Edge Transport Measurements with the New Multi-Energy Soft-X-Ray Diagnostic on NSTX

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Abstract

The new multi-energy soft-x-ray (ME-SXR) diagnostic is utilized for transport measurements in the NSTX plasma edge. The diagnostic system consists of five 20-channel photodiode arrays, four with different x-ray filters, forming a 4-color radially-resolved x-ray camera with the fifth array acting as a bolometer. The diagnostic has a mid-plane tangential view of the plasma edge from r/a ~ 0.6 to the SOL, with a spatial resolution of ~ 1 cm. Variable-gain transimpedence amplifiers provide a good signal-to-noise ratio with a time resolution > 10 kHz. The system was successfully commissioned at the end of the 2010 NSTX run campaign and an initial impurity particle transport experiment was performed using neon gas puffs. The impurity transport code STRAHL is now being used to determine the neon diffusive and convective transport coefficients D and v. An initial assessment, using previous estimates of the transport coefficients [1], shows reasonable agreement between the measured and computed SXR emissivity profiles. The capability to discriminate between D and v in this type of experiment will be discussed. For the upcoming NSTX run campaign, additional impurities will be used to study the Z scaling of impurity particle transport in a variety of conditions, including the application of 3D fields.

Overview

• ME-SXR is a compact x-ray diagnostic providing edge $T_e$, $n_e$, and impurity profile info with high spatial and time resolution

• Impurity transport modeling with a synthetic x-ray diagnostic is being implemented to determine diffusive and convective impurity transport coefficients from a perturbative gas puff

• Other ME-SXR uses include fast $T_e$ measurements and impurity monitoring in conjunction with a transmission-grating based imaging spectrometer: see P5.049 for overview of JHU plasma spectroscopy diagnostic suite

• Plans for the FY2011-12 run campaign include impurity transport measurements as part of larger experiments to characterize multi-channel transport in NSTX, particularly edge transport with the application of lithium and 3D fields
Five 20-Channel Photodiode Arrays have a Radial Resolution of ~ 1 cm, with Coverage from $r/a \sim 0.6$ to the SOL

- Plasma profiles have steep gradients in the edge, thus improved spatial resolution (vs core diagnostics) is required
  - Similarly, more filters are needed for the wide range of temperatures, and variable amps for the large variability in emission intensity
Different Filters Provide Spectral Resolution, and Variable-Gain Amplifiers Provide Good Time Resolution

- Four arrays have filters (currently 0.3 µm Ti, 5 µm Be, 15 µm Be, 50 µm Be), and the fifth array has no filter (bolometry).
- Preamplifiers have digitally-controlled variable gains and are the limiting factor on time resolution.

![Neon Emission at 450 eV](image)

<table>
<thead>
<tr>
<th>Gains</th>
<th>Bandwidth</th>
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<tbody>
<tr>
<td>25 kΩ</td>
<td>300 kHz</td>
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<tr>
<td>100 kΩ</td>
<td>120 kHz</td>
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<tr>
<td>10 MΩ</td>
<td>11 kHz</td>
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<tr>
<td>20 MΩ</td>
<td>6 kHz</td>
</tr>
</tbody>
</table>
ME-SXR is a Compact Diagnostic Providing Edge $T_e$, $n_e$, and Impurity Profile Info with High Spatial and Time Resolution

- 6” Conflat flange
- DB25 vacuum feedthroughs
- Custom PCB adaptors
- Five 20-channel AXUV20 x-ray diode arrays from IRD Inc.
- Internal baffles prevent cross-talk between arrays
- Filter holders keep foils in
- Pinhole rails allow variable aperture widths
- 20 element diode array with PCB adaptor
- 32-channel 10V/V back-end amplifiers
- 20-channel transimpedence preamplifiers with digital gain control
Transport Coefficients can be Found Using STRAHL Impurity Transport Code (R. Dux) and a Synthetic X-Ray Diagnostic

- \( n_{I,Z} \) depends on ionization/recombination/charge exchange rates (ADAS) and on impurity particle transport (STRAHL)

\[
\frac{\partial n_{I,Z}}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} \left( D^* \frac{\partial n_{I,Z}}{\partial r} - v^* n_{I,Z} \right) + Q_{I,Z}
\]

\[
Q_{I,Z} = -(n_e S_{I,Z} + n_e \alpha_{I,Z} + n_H \alpha_{I,Z}^{\text{ex}}) n_{I,Z} + (n_e S_{I,Z-1}) n_{I,Z-1} + (n_e \alpha_{I,Z+1} + n_H \alpha_{I,Z+1}^{\text{ex}}) n_{I,Z+1}
\]

- A synthetic diagnostic uses \( n_{I,Z} \) from STRAHL to calculate the intensity that should be measured with ME-SXR

\[
I = G \cdot R_{\text{diode}} \int_{\text{chord}} dl \ n_e(l) n_{I,Z}(l) \int_0^\infty dE T_{\text{filt}}(E) \cdot [P_{\text{cont}}(E, T_e(l)) + P_{\text{line}}(E, T_e(l))]
\]

\begin{align*}
\text{EFIT} & \quad \text{Thomson Scattering} & \quad \text{ADAS}
\end{align*}

- \( D, v, \) and \( Q_{I,0} \) (an additional source term from impurity gas puffing and recycling) are free parameters that are adjusted to fit synthetic data to ME-SXR measurements
A Short (5 ms) Puff of Neon Gas in the Edge of an H-mode Discharge is Utilized for Transport Measurements

• Perturbative transport measurements are performed by puffing trace amounts of neon (or other impurities for $Z$-scaling) into the plasma edge
  – Neon puff is large enough to dominate measured x-ray emission but small enough to be non-perturbative to the bulk plasma

• Trial run: 1.1 MA, 5.5 kG H-mode discharge, with temperature and density profiles shown below
STRAHL Simulations Provide a Good Match to Initial High-Resolution Inversions of ME-SXR Profile Measurements

- Transport profiles based on previous core measurements
- Core bolometer used to roughly constrain neutral source
  - ME-SXR bolometer data unavailable for trial run
- Next step: a chi square minimization to improve this fit

5 ms Ne puff

5 Micron Be Emissivity

5 Micron Be, Modeled Emissivity

15 Micron Be Emissivity

15 Micron Be, Modeled Emissivity

50 Micron Be Emissivity

50 Micron Be, Modeled Emissivity

Diffusion Profiles

Convective Velocity (m/s)

Convective Velocity (m/s)
Diffusion Dominates Transport Early in the Perturbation

- In the case of larger diffusion, neon is initially transported more rapidly towards the core.
- After about 50 ms in this simulation, $D = 0.3 \text{ m}^2/\text{s}$ and $D = 0.7 \text{ m}^2/\text{s}$ are difficult to distinguish.
Convection Changes the Neon Charge State Distribution, Causing Different Responses on Each Array

- Inward convection transports neon ions towards the core, where they are stripped of electrons.
- Outward convection keeps neon in the edge, where it remains in a lower charge state.
The Bolometer Array Enables the Differentiation of Effects of Increased Convection from those of an Increased Ion Source

- Increased inward convection increases filtered signals without a significant change to total power
- An increased gas puff increases all charge state densities, and thus all signals, uniformly
Simulated Data is Used to Understand the Capabilities and Limitations of Using STRAHL to Determine Transport

- Simulated data is generated by adding Gaussian noise, consistent with actual ME-SXR noise, to STRAHL results, using transport profiles shown below (solid lines)
- STRAHL is then run for a variety of additional transport profiles for comparison (dashed lines)
- In each case, the chi square of the fit of the model to the simulated data is computed
A Perturbation in Impurity Density is Needed to Distinguish the Diffusive and Convective Transport Coefficients

- At any given time, no unique $D$ and $\nu$ solution exists
  - Dashed lines highlight possible solutions (minimum chi squares)
- However, only one unique solution for $D$ and $\nu$ consistently exists throughout the time evolution of the perturbation

\[
\log(\text{Chi Square}), t = 2.1 \text{ ms}
\]

\[
\log(\text{Chi Square}), t = 4.6 \text{ ms}
\]

\[
\log(\text{Chi Square}), t = 10.6 \text{ ms}
\]

\[
\log(\text{Chi Square}), t = 13.4 \text{ ms}
\]

\[
\log(\text{Chi Square}), t = 20.8 \text{ ms}
\]

\[
\log(\text{Chi Square}), t = 38.6 \text{ ms}
\]
The Novel Capabilities of the ME-SXR System Allow an Examination of Various ELM Phenomena in NSTX

5 µm Be Δ(Emissivity)

Edge peaking

High-contrast Δ(Emissivity)  ELM precursor

~1 ms, 7 kHz

Profile hollowing

$D_{\alpha}$ Emission

NSTX

Edge Impurity Transport Measurements with the New ME-SXR Diagnostic on NSTX, D. Clayton (06/27/2011)
**ME-SXR Can Provide a Constraint on Total Impurity Concentrations in NSTX Plasma**

- Carbon density profiles $n_C$ are measured with CHERS
- $n_N/n_C$, $n_O/n_C$ obtained from spectrometers, including the transmission-grating based imaging spectrometer (TGIS)
- Emission from these low-Z impurities (solid lines, left plot) only constitutes ~ 50% of measured emission (points)
- Spectrometers also measure iron in the plasma core
  - Adding Fe to model increases 5 µm signal, not 50 µm signal
ME-SXR Profiles are Consistent with Measurements from Transmission-Grating Based Imaging Spectrometer (TGIS)

- TGIS provides radially-resolved XUV spectra
- TGIS measures chlorine in NSTX, consistent with 50 µm ME-SXR
- See P4.047 for more on impurity modeling with the TGIS
Filtered x-ray emissivity can be written in terms of response functions depending only on temperature ($c_{I,Z} = n_{I,Z}/n_e$ const.)

$$E(n_e, c_{I,Z}, T_e) = n_e^2 \sum_{I,Z} c_{I,Z} R_{I,Z}(T_e)$$

Linearization isolates temperature and density dependences

$$\Delta E = \frac{\partial E}{\partial n_e} \Delta n_e + \frac{\partial E}{\partial T_e} \Delta T_e = \left(2n_e \sum_{I,Z} c_{I,Z} R_{I,Z}\right) \Delta n_e + \left(n_e^2 \sum_{I,Z} c_{I,Z} R'_{I,Z}\right) \Delta T_e$$

$$\frac{\Delta E}{E} = \frac{2\Delta n_e}{n_e} + \frac{\sum_{I,Z} c_{I,Z} R'_{I,Z}}{\sum_{I,Z} c_{I,Z} R_{I,Z}} \Delta T_e$$

Difference between filters eliminates density dependence

$$\frac{\Delta E_1}{E_1} - \frac{\Delta E_2}{E_2} = \left(\frac{\sum_{I,Z} c_{I,Z} R'_{I,Z}}{\sum_{I,Z} c_{I,Z} R_{I,Z}} - \frac{\sum_{I,Z} c_{I,Z} R'_{I,Z}}{\sum_{I,Z} c_{I,Z} R_{I,Z}}\right) \Delta T_e$$
Impurity Transport Measurements are an Integral Part of Several Experiments for the FY2011-12 Run Campaign

• Transport of multiple impurities will be measured as part of the FY2012 OFES 3 Facility Joint Research Milestone investigating multichannel transport

• Transport of multiple impurities will be measured with the application of 3D fields, as part of a larger NSTX experiment to study the effects of RMP coils on multichannel transport

• The full ME-SXR diagnostic will be operating, and a fitting routine (likely MPFIT) will be used to find the diffusion and convection profiles that produce x-ray emission profiles best fitting measurement across time on all five arrays
For More Information…

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- Or Leave your e-mail address for a copy of this poster: