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Measurement of Plasma Density**

by

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ABSTRACT

This report describes an interferometer recently developed and tested in prototype form. The device combines certain features of predecessor interferometers but in a module which is simpler to use, subject to limitations on path-length and bandwidth.

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I. INTRODUCTION

The device described here combines certain advantages of both the quadrature interferometer¹ and the coupled cavity interferometer:² The quadrature interferometer can track multifringe phase excursions unambiguously, has excellent and uniform differential sensitivity, is relatively immune to small refractive bending of the scene beam, and is automatically calibrated. The coupled-cavity interferometer requires that only one light beam be aligned, not two as in a Michelson or Mach-Zehnder scheme.

II. CONCEPTUAL DESIGN

The optical layout is schematically illustrated in Fig. 1. A helium-neon laser's 6328 Å output enters an acousto-optic Bragg cell where the light is split into zero-order and first-order diffraction beams.³ The zero-order beam goes right onto a PIN photodiode detector within the device's housing. The first-order diffracted beam exits the housing and reaches a mirror which is used to retroreflect the beam along the same path. The reflected first-order beam passes again through the Bragg cell and is itself split into two beams. The zero-order product is lost, while the first-order diffracted output returns to the laser exit mirror. This light which is returned to the laser mirror has been twice Doppler-shifted by the Bragg cell. For example, in the device already built, the Bragg cell frequency is 40 MHz, so the returned light is Doppler-shifted 80 MHz relative to the original longitudinal mode in the laser. The laser used here has a longitudinal mode spacing of 435 MHz. In addition, the width of an individual laser mode is much narrower than 80 MHz. Therefore the returned beam, which is doubly Doppler-shifted, does not couple to the lasing process, thereby avoiding spurious amplitude modulation of the laser output.

Interference between retroreflected light (which is doubly Doppler-shifted by the Bragg cell) and light emitted by the laser causes a modulation of the signal on the photodiode, at twice the acoustic drive frequency of the Bragg cell. In addition, any changes of the optical path length from the laser to the retroreflector cause phase-modulation of this detected carrier. For example, a plasma can be located between the device housing and the external mirror, and plasma density excursions in the line of sight show up as phase-modulation of the detected 80-MHz carrier.

The signal processing is schematically illustrated in Fig. 2. The detected photocurrent signal is amplified and split into two channels. One channel goes right into an RF mixer. The other channel is delayed by 90° and then goes into a different mixer. The local input to each mixer is an 80-MHz signal derived from, and coherent with, the Bragg cell 40-MHz drive. The two mixers' outputs are 90° separated from each other. That is, one output is proportional to $\sin \phi$, and the other is proportional to $\cos \phi$, where ϕ is any phase shift introduced by changes in path length between the laser and the retroreflecting mirror. The amplifier following the photodiode should saturate so that the wave-trains entering the mixers contain phase information but not amplitude modulation. In this way the mixer outputs are uniquely and permanently calibrated, as long as the photodiode signal does not dip below design limits.

The sine and cosine signals contain the complete information of a quadrature interferometer. On the other hand, the alignment procedure consists of adjusting only one mirror, as in a coupled-cavity device.

III. CONCEPTUAL LIMITATIONS

There are two fundamental limitations on the use of the interferometer described here. First, the return path length between laser and retroreflector must be less than the coherence length of a single longitudinal mode of the laser. Since this coherence length is usually a few meters (for an individual laser mode), the device can be used for many close-in applications. Care must be taken to ensure that the one-way path length is nearly an integer multiple of laser cavity lengths, so that different longitudinal modes will not interfere destructively with each other. (A 5-mW Hughes model 3225 laser has been found suitable for return path lengths through five meters.)

Fig. 1.
Interferometer optics.

Fig. 2.
Interferometer electronics.

The second fundamental limitation is on bandwidth. Each mixer output consists of the desired demodulated signal as well as some carrier and carrier harmonic components. Eliminating these high-frequency components in the recorded outputs requires that the recording bandwidth be small compared with twice the Bragg cell drive frequency. In the prototype already built, a 20-MHz recording bandwidth suffices to exclude the carrier and carrier harmonic mixer output. A higher recording bandwidth could be employed if one uses a UHF Bragg cell and UHF mixers.

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