Development of Polarization Interferometer Based on Fourier Transform Spectroscopy for Thomson Scattering Diagnostics

T. Hatae, J. Howard¹, Y. Hirano², M. Nakatsuka³, H. Yoshida³, O. Naito

Fusion Research and Development Directorate, Japan Atomic Energy Agency (JAEA)
1) Plasma Research Laboratory, The Australian National University (ANU)
2) National Institute of Advanced Industrial Science and Technology (AIST)
3) Institute of Laser Engineering, Osaka University
Outline

- What is the Thomson scattering diagnostics?
- Introduction
- Fourier spectroscopy using polarization interferometer
- Design of a polarization interferometer for Thomson scattering diagnostics
- Calibration methods
- Initial results using blackbody radiation source
- Summary, remaining issues and future plan
What is the Thomson scattering diagnostics?

- **Thomson scattering** is a plasma diagnostics to measure electron temperature $T_e$ and density $n_e$.

  - **Laser beam**
    - Energy $> 2$J
    - Pulse width $\sim 30$ns

  - **Plasma**
  - **Objective lens**
  - **Spectrometer**
  - **Scattered spectrum**
    - Intensity of the scattered light
    - Doppler broadening of the scattered spectrum
    - Electron temperature

  - **Spectrum**
    - High temperature
    - Low temperature
    - Intensity of the scattered light
    - Electron density
Introduction

- Incoherent Thomson scattering that can simultaneously measure electron temperature $T_e$ and density $n_e$ profiles is a standard diagnostic in magnetic confinement experiments.
- Usually grating spectrometers or interference filter polychromators have been used to analyze the scattered spectrum, so far.
- Though these are established methods, there are some disadvantages such as small throughput (especially, in the case of grating spectrometer) and/or the necessity of relative calibration between wavelength channels.
- Fourier transform spectrometers offer some potential advantages over grating spectrometers.
• Fourier transform spectroscopy is a measurement technique whereby spectra are collected based on measurements of the temporal coherence of a radiative source, using time-domain measurements of the electromagnetic radiation.

• To measure the temporal coherence, interferometers are used as Fourier transform spectrometers.

• This method can alleviate some of the disadvantages (e.g. throughput, relative wavelength calibration).

• Optical coherence techniques for plasma spectroscopy have been developed, so far.

  ◦ High-throughput, wide field-of view polarization interferometers have been used for Doppler imaging of ion temperature in H-1 heliac.

Development of a polarization interferometer for Thomson scattering

- A method based on measurement of the optical coherence of scattered radiation at a fixed optical delay has been proposed for incoherent Thomson scattering. J. Howard, Plasma Phys. Control. Fusion 48, 777 (2006)
- However, this method has not been demonstrated.
- We are developing a prototype polarization interferometer for Thomson scattering. Proof-of-principle tests will be carried out in TPE-RX reversed-field pinch (RFP) machine.

Proof-of-principle tests

Feasibility check

Apply to burning plasma or future program (ITER, JT-60SA)

TPE-RX (AIST) $T_e < \sim 1$ keV

JT-60U (JAEA) $T_e < \sim 30$ keV
Fourier spectroscopy using polarization interferometer

The polarization interferometer is composed of a birefringent plate of fixed optical delay sandwiched between polarizers.

Advantages

- High throughput (étendue)
- Absolute measurement (No relative wavelength channels calibration)
- small amount of stray light in the interferometer
- Compact, robust
- Suitable for imaging
The collected light is transmitted by a wideband filter to a polarization interferometer that generates an image of the optical coherence at a fixed delay.

The delay plate fast axis is at 45° to the first polarizer axis.

Depending on the orientation of the final polarizer, it is possible to measure either a ‘bright’ or ‘dark’ interference fringe.

The final Wollaston polarizer produces separate images of the bright and dark fringes onto two APD detectors.

The interferometer signal at either of the final polarizer port is given by

\[ S_\pm = \frac{I_0}{2} \left( 1 \pm \xi \cos \phi_0 \right) \]

- \( I_0 \): brightness of Thomson scattered light
- \( \phi_0 \): monochromatic birefringent phase delay
- \( \xi \): fringe visibility (fringe contrast)

At fixed delay using birefringent plate, the scattered signal are

\[ S_\pm = \frac{I_0}{2} \left( 1 \pm \xi_T \right) \]

- \( \xi_T \): fringe visibility of Thomson spectrum

The signals derived from both the orthogonally polarized light components produced by final Wollaston prism are sufficient to determine the total scattered power and the contrast degradation due to the Doppler broadening:

\[ \xi_T = \frac{S_+ - S_-}{S_+ + S_-} = f(T_e) \]
Optimum quartz plate thickness is 0.555mm for Te measurement of <1keV

- Range of bandpass filter is 880-1060nm
  - reject stray light by laser
  - reduce background light
- Determination of quartz plate thickness
  - high intensity level
  - large contrast
Calibrations

- Absolute calibration using blackbody radiation source (to obtain relation between the temperature and the fringe visibility)
- Spectral transmissivity measurement through whole optical path
  - vacuum window - collection optics - optical fiber - polarization interferometer
- Spectral sensitivity of APD
- Rayleigh/Raman scattering using N\textsubscript{2} gas for absolute calibration of \(n_e\)

![Diagram of optical setup](image-url)
The magnitude of the change in fringe visibility agrees with the numerical calculation.

- To compare between the numerical simulation and the experiment, initial test using a blackbody radiation source was carried out.
- When the temperature of the blackbody radiation source (LAND R1500T) was changed, fringe visibility was measured.
- $T=1000, 1100, 1200, 1300, 1400, 1500^\circ C$
Summary

• We are developing a polarization interferometer based on Fourier transform spectroscopy for Thomson scattering diagnostics.
• We designed the prototype polarization interferometer ($T_e<\sim1\text{keV}$).
  ◆ Range of bandpass filter is 880-1060.
  ◆ Optimum thickness of a birefringent plate (quartz plate) is 0.555mm.
• As a initial result, the magnitude of the change in fringe visibility agrees with the numerical calculation in calibration using a blackbody radiation source (1000-1500°C).
Remaining issues and Future plan

Remaining issues
• Error analysis for $T_e$ and $n_e$
• Considerations for effect of plasma background light spectra

Future plan
• Proof-of-principle tests will be carried out in TPE-RX (March 2007)
• Improvement of the prototype polarization interferometer using results from proof-of-principle tests will be carried out. Improved polarization interferometer will be developed for JT-60U.
  ◦ Wider $T_e$ range: $T_e < 40$ keV
  ◦ Imaging polarization interferometer for multi-spatial channel (Maximum 20 spatial points)
  ◦ YAG laser (50Hz, 7.46J, 1064nm) or ruby laser (0.25Hz, 10Hz, 694.3nm)

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