Development of a Two-Dimensional Thomson Scattering Diagnostic System involving Use of Multiple Reflection and the Time-of-Flight of Laser Light

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Two-Dimensional Thomson Scattering Measurement (2-D TS) was designed using multiple reflections and the time-of-flight of laser light. This new approach enable us to measure the r(radial)-z(axial) profiles of electron temperature and density. In this approach, (1) multiple reflections of YAG laser light are used to cover the whole r-z plane of the ST (Spherical Tokamak) plasma, and (2) the time delay of the scattered light along the laser beam is arbitrarily arranged by adjusting the multiply reflected laser light path in order to reduce the necessary number of detectors. Rayleigh scattering lights were observed successfully at two measurement points, suggesting that the basic principle of the 2-D Thomson scattering system functions effectively as a new extension of LIDAR (LIght Detection And Ranging) Thomson scattering system.

Keywords: Thomson scattering, Rayleigh scattering, time-of-flight

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For the past 30 years, Thomson scattering measurement has been widely used as the most precise and reliable plasma diagnostics for measuring electron temperature T_e and density n_e [1]. Its single point measurement has been upgraded to multipoint and its spatial resolution has been improved significantly using the TV Thomson system which employs spectrometers and ICCD cameras. The time-of-flight of laser light was used for the first time by the LIDAR Thomson system for the purpose of realizing one-dimensional Thomson scattering measurement through a small viewing port [2]. Recently, optical fibers were used to produce sufficient time delay for scattered light signals as a way of reducing the required number of detectors [3].

Extension to 2-D TS measurement has been realized on certain devices [4], but in many cases, such measurements are carried out using soft X-ray tomography and electron cyclotron emission because of the high cost providing the many sets of laser devices and polychromators necessary for conducting 2-D TS. For the TS-4 device whose main mission is merging ST plasma and magnetic reconnection, the 2-D profile of T_e and n_e are keys to understanding the causes and mechanism for (1) the electron heating of the magnetic reconnection and (2) high-β ST formation at merging start-up. Our new, more cost-effective approach to the upgraded 2-D Thomson scattering system is composed of (1) the multiple reflections of a laser beam to cover the 2-D(r-z) plane of the plasma and (2) utilization of the laser light's time-of-flight by arbitrarily varying the laser path's length in order to reduce the number of polychromators and detectors.

Figure 1 shows the vertical and horizontal cross-

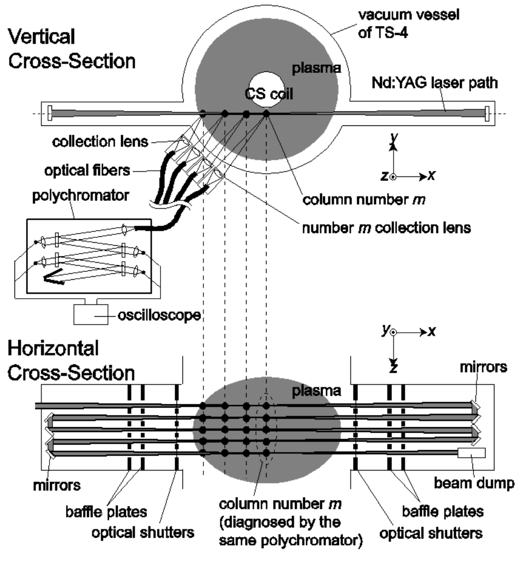

Fig. 1 Schematic of our 2-D Thomson scattering diagnostic system on TS-4.

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author's e-mail: sumikawa@ts.t.u-tokyo.ac.jp sections of the 2-D TS system developed for the TS-4 torus plasma merging device. This system is intended to measure T_e in the range of 20 eV to 200 eV for $n_e \sim 10^{20}/m^3$ with a spatial resolution of 160 mm (4 points) in the r-direction and 130 mm (5 points) in the z-direction. The YAG laser beam is reflected multiple times by 10 sets of mirrors located on the right-side and left-side extensions of the vacuum vessel. The key issue involved in these multiple reflections is the suppression of the stray lights from laser windows and mirrors. The extensions of the vacuum vessel are used to lengthen the laser path length for the time-of-flight measurement without adding any windows on the vessel that cause stray light. We also use dielectric multi-layer mirrors whose reflectance ratio is more than 99% each. The baffle plates and beam dump are placed inside the extensions in order to suppress stray light as much as possible. The optical shutters are open during the traveling time of the laser light as a way to minimize plasma damage such as plasma spattering to the mirrors and windows. The scattered lights from five measurement points (with the same column number m) in the z-direction are collected by five Gauss-type collection lenses and sent to a single polychromator through bundled optical fibers. We can distinguish the scattered light data from the five measurement points using their time delays. Elements playing key roles in successful time-of-flight measurement include (1) the width of the laser pulse, (2) the laser path length between each adjacent measuring point whose scattered lights are lead to a single polychromator, (3) the cutoff frequency of avalanche photodiode (APD) detectors and their detector circuit, and (4) the cutoff frequency of the oscilloscopes. Our YAG laser (2.4 J, 10 Hz) has an 8 nsec (2.4 m)-long pulse width, and the laser path length between the adjacent measuring points is about 5m-long, which corresponds to the laser flight-time of 17 ns. Because the RC decay time constant is 32 ns, the most convenient laser flight time is about 30–40 ns between each adjacent measurement point to distinguish their scattered lights. One option is to lengthen the vacuum vessel extension so as to make the laser path length longer and thus increase the laser flight-time. Another option is to adjust the length of the optical fiber between the collection lenses and polychromators [3]. The cutoff frequency of the APD detector circuit and the oscilloscope are 100 MHz (10 ns for each sampling) and 400 MHz (2.5 ns), respectively, satisfying our Thomson system design. In our preliminary TS system, we have already detected the multiple Rayleigh scattering lights from two adjacent measurement points. In this system, the laser path length between two points is about 15 m, increasing the laser flight time up to 50 ns. As shown in Fig. 2, the two Rayleigh scattering signals were measured by the APD detectors. These data indicate that four sets of the preliminary results will constitute a new 2-D (2 × 4 points) measurement of the Rayleigh scattering and probably suggests that the basic principle of the 2-D TS system works reasonably well. We are now planning to perform full 2-D measurement of Thomson scattering light for 2-D T_e and n_e profiles.

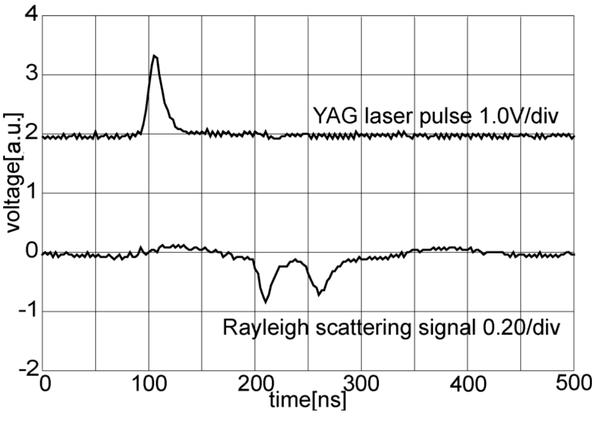

Fig. 2 Rayleigh scattering light from two adjacent measurement points.

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