Space resolved impurity detection in the EUV range using a transmission grating based imaging spectrometer on NSTX

Deepak Kumar
D. Stutman, R. E. Bell, M. Finkenthal, D. Clayton, K. Tritz, B. Gaither, B. P. LeBlanc, A. Diallo, M. Podesta

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Abstract

The transmission grating based imaging spectrometer (TGIS) is a simple and compact device to measure space resolved impurity spectra in the EUV range. This poster describes the spectral and spatial characteristics of impurity emission from different operating conditions of NSTX: Neutral beam heated, Ohmic heated and RF heated plasmas. Impurity fractions determined from modeling of such spectra are used for analyzing the data from a multi-energy soft x-ray array (P1.134). The parameters of the TGIS are – spectral coverage of 30-700 Å, spectral resolution of 10 Å, spatial resolution of 1°, exposure time of 400 ms. This poster also describes significant upgrades to spectrometer which have been tested in the laboratory - including exposure time of 10 ms, and direct photon detection using a CCD camera.
Principle of operation – space resolved spectra

Free-standing Transmission Grating (d=2000 Å)
Efficiency calibrations

Expected MCP gain variation
Kowalski et. al, Applied Optics (1986)
Spatial and wavelength calibration on a Penning Ionization Discharge

The Penning ionization discharge provides a stable dc plasma source for calibration and testing. $T_e \sim 5$ eV, $n_e \sim 5 \times 10^{13}$ cm$^{-3}$, significant fast electron population. Different combination of gases and electrodes – He/Ne/Ar, Al/Cu/CuW.
Testing and development on a Penning Ionization Discharge

Measurements can also be made along the plasma/magnetic axis.

Al electrodes with Ne gas

- Ne I 736 Å
- Ne II 461 Å
- He II 304 Å
- He II 584 Å
- Al IV 160 Å

Al electrodes with He gas

- He II 304 Å
- He II 584 Å

Magnetic Axis
Installation of TGIS on NSTX

Compact installation on NSTX

15 cm

TGIS provides impurity fractions to ME-SXR

2010 run parameters: Wavelength coverage 30-700 Å, Resolution 10 Å, Spatial resolution ~ 3 cm, Image acquisition ~ 3 fps
Typical spectrum from NB heated NSTX plasma

Region of intense beam interaction

Vignetted region

Exposure time of spectra

Traces of Cl, Fe

CX signals (C, O)

Shot142192

630 A : O V + O VIII \(_{5-4}\)

521 A : C VI \(_{4-3}\)

415 A : Cl XV

384 A : Cl XIV

384 A : 2 \times 182 A

335 A : Fe XVI

293 A : O VIII \(_{4-3}\)

268 A : 2 \times 135 A

237 A : Cl XIV

190 A : 2 \times 100 A

182 A : C VI \(_{1-2}\)

135 A : C VI \(_{4-2}\) + Li \(_{2-1}\)

102 A : 3 \times 34 A + O VIII \(_{3-2}\)

69 A : 2 \times 28 A

Tangency Radius (m)
Example of core impurity accumulation and higher $P_{\text{rad}}$

Exposure time of spectra

Cl, Fe peaking
At the core

Vignetted region
W injection experiments on NSTX

Reference

W injection

W signatures

50-70 Å W quasi-continuum

TEXTOR W spectrum
Wada et al 2001
Spectrum from RF heated plasma

Exposure time of spectra

Vignetted region

Cu from arcing in RF antenna
Computed brightness of C VI n=3-2 CX line used as an intensity reference

A model for neutral beam density was implemented.

\[ n_n(x) = n_0 e^{-\sigma l n_e} \]

- Neutral beam density
- Beam stopping cross section

\[ E(x) = n_C \sum_i n_{n_i} \sigma_i v_i \]

- Emissivity
- Carbon density (from CHERS)
- CX cross sections (literature/ADAS)
Simulated brightness profile of CX lines agrees well with measurements.

Region of vignetting
Determination of impurity fractions

- For non-resonant EUV line, the contribution from collisional excitation is negligible compared to the CX contribution. Thus the CX brightness can be directly used to measure low Z impurity fractions, e.g.,
  \[ n(O^{8+}) \approx 0.1 \times n(C^{6+}) \]

- For resonant EUV transitions, collisional excitation is comparable to CX. Without modeling transport and thermal charge exchange, the collisionally excited lines can only give an approximate impurity fraction. \[ n(\text{Cl}) \approx 10^{-4} \times n_e, \quad n(\text{Fe}) \approx 10^{-5} \times n_e \] (when present)
• The modeling of TGIS indicates $n(\text{Cl}) \sim 10^{-4} \times n_e$ and $n(\text{Fe}) \sim 10^{-5} \times n_e$
• The impurity content determined by TGIS enables modeling the ME-SXR emission.
• For further details on the novel multi-energy soft X-ray diagnostic see P1.134.

The diagnostic package consisting of ME-SXR and TGIS has very good potential in applications ranging from impurity monitoring, transport, fast $T_e$ measurements, etc. See P5.049
TGIS upgrade for NSTX 2011: fast readout

Image readout using a lens coupled CCD camera enables Time response \(\sim 10\) ms. Sample spectra from PID with 10 ms exposure is shown above.
TGIS upgrade for NSTX 2011: improved λ, space resolution, Mo detection

- Decreasing the slit sizes to 50 μm has improved the spectral resolution to 6-7 Å.
- A 1 μm Parylene-N filter has been installed on one half of the spectrum to suppress the photons from second order Carbon Ly-α, and thus enhance the detection of M-shell Mo emission around 75 Å.
A TGIS with ANDOR Ikon-M 934 [DO] was used to measure spectra from Penning Ionization Discharge.

High resolution (4 Å) spectra obtained by the ANDOR CCD.
High performance EUV CCD based TGIS for W experiments on FTU

Dimensions in inches

Total reflection mirror -optional (short-\lambda
cutoff)
The TGIS based on X-ray CCD detector is designed to provide spectra with high spectral (4 Å), time (50 ms) and space resolution (16 chords).

Princeton Instruments, PIXIS-XO: 400B
Other advanced detectors for TGIS

- Using an MCP based detector has the advantages of being robust to neutrons and gammas, and also having a wide spectral response.
- A cross delay line detection based MCP combines the advantages of the MCP with fast detection (photon counting).
Summary

• TGIS measures space resolved spectra for impurity monitoring and ME-SXR modeling on NSTX

• TGIS + ME-SXR can make a novel diagnostic package for \((n_z, T_e)\) measurements for fusion plasma experiments.

• NSTX TGIS upgrades for the 2011-12 campaign improve spectral resolution (6 Å), spatial resolution (\(\sim 1\) cm) at faster time response (\(\gtrsim 10\) ms).

• Direct detection of photons by an EUV CCD camera has been tested in the laboratory towards future W experiments on FTU.
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