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Absolute VUV spectroscopy of an eroding graphite target using a calibrated CCD camera

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Abstract

Absolute VUV spectroscopy of a graphite target plasma was performed on the MK-200UG installation (TRINITI) in cooperation with a Sandia National Laboratory team. The incoming hydrogen plasma stream had an energy density of 1.5 kJ/cm^2 and a pulse duration of 40 μs in a longitudinal magnetic field of 25 kG. The plasma facing component (PFC) under evaluation was a POCO graphite plate that was placed normal to the plasma stream and to the magnetic field. Spectroscopy was performed with a high-spatial frequency transmission grating spectrometer that was coupled to a 1024 × 1024 CCD camera.

Keywords: Spectroscopy; Graphite; Plasma facing material

1. Introduction

Experimental disruption simulations in the frame of the ITER program often deal with radiative features of target plasmas produced near the plasma facing component (PFC). Both measurements and calculations are concerned with comprehensive spectral and ion species data. These are used to estimate plasma shielding of the PFC from sudden incident power fluxes [1,2].

The plasma gun facility MK200-UG was used as a disruption simulator to explore the plasma shielding effect as well as real PFC erosion [3]. This paper presents the result of absolute imaging spectroscopy of graphite target plasma emission close to and far from the target surface. The work was performed in TRINITI in conjunction with Sandia National Laboratories, who contributed a calibrated CCD camera and associated dispersing equipment.

2. Experimental scheme

The setup of MK-200UG outlined in Fig. 1 consists of the plasma gun, a 10-metre long drift tube, and a diagnostic chamber. The long drift tube was used to increase the plasma pulse duration from 10 μs early in the tube to 40 μs at the tube output. The stream energy density in the chamber was about 1.5 kJ/cm^2.

The incoming plasma stream at the target position was characterized as follows.

Directed ion energy	1.5 keV (decreasing down to 300 eV at the end of the pulse)
Plasma density	(2–6) × 10^{15} cm^{-3}
Electron temperature	100–200 eV
Beta value	0.3
Plasma stream diameter	6.5 cm

A 14 × 4 cm^2 POCO graphite plate was placed normal to the plasma stream and to the magnetic field. The plasma stream parameters were practically constant along the target chamber length. To study the spatial distributions of plasma parameters vs. the distance from the target surface the target was shifted along the

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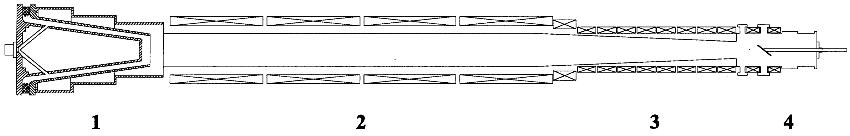

Fig. 1. Scheme of MK-200UG facility: 1 – gas-puffing plasma gun; 2,3 – transportation and compression drift tubes with magnetic coils; 4 – diagnostic chamber and target.

chamber axis from shot to shot. This permitted study of the plasma column parameters at distances from 0 to 40 cm from the target surface.

3. Diagnostic technique

Measurements of the target plasma radiation were performed with a transmission grating spectrometer which possessed space resolution. The spectrometer viewed along the shorter 4 cm side of the POCO plate. Spatial resolution was recorded in data both along and normal to the plasma stream. Two gold transmission gratings with 5000 and 2000 lpmm were used for EUV and VUV ranges.

The detector utilized in these erosion measurements was a 1024 × 1024 back-illuminated CCD camera with 24 μm^2 pixels. The XTE/CCD-1024 TKB/1 camera was provided by Princeton Instruments and utilized a CCD chip from SITe Corporation with thermoelectric cooling to reduce dark charge buildup. A calibration curve of photon sensitivity vs. photon wavelength was generated by a combination of in-lab measurements in the soft X-ray region, PI published data in the X-ray region and in the visible, and inferences from International Radiation Detectors data of silicon diode quantum efficiencies in the EUV.

The CCD camera was used in conjunction with an ultra-thin free-standing gold transmission grating. The grating had been purchased from X-OPT and was produced at MIT using a lithographic process. The grating had 5000 lpmm and was approximately 230 nm thick. Its full outer dimensions were 1 cm^2, but a spectral slit restricted its view to 100 μm × 1 cm. Calibrations of this grating and several others were performed on the Manson Inc. source and also by Gullikson at the Lawrence Berkeley Laboratory. These results were used to

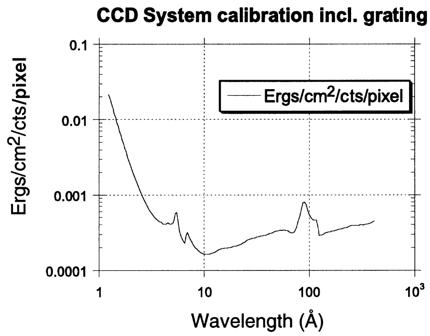

Fig. 2. Measured and calculated net sensitivity of the CCD camera and transmission grating.

estimate the effects of higher order contributions and to verify calculated estimates of first order sensitivity with wavelengths in the soft X-ray region. The combined measured sensitivities of both the CCD and the transmission grating were utilized to unfold the absolute yield of radiation from the plasma. This net sensitivity curve appears in Fig. 2.

4. Spectral measurements

An example of the target plasma spectrum is shown in Fig. 3. The sample spectrum shows impurity lines primarily to demonstrate where they are placed, rather than to represent a true ratio of carbon and impurity intensities. While oxygen and nitrogen radiation seems to be from a residual gas in long vacuum tubes, the iron radiation occurred when the occasionally deflected plasma stream touched an inner stainless steel liner. At normal experimental conditions the carbon line intensity is ten times more than the intensity of background

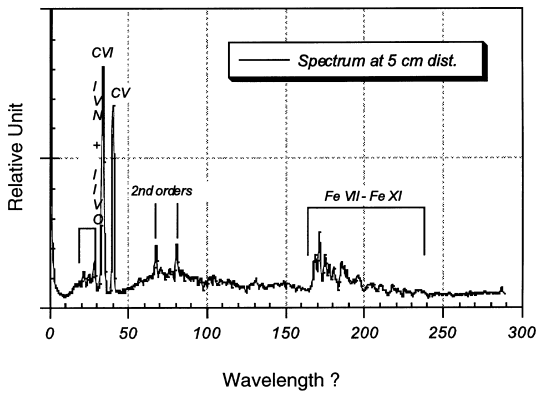

Fig. 3. POCO target spectrum at 5 cm distance in front of the target surface.

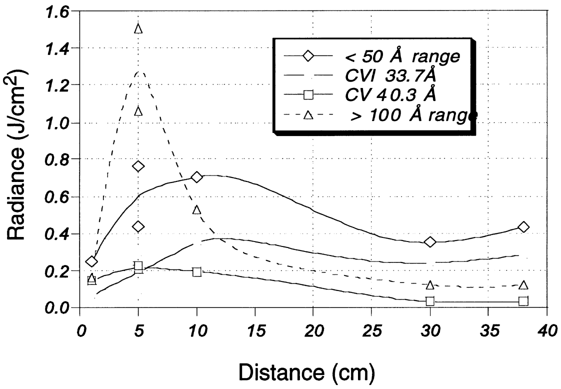

Fig. 4. Radiance of POCO target plasma vs. the distance to the surface.

impurities. The large dynamic range of the CCD camera permitted extensive line identification during survey spectroscopy with a transmission grating.

Spatial distribution of radiance vs. the distance from the target is presented in Fig. 4. Most intense lines (over the entire measured spectral range of 10–1500 Å and spatial range up to 40 cm distance) belong to CV 40.3 Å and CVI 33.7 Å. From the ratios between these two lines one can conclude that for distances of 5–40 cm the temperature exceeds 10 eV and increases with the distance. Meanwhile there are no distinct CV 3-2 (248.7 and 227.2 Å) lines. This suggests that the process responsible for carbon heating throughout the target plasma does not seem to be thermal heating by electrons. A slowdown of incoming hydrogen ions can ionize and excite carbon ions. Thus this appears to be long scale shielding of the target by eroded material.

One can estimate absolute values of radiation losses from the bulk of the target plasma from Fig. 4 data by using the measured diameter in VUV light as 5 cm. Presuming surface character of the radiation source at carbon resonances, the losses per square centimeter of stream cross-section are equivalent to 100 J/cm^2, a lower estimate due to the averaging. Thus only less than 10% of the incoming energy is radiated by eroded graphite as carbon emission.

5. Conclusions

The graphite target plasma measurements were performed on the MK-200UG installation with the incoming hydrogen plasma of 1.5 kJ/cm^2 energy density and 40 μs pulse duration in a 25 kG longitudinal magnetic field. Transmission grating spectroscopy, enhanced by using an absolutely calibrated CCD camera, have brought about the following results.

POCO target plasma spectra over the whole measured range of 10–1500 Å were identified as carbon radiation, mainly CV 40.3 Å and CVI 33.7 Å resonance lines; eroded carbon spread into the source plasma stream at least over 40 cm distance from the target surface; electron temperature of the target plasma at 5–40 cm distance was > 10 eV; absolute value of the carbon radiation yield integrated over a 40 cm length plasma column was about 0.1 kJ/cm^2 of the incoming 1.5 kJ/cm^2 energy flux.

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