Spectroscopy of a Penning discharge

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Context for the study

Large fusion experiments at other institutions require support diagnosing edge plasma – collaboration with PPPL

Our Penning discharge has temperature and density close to that of a fusion reactor’s edge plasma

\[ \sim 1\text{eV}, 10^{13} \text{ electrons/cm}^3 \]
Brief plasma primer

High temperatures ionize gas and create electron and ion species.

Inside plasma electromagnetic interactions dominate; outside, plasma is neutral.

Plasma can exist over temperature and density regimes of 7 and 30 orders of magnitude, respectively.
What we hope to accomplish

Benchmark our spectroscopic instruments for use on NSTX

Measure intensity of spectral emissions from ions in various charge states

Infer plasma conditions \((T_e, N_e)\) from relative intensity of emissions

\[ n_{ion} \propto I \]
Experimental Setup

Operating current: 0.5-2A, Voltage: 0.4-2.0kV, Neutral pressure: 4-7mTorr
Detector Specifications: Visible Spectrometer

- Resolution: 1Å at 453nm
- 1200g/mm reflection grating
- Focal length 300mm
- Range: 185nm to infrared
- Entrance slit width is 20μm
- Secondary slit placed in front of entrance slit, width 0.4mm
Detector Specifications: Apogee CCD Camera

- Operating range: 380-900nm
- Resolution: 1024x1536 pixels
Visible Spectrometer & CCD Camera Implementation

- Entrance slit & micrometer
- Visible Spectrometer
- CCD Camera
- Glass window
- Experiment chamber
- Inlet gas line with valves
- High voltage supply
- Cooling water supply
Visible Spectrometer & CCD Camera Implementation

- Spectrometer entrance slit
- Secondary slit
- Entrance slit & micrometer
Sample Data, Visible Spectrometer

Argon with copper electrodes, 5s exposure

Cu I 510.55nm
Cu I 515.32nm
Cu I 521.82nm
Cu I 529.25nm

Pixel intensity value
Wavelength (nm)

- 6.0mTorr, 0.57kV, 0.36A
- 6.1mTorr, 0.82kV, 1.03A
- 6.2mTorr, 0.70kV, 0.68A
- 6.3mTorr, 0.90kV, 1.55A
- 6.7mTorr, 0.99kV, 1.55A
- 7.3mTorr, 1.11kV, 2.00A
Sample Data, Visible Spectrometer

Argon with copper electrodes, 5s exposure

- 6.0mTorr, 0.57kV, 0.36A
- 6.1mTorr, 0.82kV, 1.03A
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Wavelength (nm) vs. Relative intensity graph showing the spectral lines for different pressures and voltages.
Sample Data, Visible Spectrometer

521nm Cu I line, 5s exposure

Pixel intensity value vs Wavelength (nm)

- 2.5mTorr, 0.95kV, 0.80A
- 4.8mTorr, 0.92kV, 0.96A
- 10.5mTorr, 0.90kV, 1.05A
- 15.4mTorr, 0.92kV, 0.96A
- 22.0mTorr, 0.95kV, 0.81A
Identifying Ar and Cu lines for future experiments with W

Argon with copper electrodes, 5s exposure

W I, 400.9nm

ITER has chosen tungsten for plasma-facing components. In a fusion plasma, W constitutes an impurity with significant energy radiating ability.
Detector Specifications: VUV Spectrometer & AXUV Photodiode

- Range: 1000-2000Å
- Resolution: ~8Å
- Entrance and exit slits set to 50µm
- Signal output fed to amplifier
- In future experiments, a photomultiplier tube with a phosphor insert will be used for increased efficiency

![Detector Diagram](Image)
VUV Spectrometer and Photodiode Implementation

Entrance slit
VUV Spectrometer
Photodiode post
Exit slit
Gate valve
Experiment chamber
Sample spectrum, VUV Spectrometer

Ne with Al cathodes 0.75kV, 0.72A, 5mTorr

- **Al II**
  - 1670.8Å
  - $2p^63s^2-3s3p$

- **Al II**
  - 1719.4Å, 1721.1Å, 1721.3Å
  - $3s3p-3s3d$

- **Al II**
  - 1760.1Å, 1762.0Å, 1763.9Å, 1764.0Å
  - $3s3p-3p^2$

- **Al III**
  - 1854.7Å
  - $2p^63s-2p^63p$

- **Al III**
  - 1862.8Å
  - $2p^63s-2p^63p$
Al II line ratios from VUV spectrometer data indicate electron temperature of 3eV and density of the order of $10^{13}$ e/cm$^3$.

Ratio of number of 3s3p-3s3d transitions to number of $3s^2$-3s3p transitions is constant under current scaling.
Summary

Penning discharge plasma has parameters comparable to that of tokamak edge plasma.

Ready to undertake study of W in Penning discharge after work with Ar Cu plasma.

Have measured the capabilities of our two diagnostic systems.
Acknowledgements

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Thank you for listening.

Questions?