Development of a new two color far infrared laser interferometer for future fusion devices

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A new two color far infrared (FIR) laser interferometer under development for future fusion devices will be presented. The laser wavelength is optimized from the consideration of the beam refraction effect due to plasma density gradient and signal-to-noise ratio for an expected phase shift due to plasmas. Laser lines of 57.2 and 47.6 μm are found to be suitable for the applications to high performance plasmas of Large Helical Device and future fusion devices such as the International Thermonuclear Experimental Reactor. The output power of 57.2 μm CH_3OD laser is estimated to be ~1.6 W, which is the highest laser power in the FIR wavelength regime. The optical configuration of a new interferometer system using two colors will be proposed. In the system, one detector simultaneously detects the beat signals of the 57.2 and 47.6 μm laser lines, and each interference signal can be separated electronically (1 MHz for 57.2 μm and 0.84 MHz expected for 47.6 μm). Mechanical vibration can be compensated by using the two color interferometer. The present status of the development of the system is also presented. © *2004 American Institute of Physics.* [DOI: 10.1063/1.1791748]

I. INTRODUCTION

Measurements of the refractive index of the plasma by using electromagnetic waves are a well-established tool for measuring electron density profiles in high temperature plasmas. In the Large Helical Device (LHD) (R_{ax}=3.5–3.9 m, a_p=0.60–0.65 m, B_o=1.5–2.9 T),[1,2] a 13-channel far infrared (FIR) laser interferometer has been routinely operated for the precise measurements of the electron density profile.[3] The optical configuration of the interferometer 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 continuous wave (cw) CO_2 laser.[4] The interferometer routinely provides density profiles almost every shot except in the case of a high-density plasma produced by an ice pellet injection, where fringe jumps sometimes occur on the density traces measured by fringe counters. In order to overcome this difficulty we have been developing new laser sources in the wavelength region of 40–70 μm, which is optimum value from viewpoints of the plasma refraction and mechanical vibration effects, since the beam bending effect can be reduced by a factor of ~4 compared with that of 119 μm as is shown in Fig. 1. On the way to search short wavelength laser oscillation lines, we have achieved high power oscillation lines at 57.2 and 47.6 μm in CH_3OD, by resonant pumping with a 9R(8) CO_2 laser line. In this article a new two color FIR laser interferometer using these oscillation lines is proposed.

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II. NEW TWO COLOR FIR LASER INTERFEROMETER

For high-density operation of the LHD and for future large fusion devices such as the International Thermonuclear Experimental Reactor, we have been developing a new two color FIR laser interferometer. One of the key issues to construct the system is to develop short wavelength laser sources with high power. The FIR laser system under development consists of a twin-type FIR cavity of 25 mm in diameter, a pump CO_2 laser and coupling optics. We have achieved a lot of high power oscillation lines from 40 to 100 μm in wavelength by changing FIR laser molecules. Among these oscillation lines the most powerful line was found to be a 57.2 μm CH_3OD laser line[5] which was able to oscillate simultaneously at 47.6 μm every 5×57.2 μm ($\sim 6\times 47.6$ μm) by tuning the FIR laser cavity length.[6] Figure 2(a) shows a Fabry-Pérot (FB) interferometer which is used to measure the wavelength of the laser oscillation line. By rotating the polarizer vertically or horizontally, one oscillating line is selected to feed to the Fabry-Pérot interferometer. The interferograms observed by changing the distance between two wire grids are shown in Figs. 2(b) and 2(c), which show that 57.2 and 47.6 μm lines oscillate simultaneously with different polarizations. These new laser oscillations enable us to develop a new two color FIR laser interferometer. Some excellent features of the new system are as follows: (i)

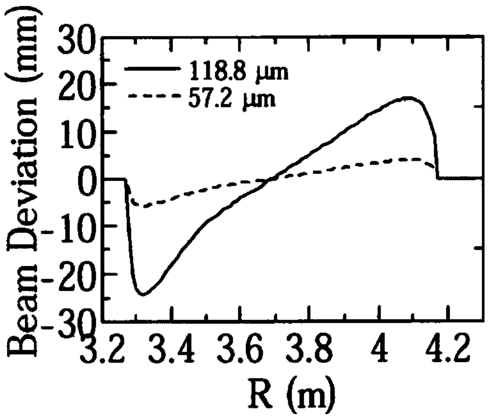

FIG. 1. Radial profiles of the beam deviation at the retro-reflectors which are located 4 m away from the median plane of the plasma. The density profile is assumed to be a parabolic profile with a line-averaged density of 1.0×10^{20} m^{-3}. The magnetic axis is at 3.6 m.

the wavelength of 57.2 μm is of optimum value to avoid refractive effects in high-density operation of LHD and future fusion devices; (ii) the optical components such as windows, beam combiners, and beam splitters can be optimized at both frequencies by choosing the thickness of the components; (iii) an additional laser instrument is not needed to compensate the fringe shift due to mechanical vibrations; (iv) both laser beams pass the same optical path in the interferometer without optical path difference, and (v) one detector simultaneously detects the beat signals of both oscillation lines, and each interference signal can be separated electrically—the 57.2 μm at 1 MHz and the 47.6 μm at 0.84 MHz.

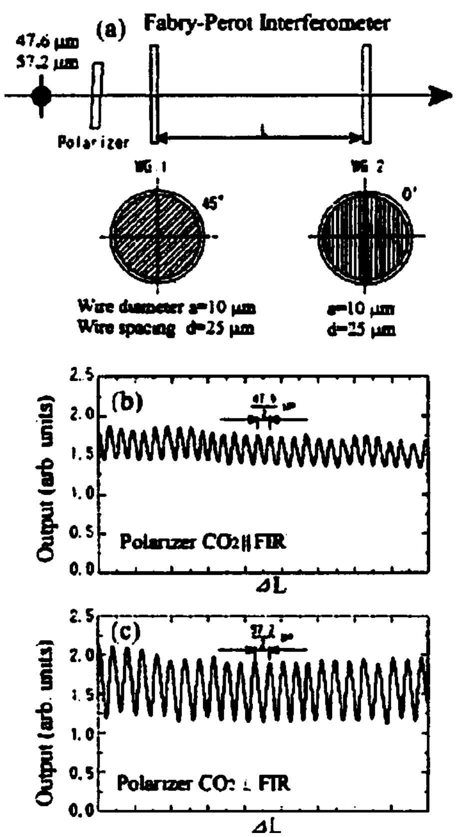

FIG. 2. Optical configuration of the Fabry-Pérot interferometer (a). Interferograms in the output of the Fabry-Pérot interferometer when the polarizer is set vertically (b) and horizontally (c).

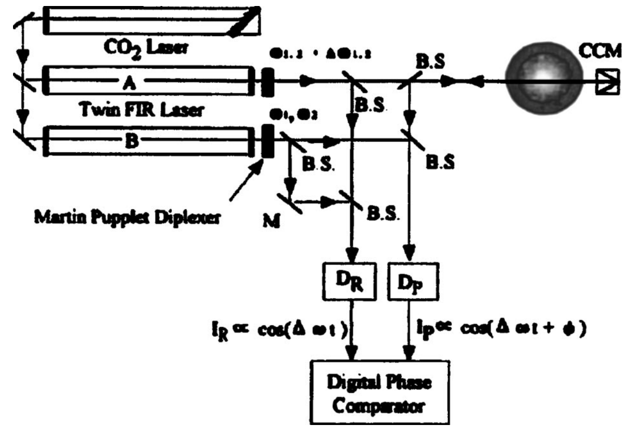

FIG. 3. Schematic drawing of a new two color FIR laser interferometer.

Figure 3 shows a schematic drawing of the new two color FIR laser interferometer system using simultaneous oscillations at 57.2 and 47.6 μm. Both oscillation lines have different polarization. The 57.2 μm line is perpendicularly polarized for the CO_2 laser, while the 47.6 μm line is parallelly polarized. In mm and sub-mm wave regions above 100 GHz, the Martin–Pupplett polarizing interferometer is widely used[7] to multiplex the two colors into a single co-aligned, co-polar output beam. However, the conventional Martin–Pupplett interferometer is not suitable for the application to the shorter wavelength region, since the diameter and the spacing of the wire grid is close to the wavelength. Some explanations for this diplexer for the application to short wavelength are needed. We constructed a conventional Martin–Pupplett polarizing Diplexer as is shown in Fig. 4(a), with a path length designed to rotate the polarization of one frequency by 90°, while the other is unaffected. The shortest path difference required to do this is for wavelengths of 57.2 and 47.6 μm is 500 μm, as the attached Mathematica plot shows in Fig. 4(b). The Diplexer is of a conventional design, but with some special features for very short wavelength operation: Particular attention has been applied to (a) The mechanical accuracy of the structure—dowels are used rather than screws to hold the structure together. In the horizontal plane directional errors of the corner reflectors are, to a significant extent, self-correcting. This is not so in the vertical plane, and attention has been applied to making these parallel to one another. (b) The sharpness of the corner in the corner reflectors is very high by fabricating the corner pieces in two parts, giving a "knife edge." This minimizes the distortion of the beam in the apex region. (c) The polarizing grid is formed by lithography to give the necessary accuracy to give good phase and amplitude transmission and reflection properties (albeit with some absorption loss not normally present in free standing grids). The grid spacing is 2 μm with a 1 μm conductive line—mounted on a 1.5 μm Mylar sheet. (d) An off-axis ellipsoidal mirror, cut from brass using a high speed milling machine, refocuses the expanding beam from the Laser as it passes into the Diplexer.

Figure 5 shows the 1 MHz heterodyne beat signal first

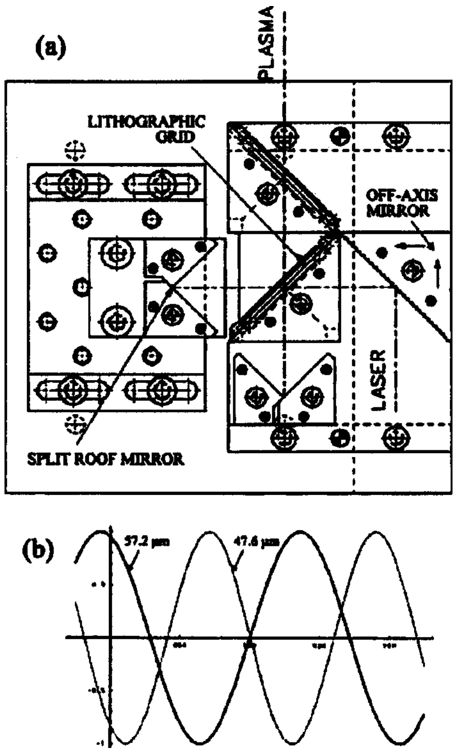

FIG. 4. (a) Schematic drawing of a Martin–Pupplett polarizing diplexer. (b) Electric field amplitude polarization as a function of a path difference between two arms. When the input polarizations are orthogonal the polarizations are both vertical at the path difference of 500 μm.

detected by using a GaAs Schottky barrier diode mixer mounted on a quasioptical corner cube-type antenna structure. The single beat signal shows that the twin laser is lasing at a single transverse and longitudinal mode. The sensitivity of the detector is not good at this laser line since the whisker antenna is optimized to detect 119 μm laser line. We might have much higher sensitivity when the detector is optimized at 57 μm. Responsivity of the Schottky barrier diode, however, is decreased with operating frequency, and the cutoff frequency of the diode is below several THz, which is close to the laser oscillation frequency. So far, we could not detect the 47.6 μm intermediate frequency signal by using the Schottky barrier diode when the laser oscillates at two oscillation lines. Therefore, we need to search for other kinds of detector, such as an InSb He-cooled detector with magnetic tuning[8] and a Ge:Ga photoconductor,[8] to obtain high responsivity for short wavelength laser lines.

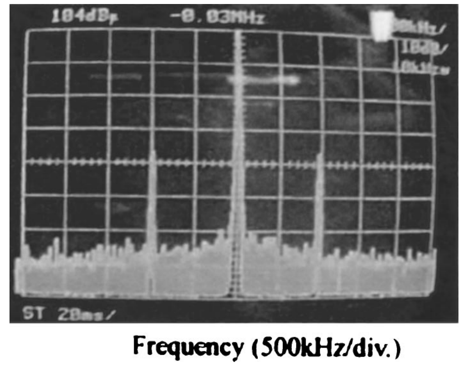

FIG. 5. A 1 MHz beat signal of the 57.2 μm laser first detected by a Schottky barrier diode. The spectrum analyzer trace shows a single beat signal at 1 MHz showing single transverse mode operation.

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