоны сжатия для различных режимов работы ускорителя. Эксперименты показали, что режим работы ускорителя и параметры генерируемого плазменного потока существенно зависят от атомной массы газа.

ДОСЛІДЖЕННЯ ІМПУЛЬСНИХ ПЛАЗМОВИХ ПОТОКІВ, ГЕНЕРОВАНИХ ІПП «ПРОСВЕТ» ПРИ РОБОТІ НА РІЗНИХ ГАЗАХ

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Досліджені параметри плазмових потоків, що генеруються імпульсним прискорювачем плазми «Просвет» при роботі з різними газами: криптон (m = 84), азот (m = 14) та гелій (m = 4). Контури спектральних ліній робочого газу (повна інтенсивність та напівширина) використовувались для визначення просторового розподілу електронної густини та температури. Проведений аналіз часових розподілів інтенсивностей спектральних ліній (нейтралів, іонів робочого газу та домішок) та інтенсивності континууму. Швидкість плазмового потоку оцінювалась по прольоту між двома монохроматорами (МУМ), з`єднаними з фотопомножувачем. Просторово-часові розподіли тиску плазми використовувались для дослідження динаміки плазмового потоку та зони компресії в різних режимах роботи. Експерименти показали, що режим роботи прискорювача та параметри плазмового потоку суттєво залежать від атомної маси газу.