CONF-851238--4

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DE86 005030

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Paper to be presented at
The 10th International Conference on
Infrared and Millimeter Waves
December 9-13, 1985
Lake Buena Vista, FL 32830

To be published in Proceedings:
The International Journal of Infrared and Millimeter Waves

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*Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc., and by U.S. DOE contract No. DE-AC02-CHO-3073.

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Abstract

The results of the first Faraday rotation measurement on the TFTR tokamak are presented. Data are reported on ohmic- as well as neutral-beam-heated plasmas including solid pellet injections. The procedure and the results of the calibration are described. The effects of various errors in the measurements as well as the problem of cross coupling laser beams are studied.

Introduction

In earlier papers [1,2], a multichord far-infrared (FIR) interferometer/polarimeter system on the TFTR tokamak was described. This paper presents the results of the first simultaneous measurements of line electron density and poloidal field-induced Faraday rotation in TFTR plasmas. The propagation of FIR waves in the plasmas have also been investigated to ensure successful measurements of electron density and plasma current distributions in large tokamaks. Detailed mathematical analyses and experiments will be reported at the conference. Only a brief description of this work is, therefore, presented in the following.

Experiments

A schematic diagram of the interferometer/polarimeter system on TFTR is shown in Figure 1. The system consists of a Michelson-type interferometer made from two cw 119 μm methanol lasers, optically pumped by a CO_2 laser. The beat frequency of the FIR lasers is usually adjusted to approximately 1 MHz by tuning the cavity length. The probing and reference beam are divided into ten channels (only five channels were in operation by

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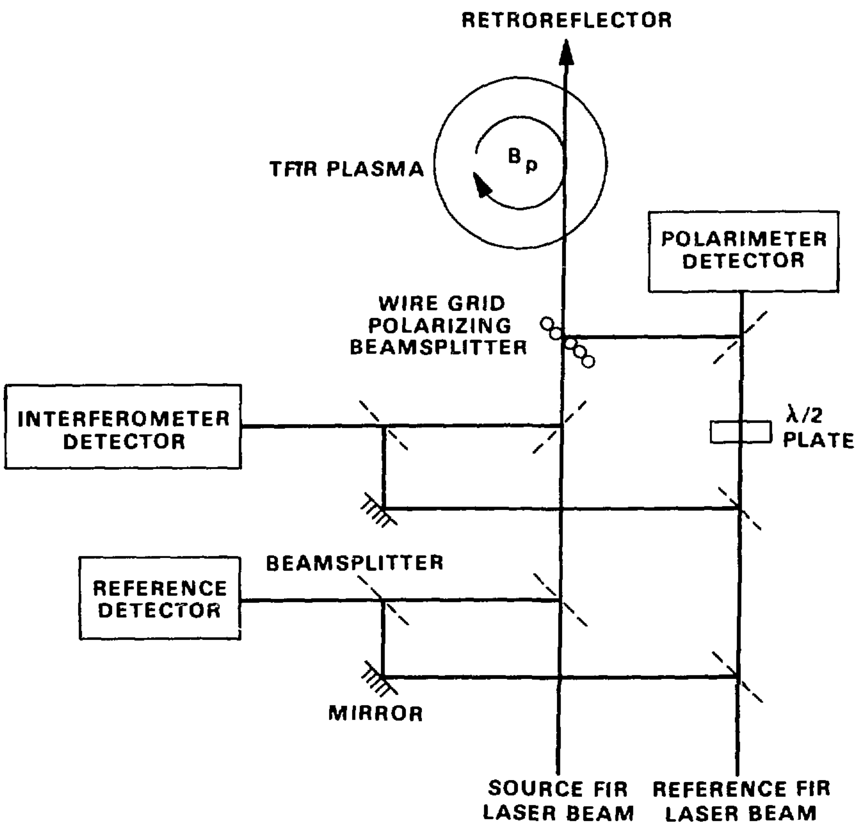

Figure 1. Schematic of the FIR interferometer/polarimeter system on TFTR.

April 1985) by metallic meshes. The probing beams go through the plasma from bottom to the top and are reflected by the retro-reflectors. All optical components are mounted on a Diagnostic Support Structure totally isolated from the TFTR machine and supported on seismic isolators. The FIR laser beams are initially linearly polarized. A wire-grid polarizer is used as an analyzer to provide the Faraday rotation signal. The analyzer is adjusted such that it passes the outgoing probing beam and reflects any rotated component of the return beam. This component is mixed with a portion of the reference beam, and is directed onto the polarimeter detector. Schottky diodes are utilized for all detectors. The output of the polarimeter detector is filtered, amplified, and fed into an envelope detection circuit. If the ellipticity of the polarization of the return beam is negligible, the output of the detection circuit is proportional to sin (θ_F), where θ_F is the Faraday rotation angle of the polarization vector, and is proportional to the line integral of electron density times the poloidal magnetic field along the double-path of the probing beam. Part of the beam from the reference laser is mixed first in the reference detector with a portion of the source laser, which is split off before passage through the plasma, and the remainder is guided to the signal detector to mix with part of the return beam. The outputs of both detectors are also filtered, amplified, and fed into a digital phase detection circuit to extract the phase shift produced by the electron density. Due to limited resources, only the outputs of the phase detectors are digitized for computer storage and processing (April 1985). The output of the envelope detection circuit is displayed on oscilloscopes for photographic recording (only one channel). The interferometer/polarimeter system was routinely employed to study the ohmic- as well as neutral-beam-heated plasma discharges in the TFTR tokamak for over four months. Figure 2 shows the time-resolved traces of (a) line electron density, (b) Faraday rotation of a neutral-beam-heated plasma discharge. During this discharge, three solid hydrogen pellets were injected into the plasma at intervals of approximately half of a second. The abrupt changes of density and Faraday rotation occur during a period of approximately 400 μs.

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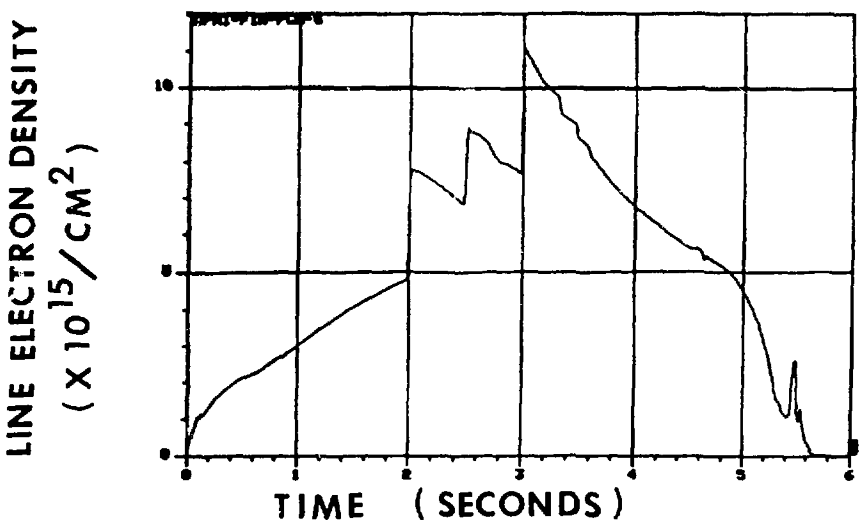
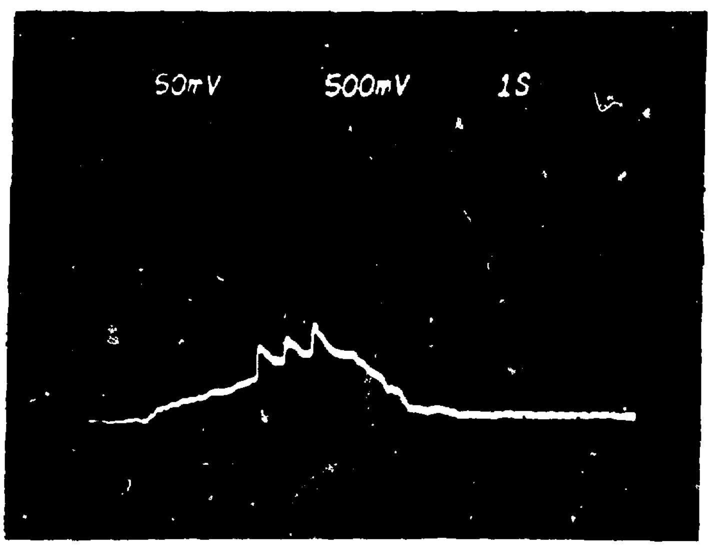


(a)



(b)

Figure 2. Time variation of (a) line electron density and (b) Faraday rotation measured by the multichord FIR interferometer/polarimeter system on TFTR tokamak. The abrupt changes of the line density and Faraday rotation are caused by the injections of the solid hydrogen pellets.

Analyses and Discussions

An algorithm for the solution of the wave propagation equation has been developed and has been used to determine the polarization evolution on the Poincaré sphere. Computer codes have been utilized to calculate the ellipticity, ε, and the rotation angle of the vibrational ellipse, ϕ, of the polarization.

The parameters for TFTR are major radius, R = 265 cm; minor radius, a = 85 cm; central electron density, $n_o = 10^{14}/cm^3$; plasma current, I_p = 2.5 MA; toroidal field, B_T = 5.2 T; wavelength, λ = 119 μm. In this case, the maximum ϕ is approximately 15° with a maximum ellipticity of 0.045 for double path of the beam. The output signals of the interferometer detector, V_i, and polarimeter detector, V_p, can be expressed by the following relations.

$$V_i = V_{io}\text{Cos}(\phi)\left[1 + \varepsilon^2\text{Tan}^2(\phi)\right]^{1/2}\ \text{Cos}(\Delta\omega t + \psi + \psi_i)$$

$$V_p = V_{po}\text{Sin}(\phi)\left[1 + \varepsilon^2\text{Cot}^2(\phi)\right]^{1/2}\ \text{Cos}(\Delta\omega t + \psi + \psi_p)$$

where V_{io} and V_{po} are the calibration constants for the interferometer and polarimeter, respectively, ψ is the phase shift due to electron density, and ψ_i and ψ_p are given by

$$\psi_i = \text{Tan}^{-1}\left[\varepsilon\ \text{Tan}\ (\phi)\right] \qquad \psi_p = \text{Tan}^{-1}\left[\varepsilon\ \text{Cot}\ (\phi)\right]$$

It can be seen in the equations that both the amplitude and the phase of the signals depend on the ellipticity of the polarization which cannot be measured easily due to limitations on the experimental techniques. The error of density measurement due to neglecting of the ellipticity is very small (0.024 percent), and the error of the Faraday rotation measurement is approximately 1.7%.

During the period of operation, sinusoidal oscillation of the Faraday rotation signal due to the cross coupling of the laser beams was observed. A modified theory for the polarimeter including the cross coupling was developed. A comparison between the theory and the experiments gave excellent agreement. Experiments for calibration of the polarimeter were also carried out to determine the sensitivity of the system and the rotation angle due to the cross coupled beams.

Acknowledgments

The authors are greatly indebted to the TFTR group for their support and cooperation.

This research was sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc., and by U.S. DOE contract No. DE-AC02-CHO-3073.

References

[1] H. Park, D. K. Mansfield, L. C. Johnson, and C. H. Ma, Fifth Topical Conference on High Temperature Plasma Diagnostics, Tahoe City, California, September 16-20, 1984.

[2] D. K. Mansfield, H. Park, L. C. Johnson, and C. H. Ma, Bull. Am. Phys. Soc., 19 1304 (1984).