MEASUREMENTS OF X-RAY SPECTRA ON ECR-II*

*Work supported by a US DOE SBIR grant and the Office of Nuclear Physics under contract # DE-AC02-06CH11357

B. P. Cluggish, I. N. Bogatu, L. Zhao, J.S. Kim, FAR-TECH, Inc.
R. C. Vondrasek, R. C. Pardo. R. Scott, Argonne Natl. Lab.
ECRIS08
Abstract

- FAR-TECH, Inc. is developing an inexpensive and robust X-ray spectral diagnostic for monitoring electron cyclotron resonance ion sources (ECRIS). To this end, FAR-TECH, Inc. has recently performed extensive measurements of X-ray emission from the ECR-II device in the ATLAS facility at Argonne National Laboratory. We find that both the intensity and the shape of the observed spectra are highly correlated with the charge state distribution (CSD) of ions extracted from the ECR-II plasma as measured by a Faraday cup.

- Experiments were performed in Feb. 2008
Summary

- Inexpensive, robust diode X-ray detectors can provide much useful information about the plasma conditions
- X-ray emission from is strongly dependent on plasma parameters
- Bremsstrahlung intensity increases strongly with RF power
- Bremsstrahlung intensity and effective temperature decreases strongly with gas pressure - opposite $K_{\alpha/\beta}$ line
- Lower frequency heating produces fewer X-rays, lower effective temperature
- X-ray intensity, effective temperature, and charge states all strongly increase with magnetic field
- Future work: Refine shielding to reduce Compton scattering signal
X-ray detector installed on ECR-II at ANL ATLAS facility

Resolution = 600 eV at 60 keV
ECR-II at the Argonne ATLAS facility

11.1 GHz Waveguide

14 GHz Waveguide

X-Ray detector (between coils, not visible)

Mirror coils
Lead Shielding and Alignment System blocks wall X-rays

Stainless Steel “Snout” for positive alignment in aperture in wall of plasma chamber

Vacuum Flange

Detector

Lead Shielding

Port

Aluminum Plasma Chamber
Diagram of Shielding/Collimation

Vacuum Boundary

Plasma

Detector

Pb Pb

W spacer

Pb Pb

Collimation sleeve (stainless steel)

Stainless Steel
Collimation ensures that detector looks only at plasma.
Spectrum provides much useful information about plasma.

Counts

- Argon
- Kα/β lines
- Lead
- Tungsten

Bremsstrahlung

Slope gives effective temperature of tail of EDF

X-ray Energy (keV)
### Argon Plasma Operating Parameters for the experiments

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECRH Power (14 GHz)</td>
<td>300 W</td>
</tr>
<tr>
<td>Argon Gas pressure</td>
<td>1.e-7 torr</td>
</tr>
<tr>
<td>Plasma radius</td>
<td>3.8 cm</td>
</tr>
<tr>
<td>Plasma length</td>
<td>27 cm</td>
</tr>
<tr>
<td>Current in Injection solenoid</td>
<td>530 A → 9200 G</td>
</tr>
<tr>
<td>Current in Extraction solenoid</td>
<td>484 A → 8400 G</td>
</tr>
</tbody>
</table>

- Two frequency heating experiment used 11.1 GHz ECRH as well as 14 GHz
- Argon was default working gas, but helium sometimes used
- Oxygen present at low level due to desorption and dissociation of H₂O.
- Mass spectrometer ion currents measured with a Faraday Cup (FC)
Definition of Measured quantities

- **Measured X-Ray Power**
  \[ P_{XR} = \frac{1}{\tau_{acq}} \int dE \frac{C(E)E}{\varepsilon(E)} \]
  - \( E \) = X-ray energy
  - \( C(E) \) = Counts at energy \( E \)
  - \( \varepsilon(E) \) = Detection efficiency
  - \( \tau_{acq} \) = acquisition time

- Effective (spectral) temperature is slope of high energy tail:
  \[ \frac{C(E)}{\varepsilon(E)} \sim \exp\left(-\frac{E}{T_{eff}}\right) \]

- Charge state distributions are uncorrected Faraday cup currents
Integrated X-Ray Power increases with RF Power

\[ P_{XR} \sim (P_{RF})^{3/2} \]

- Helium
- Argon

Measured X-Ray Power (W) vs. Microwave Power (W)
Argon ion charge state increases with RF power
Intensity of X-ray emission also depends on Argon pressure

![Graph showing the relationship between Ar Partial pressure (1e-7 torr) and Measured X-Ray Power (W)].

- **Bremsstrahlung (all energies)**
- **$K_{\alpha/\beta}$ (x100)**
Increasing argon pressure reduces charge state
X-Ray emission varies strongly with two frequency heating.
Two frequencies: higher frequency gives higher charge states

$P(14 \text{ GHz}) + P(11.1 \text{ GHz}) = 300 \text{ W}$

Ar CSD vs % 11.1 GHz RF power

Highest Charge States with non-zero amount of lower frequency

**Charge State**

11.1 GHz Power (%)

- 0
- 8
- 17
- 33
- 50
- 67
- 83
- 100

**FC current (microamps)**

0
8
17
33
50
67
83
100
X-Ray emission increases strongly with magnetic field

$B_{\text{min}}$ is minimum value of magnetic field

$B_{\text{ECR}}$ is value of magnetic field at ECR resonance

Note that mirror field profile maintained as constant
Increasing B-field increases charge states

![Graph showing Ar CSD vs B-field](image)

- **FC current (microamps)**
- **Argon Charge State**
- **B_{min}/B_{ECR}**
  - Blue: 0.55
  - Yellow: 0.62
  - Red: 0.68