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ITERの炭酸ガスレーザー協同トムソン散乱によるアルファ粒子計測法の考察とJT-60Uにおける実験結果

Prospects for alpha-particle diagnostics by CO_2 laser collective Thomson scattering on ITER and experimental results on JT-60U

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In order to understand the behavior of alpha-particles which are the dominant heat source in a burning plasma, it is necessary to measure the spatial distribution of the density of the alpha-particles and their energy spectrum. A collective Thomson scattering (CTS) measurement based on a pulsed CO_2 laser and microwave are being developed and one of them is under consideration for alpha-particle measurements on ITER.

Heating neutral beam (NB) ions (E = 1 MeV) will normally be co-injected in ITER and will have a similar velocity to the alpha-particles. An important point is that the CTS measurement cannot, in general, distinguish between beam ions and alpha-particles which have the same velocity. However, by using a vertical scattering geometry it is possible to distinguish between the beam ions and alpha-particles by measuring co- and counter-traveling ions. Calculations have shown that the vertically viewing CTS can resolve counter-travelling alphas without being masked by beam ions.

An arrangement to measure counter-traveling alpha is proposed and a preliminary design of a beam line and a receiver system of CO_2 laser based CTS with the vertical scattering geometry has been developed (Fig. 1). A heterodyne receiver system with combination of HgCdTe detector and QWIP (Quantum Well Infrared Photodetector) is proposed.

To realize the CTS measurement, a proof-of-principle test on the CTS system using the JT-60U plasma is being conducted. The energy of the pulsed CO_2 laser is 15 J and the nominal pulse length is about 1μs. The scattering angle must be small (0.5°) to obtain large ion contribution on the scattered spectrum. Stray light is reduced by a notch filter with hot CO_2 gas. The scattered signal is detected by a heterodyne receiver and the spectrum is analyzed by a filter bank with six channels. Experiments have been carried out with JT-60U plasma but so far scattered signal has not been detected due to electrical noise originating from the pulsed laser discharge and stray signal coming from mode impurities in the laser. These problems are now being rectified.

Subjects requiring further work to realize the CO_2 laser based CTS system on ITER are (i) detail optical design in the divertor and upper port, (ii) improvement in the spatial resolution (currently 40 ~ 80 cm), (iii) development of high power laser (50 J, 10Hz), and (iv) a successful proof-of-principle test on an existing plasma.

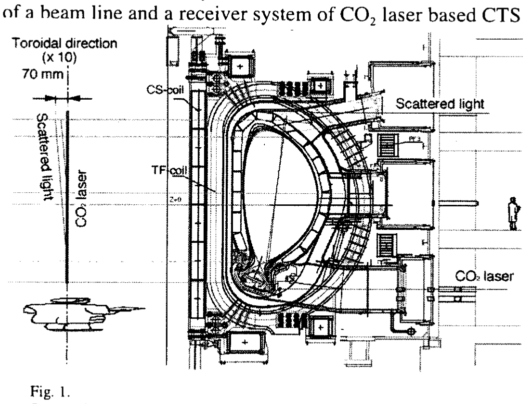

Fig. 1.
Schematic diagram of the collective Thomson scattering system in ITER

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ITERのための多重化分光方式によるダイバータ赤外温度計測装置

Multiplexing IR Divertor Thermography for ITER

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The concept of multiplexing divertor thermography was invented to observe the divertor targets in the deep slot divertor for ITER-98 [1]. The newly designed multiplexing divertor thermography for ITER satisfies the recent requirement to measure ELM heat fluxes with a spatial resolution of 3 mm and a time resolution of 20 μs[2].

An overview of the mirror optics is shown with the enlarged front-end optics and spectrometer in Fig. 1. The optics are toroidally symmetric and its toroidal width (~ 3 cm) is limited by the slit opening in the divertor cassette dome. The target length (L = 545 mm) is covered by a wavelength range of 3,400 to 4,470 nm. Therefore a spectral resolution of 6 nm is required to give a 3 mm resolution on the target. Thermal radiation from different positions on the target is multiplexed into a single beam via the elliptic multi-focus mirror (~ 80 foci) and curved diffraction grating (200 lines / mm). The multiplexed beam from Slit A is formed into a parallel beam by a parabolic mirror and guided to the outside of the divertor cassette through a hole and then transmitted to the outside of the bio-shield via relay flat mirrors. There, the spectrum of the transmitted light is focused on to a multi-channel (~ 180 ch) detector in the Czerney-Turner spectrometer. A profile of temperature on the target is recovered from the intensity of the signal in each channel, since the total power transmitted to the detector is given by Q = $t\,\varepsilon$ P. Here t (t = 0.05) is the attenuation factor in the optics and ε is the emissivity of the target materials. Detailed signal to noise ratio calculation shows that ELM measurement is possible above 300 °C for a carbon (ε = 0.8) target and above 560 °C for a metal (ε = 0.1) target while a spatial resolution of 3 mm and a time resolution of 20 μs are both satisfied.

In summary, the multiplexing thermography is feasible in principle and potentially could measure the ELM heat flux in ITER. However, several key engineering problems remain to be solved. The displacements between the front-end optics and the spectrometer due to movement of the vessel due to poloidal / toroidal field j x B forces, must be actively controlled below 0.25 mm to keep a spatial resolution of 3 mm during a discharge. Mirror coating by redeposited divertor material and carbon dusts in the dome cassette pose a survivability problem for optical components. In addition, experimental proof of principle in existing tokamak machines is needed before a successful implementation can be assured.

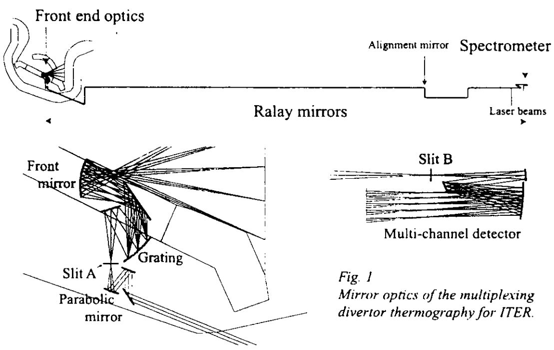

Fig. 1
Mirror optics of the multiplexing divertor thermography for ITER.

[1] A. Herrmann and H. Salzmann, in *Diagnostics for Experimental Thermonuclear Fusion Reactors* 2, Edited by P.E.Stott et al., Plenum Press, New York, (1998) 569.
[2] K. Itami, T. Sugie and G. Vayakis in the Proceedings of 30th EPS, 2003.