Optimization of 48, 57μm poloidal interferometer / polarimeter for ITER

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The determination of the profile of the toroidal plasma current (safety factor) has been considered as essential diagnostic for ITER. In absence of neutral beam, the only reliable diagnostics which can provide the information on the q-profile is polarimetry. About ten viewing chords could cover significant part of the poloidal cross section of the plasma in a fan-like arrangement at the equatorial port. The probing beams enter the vacuum vessel through a penetration in the blanket modules at the low-field side. The four additional quasi-vertical viewing chords are inserted through the upper port. Retroreflectors at the high field side mirror the laser beams back towards the initial penetrations and allowed to measure Faraday rotation and phase shift. The present work considered the combined interferometer / polarimeter configuration for laser wavelength of about 50 μm. At this wavelength the ellipticity is small but has to be taken for account. Thus, the promising Cotton-Mouton effect, which is considered as an alternative for plasma density measurements, will be difficult to implement. The initial optimization of the viewing chords arrangement for several ITER plasma scenarios (sensitivity to the toroidal current profiles) has been done. The additional issue of delivering laser radiation to the plasma will be addressed. The advantages of the waveguide approach for beam focusing in the long (more than 50 m) optical path are shown.

1. Introduction

Control of the current density profile becomes a paramount issue for the future tokamak experiments. Polarimetry can provide information on the density and magnetic field from which current profile could be reconstructed. Previous system [1] was design to operate at λ =118.8 μm CH_3OH oscillation line. It is well known that there are two main approaches to build the polarimetry system. To obtained information about magnetic field one have to measure the value of Faraday rotation angle α_F, which is proportional to poloidal magnetic field $B_{p||}$ and electron density n_e.

$$\alpha_{\mathrm{F}} = 2.62\times10^{-13}\lambda^2\int_Z n_e(z)B_{p||}(z)\,dz \quad (1)$$

From α_F values profile of the poloidal component of the magnetic field could be calculated. It became obvious that the electron density along same beam line have to be known. For this purpose along beam chord a phase measurements by interferometer or measurements of the ellipticity angle α_{CM} (Cotton-Mouton effect (CM)) have to be performed.

$$\alpha_{\mathrm{CM}} = 2.62\times10^{-11}\lambda^3\int_Z n_e(z)B_t^2(z)\,dz \quad (2)$$

2. System description

Maximum number of twelve probing beams comes into the plasma through the diagnostic plug at the low-field side (LFS). At the high field side (HFS) of the blanket shield module (BSM) small (∅37 mm) corner retroreflectors (CRR) are placed to reflect backwards the laser beams. Recently for ITER-scale experiments and for the plasma experiments on Large Helical Device (LHD) we have been developing short wavelength FIR laser. These research activities are carried out to overcome the common 'fringe jumps' phenomena which occurs because of electron density increasing during pellet injection experiments. On LHD 13-channels 119 μm laser interferometer has routinely operated to provide information on the electron density profile.

The wavelengths of the new two-color interferometer are 57.2 μm (1.6 W) and 47.6 μm (0.8 W) in a twin optically pumped CH_3OD laser [2].

For ITER experiments we advocate the classical dual interferometer / polarimeter approach for its considerable simplicity to reconstruct experimental data. We consider the propagation of polarimeter beams through a thin layer of plasma (thickness z_0) in the presence of a magnetic field. This calculation takes into account both the Faraday rotation and the Cotton-Mouton effect.

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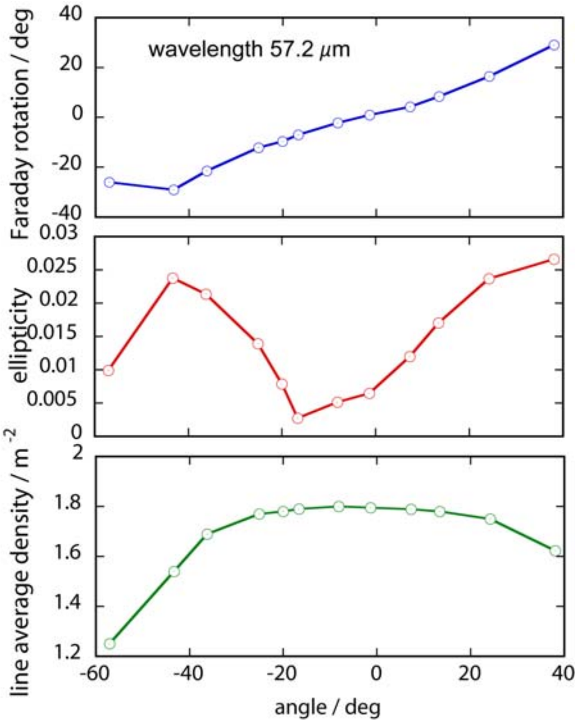

Fig. 1: Calculated Faraday rotation (top) and ellipticity (center), line density (bottom) 57 μm.

3. Alternated transmission line and numerical simulation of the expected values of the rotation angle and ellipticity

The calculation of the expected values of Faraday rotation angle and ellipticity for chosen ITER 'plasma burn' scenario #2 (plasma current I_p=15.0197 MA, q_0 = 0.99, 'flat' electron density profiles are shown at the Fig. 1. One can see that for the chosen wavelength of 57.2 μm Faraday rotation angle is about 25−30°, which is still large enough.

Recently for ITER-scale experiments and for the plasma experiments on Large Helical Device (LHD) we have been developing short wavelength FIR laser. These research activities are carried out to overcome the common 'fringe jumps' phenomena because of rapid raise of the plasma electron density, which occurs during pellet injection experiments. On LHD 13-channel 118.8 μm CH3OH laser interferometer has routinely operated to provide information on the electron density profile. The wavelengths of the new two-color interferometer are 57.2 μm (power 1.6 W) and 47.6 μm (power 0.8 W) in a twin optically pumped CH_3OD.

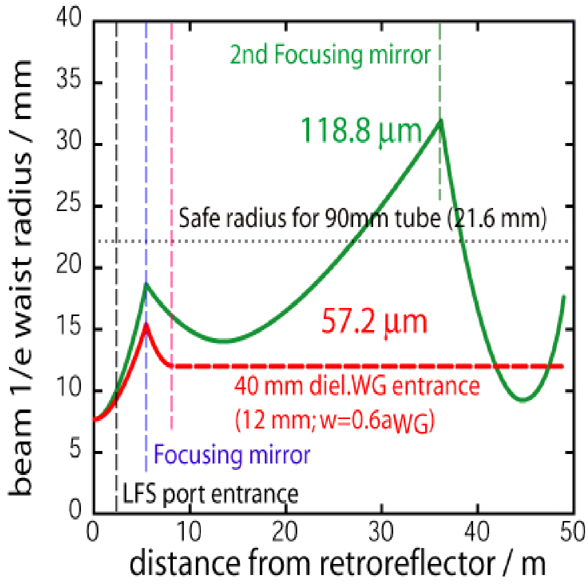

Figure 2: Calculated Gaussian beam radius (waist of 1/e intensity value) for wavelength 118 and 57 μm.

Since 47.6 μm and 57.2 μm have different polarization a Martin-Puplett diplexer is placed in front of the laser output. One of the most important issues is the developing of high quality heterodyne detection system with fast and sensitive characteristics. One of the main differences from 118.8 μm system is that instead of using quasi-optical transmission line (evacuated tubes of 90-120 mm in diameter) 40 mm dielectric waveguides become an attractive candidate. Those waveguides were made from Pyrex® borosilicate glass (with relative dielectric constant ε_r = 4.6−5.0) or acrylic resin (ε_r = 2.7−6.0)). From the other hand an oversized waveguides offer an attractive practical solution to transport light through the complicated geometry surrounding the fusion reactor.

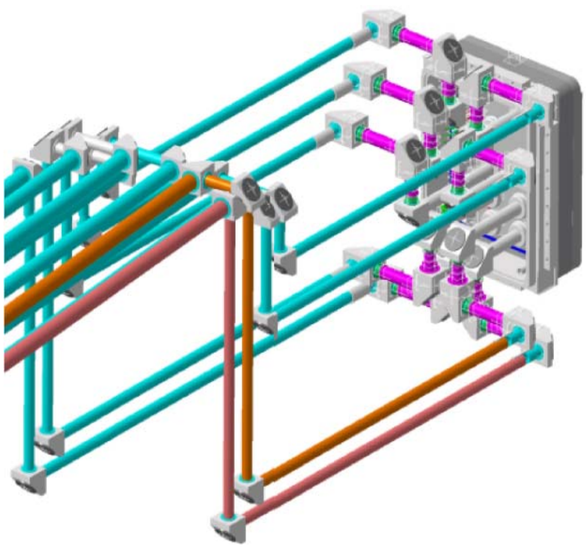

Figure 3: Poloidal polarimetry transmission lines and port plug to tokamak.

However, they can suffer from serious radiation-induced optical absorption and radioluminescence. Special fabrication and glass hardening techniques must be developed before suitable radiation -resistance dielectric waveguides can be used in ITER. By switching from pure quasi-optical (QO) beam free space propagation to 'waveguide ideology' for the transmission line that lies outside port plug (transmission line that correspond to the straight line at the Fig. 2) we can resolve several obstacles such as: mode matching / mode conversion, misalignment in the 'middle part' of the polarimeter optical path, which will be very difficult to maintain.

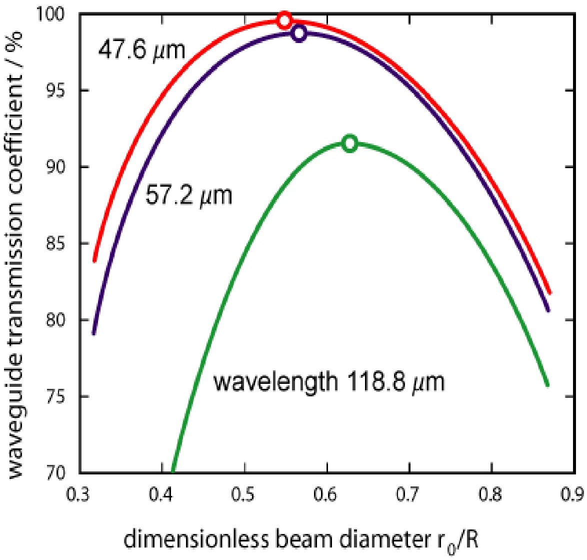

Figure 4: Coupling of Gaussian beam at the entrance of the dielectric waveguide. The inside diameter of the waveguide is 40 mm

From other hand waveguide system has precise mode matching (Fig. 2) (defined by waveguide diameter), easy alignment and more robust to mechanical vibrations. To deliver radiation from / to plasma each laser beam line is equipped with up to 8 miter-bends, with small conversion losses (Fig. 3). To avoid beam power dissipation Gaussian beam must enter the waveguide hawing optimized diameter. The calculation of waveguide transmission coefficient have been done for λ=48, 57, 118.8 μm

$$T = \left(1 - \exp\left(-F\frac{R^2}{r_0^2}\right)\right)F^{-1} \qquad (3)$$

where $F = 1 + \frac{\varepsilon_r + 1}{\sqrt{\varepsilon_r - 1}}\frac{L}{R}\frac{1}{k^2 r_0^2}$ and R, L - waveguide radius and length, $k = 2\pi/\lambda$ - laser beam wavelength, r_0-radius of the 1/e beam intensity level at the waveguide entrance, ε_r-waveguide material (relative dielectric constant) was chosen such as: $\sqrt{\varepsilon_r} = 2.1$. The calculation (refer to Fig. 4) shows that transmission coefficient values for 47.6 and 57.2 coupling into 40 mm diameter waveguide are about 99.6−98.42%, which is 7−8% higher than that for 118.8 μm.

The beam propagation inside the oversized dielectric waveguide have the same efficiency as for the free space, thus, preserves its polarization (99.6%). It was already confirmed by the long-term operation of FIR interferometer at LHD [5] (acrylic resin waveguide, length about 40m) and from several reports on JET polarimeter diagnostic (Pyrex® glass waveguide, length about 30m) that polarization of the laser beam in the waveguide remains almost constant. It was already shown [1, 3] by other research groups mechanical and optical properties of the corner retroreflectors became ultimately 'Achilles heel' of the system. The positions of the retroreflectors are limited by mechanical design of blanket shield modules on HFS inner wall (see Fig. 5). It was found that for wavelength 118.8 μm previously, which CRR can cope with misalignment up to 15 - 20 mm in poloidal plane without any serious effect on the reflectivity. For the shorter wavelength those values become twice smaller: up to 7.5 mm (see Fig. 6).

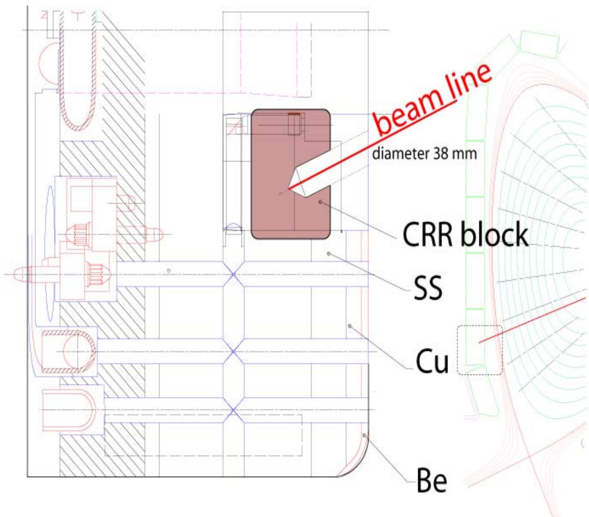

Figure 5: Outline of the retroreflector block incorporated into the blanket shield module. Without the plasma the beam is aimed at the center of the retroreflector.

This gives us much more freedom to cope with beam displacement caused by mechanical vibrations and due to refraction in plasma. Present level of CRR manufacturing could deal with 'ideal' sharp corner to sustain desirable sharpness which is about 5% from the laser beam width.

4. Final remarks

Recently proposed poloidal high power polarimeter will operate at 47.6 µm, 57.2 µm infrared oscillation. The output power of 57.2 µm laser is estimated to be over 1.6W and that of 47.6 µm is about 0.8W. Two color beat signals are simultaneously detected by a Ge:Ga detector with success. It was shown that preferable polarimeter-interferometer configuration will unveil some extra advantages in respect of 'full-polarimetric' system. Shorter wavelength laser will significantly improve (diminish) refraction problems. For present chord alignments and beam wavelength caused considerably small Cotton-Mouton effect. Alternated waveguide transmission line (with miter bends included) showed better focusing and tuning as well as much simple further maintenance, the Cotton-Mouton polarimeter becomes clear only in the case when the viewing chords are orientated in the equatorial plane, where the poloidal component of the magnetic field B_p is zero (pure toroidal polarimetry). Under some plasma condition there is a possibility of coupling Faraday and Cotton-Mouton effects.

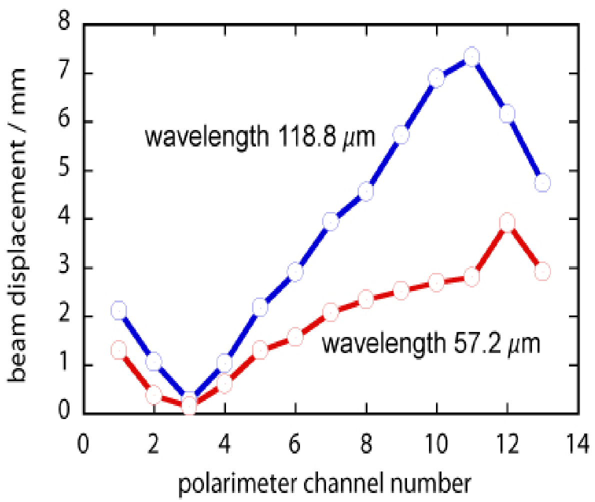

Figure 6: Beam displacement characteristics for the vertical fan of the chords at the position of the center of the correspondent corner retroreflectors.

Small Faraday rotation angle along some central chords suggests that placing additional beam lines must be done to improve spatial resolution of the system. Promotion of the dielectric waveguide addresses the issue of the radiation effect on those components. The appropriate additional 'shielding' of the waveguides studies now under the consideration. Further research is needed to define the most adapted materials for dielectric waveguides for FIR polarimetry.

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