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Application of Coherent Lidar to Ion Measurements in Plasma Diagnostics

Donald P. Hutchinson
Oak Ridge National Laboratory
P. O. Box 2008, MS-6004
Oak Ridge, TN 37831
(423)574-4730
E-mail: hutchinsondp@ornl.gov

Roger K. Richards
Oak Ridge National Laboratory
P. O. Box 2008, MS-6004
Oak Ridge, TN 37831
(423)576-2582
E-mail: richardsrk@ornl.gov

Charles A. Bennett
Oak Ridge National Laboratory
P. O. Box 2008, MS-6004
Oak Ridge, TN 37831
(423)576-2582
E-mail: bennett@ornl.gov

Marc L. Simpson
Oak Ridge National Laboratory
P. O. Box 2008, MS-6004
Oak Ridge, TN 37831
(423)574-4171
E-mail: mls@ornl.gov

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ABSTRACT

A coherent lidar system has been constructed for the measurement of alpha particles in a burning plasma. The lidar system consists of a pulsed CO_2 laser transmitter and a heterodyne receiver. The receiver local oscillator is a cw, sequence-band CO_2 laser operating with a 63.23 GHz offset from the transmitter.

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Oak Ridge National Laboratory[1]
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SUMMARY

A coherent lidar system has been constructed for the measurement of fusion-produced alpha particles in a burning plasma. The diagnostic technique used for the measurement is called collective Thomson scattering (CTS). This technique works by scattering a high-power CO_2 laser beam from clouds of electrons surrounding ions in a high temperature plasma. In a high temperature plasma all of the atoms of the filling gas, deuterium and tritium in the case of a fusion reactor, are completely ionized and will remain so if the temperature is maintained. The ions attract the fast moving electrons but recombination into atoms is prohibited by the high energy of the particles. If a probing wavelength is chosen that is comparable in size to or larger than this cloud of electrons hovering around each ion, then the spectrum of the scattered laser light, Doppler-shifted by the motion of the cloud, will be characterized by the ion velocity distribution. The criterion used to establish the proper conditions for such ion measurements in a plasma is known as the Salpeter parameter, α, given by[1]

$$\alpha = \frac{\lambda_0}{4\pi\lambda_D \sin(\frac{\theta}{2})}$$

where α = the Salpeter parameter

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[1]Managed by Lockheed Martin Energy Research Corp. For the U.S. Department of Energy under contract DE-AC05-96OR22464

λ_0= incident laser wavelength
λ_D= Debye length
θ= scattering angle.

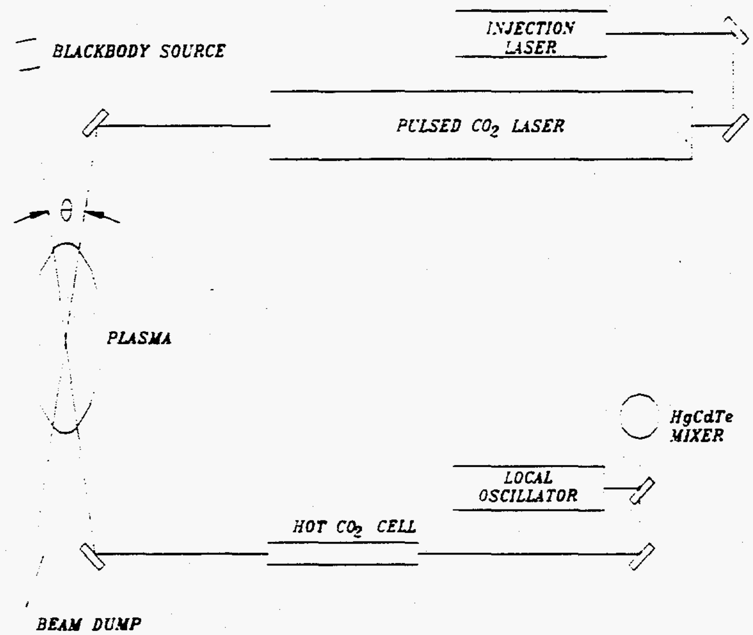

Figure 1 Schematic diagram of scattering system.

In order to measure the ion spectra in a plasma. α must be greater than one. For conditions typical in a fusion plasma. this means that for a 10 micron CO_2 laser. the scattering angle θ must be less than 1-degree. A schematic diagram of the system is shown in Figure 1.

The lidar system consists of an injection-locked. unstable resonator pulsed CO_2 laser transmitter and a heterodyne receiver. The transmitter is locked to the 10P20 line of CO_2 by the injection of 250 mW of power from a waveguide laser operating on the 10P20 transition of carbon dioxide. The transmitter cavity is a positive branch confocal resonator with a magnification of 2 and a cavity length of 3-meters. The 50 mm diameter rear mirror of the cavity has a concave radius of curvature of 12 meters and the convex scrapper output mirror has a radius of curvature of 6 meters. The output mirror is glued to an AR-coated NaCl flat which acts a pressure window on the laser cavity enclosure. The injection seed beam enters the pulsed cavity through a 2-mm hole covered by a ZnSe brewster window in the back curved mirror of the cavity. This laser produces a 1-microsec pulse with an energy of approximately 4 joules.

The back-propagated local oscillator (BPLO) beam intersects the transmitter beam at an angle of 0.86°in the center of the plasma. The scattered light from the plasma is directed through a triple-pass hot CO_2 cell which acts as a notch filter to reduce stray light from the transmitter. The local oscillator for the receiver is a cw. sequence band CO_2 grating-tuned. waveguide laser operating with a 63.23 GHz offset from the pulsed laser frequency. The waveguide local oscillator laser has an intra-cavity cell containing approximately 100 torr of CO_2 heated to 600 deg-C to force operation on the 10P15 sequence band line shifted +9.68 GHz above the 10P18 transition. The detector is a HgCdTe photovoltaic diode with a bandwidth of 1.5 GHz and a quantum efficiency of 35%. Approximately 10 mW of local oscillator power is focused on the photodetector with a 25-mm dia. ZnSe lens. The scattered signal from the plasma is combined with the local oscillator light on a ZnSe beamsplitter. The beamsplitter is coated to provide approximately 2% reflectivity for the local oscillator beam and 98% transmission for the signal beam. The output of the HgCdTe photovoltaic

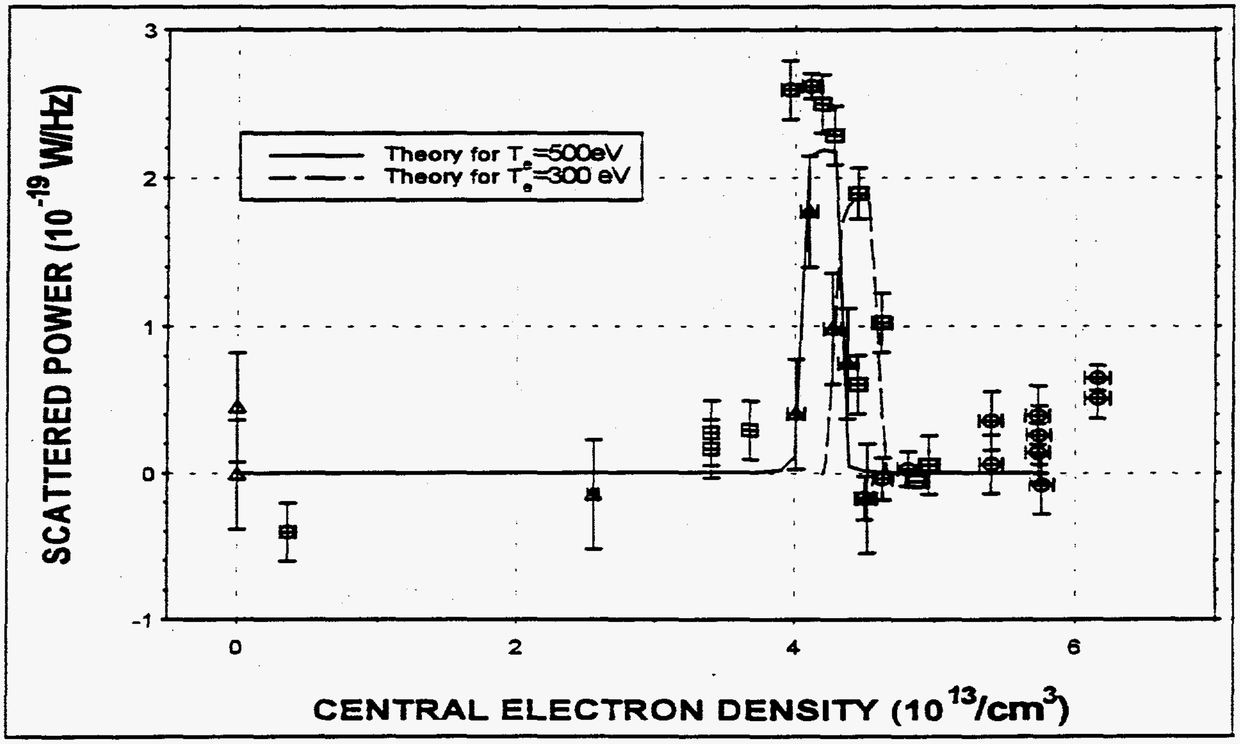

Figure 2 Scattering Data from ATF proof-of-principle test compared with theory.

mixer is fed into two 1-GHz wideband amplifiers and then an RF detector. A video amplifier (BW=2 MHZ) follows the RF detector to set the post-detection bandwidth of the receiver. The high speed data are logged by a 32-MHZ CAMAC digitizer for viewing the pulse shape and noise level.

Ion scattering in the ATF experiment is not feasible because of the low ion temperature. To properly simulate CTS for alpha particle measurements, a proof-of-principle test has been performed which relies on scattering from plasma electrons at large shifts from the pulsed laser frequency near the electron plasma resonance[3]. These resonances are only weakly dependent on electron temperature and have a scaling of $n_e^{1/2}$. Figure 2 contains a summary of data from scattering experiments that were performed on the ATF device as the plasma density was varied from 0 to about 7×10^{19} m^{-3}. The solid and dotted curves in the figure represent theoretical calculations of the scattered spectrum as a function of plasma density.

1. J. Sheffield. "Plasma Scattering of Electromagnetic Radiation." Academic Press, New York. 1975.

2. R. K. Richards, D. P. Hutchinson, C. A. Bennett, H. T. Hunter, and C. H. Ma, "Measurement of CO_2 Laser Small-Angle Thomson Scattering on a Magnetically Confined Plasma," Applied Physics Letters. 62, P. 28-30, January 1993.