PPPL-2171

(2)

I-18957

PPPL-2171

DR-0731-5

UC20-F

178

1/17/85

(15)

FAR-INFRARED LASER SCATTERING IN THE ACT-I TOROIDAL DEVICE

By

J. Goree, D.K. Mansfield, M. Ono, and K.L. Wong

DECEMBER 1984

PLASMA
PHYSICS
LABORATORY

PRINCETON UNIVERSITY
PRINCETON, NEW JERSEY

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY,
UNDER CONTRACT DE-AC02-76-CO-3073.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

FAR-INFRARED LASER SCATTERING IN THE ACT-I TOROIDAL DEVICE

J. Goree, D. K. Mansfield, M. Ono, and K. L. Wong

PPPL--2171

Plasma Physics Laboratory, Princeton University

DE85 0053 41

Princeton, NJ 08544

ABSTRACT

A far-infrared laser scattering diagnostic has been built for the ACT-I toroidal device. The optical system uses a passively stabilized 447- μm CH_3I laser. A polyethylene etalon is the beam splitter. The vacuum windows are plastic (TPX), which we found has the vacuum property Q 6.5×10^{-9} Torr-liter/sec/cm². Using paraboloidal and ellipsoidal mirrors for detection optics improves the signal strength and allows a better rf enclosure design for the detector. The diagnostic was tested by scattering from an ion Bernstein wave, a technique which can be used for ion temperature diagnostics.

1. INTRODUCTION

Laser light scattering has long been a versatile tool for nonintrusive measurements of plasma density fluctuations associated with waves in plasmas.¹ We built a far-infrared (FIR) laser scattering diagnostic for the ACT-I toroidal device² to detect radio frequency waves. This complements probe diagnostics because it resolves the perpendicular wave number $k_{\perp}$ of the wave and does not interfere with the plasma. The purpose of this paper is to provide practical information for designing FIR diagnostics, including far-infrared laser scattering diagnostics of larger plasma devices. We will explain how we used different types of optical components to obtain higher signal levels and conclude by showing data produced by the diagnostic in scattering from the ion Bernstein wave.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

II. APPARATUS

A focused laser beam enters and exits the ACT-I vacuum vessel from the side, passing vertically through the plasma where it is scattered (Fig. 1). All optics are mounted on a table which moves, for scanning the laser beam through the plasma radially. The optical system is shown in Fig. 2. A 50-W, cw CO₂ laser, operating on the 10P18 line, optically pumps the FIR laser, which is a glass tube filled with CH₃I gas. A polarizer P1 and a CdS quarter wave plate QWP1 eliminate optical feedback from the FIR laser to the CO₂ laser³; this passive stabilization method increases the FIR laser power by about 25 percent to 15 mW. Increased power improves the heterodyne detection signal strength, which is⁴

$$P_D = (P_S P_{LO})^{1/2} = \frac{1}{2} \tilde{n} r_0 \lambda_0 L (P_O P_{LO})^{1/2} . \quad (1)$$

Here $\tilde{n}$ is the wave electron density fluctuation, r_0 is the classical electron radius, λ_0 is the wavelength of the laser light, L is the length of the effective scattering volume, P_O is the laser power incident on the plasma, and P_{LO} is the local oscillator beam power.

The CO₂ laser cavity length is lock-in stabilized by modulating its length at 520 Hz with a PZT (piezo-electric translator) and detecting a 520-Hz sound wave with a microphone in the FIR laser cavity.

A polyethylene film beam splitter BS1 divides the FIR laser beam into a local oscillator beam and the incident beam. The film is an etalon, a fact we

exploit to obtain an optimal reflecting fraction of $1/3$ by selecting the etalon thickness and by orienting the incident FIR polarization with a quartz quarter wave plate QWP2. The laser beam begins circularly polarized³ and QWP2 converts it to linearly polarized. Polyethylene lens L2 focuses the beam in the plasma.

The vacuum windows on ACT-I are made of the plastic TPX, a material commonly used in the FIR.⁵ We mention here, incidentally, that no outgassing specifications for vacuum window use were available for it, so we measured it and found $Q = 6.5 \times 10^{-9}$ Torr-liter/sec/cm². A useful feature of TPX is that it has the same low index of refraction, 1.43, in the visible and in the FIR,⁵ and like polyethylene film it is transparent in both the visible and the FIR; this allows a HeNe laser to be used to align the optical system for zero angle scattering. Crystal quartz is usually used for FIR vacuum windows, but it has several disadvantages. Quartz has high absorption⁶ which means that the window should be as thin as possible; but since it has a high index of refraction, 2.1, it reflects a great deal of power unless its thickness is carefully adjusted to make it an etalon. Etalons have the additional disadvantage of working for only one wavelength, yet it is common to vary the wavelength of the FIR laser, depending on the need. Quartz is also unavailable in large dimensions. Provided that its outgassing is tolerable for the plasma device, as it is for ACT-I, TPX is preferable because less laser power is lost using it.

A wave in the plasma, with wave number $k_{\perp}$, scatters laser light at an angle θ_s according to the Bragg relation

$$\theta_s = 2 \sin^{-1} (k_{\perp}/2 k_0) \quad (2)$$

where k_0 is the laser light wave number. Mirror M7 selects θ_s ; M7 is translated and rotated by digitally controlled stepping motors to scan the scattering angle. The wave number is resolved with an accuracy⁴ $\Delta k_{\perp} = 2/w_0$ which is 4.4 cm^{-1} for our diagnostic, where w_0 is the half-width of the beam in the plasma.

The combined local oscillator and scattered beams are focused by the off axis paraboloidal mirror PM through the focal point FP1. The ellipsoidal mirror EM has its two focal points at FP1 and D, the detector. Using this pair of curved mirrors PM and EM improves the signal to noise ratio in two ways. First, by using reflecting rather than the usual refracting optics, losses of light are eliminated. Secondly, having two focal points means that one of them, FP1, can be positioned at the entrance of the rf enclosure for the detector, and the entrance hole can be very small, improving the shielding. The detector D is a room temperature Schottky diode mixer.⁷ A mechanical chopper CI modulates the detector signal.

The basic signal processing instrumentation is shown in Fig. 3. A fiber optic cable carries the detector signal to an rf lock-in amplifier. The lock-in is synchronized with the rf oscillator which drives the wave in the plasma. Since lock-in detection is a powerful method of eliminating thermal detector noise and the Schottky diode detector has an extremely low noise level,⁷ $\text{NEP} = 2 \times 10^{-19} \text{ W/Hz}$, meaning that detector signals as small as $2 \times 10^{-19} \text{ W}$ may be detected using a 1-Hz bandwidth, if there is no rf pickup. Traditional passive methods of reducing rf pickup may not suffice. To reduce actively rf pickup to very low levels, we devised a new lock-in method which we call the double lock-in method. Since this method should be generally useful in any application where synchronous rf pickup must be removed from a signal which

can be modulated, we will describe the method in detail in another publication; briefly, the method consists of applying the output of the rf lock-in amplifier to the input of a second, low frequency lock-in which is synchronized to chopper C1.

III. RESULTS FOR THE ION BERNSTEIN WAVE

We demonstrated the FIR laser scattering diagnostic by scattering from an ion Bernstein wave. This wave is a hot magnetized plasma mode which is excited by an external or internal antenna driven at a frequency just beneath an ion gyrofrequency harmonic.⁸ It has been observed in tokamaks, and is important in ion cyclotron frequency heating of plasmas.⁹ A scattering diagnostic combined with an antenna to launch this wave has been used as an ion temperature diagnostic, since $k_{\perp}$ depends on the ion temperature.¹⁰

In the present experiment, a 12.5-MHz wave was launched with an internal antenna in a hydrogen plasma with a toroidal magnetic field of 4.3 kG, and was detected on the high field side of the first harmonic layer ($\omega = 2 \Omega_{ci}$). The scattering angle was 4° , which corresponds to $k_{\perp} = 9.8 \text{ cm}^{-1}$. We observed the $k_{\perp}$ resolution of the diagnostic by changing the scattering angle by more than 1° and seeing the signal disappear.

The data are shown in Fig. 4. The lock-in amplifier output signal makes an interferometry trace as it is plotted against the radial position of the laser beam in the plasma. Interferometry traces are shown in Fig. 4 using both the double lock-in method and the single lock-in method.

ACKNOWLEDGMENTS

The authors thank W. Blanchard for helping with the TPX outgassing measurement, and C. Bennett, W. Kineyko, and J. Taylor for able assistance.

Brian Clifton of MIT Lincoln Laboratory generously supplied the Schottky diode mixer. This work was supported by US DoE Contract No. DE-AC02-76CH03073.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

REFERENCES

- ¹D. E. Evans and J. Katzenstein, *Rep. Prog. Phys.* 32, 207 (1969).
- ²K. L. Wong, M. Ono, and G. Wurden, *Rev. Sci. Instrum.* 53, 409 (1982).
- ³D. K. Mansfield, G. Tesauero, L. Johnson, and A. Semet, *Opt. Lett.* 6, 230 (1981).
- ⁴R. Slusher and C. Surko, *Phys. Fluids* 23, 472 (1980).
- ⁵M. F. Kimmitt, *Far-Infrared Techniques*, (Pion Limited Press, London, 1970).
- ⁶E. E. Russel and E. E. Bell, *J. Opt. Soc. Am.* 57, 341 (1967).
- ⁷H. R. Fetterman *et al.*, *Appl. Phys. Lett.* 33, 151 (1978).
- ⁸M. Ono and K. L. Wong, *Phys. Rev. Lett.* 45, 1105 (1980).
- ⁹P. L. Colestock, *IEEE Trans. Plasma Sci.* PS-12, 64 (1984).
- ¹⁰G. Wurden, M. Ono, K. L. Wong, *Phys. Rev. A* 26, 2297 (1982).

FIGURE CAPTIONS

- Fig. 1 Side view of the vacuum vessel showing the scattering geometry.
- Fig. 2 Schematic of the optical system, which is described in the text. The symbols are: M mirror, P polarizer, QWP quarter wave plate, L lens, BS beam splitter, PM paraboloidal mirror, EM ellipsoidal mirror, C1 chopper, and D detector.
- Fig. 3 Basic single lock-in detector instrumentation for detecting a wave driven by an oscillator, indicated by the circle. A fiber optic link is used to reduce rf pickup passively.
- Fig. 4 Ion Bernstein wave interferometry trace. The signal is obtained using both the single lock-in method (bottom) and double lock-in method (top), which reduced noise. The optical table was translated to scan the radial position of the laser beam in the plasma. The measurement was made in a region of the plasma 3 cm outside the magnetic axis, where the magnetic field is 4.3 kG. The 12.5-MHz wave was driven by an antenna inserted into the hydrogen plasma, and was detected with a 4° scattering angle.

84X1367

Fig. 1

84X0876

Fig. 2

11

#84X0798

Fig. 4

EXTERNAL DISTRIBUTION IN ADDITION TO TIC UC-20

Plasma Res Lab, Austro Nat'l Univ, AUSTRALIA
 Dr. Frank J. Paoloni, Univ of Wollongong, AUSTRALIA
 Prof. I.R. Jones, Filinders Univ., AUSTRALIA
 Prof. M.H. Brennan, Univ Sydney, AUSTRALIA
 Prof. F. Cap, Inst Theor Phys, AUSTRIA
 Prof. Frank Verheest, Inst theoretische, BELGIUM
 Dr. D. Patumbo, Dg XII Fusion Prog, BELGIUM
 Ecole Royale Militaire, Lab de Phys Plasmas, BELGIUM
 Dr. P.M. Sakanaka, Univ Estadual, BRAZIL
 Dr. C.R. James, Univ of Alberta, CANADA
 Prof. J. Teichmann, Univ of Montreal, CANADA
 Dr. H.M. Skarsgard, Univ of Saskatchewan, CANADA
 Prof. S.R. Sreenivasan, University of Calgary, CANADA
 Prof. Tudor W. Johnston, INRS-Energie, CANADA
 Dr. Hannes Bernard, Univ British Columbia, CANADA
 Dr. M.P. Bachynski, MPB Technologies, Inc., CANADA
 Zhenggu Li, SW Inst Physics, CHINA
 Library, Tsing Hua University, CHINA
 Librarian, Institute of Physics, CHINA
 Inst Plasma Phys, Academic Sinica, CHINA
 Dr. Peter Lukac, Komenskoho Univ, CZECHOSLOVAKIA
 The Librarian, Culham Laboratory, ENGLAND
 Prof. Schatzman, Observatoire de Nice, FRANCE
 J. Rader, CEN-BP6, FRANCE
 AM Dupes Library, AM Dupes Library, FRANCE
 Dr. Tom Mual, Academy Bibliographic, HONG KONG
 Preprint Library, Cent Res Inst Phys, HUNGARY
 Dr. S.K. Trehan, Panjab University, INDIA
 Dr. Indra, Mohan Lal Das, Banaras Hindu Univ, INDIA
 Dr. L.K. Chavde, South Gujarat Univ, INDIA
 Dr. R.K. Chhajlani, Var Ruchi Marg, INDIA
 P. Kew, Physical Research Lab, INDIA
 Dr. Phillip Rosenau, Israel Inst Tech, ISRAEL
 Prof. S. Cupperman, Tel Aviv University, ISRAEL
 Prof. G. Rostagni, Univ Di Padova, ITALY
 Librarian, Int'l Ctr Theo Phys, ITALY
 Miss Ciella De Palo, Assoc EURATOM-CNEN, ITALY
 Biblioteca, del CNR EURATOM, ITALY
 Dr. M. Yamato, Toshiba Res & Dev, JAPAN
 Prof. M. Yoshikawa, JAERI, Tokai Res Est, JAPAN
 Prof. T. Uchida, University of Tokyo, JAPAN
 Research Info Center, Nagoya University, JAPAN
 Prof. Kyoji Nishikawa, Univ of Hiroshima, JAPAN
 Prof. Sigeru Mori, JAERI, JAPAN
 Library, Kyoto University, JAPAN
 Prof. Ichiro Kawakami, Nihon Univ, JAPAN
 Prof. Setsuichi Itoh, Kyushu University, JAPAN
 Tech Info Division, Korea Atomic Energy, KOREA
 Dr. R. England, Ciudad Universitaria, MEXICO
 Bibliotheek, Fom-Inst Voor Plasma, NETHERLANDS
 Prof. B.S. Lilley, University of Waikato, NEW ZEALAND
 Dr. Suresh C. Sharma, Univ of Calabar, NIGERIA
 Prof. J.A.C. Cabral, Inst Superior Tech, PORTUGAL
 Dr. Octavian Petrus, Ali CUZA University, ROMANIA
 Prof. M.A. Mollberg, University of Natal, SO AFRICA
 Dr. Johan de Villiers, Atomic Energy Bd, SO AFRICA
 Fusion Div. Library, JEN, SPAIN
 Prof. Hans Wilhelmson, Chalmers Univ Tech, SWEDEN
 Dr. Lennart Stenflo, University of UMEA, SWEDEN
 Library, Royal Inst Tech, SWEDEN
 Dr. Erik T. Karlson, Uppsala Universitet, SWEDEN
 Centre de Recherches, Ecole Polytech Fed, SWITZERLAND
 Dr. M.L. Weisse, Nat'l Bur Stand, USA
 Dr. W.M. Stacey, Georg Inst Tech, USA
 Dr. S.T. Wu, Univ Alabama, USA
 Prof. Norman L. Oleson, Univ S Florida, USA
 Dr. Benjamin Ma, Iowa State Univ, USA
 Prof. Magna Kristiansen, Texas Tech Univ, USA
 Dr. Raymond Askew, Auburn Univ, USA
 Dr. V.T. Tolok, Kharkov Phys Tech Ins, USSR
 Dr. D.D. Ryutov, Siberian Acad Sci, USSR
 Dr. G.A. Eliseev, Kurchatov Institute, USSR
 Dr. V.A. Glukhikh, Inst Electro-Physicist, USSR
 Institute Gen. Physics, USSR
 Prof. T.J. Boyd, Univ College N Wales, WALES
 Dr. K. Schindler, Ruhr Universitat, W. GERMANY
 Nuclear Res Estab, Jülich Ltd, W. GERMANY
 Librarian, Max-Planck Institut, W. GERMANY
 Dr. H.J. Kaeppeler, University Stuttgart, W. GERMANY
 Bibliothek, Inst Plasmeforschung, W. GERMANY