Exploration of using neon-like xenon lines on X-ray crystal spectrometers on EAST

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Outline

- Background
- Upgrade of XCS on EAST
- Performance and data validation
- Future collaboration plan
- Summary
Background

- Ar XVII becomes hollow and Ar XVIII is relatively low in the outer low electron temperature region.
- Measuring two spectra simultaneously is one of the way of obtaining the whole profile.

- He-like Ar 0.3-3 keV
- H-like Ar 1.5-10 keV
- He-like Fe 1.5-7 keV
## Parameters of the two-crystal assembly

### Double-crystal assembly for TXCS (He- and H-like Ar)

<table>
<thead>
<tr>
<th>Impurity</th>
<th>Crystal</th>
<th>2d of crystal / Å</th>
<th>Wavelength Å</th>
<th>Bragg angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar XVII</td>
<td>Quartz 110</td>
<td>4.91304</td>
<td>(\lambda_1=3.9494) (W) (\lambda_2=3.9944) (Z)</td>
<td>(\theta_1=53.5010) (\theta_2=54.3927)</td>
</tr>
<tr>
<td>Ar XVIII</td>
<td>Quartz 102</td>
<td>4.56225</td>
<td>(\lambda_3=3.7300) (Ly(<em>\alpha_1)) (\lambda_4=3.7353) (Ly(</em>\alpha_2))</td>
<td>(\theta_3=54.8432) (\theta_4=54.9589)</td>
</tr>
</tbody>
</table>

### Double-crystal assembly for PXCS (He-like Ar and Fe)

<table>
<thead>
<tr>
<th>Impurity</th>
<th>Crystal</th>
<th>2d of crystal / Å</th>
<th>Wavelength Å</th>
<th>Bragg angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar XVII</td>
<td>Quartz 110</td>
<td>4.91304</td>
<td>(\lambda_1=3.9494) (W) (\lambda_2=3.9944) (Z)</td>
<td>(\theta_1=53.5010) (\theta_2=54.3927)</td>
</tr>
<tr>
<td>Fe XXV</td>
<td>Ge 422</td>
<td>2.3098</td>
<td>(\lambda_3=1.8480) (W) (\lambda_4=1.8730) (Z)</td>
<td>(\theta_3=53.1367) (\theta_4=54.1832)</td>
</tr>
</tbody>
</table>
Current XCS system on EAST

- Large area: 83.8*325.3 cm$^2$ /300Hz
- Pixelated: single-photon counting > 1GHz
- Water-cooled for long-pulse operation

Poloidal XCS

- Tokamak chamber
- Crystal chamber

Toroidal XCS

PILATUS 900K

B. Lyu et al. RSI 85 (2014) 11E406
He-like and H-like spectra measured by XCS

TXCS: He- and H-like Ar

PXCS: He-like Fe and Ar

Raw spectra data from TXCS

Helium-like and Hydrogen-like Argon spectra

B. Lyu et al. RSI 87 (2016) 11E326
Data validation of H-like Ar spectra

Good agreement between two spectra was observed!
Comparison between PXCS and TXCS

- Both evolution and radial profiles of Te and Ti for two spectrometers agrees within the uncertainty.
Method of wavelength calibration

- Locked mode
- Comparison with MHD frequency
- Cross comparison with CXRS
Consideration for ITER and CFETR

- ITER XCS is proposed to use W or Kr as the diagnosing ion
- Xenon is another good candidate as for both core and edge diagnostics
  - Higher line intensity than Kr for same radiated power loss

$T_e \approx 4\text{--}10\text{keV}$

$T_e$ up to $30\text{keV}$

Impurity profile prediction on ITER

L.F. Delgado-Aparicio et al., 32nd Meeting of ITPA Topical Group on Diagnostics, May 9-12, 2017, Chengdu, China.
➢ Te > 5 keV, Coronal equilibrium, collisional radiative model.

➢ A simulation of emissivity for Xe and W lines. Coronal equilibrium, collisional radiative model. $n_e = 10^{20}\text{m}^{-3}$. 
Xe-Ar crystal assembly

- New Ne-like Xe crystals with similar Bragg angle to He-like Ar
- Installed on the poloidal XCS to measure two-spectra simultaneously
- X-ray testing with titanium anode shows the crystal reflectivity and potential application for wavelength calibration

<table>
<thead>
<tr>
<th>Line</th>
<th>Wavelength (Å)</th>
<th>Crystal 2d (Å)</th>
<th>Bragg angle (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar XVII W</td>
<td>3.9494</td>
<td>4.913</td>
<td>53.5010</td>
</tr>
<tr>
<td>Xe XLIV</td>
<td>2.7368</td>
<td>6.686</td>
<td>54.9515</td>
</tr>
</tbody>
</table>

Crystal assembly and specification

Setup and test results

Hu et al, RSI 89(2018)10F110
Measurement of Xe spectra

- New lines were observed with Xe injection in both XCS and EUV spectrometers.
- One line was determined to be Xe line through 2\textsuperscript{nd} order diffraction from the crystal.

Comparison of measured spectra with/without Xe:

![Graphs showing comparison of spectra](image)

Lyu et al, RSI in preparation
Ion temperature measurement

- Simultaneous measurement of two spectra provides additional data validation through $T_i$ comparison
- Consistency in the $T_i$ evolution is observed although there is some difference in the absolute value: possibly due to the strong line averaged effect in Ar spectra
- Proof of concept for future high temperature diagnostics

Gaussian fitting for Xe spectra

$T_i$ comparison for Ar and Xe ions

Lyu et al, RSI in preparation
Collaboration plan

➢ Further experimental analysis on Xenon spectra:
  ● Effect on the discharge performance
  ● Wavelength, intensity (effect of impurity transport)
  ● Comparison with EBIT for verification

➢ Wavelength calibration with external source and Ti/Cd anodes
  ● Preliminary lab test proved the feasibility

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ebeam energy</td>
<td>5-30keV</td>
</tr>
<tr>
<td>Beam current</td>
<td>~20mA</td>
</tr>
<tr>
<td>Magnetic field</td>
<td>~1.0T</td>
</tr>
<tr>
<td>Magnet type</td>
<td>NbTi</td>
</tr>
<tr>
<td>Cooling method</td>
<td>Conduction cooled (dry)</td>
</tr>
<tr>
<td>Spectra range</td>
<td>Visible to X-ray</td>
</tr>
<tr>
<td>Element</td>
<td>W (Fe, Xe, Ar)</td>
</tr>
</tbody>
</table>

A compact EBIT for impurity spectra
Summary

- Upgrade of detector technology and two-crystal assembly has significantly elevated the performance in terms of time resolution and high temperature on EAST.

- XCS can provide the ion temperature and rotation velocity profiles in high temperature after the application of double-crystal, with results from He-like and H-like spectra consistent with each other in low electron temperature.

- New crystal testing was ready for probing the Ne-like Xe spectra: a testbed for fusion reactor.
Thank you!

We are here!