INVESTIGATION OF HELIUM PLASMA STREAM PARAMETERS IN EXPERIMENTS ON SURFACE MODIFICATION

A.N. Bandura, O.V. Byrka, V.V. Chebotarev, I.E. Garkusha, M.S. Ladygina, A.K. Marchenko, V.I. Tereshin, S.A. Trubchaninov, A.V. Tsarenko

Institute of Plasma Physics, NSC Kharkov Institute of Physics and Technology, Akademicheskaya St. 1, 61108 Kharkov, Ukraine

Processing of different constructional materials with pulsed plasma streams is one of prospective methods of surface modification. The main objection of this study is adjustment of plasma treatment regimes for different materials that allows achieving optimal thickness of modified layer with simultaneously minimal value of surface roughness. With use of optical spectroscopy, detailed information about the basic plasma parameters – electron density, electron and ion temperatures, plasma stream duration and velocity, was obtained. Integrated spectra of plasma radiation were analyzed. The majority of helium and impurity spectral lines were investigated on a subject of Stark broadening. Plasma pressure and energy density values measured with piezodetectors and calorimeters are in good agreement with plasma parameters obtained by optical techniques.

PACS: 52.77.-j

INTRODUCTION

Surface modification of constructional steels, alloys and hard magnetic materials by pulsed plasma flows is a promising technique of improvement of the microstructure and surface properties of materials for number of applications in modern industry. Metallographic analysis of different materials processed with helium, oxygen and nitrogen plasma streams as well as results of XRD, microhardness and wear resistance tests for the sample surfaces after modification with nitrogen and helium plasma are presented in [1]. Comparative results with helium and nitrogen plasmas showed that two mechanisms, both thermal hardening and formation of γ_N phase enriched with nitrogen (when operating with nitrogen plasma), are approximately equally responsible for improvement of wear resistance of processed surfaces. As to the microhardness, it was increased mainly due to high speed quenching and maximal values were obtained with use of helium plasma.

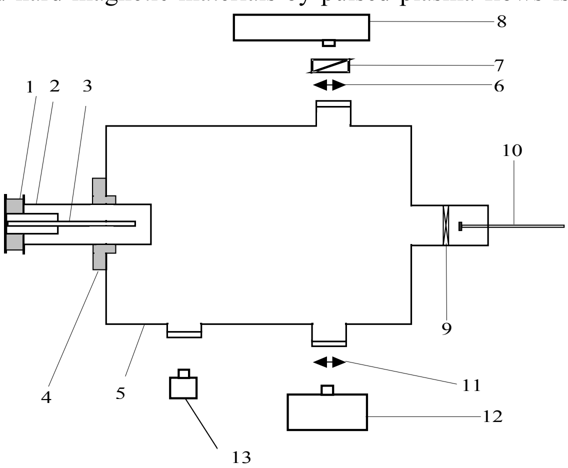


Fig.1. Experimental setup:
1, 4 - insulator, 2 - anode, 3 - cathode, 5 - vacuum chamber, 6, 11 - lens, 7 - turning mirror, 8 - DFS-452, 9 - vacuum valve, 10 - target, 12 - MDR-23, 13 – compact universal monochromator

This paper is focused on investigation of helium plasma streams generated by pulsed plasma accelerator (PPA) "Prosvet" [1] in experiments on surface modification and adjustment of accelerator working regimes for different gases used.

EXPERIMENTAL DEVICE

The PPA device consists of coaxial plasma accelerator (with anode diameter of 14 cm and cathode diameter of 4 cm) and the vacuum chamber of 120 cm in a length and 100 cm in a diameter. The power supply system of the accelerator is a capacitor battery with the stored energy of W=68 kJ. The experiments were carried out with varying the discharge voltage in the range of 18-25 kV, causing an increase in the peak values of discharge current from 400 to 500 kA. The time duration of the plasma stream generation is 3-6μs. Average specific power is achieved 10 MW/cm^2, energy density of the plasma stream is varied in the range of 5-50 J/cm^2. As working gases nitrogen and helium were used. The scheme of experiments is presented in fig.1.

Measurements of plasma stream pressure were carried out with piezodetector. Energy density was determined using thermocouple calorimeter. Complex of optical diagnostics included diffractional spectrograph DFS-452, monochromator MDR-23, compact universal monochromators, photodiodes, photomultiplier tubes.

EXPERIMENTAL RESULTS

Examples of spatial distributions of both plasma pressure and energy density are represented in fig.2,3 for helium and nitrogen plasmas in regime with U_d=19 kV. At the distance of 35 cm from accelerator output, where the samples are typically installed in experiments on surface modification, the plasma stream pressure is 10 and 12 bar, energy density value – 30 and 23 J/cm^2 for helium and nitrogen plasma accordingly.

Plasma stream velocity was estimated by two methods: photoelectric method using two compact universal monochromators and by time-of-flight method. Its value for this low-energy regime of accelerator is (1.5-2)×10^7 cm/s for both gases.

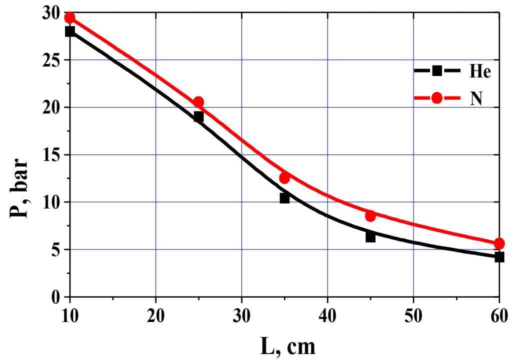


Fig.2. Plasma stream pressure vs. the distance from accelerator output

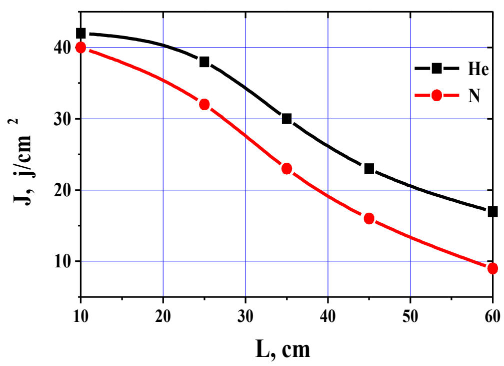


Fig.3. Plasma stream energy density vs. the distance from accelerator output

Temporal distributions of helium and impurity spectral lines, as well as continuum are presented in fig.4. Maximal concentration of helium ions is observed at 10 µs after the discharge beginning. For the same time moment the luminescence intensity of neutral helium is minimal, but it is increased for subsequent time moments (18-20 µs). Experimental results indicate that with decreasing of helium ions concentration for late moments of time the impurity intensity is start to increase.

Plasma electron density was estimated from half-widths of HeII 4686 Å spectral line based on the experimental and theoretical data [3] of the Stark broadening values of HeII 3202E and 4686E spectral lines in dependence on plasma electron density. The value of electron density in plasma stream is calculated as (2-2.5)×10^{16} cm^{-3} with following formula:

$$N_e = 2.04\times10^{16}\left(\Delta\lambda_{1/2}\right)^{1.21} cm^{-3},\ .$$

Under the plasma processing of steel samples the plasma density near the target surface achieved (6-8)×10^{16} cm^{-3}.

Shielding characteristics of plasma layer, which is formed close to the target surface, are analyzed with calorimetry for different target materials. It is shown that energy losses due to the shielding effect are not more than 20%.

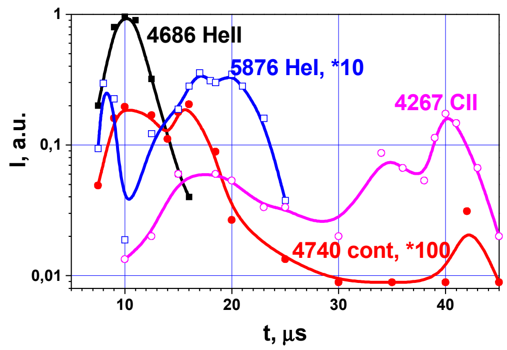
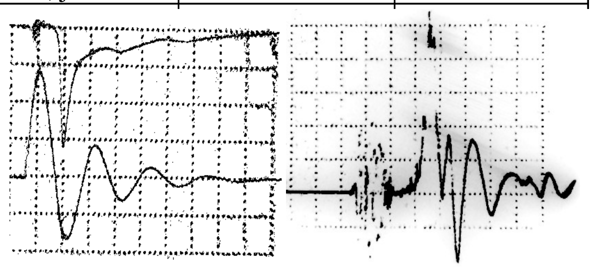


Fig.4. Temporal distributions of the spectral lines intensities for He I, He II, C II and continuum in a free

Plasma electron temperature measurements were carried out by two methods: the Gunningham method [4] – using the ratio of total intensities HeII/HeI spectral lines, and by the ratio of helium spectral line to the continuum intensity in the same range of wavelengths. In free plasma stream the electron temperature value estimated for comparison by two methods is equal to 8-10 eV and it value near to the target surface is about 30-40 eV.

Plasma pulse duration was determined from photodiode (fig.5a) and piezodetector (fig.5b) signals. For He plasma it is ~ 4-6 µs and for N – 5 µs. Helium and nitrogen plasma stream parameters obtained in result of these experiments are summarized in the table.

	He	N
V, cm/s	1.2-1.5 × 10^7	1-1.2 × 10^7
P, bar	10	12
N_e	1.6 × 10^{16}	8 × 10^{15}
E, eV	500	800
J, j/cm^2	29	19



a *b*

Fig.5. a) signals of photodiode and discharge current (10 µs/div); b) Signal of piezodetector (5 µs/div)

SUMMARY

The results of these investigations can be summarized as follows:

- Electron temperature in free plasma stream is measured as 8-10 eV. Under the plasma stream interaction with the target surface, thin plasma layer with Te increased up to 30-40 eV is formed close to the target surface.

- Variation of plasma electron density can be achieved by changing of the valve pressure or assortment of the working gas sort. The value of plasma electron density in a free plasma stream is about $(1.5\text{-}2)\times10^{16}$ cm^{-3}. This value is increased up to $(6\text{-}8)\times10^{16}$ cm^{-3} in the vicinity of the target.
- Shielding characteristics of plasma layer, which is formed close to the target surface, are analyzed for different target materials. It is shown that energy losses due to the shielding effect are not more than 20%.
- Plasma pressure and energy density values measured with piezodetectors and calorimeters are in good agreement with plasma parameters obtained by optical techniques.
- The obtained results are used in technological applications of pulsed plasma streams for processing of materials.

ACKNOWLEDGEMENTS

The work is supported in part by STCU grant # 881C.

REFERENCES

1. I.E. Garkusha, A.N. Bandura, A.M. Bovda et al. //*Proc. of the 1st International Congress on Radiation Physics, High Current Electronics and Modification of Materials. 5th Conference on Modification of Materials with Particle Beams and Plasma Flows. Tomsk, Russia*, *2000*. p.299-302.
2. A.M. Bovda et al.// *18th Int. Workshop on High Performance Magn. and their Application, Annecy, France*, *2004*.
3. T.L. Pittman, C. Fleurier // *Phys. Rev.* A 33. 1986, p.1291
4. L.C. Johnson, E. Hinnov. Electron temperatures from HeI intensity measurements // *Phys. of Fluids*. 1969, v.19, № 9, p.1947-1949.

ИССЛЕДОВАНИЯ ПАРАМЕТРОВ ГЕЛИЕВЫХ ПЛАЗМЕННЫХ ПОТОКОВ В ЭКСПЕРИМЕНТАХ ПО МОДИФИКАЦИИ ПОВЕРХНОСТИ

А.Н. Бандура, О.В. Бырка, В.В. Чеботарев, И.Е. Гаркуша, М.С. Ладыгина, А.К. Марченко, В.И. Терешин, С.А. Трубчанинов, А.В. Царенко

Одним из перспективных методов модификации поверхности является обработка различных конструкционных материалов импульсными плазменными потоками. Главная цель этой работы – оптимизация режимов плазменной обработки для различных материалов, что одновременно позволяет достигать максимальной толщины модифицированного слоя и минимальной величины шероховатости поверхности. Детальная информация об основных плазменных параметрах – электронная плотность, электронная и ионная температуры, длительность генерации и скорость плазменного потока, была получена с помощью оптической диагностики. Проанализированы интегральные спектры излучения плазмы. Большинство гелиевых и примесных спектральных линий исследовались на предмет Штарковского уширения. Пьезодатчиками и калориметрами измерены соответственно величины давления и плотности энергии плазмы, которые хорошо согласуются с параметрами плазмы, полученными с помощью оптической диагностики.

ДОСЛІДЖЕННЯ ПАРАМЕТРІВ ГЕЛІЄВИХ ПЛАЗМОВИХ ПОТОКІВ В ЕКСПЕРИМЕНТАХ З МОДИФІКАЦІЇ ПОВЕРХНІ

А.М. Бандура, О.В. Бирка, В.В. Чеботарьов, І.Є. Гаркуша, М.С. Ладигіна, А.К. Марченко, В.І. Терьошин, С.А. Трубчанінов, О.В. Царенко

Один з перспективних методів модифікації поверхні – це обробка різних конструкційніх матеріалів імпульсними плазмовими потоками. Головна ціль досліджень є оптимізація режимів плазмової обробки різних матеріалів, що одночасно дозволяє досягати оптимальної товщини модифікованого шару та мінімальної величини шорсткості поверхні. Детальна інформація про основні параметри плазми – електронна густина, електронна та іонна температури, тривалість та швидкість плазмового потоку, була отримана за допомогою оптичної діагностики. Проаналізовані інтегральні спектри випромінювання плазми. Більшість гелієвих та домішкових спектральних ліній досліджувались на предмет Штарківського розширення. П`єзодатчиками та калориметрами виміряні величини тиску та густини енергії плазми, які добре погоджуються з параметрами плазми, отриманими за допомогою оптичної діагностики.