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Study of Material Response under High Heat Plasma Load Relevant to Plasma Disruptions

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Abstract

The results of the experimental study of visible radiation power flux from plasma Shielding Layer (SL) on the target surface during high heat plasma loading are given in the report. The level of plasma irradiation power flux (P_{irr} ~ 100 GW/m^2) is close to expected one during plasma disruptions in fusion system type ITER.

The effects of both the value (B = 0–3 T) and inclination ($\alpha = 0°$ - normal , 45°, 70°) of magnetic field on the value of visible ($\Delta\lambda \approx$ 400–700 nm) radiation power flux reached the target surface were studied.

It is shown that the measured values of such radiation power flux can be characterised by the level of P_r ~ 1 GW/m^2 (for normal irradiation). The inclination of target results in the decreasing this flux due to corresponding fall of irradiation power.

Keywords:

plasma disruptions, shielding layer, incident radiation power flux, inclined target.

1. Introduction.

The achievement of (quasi) stationary mode of operation for fusion systems such as ITER depends also on the successful resolution of the problem of ensuring adequate lifetimes of PFCs (Plasma Facing Components) with respect to needed life-time ensuring with respect to off-normal events such as plasma disruptions and edge localised modes. Therefore the study of material response under high heat plasma load relevant to expected one for above-mentioned global plasma instabilities is actual problem for steady state operations too.

One of the critical problems in this activity is to determine the power flux reached at the surface of PFC (incident power flux). Both numerical modeling and experimental simulation are performed to gain insight.

As to simulation experiments such activity is carried out on the VIKA facility in Efremov Institute. As a first step in resolving the issue of incident power flux determination the level of power flux absorbed by irradiated sample was measured. It was shown that measured values can be characterised by the level of P_{abs} ~ 3–5 GW/m^2 for different materials (Al, W, graphite) irradiated by plasma power flux around P_{irr} ~ 100 GW/m^2 [1]. We believe this level is close to the average level of power flux reached to the target surface which is shielded by a shielding layer (SL) generated above the target surface from erosion products. The first experimental data about visible radiation from SL on the target surface are given in [2,3].

This paper describes the results of the experimental study of radiation power flux on the target surface at high power plasma loading with the level and duration

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relevant to expected ones during plasma disruptions in ITER. Such data are interesting in general because there are not similar direct measurements up to now and such data are necessary for numerical codes verification.

2. Experimental Conditions

A long-pulse coaxial plasma accelerator is the source of plasma high heat flux in the VIKA facility [4]. The sectionalised power supply - Pulse Forming Network (5 kV, 100 kJ) - permits formation of rectangular current pulse in plasma gun that results in quasistationary character of plasma parameters during pulse duration. The level of impurities in hydrogen plasma does not exceed ~1% for any mode of operation. The ion energy is $E_i \leq 200$ eV. The effective diameter of plasma stream is $d_p \sim 4$ cm.

The variation of specific plasma heat flux values ($w_p \leq 30$ MJ/m^2) and pulse duration ($\tau_p = 0.09$–0.36 ms) are achieved by power supply voltage variation and sections reconnection correspondingly. A pulse duration $\tau_p = 0.36$ ms was used in described experiments.

The quasi-stationary magnetic field produced by two coils in the interaction chamber was varied in the range $B = 0$–3 T. To understand the possible effects of target inclination (damp target plates in tokamak divertor) both normal to the target surface ($\alpha = 0$) and inclined ($\alpha = 45°$; $70°$) field was used.

The samples of graphite and tungsten were used in described experiments.

To study the parameters of incident visible radiation an optical scheme with quartz fiber ($L = 6$ m length; $d = 10^{-3}$ m – diameter) inserted into the hole in the target body was used. The light flux collected by fiber from SL was transported to the analysing setup (spectrograph or monochromator) and register (photomultiplier).

To measure the absolute values of radiation power flux the optical tract was calibrated with a certificated tungsten lamp. Typically the registered range of wave length was limited as $\Delta\lambda \approx 400$–$700$ nm.

3. Experimental Results

The typical dynamics of registered light is given in Fig. 1. One can see that the time delay of sharp growth of intensity is $\tau_d \sim 30$–50 μs that corresponds to the real front of irradiation power. In general the dynamics of light intensity depends on irradiation conditions, but one can mark the typical peculiarity of temporal behaviour of radiation intensity – the existence of two peaks with the fall of intensity around the middle of irradiation pulse.

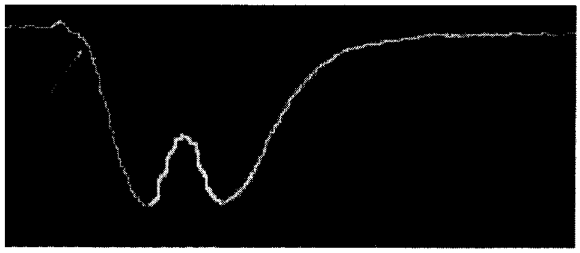

Fig. 1 The typical oscillogram of registered radiation (λ = 670 nm) intensity. The time scale is 0.1 ms/div. The pointer shows the irradiation start. P_{irr} = 120 GW/m^2. B = 3 T.

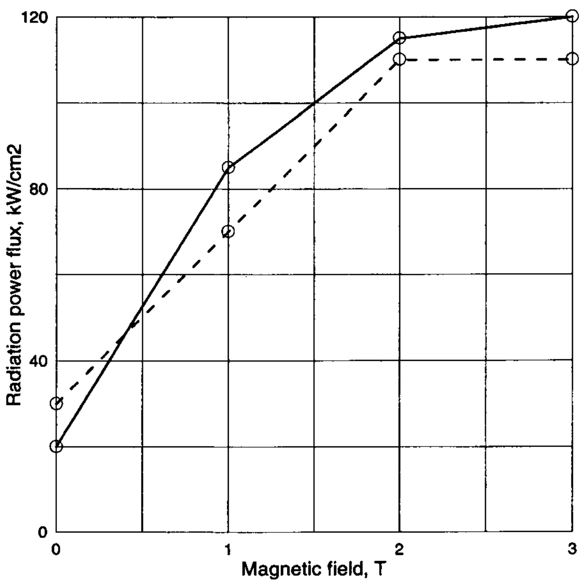

Fig. 2 Radiation power flux on the target surface vs magnetic field. Irradiation power $P_{irr} \sim 10$ MW/cm^2. Target material: tungsten (solid line), graphite (dotted)

Applying a magnetic field results in the sufficient growth of measured values of visible radiation power flux (Fig. 2).

One can see the tendency to saturation of the level of radiation power flux around $P_R \sim 1$ GW/m^2 at magnetic field value B = 2–3 T. In spite of strong difference in irradiated materials characteristics the level of measured values of visible radiation power flux are similar.

The inclination of target leads naturally to decreasing incident radiation flux (Fig. 3). Irradiation power is P_{irr} = 12 MW/cm^2 at normal irradiation and

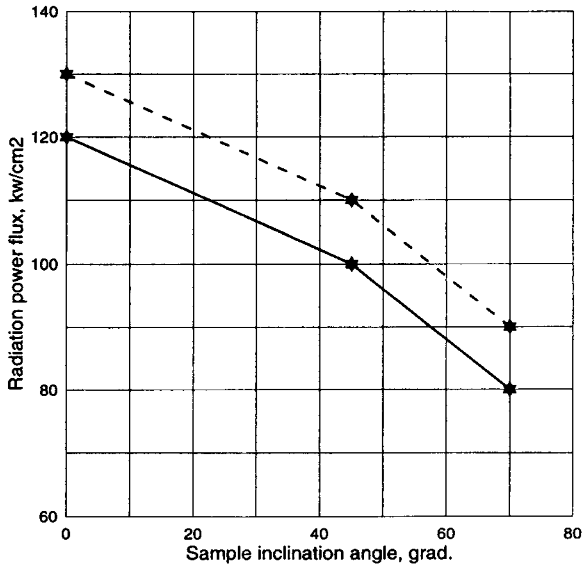

Fig. 3 Radiation power flux on the target surface vs its inclination angle. Materials: tungsten (solid line), graphite (dotted). $B = 3$ T.

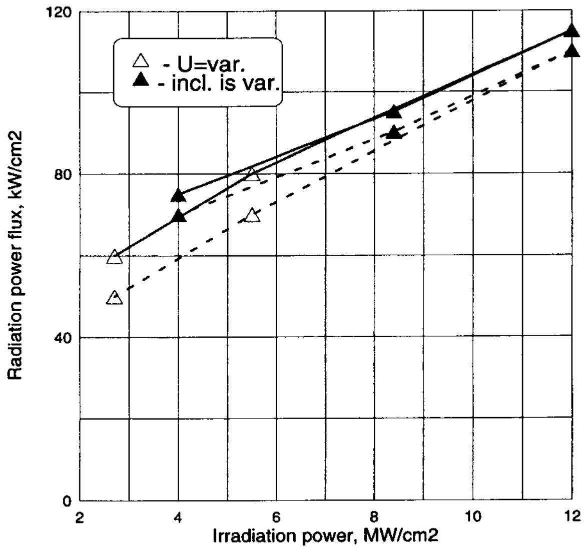

Fig. 4 Radiation power flux on a target surface vs irradiation power for tungsten (solid line) and graphite (dotted). $B = 3$ T

falls up to ~8 MW/cm^2 and ~4 MW/cm^2 at target inclination $\alpha = 45°$ and $\alpha = 70°$ respectively.

To understand the nature of this effect the measurements of radiation power flux at variation of irradiation power by varying the PFN voltage (at normal incidence of both plasma stream and magnetic field) were performed. The comparison of these data with above one at variation of target inclination (Fig. 3) is given on Fig. 4.

One can see that radiation power flux depends only on the value of irradiation power.

4. Discussion and Conclusions

For the first time we carried out direct measurements of visible radiation power flux on the target surface during high heat plasma loading and conclude that these values can be characterised by the level of $P_R \sim 1$ GW/m^2 for different materials irradiated by plasma stream with heat flux $P_{irr} \sim 100$ GW/m^2 at the presence of normal magnetic field $B = 2$–3 T.

Strong difference in the type of irradiated materials has little influence on the level of visible radiation power flux on the target surface. This result agrees with our previous measurements of power flux absorbed by target during irradiation.

We find no "deep" physics in the behaviour of incident power flux at inclination of target. The radiation power flux falls accordingly decreasing of irradiation power at inclination.

Assuming Plank distribution of spectral intensity the total radiation power flux on the target surface is evaluated as $P_{tot} \sim 5$ GW/m^2 (at emitted plasma temperature $T_e \sim 1$ eV). This is too in a satisfactory agreement with measured level of absorbed power (the last can include in general radiation and heat conduction fluxes).

We conclude that radiation power flux determines to a considerable extent the level of total power flux reached the target surface during high heat plasma loading.

The observed fall of the radiation intensity (and hence probably total incident power flux) in the middle of irradiation pulse is the most probable cause of experimentally observed pause in erosion [1]. In its turn the probable reason of such fall is the increasing of SL opacity due to plasma density growth. The opacity of SL plasma for visible radiation was experimentally observed earlier in our experiments too [2].

The received data does not contradict to the results of both modeling and experimental simulation and can be used for verification of numerical codes and evaluation of power flux on PFCs during off-normal events in existent and future fusion machines.

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