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FIR INTERFEROMETER AND SCATTERING MEASUREMENTS ON ATF*

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Abstract

A 15-channel far-infrared (FIR) interferometer system has been constructed to measure the electron densities on the ATF plasmas. The system consists of a pair of cw 214-μm difluoromethane (CH_2F_2) lasers, optically pumped by separate CO_2 lasers. The large number of channels is achieved by the use of reflective beam expansion optics to create a beam of 2 cm × 45 cm. After passing through the plasma discharge, the elongated beam produced by the cylindrical mirrors is dissected by an array of 15 off-axis paraboloid reflectors, each of which illuminates a single Schottky-diode detector. The use of the beam expanding optics system reduces the number of optical elements required for the interferometer to approximately 2-3 per channel. The FIR laser beams are transported from the laser room to the experimental area by 25 mm i.d. dielectric waveguides purged with dry nitrogen. The system can also be operated at a wavelength of 119-μm by changing the gas in FIR laser cavities to methanol for high density experiments. Details of the system are described.

A study is underway to determine the optimum design of a FIR scattering system for the ATF. This scattering system will be used to investigate density fluctuations with scale lengths from 0.1 cm to the plasma radius. The laser for this scattering system may be operated at wavelengths of 447, 307, 214, 184, and 119 μm with power levels of 100 to 500 mW. A summary of the study is presented.

FIR Interferometer System

The interferometer system is configured to measure the line-integrated electron density along 15 vertical chords on the $\phi = 0$ plane of the ATF plasma. The system is a

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modification of the FIR interferometer system that was used on the ISX-B tokamak [1]. However, instead of using separate probing beams, a phase image technique [2] is used to improve the spatial resolution of the measurement. A schematic diagram of the interferometer system is shown in Fig. 1. Briefly, the system employs a pair of cw CH_2F_2 lasers, optically pumped by separate CO_2 lasers. The FIR cavities are tuned such that the two oscillate at frequencies differing by Δf of the order of 1 MHz. As shown in the figure, cylindrical mirrors and mirrors shaped parabolically in one direction are used to create a slab-like probing beam of 2 cm × 45 cm. The beam is transmitted through almost the whole cross section of the plasma. After passing through the plasma, the probing beam is dissected at the focal plane of the optics system by an array of 15 off-axis paraboloid reflectors, each of which illuminates a signal detector. Part of the beam from the

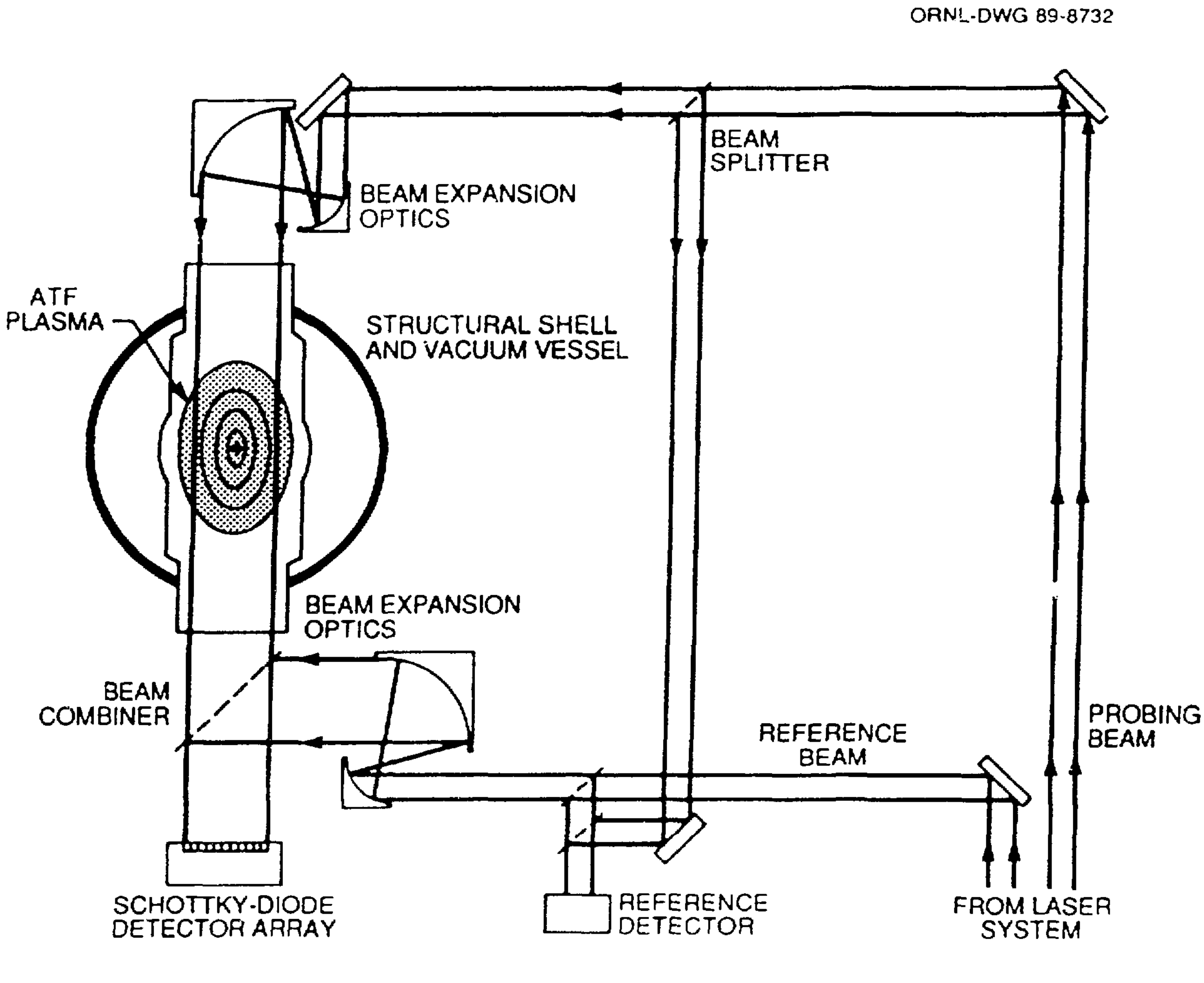

Fig. 1. Schematic of the 15-channel FIR interferometer system on ATF.

reference laser is mixed first in a reference detector with a portion of the probing laser, which is split off before passing through the beam expansion optics, and the remainder is also expanded and is guided to the signal detectors to mix with the probing beam. Schottky diodes are utilized for all detectors. The detector signals are filtered, amplified, and fed into a digital phase detection circuit to extract the phase shift between the output of the signal detector and the reference signal, which is proportional to the line-integrated electron density. The outputs of the phase detectors are displayed on oscilloscopes for photographic recording and are digitized for computer storage and processing.

The pump laser is a 80-W invar-stabilized waveguide CO_2 laser, grating tuned to the 9R34 line. The resonator is formed by a grating of 150 lines/inch and a piezoelectric tunable ZnSe output mirror with radii of curvature R = 20 m and reflectivity r = 69% and two sections of 1.1 cm i.d. correlated Pyrex tube. The discharge length is approximately 215 cm. The FIR laser, also invar-stabilized, produce about 200 mW power on the 214-μm line. Each resonant cavity consists of a 1-in. i.d. Pyrex waveguide and two flat reflectors which are separated by 240 cm. The input reflector is a 2-in.-diam gold-coated copper mirror with a 4-mm hole. The input end is sealed by a ZnSe Brewster window. The output reflector is a gold-coated Si mirror with a 1-cm hole, and is attached to a motorized translation stage. The output end is sealed by a Z-cut crystalline quartz window. Each reflector is set between two bellows in order to be free from atmospheric pressure changes. CH_2F_2 is used as the active gas in the cavity and is sealed off at a pressure near 200 m Torr. The laser is operated at the waveguide EH_{11} mode. The frequency difference between two FIR lasers is obtained by slightly detuning the two cavities by mechanically changing their lengths. The entire laser system is mounted on an optical table of 2 ft × 12 ft, and is enclosed in a Plexiglas shield. The enclosure is slightly pressurized with breathing air to eliminate the water vapor absorption.

Because the electron density is measured interferometrically, vibrations must be reduced to the lowest possible level. Therefore, all the optical elements and waveguides are mounted on a single frame which is independent from the ATF. The frame is constructed of 1 ft × 1 ft fiberglass I beam to eliminate the effects of eddy currents. The frame consists of three vertical mounts, an upper shelf and a lower I beam. The structure stands approximately 5.5 meters tall. The waveguides are made of 1-in. i.d. Plexiglas tubing. Water vapor absorption is eliminated by slightly pressurizing the waveguide with dry nitrogen. Emerging from the FIR laser, the beam is immediately passed into the waveguide where it is directed vertically to the ATF area. In the waveguide, the FIR laser beam assumes an EH_{11} high-order waveguide mode and is transmitted without the need for relay lenses to maintain a uniform beam size. Transparent pellicles of mylar are used to seal the ends of the waveguide against the atmosphere. The waveguide system consists of ten 90° bends and two 60° bends. The total beam pathlength is approximately 30 meters.

Because stray magnetic field levels at the interferometer can exceed 500 Gauss, it is necessary that all components be nonmagnetic, hence all optical mounts are constructed of stainless steel while the frames of beam splitters and the joints of waveguides are constructed of Plexiglas. All mirrors are made of first surface gold-coated glass. The beam splitters are made of quartz which exhibits the double advantage of having a low absorption coefficient for CH_2F_2 radiation and being transparent to visible light for easy alignment. The vacuum windows on ATF consist of six 2-in. × 6-in. × 0.25-in. Z-cut crystalline quartz. To reduce absorption, the windows are made as thin as possible, consistent with their size, which is the minimum needed to pass the FIR beam through the vacuum vessel. Shutters are installed to minimize window coating which could occur during discharge cleaning or other similar operation. The beam combiner is a free-standing wire grid with the electric field of the FIR beams parallel to the wires. The wire grids are made of 10-μm-diam copper wires with 70-μm spacing.

Sixteen Farran Technology quasi-optical Schottky diode detectors are utilized: fifteen are configured in an array to detect the probing beams, and one is used for the reference detector. Each detector has a corner cube wire antenna mixer with a whisker contacted Schottky barrier diode. This type of detector was chosen because it is fast enough to respond to the 1 MHz interferometer modulation signals and sensitive enough so as not to require cryogenic cooling with all the attendant complications. An off-axis paraboloid is used to focus the FIR beams into the antenna pattern of the diode. Parabolic reflectors work well with corner cubes since the relatively small effective waist radius at the apex of the mirror ensures that one is operating in the far field. Each mirror and mixer is pre-assembled and tested in a right angle bracket, with the mirror oriented so that the input beam is vertical. This unit is held in place by fixing screws and compressed against a ball pivot so that angular adjustment of the unit with respect to the input beam is possible. Five of these units are stacked closely together and are held in place on two sliding rails with locking screws. The signal processing circuitry consists of a phase comparator, a fringe counter, and low-pass filters. The heart of the phase comparator is a phase-locked tracking filter. The output of the phase comparator is sampled by the fringe counter which stacks the individual fringes in real time. A digital-to-analog convertor then samples the output of the fringe counter so that the output of this circuitry is proportional to the line density. The analog voltages are displayed on oscilloscopes and are digitized at typically a 10 kHz sampling rate. The data are read by the CAMAC acquisition system and are archived for data analysis.

FIR Scattering System

Collective Thomson scattering of FIR laser radiation has been successfully used to measure the electron density fluctuations in tokamak plasmas [3-5]. However, to our knowledge, this powerful technique has not been utilized on stellerators. Fluctuations in ATF plasmas have been investigated using soft X-ray detectors and Mirnov coils [6]. A study is carried out to determine the optimum design of a FIR scattering system for the measurements of spatial and temporal fluctuations in ATF plasma. The system may be operated at wavelengths from 447 μm to 119 μm. Lasers operated at these wavelengths have been designed, constructed, and tested. Output power levels from 100 to 500 mW have been achieved. A pair of crystal quartz windows 38 mm × 300 mm located adjacent to the multichannel FIR interferometer windows will allow scattering angles of ±15° from the incident beam. A single FIR laser beam will be split to provide both the scattering beam and local oscillator beam in a 3 to 5 channel detector array. The detector is designed to observe scattering from a single point at 3 to 5 different angles or several points at the same angle. Storage of the scattered signals will be accomplished by a PC-based CAMAC data acquisition system.

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