Investigation of Plasma Instabilities by Fast Profile Reflectometer Measurements in DIII-D

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Outline

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• Investigation of Edge Harmonic Oscillation (EHO) by fast profile reflectometer measurements
• Summary
Motivation

- The improved fast profile reflectometer (Q-band, 33-51 GHz) has:
  - high temporal resolution (10 µs)
  - high spatial resolution (≥ 2 mm)
  - The measured density range from 0 to 3.2x10^{19} m^{-3} for high time resolution in dual-polarization (X- and O- modes) received simultaneously

- The profile measurement can provide profile modification associated with plasma instabilities
  - Edge localized mode (ELM) in H-mode plasma
  - Edge harmonic oscillation (EHO) in quiescent double barriers (QDB) plasma
Some Key Improvements of Q-band System for Instability Investigation

• The detail improvements for our system presented by Dr. Guiding Wang

• Hardware
  – Optimization of polarization match, reducing the spurious reflections and increasing the SNR
  – Currently, dual-polarization simultaneous operation, increasing density coverage up to $3.2 \times 10^{19} \text{ m}^{-3}$ in high performance measurement

• Software
  – Implementation of robust method for automated identification of the zero density start position, reducing uncertainties associated with automatic analysis
  – Implementation of robust and automatic profile analysis program to cope with large volume of reflectometer data, up to 60 MB per shot
Fast Profile Reflectometer Can Track SOL Density Profile Evolution for Type I ELMs in Long Time Record

- SOL density rise up during every ELM
- Robust Analysis of 6000 density profiles demonstrates the good capability of our fast profile reflectometer to study the edge density modification by ELMs in long time record.
- Reflectometer: X-mode
- Plasma condition:
  - \( I_p = 1.4 \text{ MA} \)
  - \( \langle n_e \rangle = 4.5 \times 10^{13} \text{ cm}^{-3} \)
  - Lower single node configuration
Reflectometer Profiles Are in Good Agreement with Thomson Scattering Data During ELMs

Reflectometer Profiles Compared to Thomson Data pre- and post-ELM

Reflectometer (in X mode)

pre-ELM
post-ELM

TS Data

n_e (m^-3)

1x10^{19} 2x10^{19} 3x10^{19} 4x10^{19}

ρ

0 0.9 1 1.05 1.1 1.15

110399
SOL Density Profile Modification by Type I ELM-Density Expands to Wall

- Profile time resolution is 25 µs
- Profile is expanded to the wall position at the onset of Type I ELM.
- Calculation of $V_r$ of density layer will show next
Measured Density Profile Expansion Velocity is Close to $E_\theta\times B$ Drift Velocity During ELM

- At onset of ELM, Langmuir probe measured $E_\theta$, and $V_r = E_\theta\times B/B^2$ similar to the radial velocity measured by fast reflectometer.
- BES result: $V_r \sim 500 - 1000$ m/s for other shot, close to our measurement.
- The measurement is consistent with the ELM filaments expand radially at $E_\theta\times B$ drift velocity.
SOL Density Evolution Can Be Tacked During Short Duration and Varied Repetition Type III ELMs

- Fast profile reflectometer measurement can track the density modifications by Type III ELMs with short duration (1 ms) and varied repetition.

- Profile time resolution is 25 µs
SOL Density Profile Modification by Type III ELM

- Profile expansion distance during Type III ELM is smaller than during Type I ELM
- Profile temporal resolution is 25 μs
Dual-Polarization Profile Measurement Can Track Density Modification Inside Separatrix During ELMs

- The measured density range from 0 to $3.2 \times 10^{19} \text{ m}^{-3}$ with time resolution is 25 $\mu$s.

- Density increase outside the separatrix, but decrease inside the separatrix during ELMs.
Edge Profile Including Pedestal Density Evolution During ELM

- Time slices show, density expanded to the wall first, followed by density pedestal collapses, then pedestal gradually re-builds up.
Time History of Typical QDB Plasma

- QDB, Quiescent Double Barriers — high performance steady state regime
- EHO, Edge Harmonic Oscillation — a continuous magnetic and electrostatic oscillation, provides the edge particle transport necessary for QDB regime.
SOL Profile Modulation by the Edge Harmonic Oscillations in QDB Plasma

- Time resolution: 10 µs
- Total 200 profiles in 2 ms
- SOL density profile is modulated at the EHO fundamental frequency (about 6 kHz)
- Corresponding well to time history of \( \hat{B} \) associated with EHO
No Profile Modulation When EHO is Absent

- The same data acquisition analysis parameters as in EHO case

- The residual fluctuations are about 2 mm, 5 times smaller than the profile modulation generated by EHO
SOL Density Fluctuation Profile Associated with EHO

- RMS of density profile perturbation associated with EHO fundamental frequency (5-9 kHz)
- The peak of fluctuations is at the large density gradient regime
- Consistent with the Langmuir probe measurement at 5 cm outside the separatrix position in shot 103818
Double Peaks Structure in Fluctuation Profile Is Observed By BES Measurement

- BES measures not only SOL density fluctuation profile but also inside the separatrix, so will dual-polarization reflectometer try to measure in future.
- Double peaks localized in two large density gradient regimes.

![Graph showing edge density profile and BES data](image-url)
Double-Peak Structure in Fluctuation Profile Could Be Derived from Assumption of Edge Profile Rigid Movement

- When edge density profile rigid movement at EHO frequency is assumed, the fluctuation profile could be double-peak structure.
- The simulation indicates that EHO actually could locate inside or within the separatrix and rigidly modulate the edge density profile.
- There is discrepancy in fluctuation amplitude between reflectometer and BES measurements.
- Further more investigation is needed.
Summary

• The improved fast profile reflectometer has been successfully applied to study the edge density profile modifications due to edge localized mode (ELM) and edge harmonic oscillation (EHO) in DIII-D plasma.
• The radial density velocity of in Type I ELM is about 500 m/s, which is consistent with Langmuir probes and BES measurements, also consistent with ELM radial motion velocity close to $E_\theta \times B$ drift velocity.
• SOL Density profile is expanded at onset of ELM, indicating the enhanced radial particle and energy transports to wall during ELM.
• Inside separatrix density profile evolution, especially pedestal density evolution, during ELM is observed by reflectometer with dual-polarization received simultaneously.
Summary (continued)

- SOL density profile is modulated at the fundamental frequency of the edge harmonic oscillation (EHO).
- Both BES and fast reflectometer data shows that the fluctuation profile associated with EHO peaks in the large density gradient regimes. The fluctuation amplitude measured by Langmuir probe at far away from the separatrix is consistent with reflectometer measurement.
- Assumption of rigid edge profile modulation by EHO fundamental frequency could also produce double-peak structure in fluctuation profile.