Modeling impurity distribution in an ST using a transmission grating based diagnostic in the EUV range

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Motivation

• The Transmission Grating Imaging Spectrometer (TGIS) forms a diagnostic suite with the Multi Energy Soft Xray (MESXR BP9.00086) system with the following capabilities
  – Model impurity fractions from edge to core, providing spatial distribution over a wide range of plasma temperatures
  – Ability to observe radiation from low Z, medium Z and high Z impurities.
  – Also measures charge exchange signals from low Z impurities
  – Has a very simple design

• This poster highlights the capability of TGIS and also illustrates the modeling of relative impurity fractions
The diagnostic suite – TGIS + MESXR

NSTX mid plane view of TGIS

Schematic of MESXR measuring edge/core emission by filtered diodes
TGIS setup

- Imaging slit
- Entrance slit
- XUV grating
- detector
- 6” conflat
- MCP assembly
- Zero order block
- NSTX mid plane plasma
Device Setup

• Detection
  – CsI coated MCP
  – Phosphor screen
  – CMOS imaging system (380 ms exposure)

• Design advantages
  – Survey spectrometer (50-700 Å)
  – Robust to neutrons
  – Provides spatial impurity distribution
  – Simple and compact

TGIS installed on NSTX
Grating details

- Free standing transmission grating (NTT-ATN/TG-200/11W)
  - Dimensions: 1 mm x 1 mm
  - 5000 lines/mm

![SEM image of the transmission grating area](image)

- Ta absorber
- 0.625mm
- Ta/SiC/SiN/Si
- Si substrate
- Transmission grating area
- Strut width: 0.5 μm
- Grating part: 2.0 μm
Efficiency calibrations

- NIST grating calibrations
- Expected MCP gain variation

Kowalski et al., Applied Optics (1986)
Wavelength calibration using a Penning discharge

Absolute calibration of TGIS will be done by using Andor iKon-M camera as detector
Wavelength calibration using a Penning discharge

He gas + Al cathodes

Ne gas + Al cathodes

He II 584 Å
He II 304 Å
Ne I 736 Å
Ne II 461 Å
Al IV 161 Å
24 Å
Spectra from NBI heated plasma

- Spectra is dominated by low Z CX signals.
- With traces of Cl

Region of intense beam interaction
TGIS is a sensitive monitor of med Z impurity accumulation in the core.

The radiated power is very high because of impurity accumulation.

Exposure time of spectra

Accumulation in the core
Spectra obtained from ohmic shot

- Spectra from ohmic shots is dominated by edge emissions
- It confirms the interpretation of low Z charge exchange lines in NBI heated shots
Spectra of high Z impurity - Tungsten

- Reference
- W injection

W signatures

50-70 Å W quasi-continuum

Intensity vs. λ (Å)
Model for TGIS charge exchange emission

- Neutral beam density modeled for each beam (and each component). Attenuation of different beam components is illustrated.

\[ n_n(x) = n_0 e^{-\sigma_l n_e} \]

Path length along beam

Neutral density from each beam component

Stopping cross section

A Gaussian profile is assumed for each beam

Coefficients from Janev et. al. Nuclear Fusion (1989)
Calculation of C charge exchange emissivity

\[ E(x) = n_C \sum_i n_{n_i} \sigma_i v_i \]

- Emissivity
- Neutral beam density
- Carbon density (obtained from CHERS)
- Neutral velocity
- CX cross section
- Sum over beam components
The model successfully predicts the spatial profile of brightness of CX lines.

Charge exchange coefficients obtained from Isler (1994), Isler and Langley (1985)
Charge exchange brightness strongly dominates collisional excitation for non-resonant lines

- Representative simulated examples of C and O shown below.
For resonant transitions – brightness from collisional excitation is comparable to brightness from CX.

Brightness profile of simulated collisional excitation is expected to fit the experimental data better after including transport in the model.
Determination of impurity fractions
Low Z impurity fraction from CX lines

- Closest lines are chosen to mitigate the effect of gain variation of grating and MCP over wavelength.
- The brightness of C charge exchange lines obtained from modeling using CHERS data is used as a reference for absolute calibration.
- By the measured brightness of O CX lines (4-3: 293 Å and 5-4: 630 Å) –
  \[
  \frac{n(O^{8+})}{n(C^{6+})} \sim 12\%
  \]
- N is observed sometimes in NSTX. However, the CX line of 4-3 transition at 382 Å, is blended with Cl line. Thus an upper limit from recent NSTX runs is \(n(N^{7+})/n(C^{6+}) < 20\%\).
Spectral signature of Li

- Li III (2-1) transition at 135 Å is blended with CX lines from C VI (4-2) and N VII(3-2).
- An estimate of the CVI (4-2) brightness compared to the measured brightness is shown.
- The blend makes it extremely difficult to quantify the amount of Li in the plasma.
- SOLUTION: Extending the spectral range of TGIS to include Li III (3-2) transition at 728 Å. (Planned for 2011).
Li Lyman alpha is the most dominant line in loweus spectrometer.
Amount of Cl in the plasma

- The collisional modeling of TGIS suggests $n(\text{Cl}) \sim 10^{-4} \, n_e$. Change in MCP and grating efficiency over the wide spectral range can account for the presence of higher concentrations of $\text{Cl} \sim 1 \times 10^{-3} \, n_e$, as predicted by ME-SXR.
TGIS complements high resolution spectrometer

- Data from XEUS is dominated by low Z charge exchange spectra
- Trace Cl does not appear in short wavelengths (explained in the following slides)
SPRED sees strong Cl lines

Cl XIV 237 A

Cl XV doublet
384 and 415 A
Synthetic spectra helps explain the absence of Cl lines in shorter wavelengths

- The synthetic spectra of Ar and Fe below illustrates the fact that the brightness of medium Z impurities is highest in the wavelength range (100-500 Å). Thus this wavelength region is better suited to detect medium Z impurities.

Note: Because of the lack of Cl data in Chianti, Ar lines were simulated instead.
Future work

- Modify the model to generate all the beam stopping cross sections, the charge exchange cross sections and the collisional excitation cross sections using ADAS.
- Absolute calibration of grating and MCP at higher wavelengths (planned after the run) will be done against a calibrated Xray CCD camera.
Advanced detectors which can provide better efficiency and time resolution

- Cross delay line anode + MCP
- Direct photon detection

Princeton Instruments, PIXIS-XO: 400B
Summary

• TGIS provides strong constraints on impurity densities needed for ME-SXR modeling.
• Further calibrations will improve the accuracy of the impurity densities.
• Results from the 2010 run indicate that the optimal spectral range for the TGIS on an ST device like NSTX should be 100-800 Å.
• TGIS + ME-SXR make a novel diagnostic suite to provide \((n_e,n_z,T_e)\) for fusion plasma experiments.
• Direct detection of photons by an X-ray CMOS camera can improve the time and spectral response of TGIS.
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References

• http://www.chem.queensu.ca/people/faculty/Stolow/Research/Facilities.html

• http://www.sensorsciences.com/
Chlorine (accumulation)
Ohmic shot – spatial profile (edge)
Typical shot – spatial profile
(Edge + CX + core)