A Multichannel 118.8 μm-CH_3OH Laser Interferometer for Electron Density Profile Measurements in LHD

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Abstract

A 13-channel far infrared laser interferometer has been developed and routinely operated for the measurements of the spatial and temporal behaviors of the electron density in the Large Helical Device (LHD). The optical configuration is of the Michelson interferometer type with a heterodyne detection system. The light source is a highly stable twin 118.8-μm CH_3OH laser pumped by a cw CO_2 laser, which is developed in NIFS. All the optical components of the interferometer except laser sources are mounted on a massive stainless steel frame, which encircles the plasma vacuum vessel and is placed on three vibration-isolating mounts. The observed fringe shifts caused by the mechanical vibrations of the system is 1/100 fringes for the high frequency components of f > 1 Hz and 1/50 fringes for the low frequency components. The phase-shift measurement is made with an accuracy of 1/100 of a fringe, corresponding to a minimum measurable line-averaged density of 5.6×10^{16} m^{-3} at the central chord.

1. Introduction

The Large Helical Device (LHD) experiments has successfully started [1,2] after the eight-years of construction period(1990-1997). The major and minor radii of the plasma are 3.6 — 3.9 m and 0.6 — 0.65 m, respectively. The magnetic field up to 3 T is generated by a pair of superconducting helical winding of pitch parameters of m/l = 2/10 and three sets of superconducting poloidal coils. The plasma is generated by ECRH of 84 and 82.6 GHz, and heated up by NBI and ICRF [3]. The plasma parameters obtained to date are: the electron/ion temperature of 1.0 - 4.5/3.5 keV, the line-averaged electron density of < 1.5×10^{20} m^{-3} and the maximum stored energy of 1.0 MJ. A multi-channel FIR laser interferometer has been developed [4] for the density profile measurements on LHD. There are no mechanical disturbances caused by the change of the magnetic field in the laser diagnostics which usually need the exact spatial alignment. Here, we shall present the characteristics of the major components of the interferometer and typical experimental results.

2. General Layout of the System

Figure 1 shows a schematic drawing of the interferometer system [4] in the LHD experimental hall, including the other major diagnostics. The FIR lasers are installed in the laser room biologically shielded with thick concrete walls, and their beams are transmitted about 40 m through a couple of the dielectric wave guides (Acrylic resins tubes ~47 mm inner diameter) to reach the optical bench of the interferometer. The optical housing, where ~150 optical components are installed, is mounted on a massive frame. The frame encircles the plasma vacuum vessel and is placed on three pneumatic vibration isolation mounts in order to isolate it from floor vibration. This isolation stand is 18.4 meters tall and weights about 30 tons. The diameter of the three main supports is 712 mm. The upper shelf of the stand supports thirteen corner cube reflectors (75 mm aperture, 1 second accuracy), and the interferometer housing (3900 x 1500 x 4500 mm^3) is supported by the lower shelf, which is located below the floor of the LHD. The optical housing is air tight and filled with dry air in order to reduce absorption of the CH_3OH laser radiation by atmospheric water vapor. Z cut crystal quartz etalons are used for the beam splitters, beam combiners and vacuum windows. The measured transmission of the windows (73 mm clear aperture, 2999 μm in thickness) is about 80 %. The each probe beam is focused to a beam waist diameter of 44 mm on the corner cube reflectors. The reflected beams are combined with the local beams and down-converted into I.F. signals (f = 1 MHz) by GaAs Schottky barrier diode mixers mounted on a corner cube reflector. For the detection of the mechanical vibration the He-Ne laser interferometer is equipped at the central chord channel.

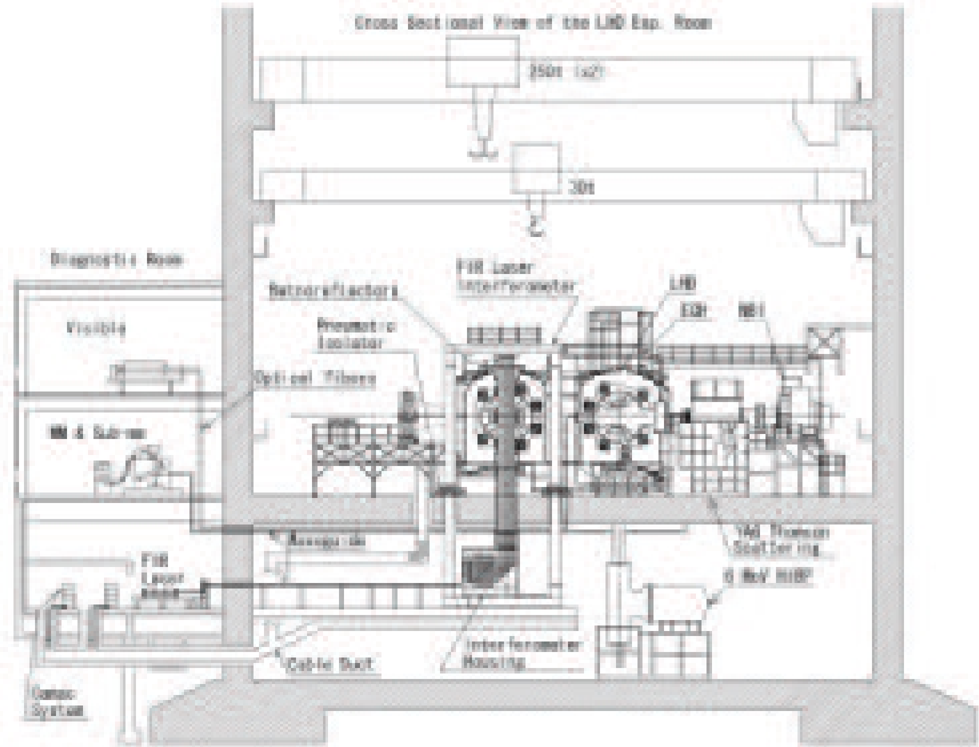

Fig. 1. Cross-Sectional view of the LHD experimental hall.

3. The Laser System

For the interferometry of the LHD plasma, the probing laser wavelength should be smaller than 200 μm in order to avoid the beam refraction effects owing to the plasma density gradient. There are two kinds of laser sources with high power in the FIR wavelength region, 119 μm CH_3OH and 195 μm DCN lasers. We have chosen the 119 μm CH_3OH laser from the view points of the output power (620 mW), small refraction effect, high beat frequency available and so on. Figure 2 shows the schematic drawing of the laser system we have developed. In the optically-pumped FIR laser, the pump CO_2 laser plays important role for output power, laser mode, and stability of the FIR laser oscillation. In order to stabilize the CO_2 laser frequency, DC and AC the stark effects of the external CH_3OH Stark cell are applied. The twin FIR laser is of the waveguide type, consisting of 35 mm ID Pyrex-glass tubes of 2.2 m in length with coaxial water coolant jacket. The laser cavity are formed by gold coated Cu input couplers with a off-axis 3 mm hole and gold coated Si hybrid couplers with a 13 mm diameter clear aperture. The cavity mirrors are mounted on the base plates made of stainless steel, of which separations are fixed by using two super-invar rod of 25 mm in diameter. The position of the mirror mounts is controlled by stepping motors with the minimum step size of 0.01 μm, which enable us to control the beat frequency within an accuracy of 5 kHz, 0.5 % of the beat frequency (1MHz). The output power can be as high as 680 mW in total, but a typical operation power at the experiments is 250 mW (150 mW for a probe beam and 100 mW for a local beam).

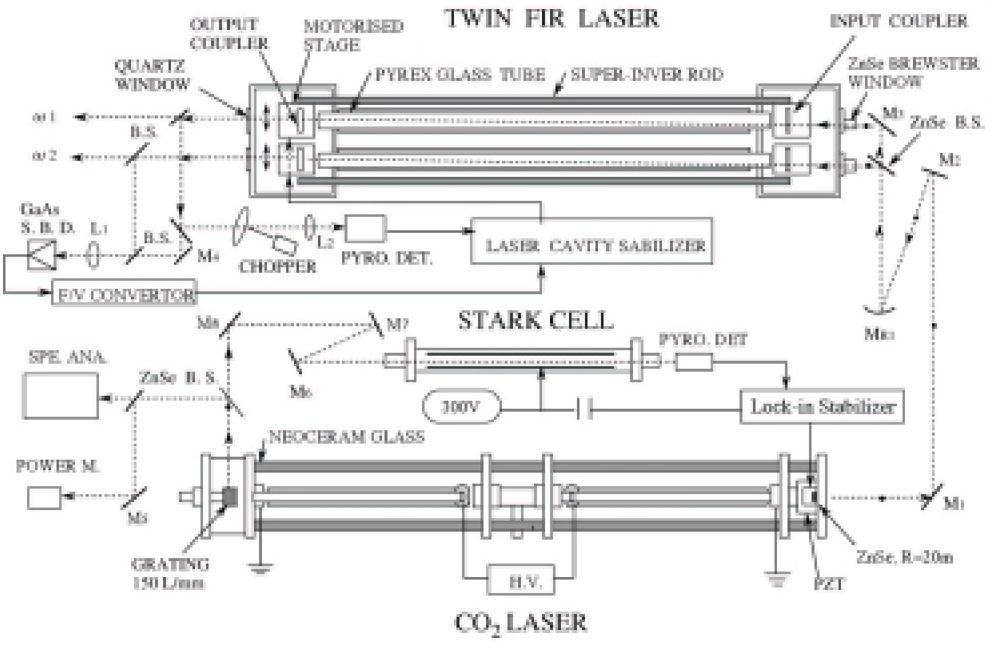

Fig. 2. Schematic drawing of the optically pumped twin FIR laser with a feedback control system

4. Data Acquisition System and Results

The 1 MHz beat signals from the detectors are amplified and converted to TTL signals in the electro-optical converters. For the measurement of the phase difference between the probe signal and the reference one a new type of digital phase linearizer has been developed [5]. The phase linearizer can measure phase shifts up to 640 fringes with an accuracy of 1/100 of a fringe. The size of internal memory is 16 bits — 2 Mwords and the sampling frequency of the waveform data is up to 1 MHz. For real-time phase measurements the phase linearizer has a digital-to-analog converter output, and its output signal has been used for the density feedback control.

Figure 3 shows typical direct output signals of 12 channels when an ice pellet was injected into the LHD plasma. The amplitude of the phase shift due to the mechanical vibrations was measured to be less than 1/100 fringes during the standard duration discharges, so that the compensating interferometer is unnecessary at the present. In order to obtain density distribution, we applied the simple slice and stuck technique for the Abel inversion procedure [6]. Figure 4 shows the time evolution of inverted chordal data for a pellet injected discharge. The observed density profile is hollow one before the pellet injection, and becomes relatively flat just after the injection. The profile keeps the same one for ~100 ms after the pellet is injected, and then changes to the peaked one. A steep density gradient is observed at the peripheral region of the plasma, which often causes the fringe jumps at the corresponding channels when a large sized pellet is injected. In order to solve this problem, shorter wavelength laser sources are under development [7].

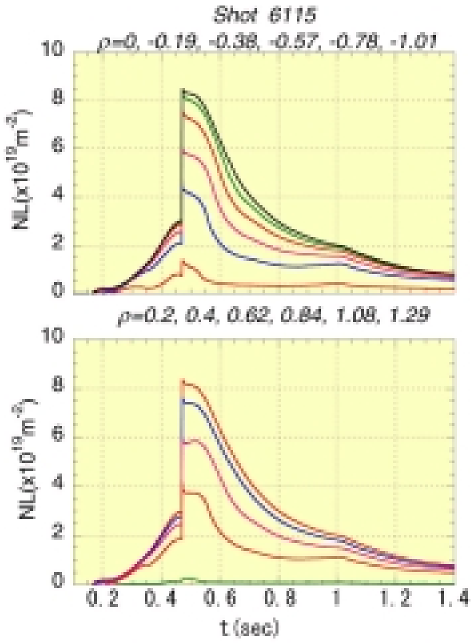

Fig.3. Time behaviors of the line integrated densities.

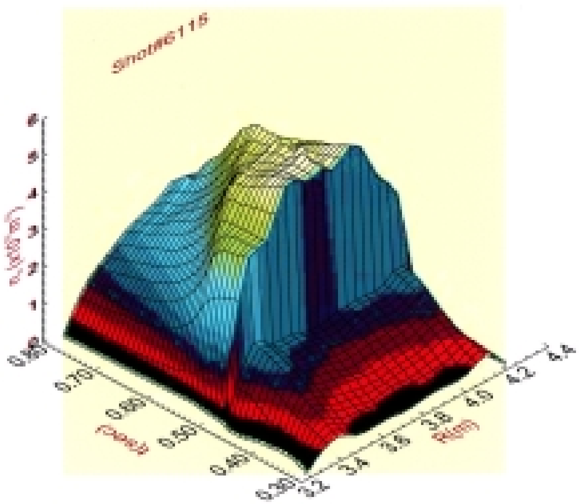

Fig.4. Time evolution of the density profile during ice pellet fuelled discharge.

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