A SUBMILLIMETER-WAVE POLARIMETER FOR PLASMA DIAGNOSTICS*

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A submillimeter-wave laser polarimeter with ferrite polarization modulators is described. The poloidal magnetic field and the plasma current density of a tokamak can be determined by measuring the Faraday rotation of the laser beam in plasma. High polarization sensitivity was observed in a stimulated tokamak plasma experiment.

When tokamak plasmas are studied experimentally, it is important to be able to measure the poloidal magnetic field and the toroidal plasma current, as these parameters confine and heat the plasma and are responsible for mhd instability. Theoretical analyses have shown that in some cases the poloidal magnetic field, and thereby the plasma current, can be determined by directing a linearly polarized electromagnetic wave through the plasma and measuring the Faraday rotation of the polarization. Even though the rotation angle is proportional to the square of the wavelength, the general trend has been to use shorter wavelengths so as to improve the spatial resolution and wave transmission. As a result, even at far-infrared (FIR) wavelengths, techniques are required to measure rotation angles which, for present-day tokamak experiments, may be only a fraction of a degree. To measure such small rotation angles with accurate time resolution, the possible use of polarization modulation techniques in a submillimeter-wave polarimeter has been investigated experimentally at ORNL.

The experimental configuration is shown schematically in Fig. 1. The source of the system was a 393-μm cw HCOOH laser, pumped with a CO_2 laser. The FIR laser beam passed through two wire-grid polarizers, a plasma simulator, and a polarization modulator that was driven by a radio frequency (rf) current. The polarizers were mounted in crossed orientation. The power transmitted by the second polarizer is given by

$$P_T = P_0 \cos^2 \theta_p,$$

where P_0 is the effective power at the detector for $\theta_p = 0$. The change in P_T as θ_p is varied is small, only 4% for $\Delta\theta_p = 10°$. When the polarization is modulated with an amplitude of θ_m and a frequency of ω_m, the power at the detector becomes

$$P_T = P_0 \cos^2[\theta_p + \theta_m \sin \omega_m t].$$

Expanding and retaining terms of order θ^2_m, one obtains

$$P_T = P_0 \cos^2 \theta_p [1 - \theta_m^2/2] + P_0 \frac{\theta m^2}{2} \cos 2\theta_p \cos 2\omega_m t - P_0 \theta_m \sin 2\theta_p \sin \omega t.$$

For small modulation, the amplitude of the output signal at the modulation frequency is directly proportional to $\theta_m \sin(2\theta_p)$, where θ_m is the amplitude of the modulation angle, and θ_p is the angle of the simulated plasma rotation. Ferrite polarization rotators were used as the plasma simulator and the rf modulator. A liquid-helium-cooled InSb detector and lock-in amplifier were employed to measure the low-level laser signal.

The simulated plasma rotation and the output of the lock-in amplifier are shown in Fig. 2. In Fig. 3, both theoretical and experimental results for simulated plasma are summarized, with the modulation angle given as a parameter. A polarization sensitivity of 26 mV/milliradian was achieved at a modulation angle of 149 milliradians with a FIR laser power of 4 mW. The system is being used to determine the poloidal magnetic field in ISX, a tokamak device at Oak Ridge National Laboratory.

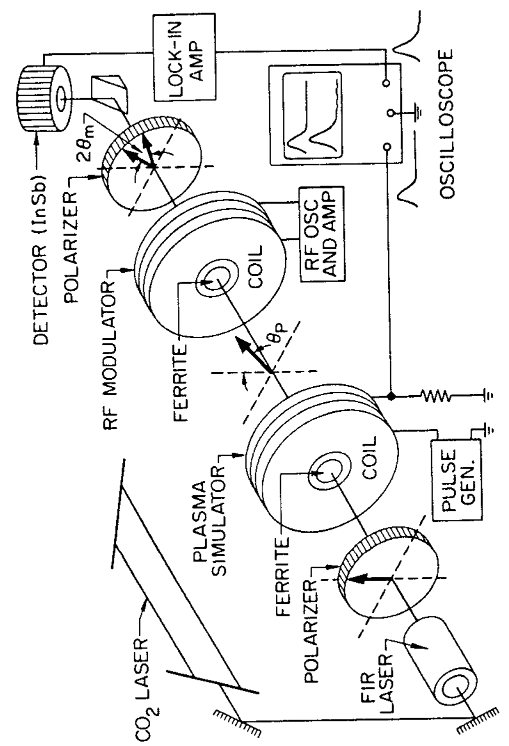

Fig. 1. Experimental Configuration for the Submillimeter Wave Polarimeter.

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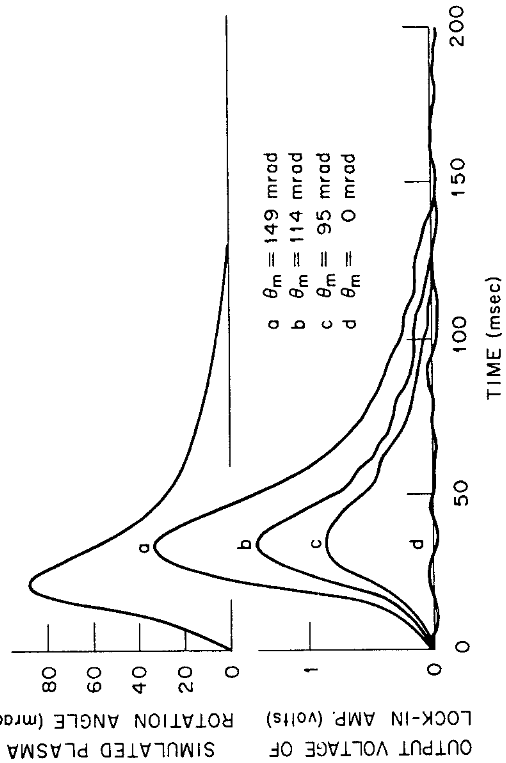

Fig. 2. Simulated and measured rotation angles at a modulation frequency of 9.1 KHz.

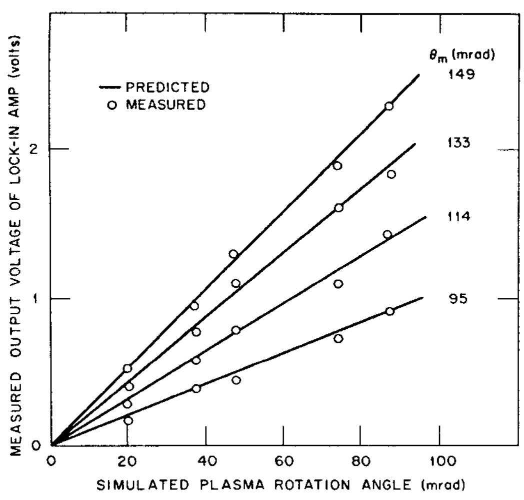

Fig. 3. Predicted and measured rotation angles at a modulation frequency of 9.1 KHz.