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Spectroscopic Measurement System for ITER Divertor Plasma: Divertor Impurity Monitor

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1. Introduction: The main functions of the Divertor Impurity Monitor are to measure the parameters of impurities and isotopes of hydrogen (tritium, deuterium and hydrogen) in the divertor plasmas by using spectroscopic techniques in the wavelength range of 200 - 1000 nm. The detailed requirements are given in the reference [1]. The measurements are required for the full duration of the ITER pulse (>600 s) and special provisions are necessary to provide the measurements in the harsh environment for diagnostic components.

The expected impurities are carbon, tungsten, beryllium and copper originating from the divertor target plate and from the surface of the first wall in the main chamber. Neon, argon, krypton or other impurity gases injected into the plasma for radiation cooling in the divertor and the plasma edge will also be observed.

2. System arrangement: The divertor region will be observed from the divertor port, the equatorial port and the upper port as shown in Fig. 1. For the viewing access at the divertor port, the light from the divertor region passes through the quartz windows on the divertor port plug, and goes through the labyrinth in the biological shield. It is then focused on the ends of the fiber bundle by collecting and focusing optics. The fiber bundle guides the light

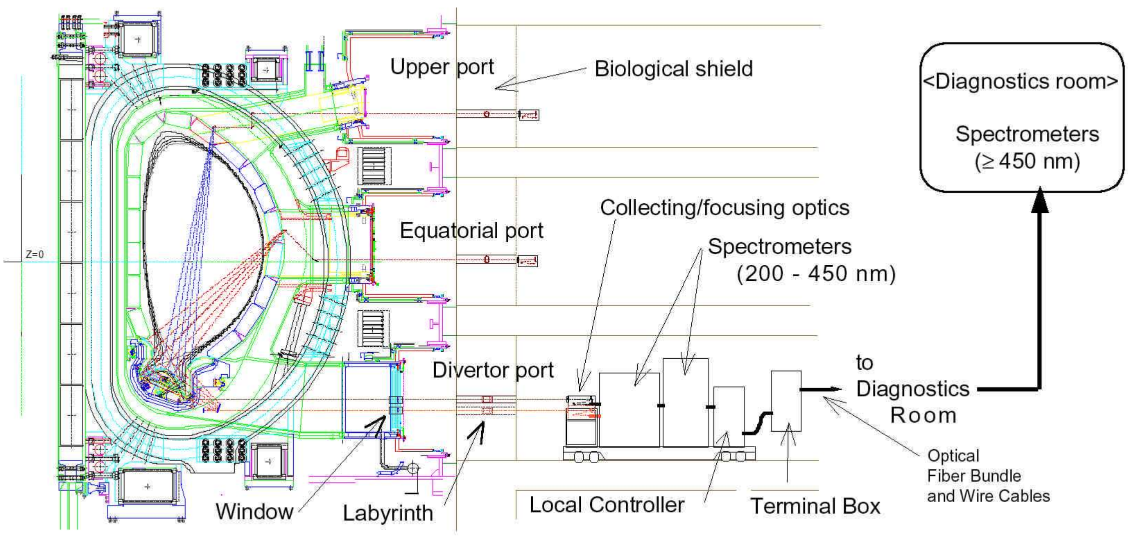

Fig. 1 Arrangement and lines of sight of Divertor Impurity Monitor.

to the spectrometers. The spectrometers with the wavelength $\lambda < 450$ nm are installed just behind the biological shield to minimize the transmission loss in fiber. The light with $\lambda \geq$ 450 nm is guided by long optical fibers to the spectrometers located remotely in the diagnostic room.

The lines of sight at the divertor region are shown in Fig. 2. The outer and inner divertor regions will be observed by using mirrors located on the bottom of the divertor cassette and just under the dome. In addition, lines of sight through the gap of 10 mm between the divertor cassettes will be provided to observe the divertor leg and the X-point region. Two-dimensional measurements will be achieved by combining measurements made with the sight lines in the divertor with those made from the equatorial and upper ports.

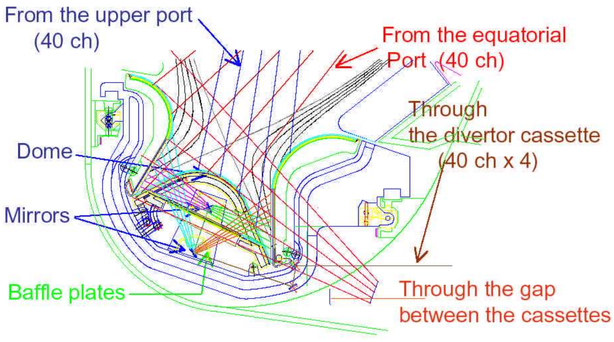

Fig. 2 Lines of sight in the divertor.

3. Measures for special environment of ITER: Optical components, such as mirrors, windows etc, mounted close to the plasma will experience higher levels of radiation due to neutron, gamma ray and/or particle irradiations than in present devices. The degradation of their performance by these effects must be minimized. The materials of the components have to be carefully selected and mitigating methods adopted where possible. Molybdenum is chosen as the material of the plasma facing mirrors since it offers the best compromise of high reflectivity in the wavelength range of interest (200 – 1000 nm) and resistance to erosion due to sputtering. Baffle plates will be installed in front of the mirrors to reduce the solid angle of exposure to the plasma and thereby reduce the number of particles impinging on the mirrors (Fig. 2, 3). The number of particles impinging on the mirrors at the equatorial/upper ports is expected to be less than that at the divertor cassette.

4. Optical design and spectrometers: The optimum optical arrangement and parameters of mirrors have been designed by using a ray trace analysis. As a result, 10 mm and 40 mm spatial resolutions will be achieved for the optics viewing through the divertor port and from the equatorial/upper ports, respectively. A typical result for the line of sight which observes the outer divertor from the dome through the

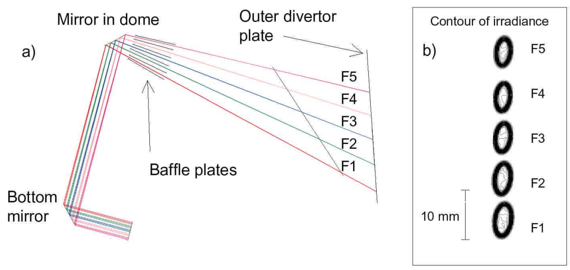

Fig. 3 a) Traced rays and b) contours of irradiance for the images of the fiber cores for the line of sight, which observes the outer divertor from the dome through the divertor port.

divertor port, is shown in Fig. 3. The traced rays and the contours of irradiance for the images of the fiber cores are shown in this figure. Here, it is assumed that the fiber core emits the light uniformly.

Three different types of spectrometers will be employed [2]. a) Visible survey spectrometers for impurity species monitoring and particle influx measurements. The spectral lines emitted from 200 - 1000 nm will be measured simultaneously. b) Filter spectrometers for two-dimensional measurements of particle influxes. These spectrometers will be able to measure 12 spectral lines for every line of sight. The position of the ionization front and the helium density will also be measured. c) High dispersion spectrometers for measuring the ion temperature, the particle energy distribution and the ratios of tritium/deuterium/ hydrogen density ($n_T/n_D/n_H$). The ion temperature will be derived from the Doppler broadenings of impurity lines. The ratios of $n_T/n_D/n_H$ will be estimated from the intensity ratio of tritium T_α, deuterium D_α and hydrogen H_α.

5. Performance: The particle influx density Γ is given by $\Gamma = 4\pi \cdot K \cdot I$, where K is the number of ionization events per photon for the observed line with the intensity of I [3]. The required range to be measured for the deuterium influx density Γ to the divertor is 10^{18} - 10^{24} at·m^{-2}·s^{-1}, and those are 10^{16} - 10^{21} at·m^{-2}·s^{-1} for carbon and beryllium. The intensities of spectral lines for each required influx density region were calculated by using the above equation under the conditions of electron density of 1x10^{19} - 1x10^{22} m^{-3} and electron temperature of 1 - 50 eV. These values are expected for ITER divertor plasmas. The calculated results for CII (3s-3p, 657.8 nm) are shown in Fig. 4 as an example. The lower limit of the number of photons that can be detected on existing machines is typically 1000 photons·ms^{-1} at the detector. Assuming the same number for ITER, the measurable intensity limit in the divertor would be about 10^{17} photons·m^{-2}·sr^{-1}·s^{-1} for the optics with the lowest efficiency. The measurable limits for influxes will depend on the electron density and temperature as shown in Fig. 4. In the case of CII, it will be difficult to measure the carbon influx density of 1x10^{16} m^{-2}·s^{-1} for T_e= 5 - 50 eV. The calculated line integrated intensity of bremsstrahlung (Z_{eff}=1.5, T_e= 5-50 eV) is also shown in Fig. 4. Here,

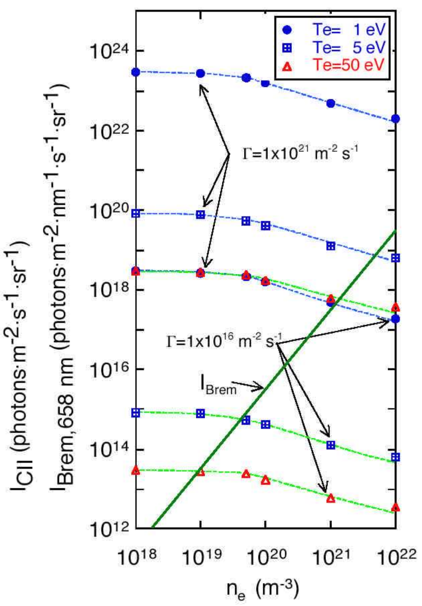

Fig. 4 CII intensities for various influx densities and electron temperatures.

we assume the integrated length is 5 cm and the wavelength bandwidth is 1 nm. In the high-density region, the bremsstrahlung component should be measured by filter spectrometers or survey spectrometers.

6. Calibration and alignment: In order to obtain the required plasma information it is important to know the sensitivity of the optical systems and since this may change due to the environmental effects in-situ calibration is required. It is not feasible to install a light source in the divertor and so an alternative method is needed. In-situ and remote calibration methods, which will be installed in the strong radiation field, are essential. To achieve this, retroreflectors will be installed between the baffle plates where there is minimum neutral particle bombardment. A standard light will be set behind the biological shield and the light applied to the retroreflector in the divertor cassette through the same optics as used in the plasma measurement. The reflected light will be measured by a spectrometer. The detailed design of the calibration system is in progress. To compensate for the movement of the optical components in the divertor cassette and other components during the plasma discharge, optical alignment will be maintained by moving a mirror located at the biological shield.

7. Conclusions and remaining issues: It is expected that many of the target measurement requirements will be met although the final measurement capability will not be known until more design work has been done. The high priority issues remaining for the Divertor Impurity Monitor are the accurate estimation of the potentially damaging effects due to impurity deposition and dust on mirrors and development of mitigating measures. The development of in-situ/remote calibration techniques must be completed. The inclusion of optics for the measurement of the ion flow velocity in divertor towards divertor plate should be considered.

Acknowledgement

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