Plasma investigation using SPD XUV silicon photodiodes on the Globus-M tokamak

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Introduction

One of the effective ways for high temperature plasma investigation is measurement of radiation losses. Diagnostic methods based on appliance of such silicon photodiodes as AXUV (Absolute eXtreme UltraViolet) [1] or SPD (Silicon Precision Detector) [2] are connected with developing comprised system. Diagnostic complex should take into account drop of sensitivity of the photodiodes to electromagnetic radiation in <30 eV region [3-5]. The contribution of this band to the total radiation power could be significant as was obtained by methods of filtered AXUV with VUV spectrometer [5] and by comparing with thermal bolometers as was made in a wide range of experiments on tokamaks. Nevertheless high sensitivity, temporal resolution and relative simplicity of AXUV or SPD based diagnostics make them attractive instruments for plasma radiation exploring.

Experiment

Experiment was performed on the compact spherical tokamak Globus-M (B_T=0.4 T, I_p<0.25 MA, R/a=1.5) [6]. The diagnostics for radiated power measurements based on SPD was supplemented with four-channel filtered SPDs. Detectors are sensitive to radiation in the following spectral ranges: channel 1 – 1.12–7.7 eV, channel 2 – 1.12–10.9 eV, channel 3 – 330 eV–15 keV, channel 4 – 1.12 eV–15 keV (10% cut-off transmittance). Thus low energy range is covered by first two channels using 0.95 mm magnesium fluoride and 0.7 mm quartz filters respectively. Soft X-ray range is measured by channel 3 using silicon nitride film with aluminum coating [7] instead of traditional beryllium foil. Channel 4 remained unfiltered. Spectral sensitivities of the channels are presented in

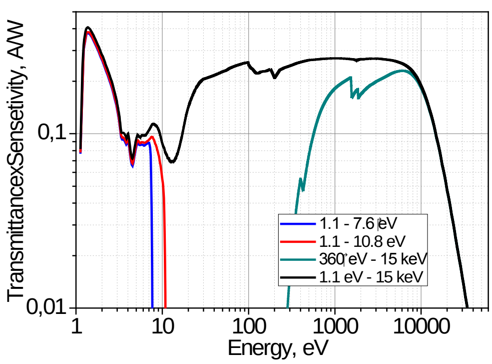

Figure 1. Spectral curves of 4-channel spectroscopic system based on SPD.

the figure 1. Detected radiation spectrum was split in 4 bands: A (1–7.7) eV, B (7.7–10.9) eV, C (10.9–330) eV, D (330–1.5·10^4) eV. Radiation in A and D bands was measured directly; radiation in B band was obtained as difference between two first channels, radiation in C band was derived by subtraction of radiated power measured by channels 2 and 3 from 4th. Each channel is collimated by two 1 mm apertures and has tangential field of view (FOV) through plasma core. SPD FOV layout on the tokamak is shown in the figure 2. Experiments were performed with deuterium plasmas, plasma current was 170 kA. Deuterium beam with P_{NBI}=450 kW, E_{beam}=27 keV was used as auxiliary heating method.

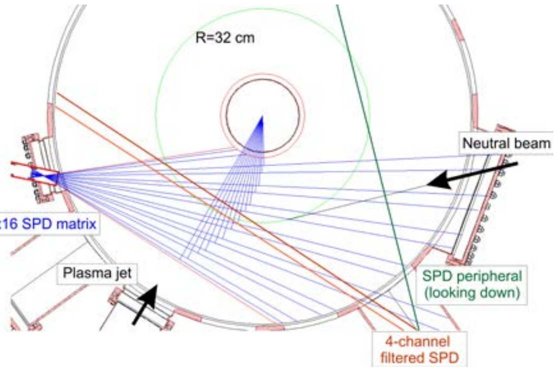

Figure 2. FOV layout of SPDs in the equatorial midplane of Globus-M (cones are not shown). Lines of view of 2 remained channels in filtered system are duplicating.

Results

Radiated power in various spectral ranges and its contribution to the total spectral range (1.12eV – 15 keV) – P_i/P_{tot} – was investigated. It was found nearly linear dependence of radiated power in the whole and SXR ranges on electron density for both ohmic heated and NBI discharges (figure 3a, b). As seen from the figures radiated power detected by filtered SPD based system for NB heated discharges was higher than for OH for the whole spectrum and D band.

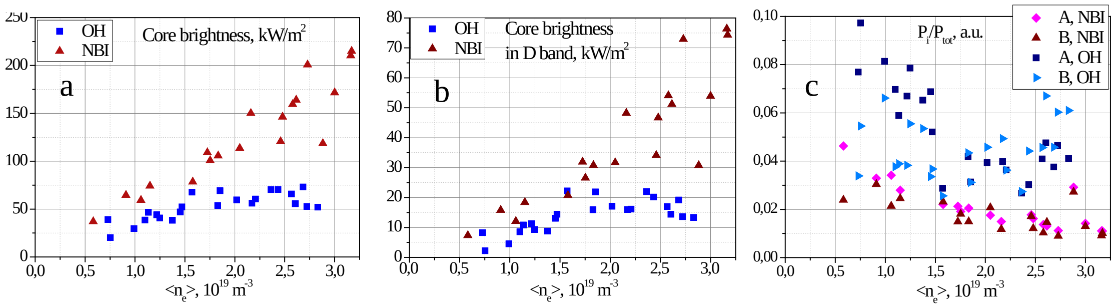

Figure 3. a) Core brightness for NBI and OH discharges in whole spectral range, b) the same in D SXR band. c) Dependence of P_i/P_{tot} from chord average electron density at R=42 cm for NBI and OH shots in A, B spectral ranges; P_i – radiated power in i-th spectral range (i=A, B), P_{tot} – power radiated in the whole spectral range.

Slight increase of radiation in B range, where Ly-alpha and CIV (8 eV) are apparently dominated, for OH discharges was also observed. Besides lower electron temperature in OH, gas puff might cause more radiation by cold neutrals injection to the plasma periphery. Radiated power in A band and CIII (465 nm) line intensity have shown no significant difference between two heating regimes. So contribution P_i/P_{tot} for low energy ranges up to

11 eV (A and B ranges), for ohmic discharges was higher than for NBI heated plasmas (fig.3c).

Possible reason of increased radiation in NB heated regimes could be higher impurity content due to high energy particle interactions with plasma facing materials. However further spectroscopic measurements and precise calculation of ionization balance are needed.

For the discharges contribution to radiation losses was: in C band ~ 60-70%, in D band ~ 30-20%, A and B bands up to ~ 15%. Introducing <*S*> as the ratio of photocurrent in 4th channel and sum of radiated power in all spectral ranges led to the values of ~0.21-0.22 A/W mean spectral responsivity in various regimes.

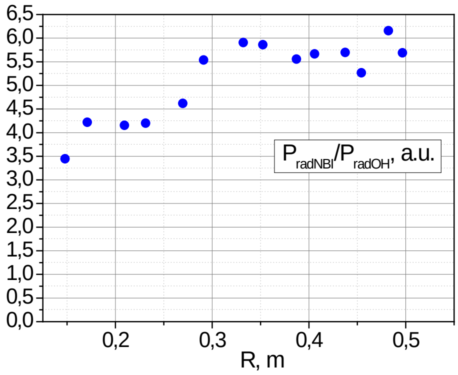

Figure 4. Ratio of radiation losses in NB and OH discharges from equatorial linear array of 16x16 SPD for $<n_e>=3*10^{19}$ m^{-3}.

Brightness distributions measured by 16x16 SPD hybrid array were compared for two heating regimes. Typical ratio of brightness in NBI and OH discharges for $<n_e>=3\cdot10^{19}$ m^{-3} from equatorial arrays is presented in the figure 4. It is seen that for plasma core and outer border the ratio is increased compare to values measured by SPD from filtered system (fig. 3a). Also values obtained by single peripheral SPD with chord of view passing down tangentially to the outer border of plasma showed radiation augmentation in NBI shots only up to 30%. Even though there is no accurate spectral responsivity to high energy particles for SPDs their contribution to array signal due to 16x16 matrix viewing geometry is obvious.

Injection of helium and deuterium jet using plasma gun [8] into the tokamak with deuterium discharges for diagnostic and fuel delivery purposes correspondingly was carried out. Plasma jet parameters were: density ~10^{22} m^{-3}, kinetic energy ~200 - 300 eV, vacuum plasma velocity ~ 150 km/s. After He injection electron density rose in accordance with diffusion time along whole

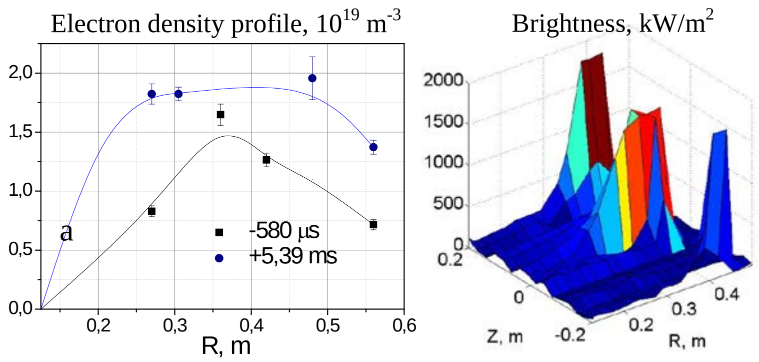

Figure 5. He jet penetration in tokamak plasma. a) Electron density profile before and after jet injection. b) Brightness distribution at t=46 µs after He jet injection obtained by 16x16 SPD matrix array; R-major radius, Z – vertical coordinate.

major radius of plasma (fig. 5a). Slightly decrease of electron temperature was also observed. Brightness distribution corresponding to maximum He jet penetration is presented in the figure 5b. Permeation up to the plasma core was seen. In the deuterium injection case poor penetration was achieved. Core density rose insignificantly, although electron temperature fell down almost twice. Evolution of the images registered by matrix array showed increase in radiation spreading toward to plasma core with high velocity.

Conclusions

For the goals of more accurate radiation losses measurements using silicon photodiodes diagnostic system containing 4 channels based on SPD with filters was installed on the Globus-M tokamak. Filtered channels provide different energy cut-offs in SPD spectral sensitivity and allow to take into account reduced sensitivity of SPDs in low energy range. The values of effective spectral sensitivity that could be used for direct calculation was achieved, although additional spectroscopic data in UV range will be necessary for more precise calculation. Radiation losses measurements for NB heated plasmas have shown up to 4-fold higher level compare to OH regimes. This could be probably because of additional impurity inflow. No increase in radiation for NB plasmas in 1-10.9 energy band was observed. Remarkable contribution of high energy particles to 16x16 SPD array response is revealed for NBI shots. Penetration of He plasma jet up to plasma core was obtained with high reproducibility.

Acknowledgments

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