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

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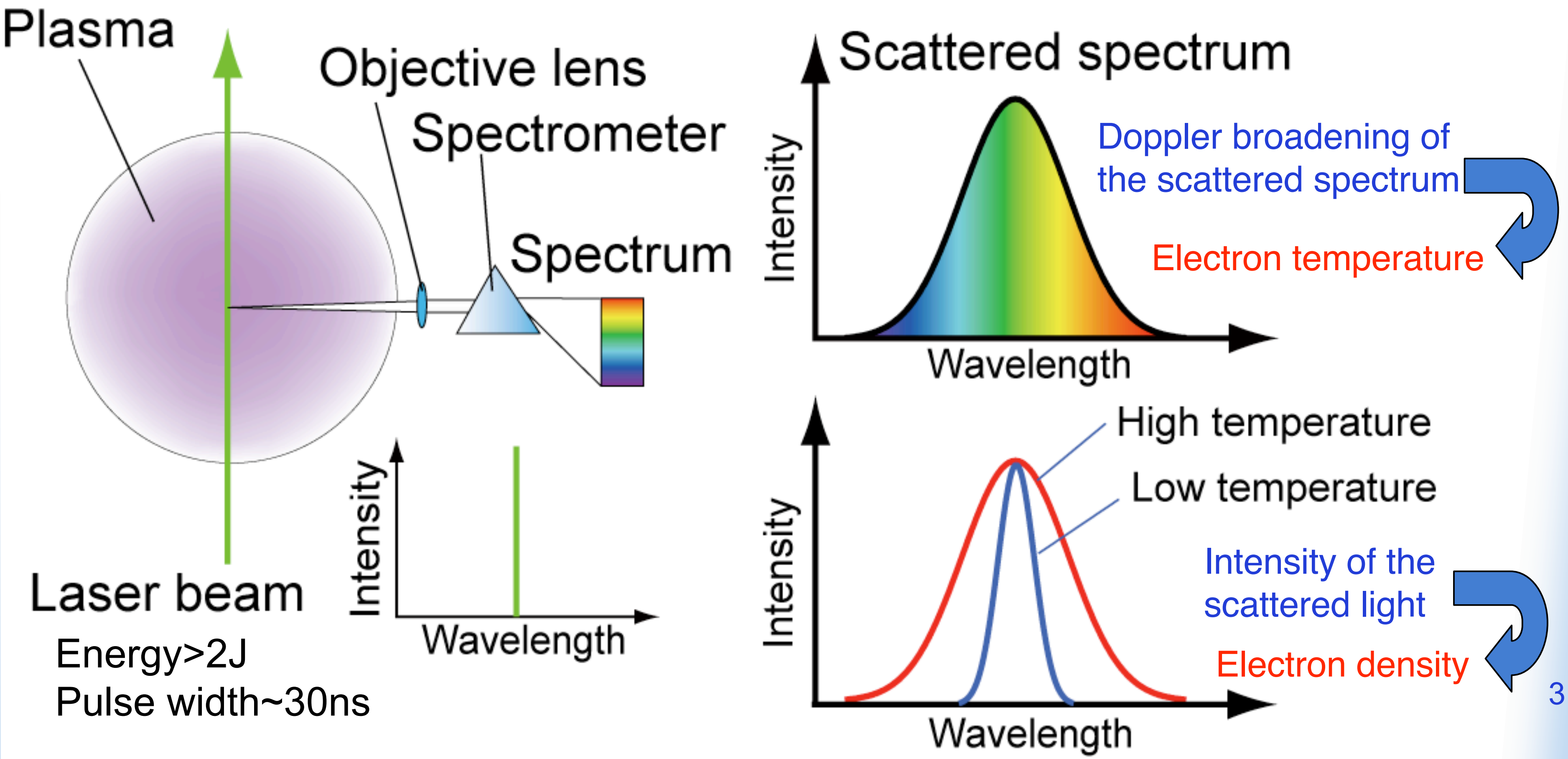
Advanced Diagnostics for Burning Plasmas

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

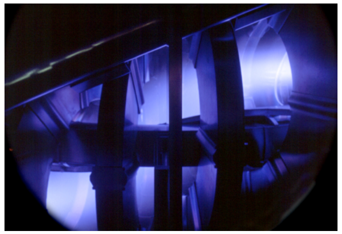


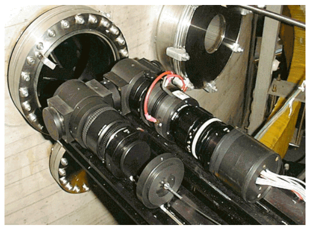
Introduction

- 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.

Introduction (continued)

- 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.



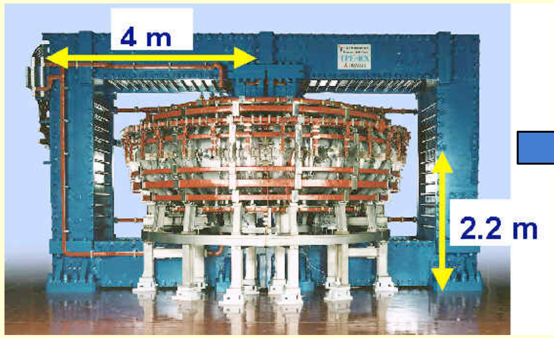


J. Howard, Appl. Opt. 41, 197 (2002).

Development of a polarization interferometer for Thomson scattering

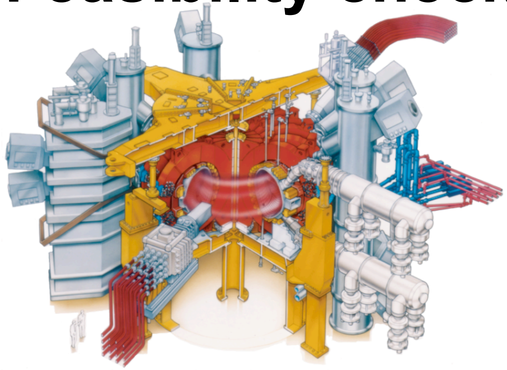
- A method based on measurement of the optical coherence of scattered radiation at a fixed optical delay has been proposed for incoherent Thomson scattering. J. Howard, Plasma Phys. Control. Fusion 48, 777 (2006)
- However, this method has not been demonstrated.
- We are developing a prototype polarization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

Proof-of-principle tests



TPE-RX (AIST)
T_e < ~1 keV

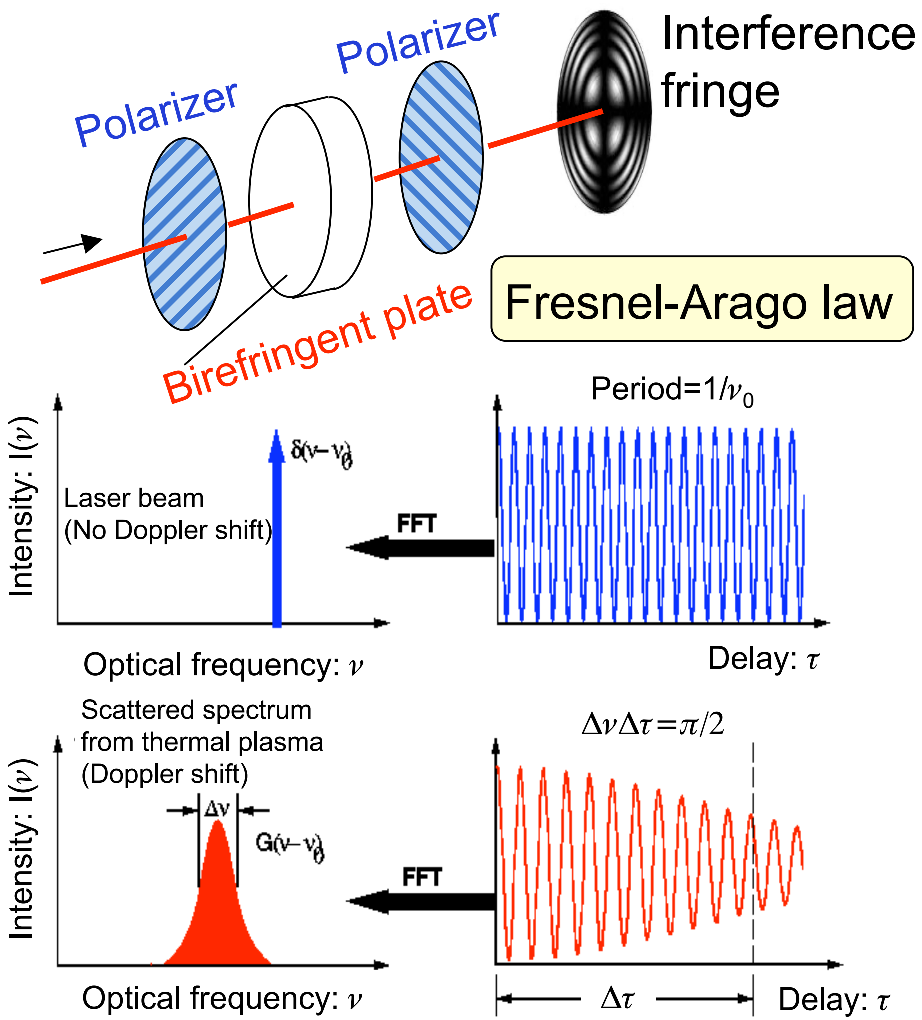
Feasibility check



JT-60U (JAEA)
T_e < ~30 keV

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

Fourier spectroscopy using polarization interferometer

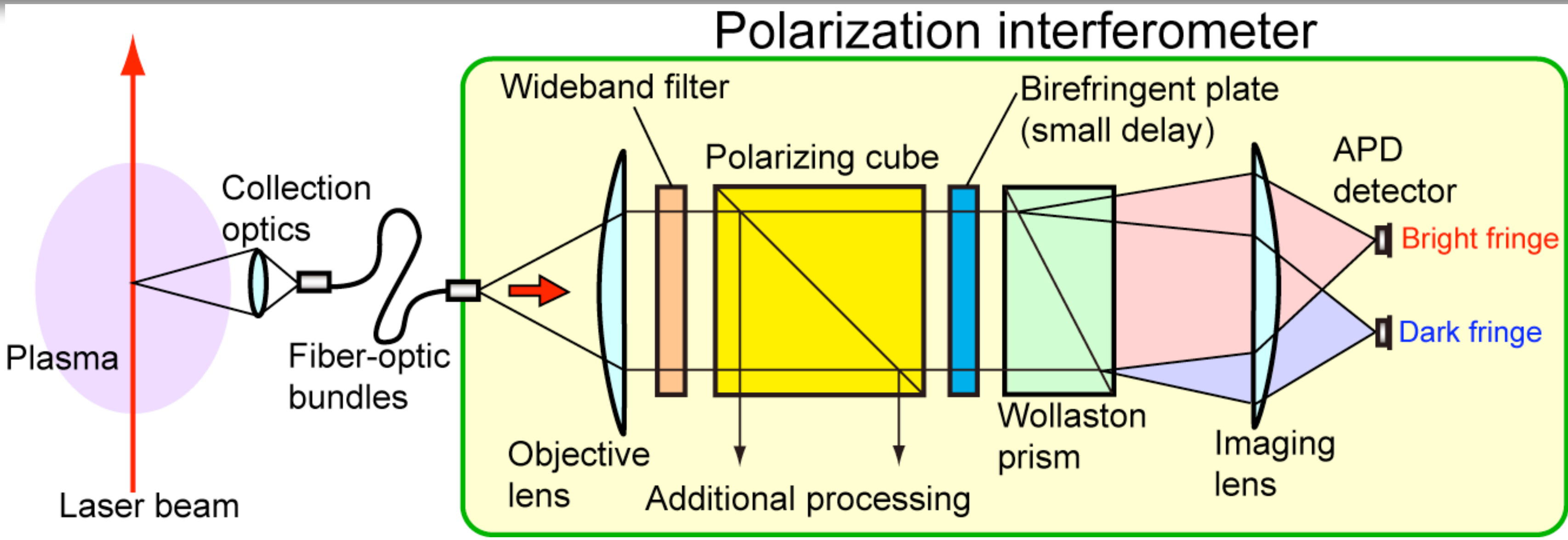


The polarization interferometer is composed of a birefringent plate of fixed optical delay sandwiched between polarizers.

Advantages

- High throughput (étendue)
- Absolute measurement (No relative wavelength channels calibration)
- small amount of stray light in the interferometer
- Compact, robust
- Suitable for imaging

Polarization interferometer for Thomson scattering diagnostics



- 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.

J. Howard, Plasma Phys. Control. Fusion 48, 777 (2006)

Relation between the electron temperature and the interferometer signal

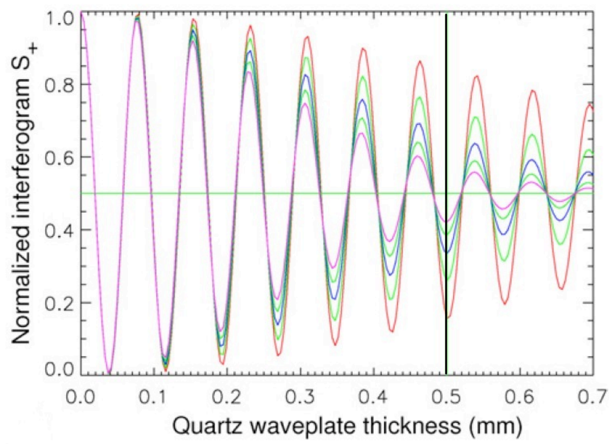
- The interferometer signal at either of the final polarizer port is given by

$$S_{\pm} = \frac{I_0}{2}\left(1 \pm \zeta \cos\phi_0\right)$$

I_0: brightness of Thomson scattered light

ϕ_0: monochromatic birefiringent phase delay

ζ: fringe visibility (fringe contrast)



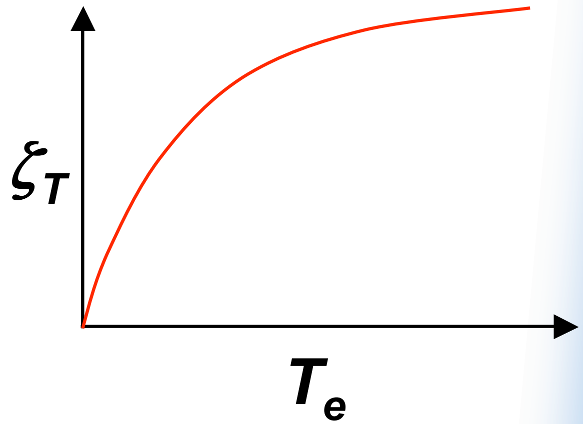
- At fixed delay using birefringent plate, the scattered signal are

$$S_{\pm} = \frac{I_0}{2}\left(1 \pm \zeta_T\right)$$

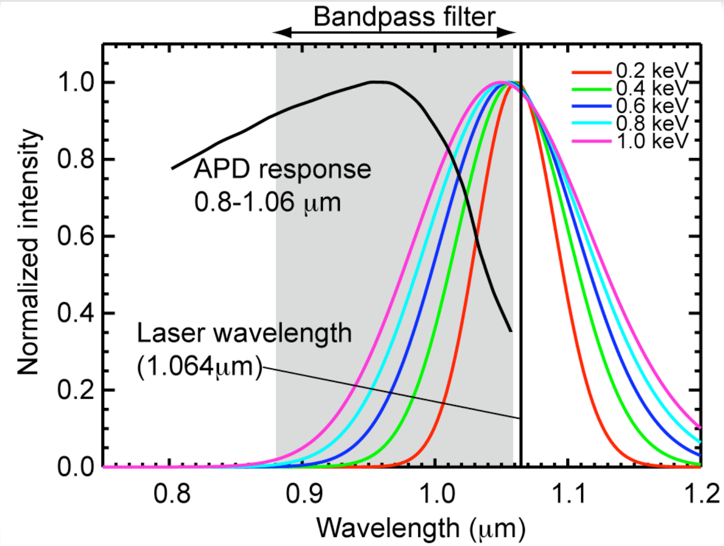
ζ_T: fringe visibility of Thomson spectrum

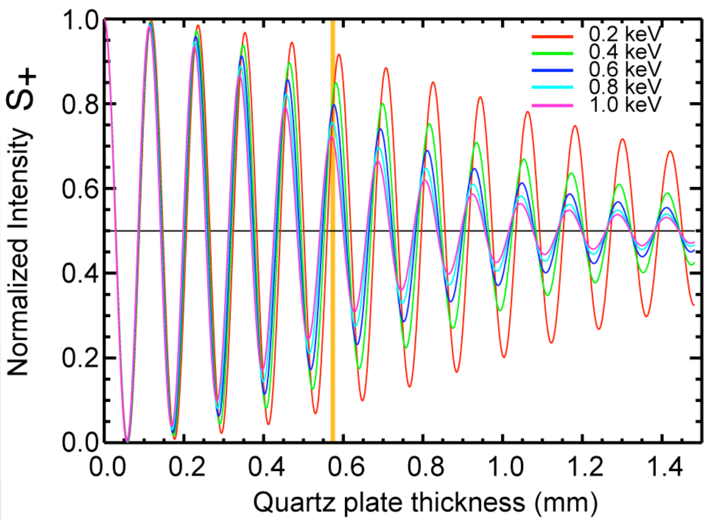
- The signals derived from both the orthogonally polarized light components produced by final Wollaston prism are sufficient to determine the total scattered power and the contrast degradation due to the Doppler broadening:

$$\zeta_T = \frac{S_+ - S_-}{S_+ + S_-} = f(T_e)$$

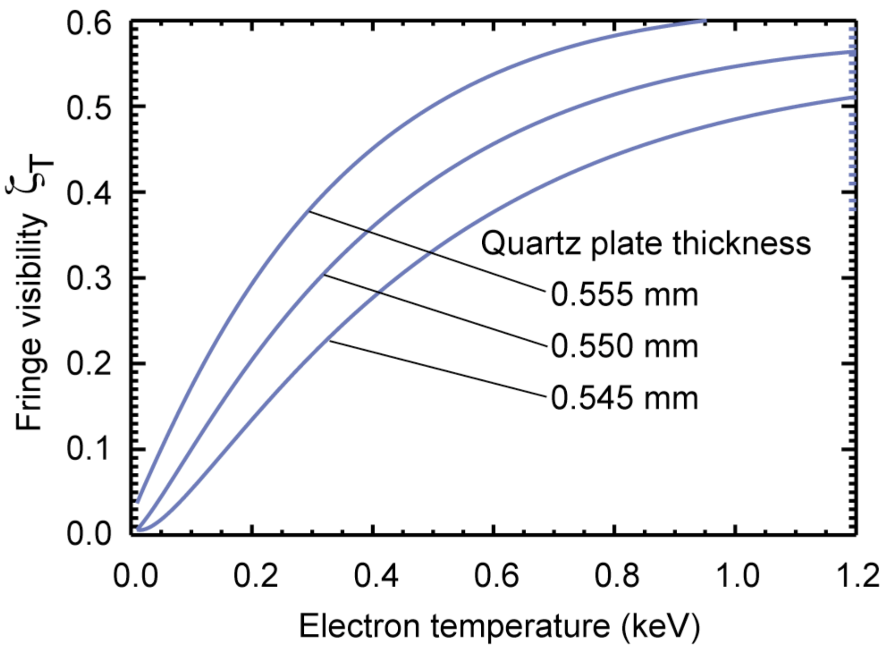


Optimum quarts plate thickness is 0.555mm for Te measurement of <1keV



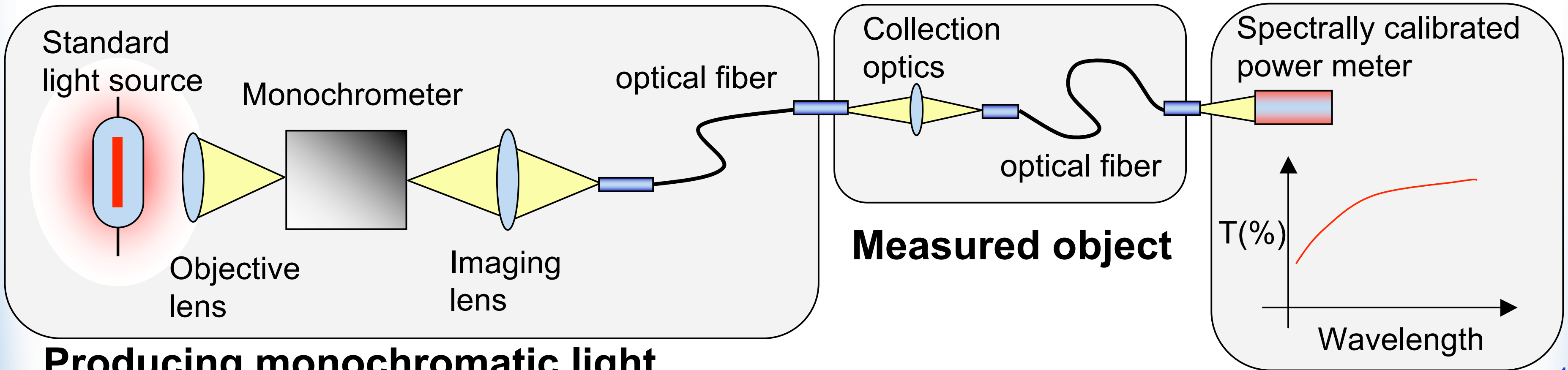


- Range of bandpass filter is 880-1060nm
  - reject stray light by laser
  - reduce background light
- Determination of quarts plate thickness
  - high intensity level
  - large contrast



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_2 gas for absolute calibration of n_e**



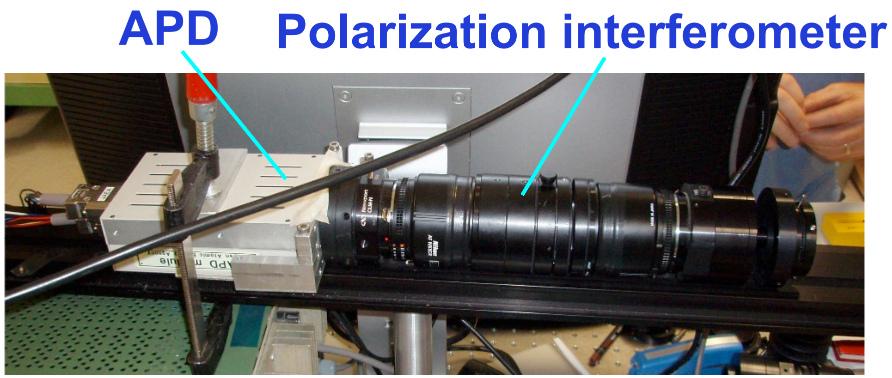
Producing monochromatic light

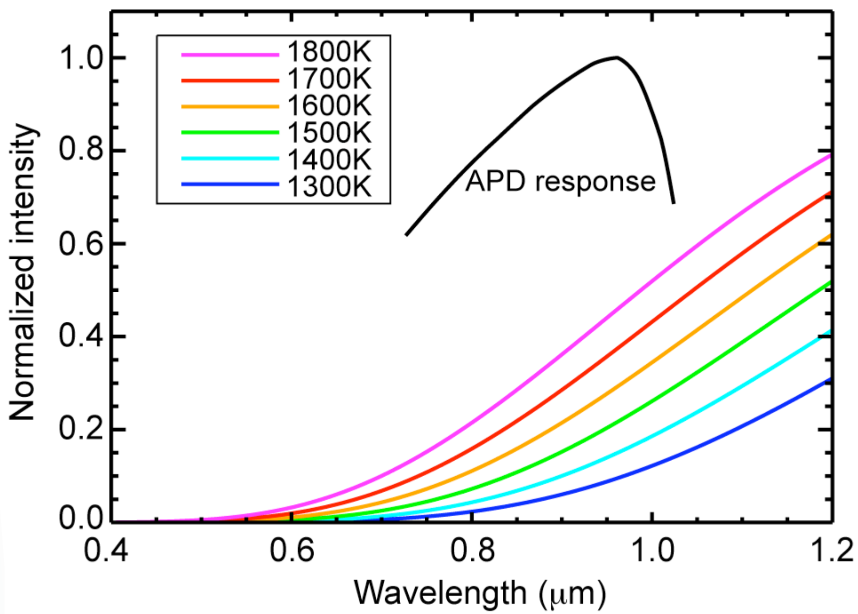
Measured object

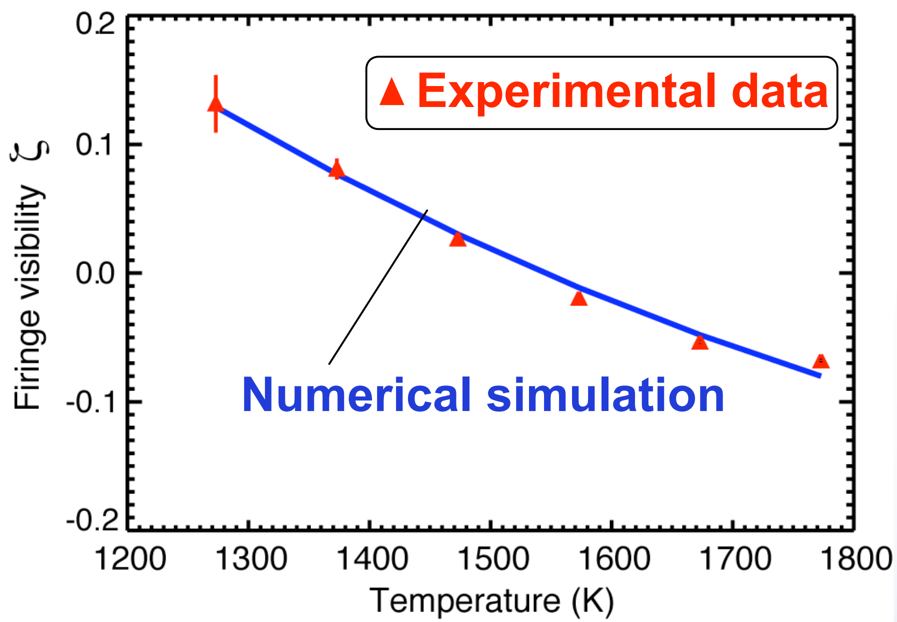
Measure spectral response

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°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<~1keV).
  - 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 carry 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 <40keV
  - Imaging polarization interferometer for multi-spatial channel (Maximum 20 spatial points)
  - YAG laser (50Hz, 7.46J, 1064nm) or ruby laser (0.25Hz, 10H, 694.3nm)

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Advanced Diagnostics for Burning Plasmas