Dual transmission grating based imaging radiometer for tokamak edge and divertor plasmas

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Outline

• Results from a XUV Transmission Grating Imaging Spectrometer (TGIS)
• Applicability of moderate spectral resolution, and good space and time resolution radiated power measurements ($P_{rad}(\lambda)$) from the divertor/edge
• Design and results from the operation of single transmission grating imaging spectrometers.
• Design of dual transmission grating imaging radiometer for the divertor/edge.
Transmission grating based imaging spectrometer

**Principle of operation: space resolved spectra**

- **2-D detector**
- **Free-standing Transmission Grating (d=2000 Å)**
- **imaging slit**
- **entrance slit**
- **Plasma**
- **Heating neutral beam**
- **150 mm conflat**
- **CsI coated MCP detector**
- **Entrance slit**
- **Imaging slit**
- **Zero order block**
- **image readout**
Installation of TGIS on NSTX

Compact installation on NSTX

2010 run parameters: Wavelength coverage 30-700 Å, Resolution 10 Å, Spatial resolution ~ 3 cm, Image acquisition ~ 3 fps
TGIS on NSTX – NB heated shot

Region of intense beam interaction
Shot142192

Traces of Cl, Fe

CX signals (C, O)

630 Å: O V + O VIII\textsubscript{5-4}
521 Å: C VI\textsubscript{4-3}
415 Å: Cl XV
384 Å: Cl XV
364 Å: 2 x 182 Å
335 Å: Fe XVI
293 Å: O VIII\textsubscript{4-3}
268 Å: 2 x 135 Å
237 Å: Cl XIV
200 Å: 2 x 100 Å
182 Å: C VI\textsubscript{3-2}
135 Å: C VI\textsubscript{4-2} + Li III
102 Å: 3 x 34 Å + O VIII\textsubscript{3-2}
66 Å: 2 x 33 Å
Impurity fractions determined for NB heated shots: (a) $n(O) \sim 0.002 \times n_e$

(b) Li outside LCFS, not inside

(c) $n(Cl) \sim 0.001 \times n_e$

(d) $n(Fe) \sim 10^{-5} \times n_e$ (when present)
TGIS on NSTX – Ohmic shot

Shot141739

Electron Density \times 3 \times 10^{13} (\text{cm}^{-3})

Electron Temperature (\text{keV})

Plasma Current (\text{MA})

Radiated Power (\text{MW})

Line density \times 10^{-16} \text{ cm}^{-2}

Tangency Radius (\text{m})

1.43 1.37 1.31 1.24 1.17 1.1 1.03 0.95 0.88 0.8

420 A: C IV
384 A: C IV
312 A: C IV
135 A x 2: Li I
135 A: Li III
34 A: C VI
Abel inversion reveals space localized edge emissivities.
Detection of Li, C, He in the edge and Cu (from antenna arcs) further inside.

Shot142001

TGIS provided moderate spectral resolution space resolved spectra from a wide range of charge states Cu XIX to Li III and C IV. Thus TGIS can be used to diagnose wide range of $T_e$ as available in divertor and edge of tokamaks.
TGIS - modified

- TGIS modified to use Princeton Instruments PIXIS XO 400B as 2D detector
- XUV spectrometer
  - Range = 30-800 Å
  - Wavelength resolution = 4 Å
  - Field of view = 5.7°
  - Angular resolution = 0.6°
- VUV spectrometer
  - Range = 100-2000 Å
  - Wavelength resolution = 40 Å
  - Field of view = 3.2°
  - Angular resolution = 0.3°
Sectional cuts for the XUV and VUV TGIS
Initial work on divertor diagnostics done on Penning Ionization Discharge

Operating characteristics:

Voltage = 0.5-2.5 kV  
Current = upto 2.5 A  
Background pressure = 3-25 mTorr  
Magnetic field ~ 0.2 T

$T_e \sim 1-2 \text{ eV}$  
$n_e \sim 10^{13} \text{ cm}^{-3}$

Fast electron population  
Gases – He, Ne, Ar  
Electrodes - C, Al, Cu, CuW, W
XUV and VUV spectrometers tested with Ne-Al

- Transmission grating based spectrometers with CCD detection (Princeton Instruments PIXIS) have been tested with XUV (d=2000 Å) and VUV (d=1 μm) gratings.

- The spectrometers operate in a survey mode. Binning the pixels on the detector exploits the trade off between high spectral resolution and high spatial/time resolution. See the XUV spectrum from Ne-Al operation of Penning on the next slide.

Ne-Al spectrum with VUV grating and PIXIS detector

- Ne II 2s^22p^5-2s2p^6 461 Å
- Al II 3s^2-3s3p 1670 Å
- Al II 3s-3p 1860 Å
No binning
3 s exposure

15x spatial binning
10 ms exposure

15x spatial binning
15x spectra binning
1 ms exposure

Al IV 160 Å
Ne IV
Ne II, III
Ne II 446 Å
Ne III 489 Å
Binning enabled fast time response in both XUV and VUV

Example of 10 ms exposure spectra obtained from PID
Future plans – extension to dual grating imaging radiometer

Space resolved $P_{\text{rad}}(\lambda)$ measurements will give approximate $T_e$ and $D$ estimates. See Details in Poster by D. Clayton et. al. (P.4.48 Tuesday afternoon).
Design of dual grating Imaging Radiometer

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VUV range</th>
<th>XUV range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral coverage</td>
<td>200 – 2000 Å</td>
<td>20 – 200 Å</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>43 – 61 Å</td>
<td>~ 10 Å</td>
</tr>
<tr>
<td>Angular view</td>
<td>±8°</td>
<td>±8°</td>
</tr>
<tr>
<td>Angular resolution</td>
<td>0.33°</td>
<td>0.33°</td>
</tr>
<tr>
<td>Detector coverage</td>
<td>1300 × 990 px</td>
<td>1300 × 445 px</td>
</tr>
<tr>
<td>Grating period</td>
<td>1000 line-pairs/mm</td>
<td>5000 line-pairs/mm</td>
</tr>
<tr>
<td>Input slit dimensions</td>
<td>50 μm × 2.5 cm</td>
<td>100 μm × 2.5 cm</td>
</tr>
<tr>
<td>Imaging slit dimensions</td>
<td>100 μm × 0.5 cm</td>
<td>100 μm × 0.5 cm</td>
</tr>
</tbody>
</table>

Design parameters for the low-cost and compact imaging radiometer. Moderate spectral resolution ideal for measuring radiation from high Z materials like W. Expected time resolution ~ 10 ms.
Design of dual grating Imaging Radiometer

Section showing spectral dispersion inside the radiometer.

- Spectrum block
- XUV coverage
- VUV coverage
- Princeton instruments PIXIS XO 1300B
- Face plate
- Baffle
Design of dual grating Imaging Radiometer

Section showing spatial dispersion inside the radiometer.

- 6" conflat nipple
- Spectrum block
- Princeton instruments PIXIS XO 1300B
- Transmission grating
- Baffle
- Imaging slit
- Pumping port
- Face plate
- Input slit
Conclusions

- XUV TGIS demonstrated the capability of measuring impurity emission from a wide range of $T_e$.
- Single grating XUV and VUV TGIS developed with direct photon CCD detector (PIXIS XO 400B).
- A dual TGIS Divertor Imaging Radiometer measuring $P_{\text{rad}}(\lambda, x)$ over the entire XUV-VUV spectral range is a powerful tool for divertor physics studies and code validation (see Clayton et. al. P.4.48 Tuesday afternoon).
- Design study of a dual grating imaging radiometer for simultaneous measurement completed.

References: Click on “Publications” link at http://plasma.pha.jhu.edu/