COMPARABLE ANALYSIS OF SHIELDING LAYER PARAMETERS FOR DIFFERENT TARGET MATERIALS UNDER THE PLASMA STREAM EXPOSURE

A.V. Tsarenko, S.A. Trubchaninov, A.K. Marchenko, V.V. Chebotarev, V.V. Staltsov, V.I. Tereshin, I.E. Garkusha, V.A. Makhlaj, D.G. Solyakov, I.S. Landman*

Institute of Plasma Physics of the National Science Center "Kharkov Institute of Physics and Technology",61108 Kharkov, Akademicheskaya Str.1, Ukraine;
****Forschungszentrum Karlsruhe, IHM, 76021 Karlsruhe, Germany***

Numerous experiments on the plasma-wall interaction problem have been performed with the powerful quasi-stationary plasma accelerator (QSPA) K-50 device during last decades. These investigations were performed with different target materials (carbon, tungsten, steel etc.) at the different plasma stream parameters. But such problems as, for example, impact of target material on the basic plasma characteristics at the same plasma stream parameters were unsolved. So this paper is summarizing data of researches of plasma shielding layer using different materials of targets. The plasma parameters (peak values) obtained at the longitudinal magnetic field B=0.54 T were as follows: N_e~10^{17} cm^{-3} (measured from H_β linear Stark-effect), T_e~2.7 eV, plasma pressure ~16 Bar. Working gas was hydrogen with a small diagnostics dope of nitrogen.

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1. INTRODUCTION

The experiments on analysis of plasma shielding layer parameters, calculations of basic characteristics of plasma streams, diagnostics of plasma shielding layer at simulation energy loads on constructional elements of reactor-tokamak ITER were carried out. Parameters of the plasma shielding layer at conditions of interaction of plasma with material walls made of different materials are obtained. Spectra of plasma radiation with using of different target's materials (aluminum, copper, tungsten, fluoroplastic and titanium) were recorded and completely decoded. Magnitudes of plasma electron density, electron and ion temperatures were calculated as a result of their processing. Estimations of concentrations of target's material in plasma shielding layer are held in some cases. The present work also contains some necessary corrections of our previous results. Namely, it is concerned the ion temperature values – [1], and the aluminum density evaluation for the near target space – [2].

2. EXPERIMENTAL SETUP

Experiments at interaction of plasma streams generated by quasi-stationary plasma accelerator (QSPA) with the different targets were conducted. Targets were irradiated by plasma flows at usual operational mode of QSPA Kh-50 [3, 4]. There are two operational modes of this installation: first – gas that ionized in the channel inputs continuously (single-stage regime), second – plasma inputs (double-stage regime). Basic spectroscopic measurements were carried out in single-stage mode of QSPA operations. In this case ionization of working gas, preliminary acceleration of the received plasma and its delivery in the basic accelerating channel is carried out with the help of additional discharge. In every case target's diameter was equal 12 cm (except the tungsten target – 5 cm). Main characteristics of plasma stream in this mode are: energy density – 10 MV/cm^2, plasma stream duration – 150 μs. The principal scheme of experiments is shown on the fig.1.

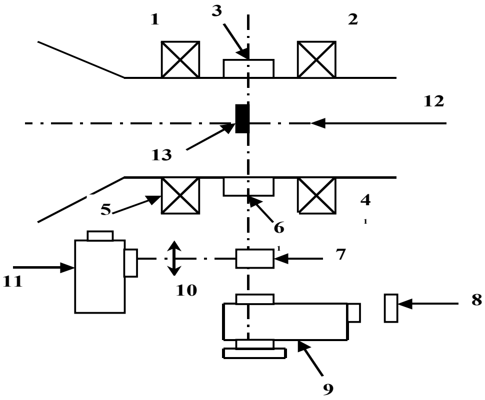

Fig. 1. The scheme of experiments
1, 2, 4, 5 – magnetic coil; 3, 6 – window; 7 – turning mirror; 8 - electron-optical converter; 9 – monochromator; 10 – lens; 11 – spectrograph; 12 – plasma stream; 13 - target

3. EXPERIMENTS AND RESULTS

Special attention was focused on the dense plasma layer - so-called shielding layer, which is formed near target surface under the influence of a high-power plasma stream. Plasma parameters of a shielding layer – the electron density and temperature, impurity composition and densities of evaporated target material – determine its radiant emittance and other thermal properties, and so the screening effect.

This work sum up on the systematical spectroscopic investigations of a shielding layer parameters for different target materials at the same experimental conditions: plasma stream parameters, geometry of a plasma-target interaction. We used following target materials: tungsten (W, atomic weight

– 184), copper (Cu – 64), titanium (Ti – 48), aluminum (Al – 27), fluoroplastic (F_2C – 19; 12).

The electron density measurements with spatial and temporal resolution were carried out using interferometer (field of view – 200mm) [3,4] or high-speed camera (VFU-1) conjugated with spectrograph [3]. In spite of the enormous content of the experimental data, a whole series of problems were remaining undecided. That is, particularly, relationship between target material and basic plasma parameters of a shielding layer (and its radiant emittance).

The electron density was obtained using quadratic Stark broadening of the impurity spectral lines of NII 4621E. This line was choosing because it is observable in all spectra and Stark constant for this line is known. In order to minimize relative uncertainties we used the same spectral lines for all targets. Spatial distributions of electron density estimated and averaged are presented in fig.2, averaging was carried out for all targets also. It is visible from this figure, that the maximum value of plasma electron density is $5.3 \cdot 10^{17}$ cm^{-3} near to the target and fluently falls down up to $2.3 \cdot 10^{17}$ cm^{-3} on the distance 7 cm from the target.

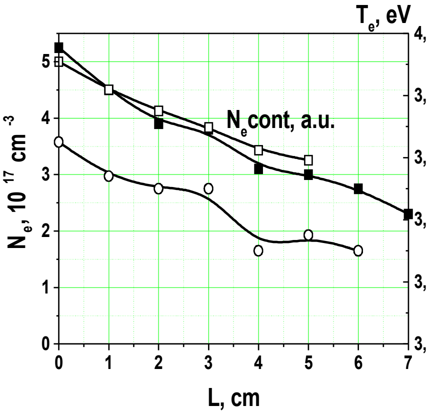

Fig.2. Plasma electron density, temperature

As √Icont characterizes total density of plasma ions, continuum intensity (in our case the regions near 4607E and 4267E were more comfortable) depending on the distance from the target represented in fig.2 also. It is easy to see that distribution of continuum intensity repeats the behaviour pattern of the plasma density. This fact justifies adequacy of technique we used for determination of plasma density. The electron temperature distributions were found from the ratio intensities of NII, NIII and NIV spectral lines. Its value changes from 3.3 eV to 3.65 eV.

The method based on a phenomenon of self-absorption of spectral lines was used for calculation of absolute concentrations of the target's material (only for Al target). Absolute concentrations of C and F were estimated relative to its values in the case of the other target material. Knowing its percentage in a stream, for example with Cu target, it's easy to estimate the quantity of C and F which was added from the fluoroplastic target.

Spatial distributions of target's materials were obtained near to the target for each case. It will be expediently to note that the material with higher atomic weight value is more pressed to the target's surface. The fig.3 illustrates this fact. It's evident that copper is the heaviest element (64) in our experiments and carbon is the lightest (12). One can see from this graph – the character of distribution of elements nearby the surface taking into account atomic masses is quite logical.

It turned out, that impurity elements are distributed equally although the target's materials are various and have different atomic weights. As to the distributions of target's elements, some difference is observed and it is explained by the difference of atomic weight values.

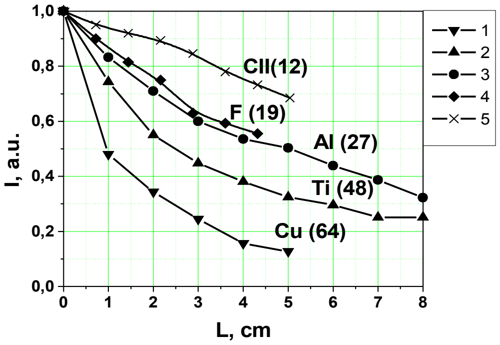

Fig.3.Spatial distributions of target's materials and impurity elements

1- *CuII 2590Å, 2 – TiII 4534Å, 3 – AlII 5593Å, 4 – FII 4109Å, 5 – CII 4267Å*

The main spectral lines used in our calculations are presented in the Table.

Element	λ, Å	E_{upp}, eV	Transition	Δλ, Å
Al II	5593	$4p^1P^0$-$4d^1D$	15.47	
	2816	$3p^1P^0$-$4s^1S$	11.82	
Al III	5722	$4s^2S$-$4p^2P^0$	17.80	
	3601	$3d^2D$-$4p^2P^0$	17.81	
Cu II	2400	$4s^1D$-$4p^3P^0$	8.42	0.48
	3686	$4p^3F^0$-$4s^{21}G$	11.85	0.56
	2544	$4p^3F^0$-$5s^3D$	13.39	1
Cu III	2644	a^2G-z^2F^0	15.72	0.48
	2609	a^4P-z^4D^0	14.74	0.4
Ti II	4572	a^2H-z^2G^0	4.28	
	4488	c^2D-x^2F^0	5.88	
Ti III	2514	b^1D-z^1F^0	10.30	
F II	4299	$3s'^1D^0$-$3p'^1F$	29.55	1.04
	4109	$3s'^3D$-$3p'^3D^0$	29.28	1.2
C II	3876	$3d^4F^0$-$4f^4G$	27.47	3.6
	2837	$2p^{22}S$-$3p^2P^0$	16.33	0.96
C III	2296	$2p^1P^0$-$2p^{21}D$	18.09	0.62
C IV	5801	$3s^2S$-$3p^2P^0$	39.68	
N II	4621	$3s^3P^0$-$3p^3P$	21.15	0.88
N III	4634	$3s^4P^0$-$3p^4D$	38.40	1.06
N IV	3478	$3s^3S$-$3p^3P^0$	50.33	

4. CONCLUSIONS

- The electron density and temperature values (and its spatial distributions) for shielding layer are independent on the target materials. Their maximum values, reached close to the target surface, are correspondently: $N_e \approx 5.2\cdot10^{17}$ cm^{-3}, $T_e \approx 3.6$ eV. As for the ion temperature, we may adduce the upper limit only – $T_i \leq 5\text{-}7$ eV.

- Since the listed above result remains valid in the case of the tungsten target, for which the evaporated material concentration is negligible quantity (in comparison with total plasma density), one may conclude that corresponding concentrations are also small for any target materials. Direct measurements of the evaporated material concentrations justify this conclusion. For the Al, C and F corresponding quantities don't exceed 4% of plasma density, for W the upper limit is 10^{-3}.
- Radiant emittance of shielding layer, which is completely defined by the N, T values and impurity composition, are also independent on the target material in our case. Thus the screening effect is defined by the plasma stream parameters (mainly – by the impurities concentrations) and the geometry of plasma-target interaction.
- Thickness of the evaporated material layer strongly depends on the atomic weight and increases with the decreasing one.

5. ACKNOWLEDGEMENTS

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ ПАРАМЕТРОВ ПЕРЕХОДНОГО СЛОЯ ДЛЯ РАЗЛИЧНЫХ МАТЕРИАЛОВ МИШЕНЕЙ ПРИ ПЛАЗМЕННОЙ ОБРАБОТКЕ

А.В. Царенко, С.А. Трубчанинов, А.К. Марченко, В.В. Чеботарев,
В.В. Стальцов, В.И. Терешин, И.Е. Гаркуша, В.А. Махлай, Д.Г. Соляков, И.С. Ландман

В последнее время были представлены многочисленные эксперименты по проблеме взаимодействия плазма-стенка, которые проводились на квазистационарном плазменном ускорителе КСПУ Х-50. Эти исследования представлялись с использованием различных материалов мишеней (углерод, вольфрам, сталь и др.) при разных параметрах плазменного потока. Такие проблемы, как влияние материала мишени на основные характеристики плазмы при одинаковых параметрах потока, все еще не решены. Поэтому эта работа подводит итоги исследований переходного плазменного слоя с использованием различных материалов мишеней. Параметры плазмы (пиковые значения) в продольном магнитном поле B=0.54 T следующие: $N_e \sim 10^{17}$ см$^{-3}$ (определялось по линейному Штарк-эффекту H_β), $T_e \sim 2.7$ эВ, давление плазмы ~16 Бар. В качестве рабочего газа использовался водород с небольшой добавкой азота.

ПОРІВНЯЛЬНИЙ АНАЛІЗ ПАРАМЕТРІВ ПЕРЕХІДНОГО ШАРУ ДЛЯ РІЗНИХ МАТЕРІАЛІВ МІШЕНІ ПІСЛЯ ПЛАЗМОВОЇ ОБРОБКИ

О.В. Царенко, С.А. Трубчанінов, А.К. Марченко, В.В. Чеботарьов,
В.В. Стальцов, В.І. Терьошин, І.Є. Гаркуша, В.А. Махлай, Д.Г. Соляков, І.С. Ландман

Останнім часом були представлені численні експерименти з проблеми взаємодії плазма-стінка, які проводилися на квазістаціонарному плазмовому прискорювачі (КСПП) Х-50. Ці дослідження були представлені з різними матеріалами мішеней (вуглець, вольфрам, сталі та ін.) при різних параметрах плазмового потоку. Такі проблеми, як вплив матеріалу мішені на основні характеристики плазми при однакових параметрах плазмового потоку досі не вирішені. Тому ця стаття підводить підсумки досліджень перехідного шару плазми з використанням різних матеріалів мішеней. Параметри плазми (максимальні величини) у магнітному полі B=0.54 Т такі: $N_e \sim 10^{17}$ см$^{-3}$ (виміряні по лінійному Штарк-ефекту H_β), $T_e \sim 2.7$ еВ, плазмовий тиск ~16 Бар. В ролі робочого газу використовувався водень з невеликим додатком азоту.