J. Plasma Fusion Res. SERIES, Vol. 2 (1999) 324–327

Experimental Study of Shielding Layer Plasma Radiation at High Power Plasma-Material Interaction

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(Received: 8 December 1998 / Accepted: 13 May 1999)

Abstract

Some results of the study of radiation of shielding layer plasma in visible and VUV regions of spectrum during high power (P_{irr}~10MW/cm^2) plasma irradiation to targets (graphite and tungsten) are given in the report. It is observed the difference of some radiation characteristics in dependence of registration direction.

It is concluded that visible radiation power flux on the target surface can be characterised by quasistationary level during irradiation.

Keywords:

plasma-material interaction, shielding layer, radiation.

1. Introduction

The dense plasma Shielding Layer (SL) - product of material evaporation - appeared near the surface of the target at high heat plasma flux-material interaction protects effectively the material against irradiation power. The study of this phenomenon is an important problem taking into account the wide spectrum of present and future applications of plasma-material interaction (fusion technology, plasma processing of structural materials, space technology etc.).

The power balance at the interaction process can be described schematically by the following expression:

$$P_{irr} = P_{inc} + (P_i + P_r),$$

where P_{irr} - plasma irradiation power flux, P_{inc} - power flux reached the exposed material surface, P_i - power flux spent for the growth of SL internal energy, P_r - power flux emitted from SL as a background radiation. The sum ($P_i + P_r$) includes components that provide shielding effect itself. So, the shielding coefficient $K_{sh} = (P_i + P_r)/P_{irr}$ represents the portion of irradiation power that is dissipated by SL and does not influence on irradiated target.

The performed experimental measurements of SL radiation have shown the ability of SL to convert the greater part of plasma irradiation power into background radiation with high efficiency. Typically the values of shielding coefficient K_{sh} are around ~0.8 in experiments with plasma irradiation power P_{irr}~10MW/cm^2 [1]. Other part of power flux-P_{inc}- is responsible for the material damage. This power flux is determined by SL thermal radiation and material plasma electron heat conduction [2]. It is absent up to now the direct measurements of P_{inc}. So, any knowledge about radiation flux to the target surface will be useful for the study of P_{inc} parameters.

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2. Experimental Conditions

The experiments were performed at the VIKA facility [3]. Long-pulse coaxial plasma accelerator - the source of plasma high heat flux in the VIKA facility - is able to generate hydrogen plasma flows with power flux on the target up to ~10MW/cm^2 at pulse duration up to τ_p = 0.36ms. The use of power supply - Pulse Forming Network (5 kV, 100 kJ) - allows to form plasma flows with quasistationary parameters during pulse duration. The effective diameter of plasma stream is d_p~4cm.

The diagnostic complex to determine the main parameters of both incident plasma stream and SL is used in experiments. The spectroscopic apparatus allows to be studied plasma radiation in a wide range of wavelength - from visible region to deep UV-vacuum region [4].

Two schemes of the observations of SL radiation were used in described experiments: 1. side on view through quartz window or vacuum tube; 2. view through the hole in target (graphite) with use of quartz fiber (registration of SL "back side" (BS) radiation). For second case the registered spectral range was $\lambda \cong$ 400–800nm.

It was used also the data of the measurements of probing laser beam (λ = 632.8nm) absorption in SL plasma. The measurements were performed in the direction parallel to target surface for several distances from the target.

3. Experimental Results

The performed earlier study of SL plasma properties during irradiation of tungsten and graphite targets has shown that this dense (n_e~10^{24}m^{-3}) plasma layer can be optically thick for visible radiation for developed phase of SL formation [4]. In this connection the study of SL radiation in VUV region of spectrum (for tungsten and graphite targets) was continued. It was observed that carbon, oxygen and nitrogen ions lines give the main contribution in the line emission of near surface plasma zone for both targets (Fig.1.) This spectral region is characterised by the maximal intensity of radiation in neighbourhood of wavelength $\lambda \cong$ 15nm. As it is seen the thickness of intensively radiated plasma layer is of ~15mm.

The comparison of observed spectra data with the calculations of the plasma ionisation state for the LTE approximation (Saha-equilibrium) shows that the values of the electron temperature should lie in the range from $T_e \cong$ 8–12eV (in the central region of SL) up to $T_e \cong$ 3–4eV (in a periphery).

The main difference of SL radiative characteristics (for tungsten and graphite targets) was observed in the visible region. It indicates that main variations in the SL structure for different target materials consist of both the change of the thickness of the plasma layer that emitted continuum radiation and variation of continuum radiation intensity. So, for tungsten target the continuum is radiated from a very thin layer above the surface (~0.5mm), for carbon this thickness is 3–4mm [5].

The registration of the time- and space-integrated SL plasma spectra for graphite target in visible, UV and

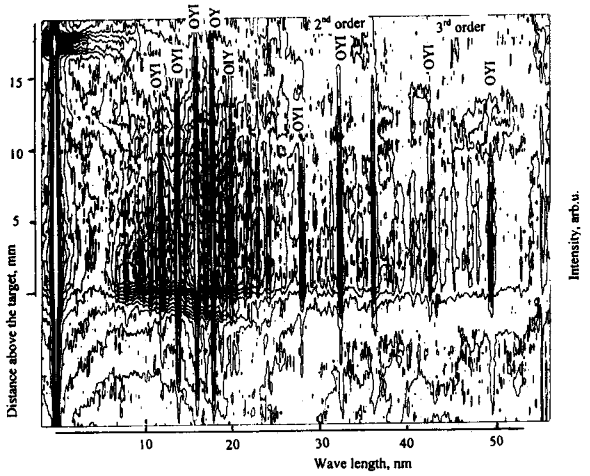

Fig. 1 The fragment of typical space resolved VUV spectrum of SL radiation. Target - tungsten. Irradiation power P_{irr}~5MW/cm^2.

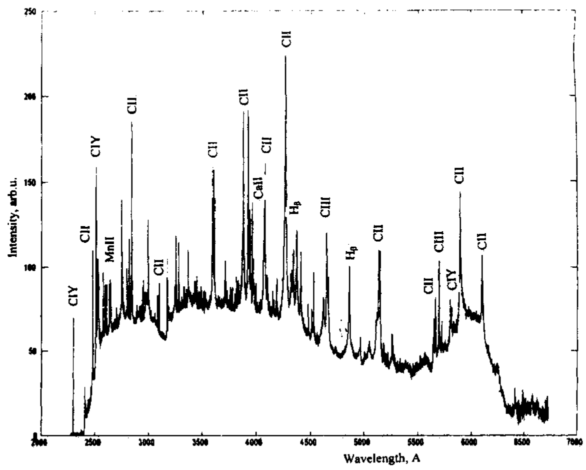

Fig. 2 The typical observation spectrum of SL radiation in visible and UV regions of spectrum. Target - graphite. Irradiation power P_{irr}~5MW/cm^2.

near VUV spectral ranges reveals the presence of carbon spectral lines CII, CIII and CIY, the most intensive being the lines CII (z = 1) in visible range (Fig. 2). It was observed also some impurities (Al, Mn, Na, Cu) and hydrogen spectral lines. The most probable source of the impurities is due to plasma gun. One can suppose that the observed structure of visible radiation can be distorted by the opacity of the near-surface plasma layer with the density $n_e \geq 10^{24}m^{-3}$. Really, one can see that dynamics of observed SL radiation is modulated sufficiently by high absorption in the plasma layer closed to the target surface (Fig. 3, bottom curve of Fig. 4).

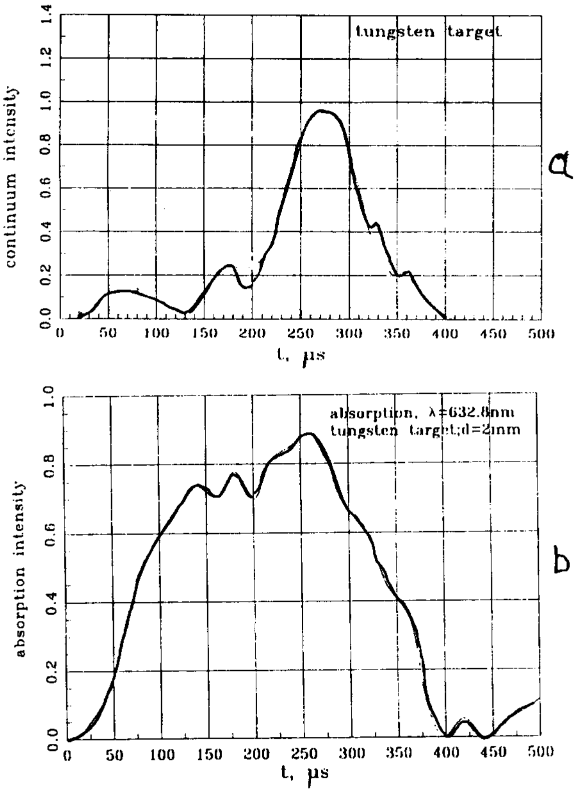

Fig. 3 a, b. The dynamics of the continuum (a) and absorption (b) intensities. Target - tungsten. Irradiation power P_{irr}~5MW/cm^2.

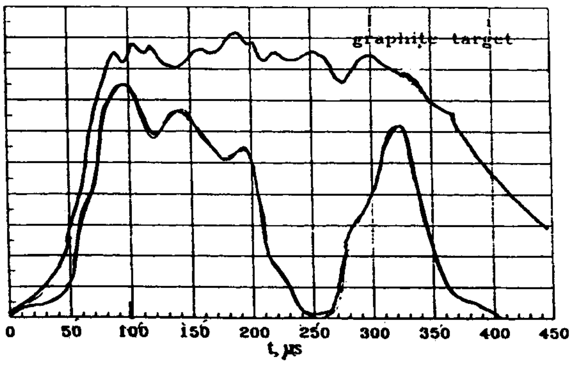

Fig. 4 The dynamics of the relative radiation intensities for two directions of registration. Target - graphite. Irradiation power P_{irr}~5MW/cm^2. bottom curve - CIII carbon line (λ = 229.7nm), side-on registration; upper curve - CII resonance line (λ = 426.7nm), registration through the hole in the target.

With the aim to exclude this effect it was performed the registration of visible radiation through the hole in the target. Its difference from SL background radiation (in a corresponding region of spectrum) was observed: practically full absence of impurities spectral lines and increased intensities of lines and continuum radiation. Besides one can see the absence of strong modulation of intensity even for more long-wave radiation (upper curve of Fig. 4).

4. Discussion and Conclusions

The observed spectra of background radiation in VUV region have shown practical absence of target material spectral lines. As to graphite target, the absence of carbon lines in the spectrograms of the far VUV range can be explained by the lack of the intensive spectral lines CIII and CIV in this range. Ions with z = 4 (CV-lines) are not emit the spectral lines at evaluated electron temperature. As to tungsten target, one can assume that the "tungsten plasma" layer is very thin, and besides its radiation is masked by the intensive continuum radiation.

Taking into account all abovementioned data, one can assume that SL has an intricate structure in described experiments. The estimation shows that bulk of irradiation power can be reradiated by the impurities in the upper plasma layer with composition determined mainly by the compressed incident plasma stream. This mixed layer has the highest electron temperature, determined by the thermalisation of kinetic energy ($\varepsilon_i \cong$ 0.2keV [4]) of the incident plasma flow. The observed parameters and temporal behaviour of this radiation are determined by this plasma layer properties that can be strongly changed in this open system under both irradiation conditions and target material response.

As to SL BS radiation one can believe that its structure is determined by the radiative properties of cold and very dense material plasma in a considerable extent. The observed quasistationary character of BS radiation intensity during irradiation reflects the true dynamics of visible radiation power flux on the target surface (at the absence of opaque plasma layer between this radiation source and the target surface). Assuming the sufficient role of the radiation in the level of power flux reached the material P_{inc} one can suppose that last value is quasistationary too during irradiation. The last supposition is confirmed indirectly by our measurements of power flux absorbed by material during irradiation [6]. It is shown that absorbed power flux value is quasistationary during greater part of irradiation period and depends feebly on target material and irradiation conditions. The absolute values lie in the range $P_{abs} \cong$ 0.3–0.5MW/cm^2 for wide region of irradiation conditions.

So, one can believe that in spite of intricate structure of SL background radiation determined by the features of studied open plasma system - SL, the radiation flux reached the surface of target is quasistationary.

Acknowledgements

The authors would like to thank Drs. I. Konkashbaev (TRINITI, RF) and A. Hassanein (ANL, USA) for fruitful discussions.

The work is performed under partial support of ISTC (Project #539).

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