Design of ITER VUV Spectrometer & Prototype Test in KSTAR

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Design of ITER VUV Spectrometers
Overview of ITER VUV spectrometer

- **VUV Edge Imaging spectrometer (17 nm - 32 nm)**
  - 2 cm spatial resolution at rho/R = 0.85 – 1.03
  - 1-dimension spatial monitoring

- **VUV Core Survey spectrometer (2.4 nm - 160 nm)**
  - 5-channel spectrometers divided in wavelength
  - Mirror optimization for DSM slot minimization

- **Divertor VUV spectrometer (15 nm - 32 nm)**
  - Tungsten influx monitoring at divertor

### 5-channel Core Survey

<table>
<thead>
<tr>
<th>Spectral Channel</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength Range (nm)</td>
<td>2.4-7.8</td>
<td>7.0-16.2</td>
<td>14.4-32</td>
<td>29-60</td>
<td>55-159</td>
</tr>
<tr>
<td>Line Width (nm)</td>
<td>0.021</td>
<td>0.035</td>
<td>0.044</td>
<td>0.054</td>
<td>0.106</td>
</tr>
<tr>
<td>Spectral Resolution (MCP ~80 um)</td>
<td>~236</td>
<td>~296</td>
<td>~382</td>
<td>~465</td>
<td>~377</td>
</tr>
<tr>
<td>Incidence Angle (degree)</td>
<td>3.5</td>
<td>7.0</td>
<td>20</td>
<td>28</td>
<td>45</td>
</tr>
<tr>
<td>Distance: Slit to Grating (mm)</td>
<td>650</td>
<td>470</td>
<td>550</td>
<td>400</td>
<td>300</td>
</tr>
<tr>
<td>Distance: Grating to Det. (mm)</td>
<td>~550</td>
<td>~550</td>
<td>~550</td>
<td>~400</td>
<td>~300</td>
</tr>
</tbody>
</table>

Design Updated by Dr. W. Biel (FZJ, Julich Univ.) using BI CCD instead of MCP detector.
Mirror Tube Mock-up for Alignment Test

Mirror Box Mock-up

Shutter Operation Using Feed-through (double bellows type)
Test of 2-channel prototype spectrometer (VUV survey)
2-Channel Prototype ITER VUV Spectrometer (Ch. 3, 4)

- Hollow Cathode Lamp
  - He, Ne, Ar gas, DC
  - 1-2A, 400-500 V discharge
2-channel Prototype Detector Test

Back-illuminated
CCD, He 2 A, Ch.3

MCP,
He 2 A, Ch.3

Back-illuminated
CCD, Ne 2 A, Ch.4

MCP,
Ne 2 A, Ch.4
Expected Calibration Curves from Efficiencies

- Mirror Reflectivity
- Grating Efficiency
- Detector Efficiency
New Back-illuminated CCD in 2014 Campaign

DO940P-BN (ANDOR) is to be used for 12-30 nm wavelength of VUV survey spectrometer in KSTAR (Until now, MCP+Camera was used, and MCP+Camera will be used for VUV imaging spectrometer)

- Active pixels: 2048 x 512 100 % fill pixels
- Pixel size (W x H): 13.5 x 13.5 μm
- Image area: 27.6 x 6.9 mm
- Maximum TE air cooling: -80 °C
- Maximum spectra rate: more than 1,500 spectra/sec for lower pixels binning, more than 70 spectra/sec for full vertical binning
- Read noise: less than 15 e- at 3 MHz mode
- Dark current: less than 0.00100 e-/pixel/sec
- ADC speed/bits: 16-bit at 3 MHz
- Multi track (row) acquisition rate: ~20 Hz for 20 tracks with 1x20 pixels

Specifications Summary

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active pixels</td>
<td>1024 x 255, (1024 x 256 for BR-DD models only) or 2048 x 512</td>
</tr>
<tr>
<td>Pixel size (W x H)</td>
<td>26 x 26 μm or 13.5 x 13.5 μm</td>
</tr>
<tr>
<td>Image area</td>
<td>Up to 27.6 x 6.9 mm</td>
</tr>
<tr>
<td>Register well depth</td>
<td></td>
</tr>
<tr>
<td>Standard mode</td>
<td></td>
</tr>
<tr>
<td>High Capacity mode</td>
<td>1,000,000 e-</td>
</tr>
<tr>
<td>High Sensitivity mode</td>
<td>600,000 e-</td>
</tr>
<tr>
<td></td>
<td>150,000 e-</td>
</tr>
<tr>
<td>Maximum cooling</td>
<td>-100°C</td>
</tr>
<tr>
<td>Maximum spectra rate</td>
<td>1612 spectra/sec</td>
</tr>
<tr>
<td>Read noise</td>
<td>2.8 e-</td>
</tr>
<tr>
<td>Dark current</td>
<td>As low as 0.00007 e/pixel/sec</td>
</tr>
</tbody>
</table>
Tokamak Test of prototype survey spectrometer
KSTAR VUV Spectrometer Test 2012 Campaign (F-Port)

- Spectrometer table on the F-port deck
- 3 m - long Vacuum Extension Tube
- Two Gate Valves
- One Bellows
- Collimation Mirror Set
  1. Cylindrical 10 cm x 5 cm, R.O.C. = 13.5 cm
  2. Convex 10 cm x 5 cm, R.O.C. = 700 cm
Line of Sight (KSTAR Collimation Mirror)

Plasma area 14 cm

Valve area 7 cm

Slit 14 mm
Ar Puffing Experiment (L-mode)

- #7566, L-mode, Flat-top Ar 20ms Puffing at 2.0s, Ip=400kA

**Before Ar Puffing**

Counts for 13 ms

Counts for 41 ms

**After Ar Puffing**

Counts for 13 ms

Counts for 41 ms

- OVI
- He II
- C IV Fe XVI
- Fe XVI
- Ar XVI
- Ar XV
- Ar XVI

Wavelength (nm)

BI CCD Counts (A.U.)

MCP Detector Counts (A.U.)
Results of UTC-SANCO analysis (KAIST team, J.H. Hong)

- Ar Ion Transport in KSTAR #7566, No ECH, SXR: Soft X-ray (KAIST), VUV: VUV Spectrometer

Red: SANCO Simulation
Blue: Measurement

- Ar ion density: ~10^{16}/m^3 from SANCO

Above result is preliminary one, and fine fitting is on-going.
Both SXR and VUV show an increase in emission intensities of $\text{Ar}^{15+}$ - $\text{Ar}^{17+}$ due to ECH.

Opposite behavior compared to the 2012 L-mode case ($I_p \sim 400$ kA).

Emissivity $\epsilon_z(n_e, T_e) = n_e n_z A(n_e, T_e)$
Correlation between impurity lines (2012-2013)

- Strong positive correlation between C IV vs O VI
- Weak correlation between C IV vs Fe XVI
- Weak negative correlation between (C IV / n_e) vs n_e
- Time evolution of impurity lines also show correlation between CIV and OVI
- The reason is that water on the surface of carbon tiles comes out when plasma surface interaction occurs.
High Ar shot & High Carbon shot

Accumulation of Ar impurity ions or Carbon ions → Cool down of plasma until $T_e < 1$ keV

![Graphs showing impurity emission and discharge time](image)

![Imagery showing plasma accumulation and cooling](image)
Installation of prototype VUV imaging spectrometer
VUV Imaging Spectrometer Optics

Wavelength Range (5-20 nm), Time resolution (~ 3 ms)

Field Mirror (Convex R.O.C = 50 cm)

Ellipsoidal Mirror

Imaging Spectrometer

Slit

220 cm

280 cm

50 cm

120 cm

Field Mirror Reflectivity

~ 10% at 30 deg. incidence

Image Resolution

Incoherent Irradiance

Y coordinate value

Reflectivity (%) vs. Wavelength (nm)
Shutter, Field mirror, Imaging Spectrometer

Field Mirror Box with Goniometer
(Concave R.O.C = 50 cm, Size = 20 cm x 3 cm)
Imaging Pattern of VUV imaging spectrometer

- Active pixels: 1024 x 256 100% fill pixels of CCD
- Pixel size (W x H): 26 x 26 μm
- Image area: 40 mm x 12 mm of MCP adopted to CCD of 27.6 x 6.9 mm by fiber optic taper (40/25 mm reducing)
- Full vertical binning spectra rate: ~90 spectra/sec
- Multi track (row) acquisition rate: ~5 Hz for 6 tracks with 1x20 pixels

25.4 nm He II from Hollow Cathode Lamp

5~7 nm W(tungsten) expected in KSTAR

~5.5 mm Slit Imaged to CCD
Slit Pattern Spacing ~ 2mm

24.6 nm

23.4 nm
ITER VUV Spectrometer is under preliminary design phase: Detailed modeling and mock-up test is on-going

Functional prototype of VUV survey spectrometer is installed in KSTAR, and tested for two years campaign

- C, O, Fe, Ar impurities were found, and statistical analysis was performed
- Ar puffing experiment was performed to study impurity transport for ECH effect

VUV Imaging spectrometer is under preparation to test in KSTAR