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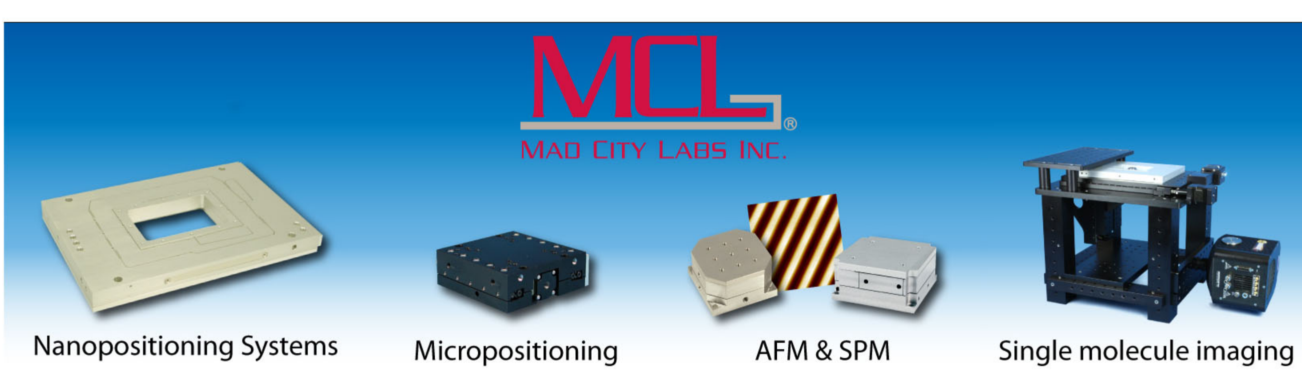

In situ dye laser calibration for Thomson scattering diagnostics

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The standard laser Thomson scattering calibration technique involves the convolving of density and wavelength response calibrations. This usually includes an *in situ* Rayleigh scattering from neutral gas for an absolute density calibration at the laser wavelength. In addition, a spectral calibration (i.e., a National Bureau of Standards traceable lamp and white reflective plate) is required to determine the relative wavelength channel responses for the combination of collection optics, spectrometers, and associated detectors. This technique involves a considerable amount of time and effort in two-dimensional scattering systems because of the number of spectrometers/detectors and the large range of scattering and collection angles. An alternative technique employing a nominal 40-mJ, small-divergence tunable dye laser substituted into the Thomson scattering laser beam path is proposed. Rayleigh scattering (from ~10-Torr H_2) measurements are made at a high repetition rate (1–10 Hz) while the dye laser output wavelength is scanned. This includes in one step the *in situ* density and channel response calibrations.

INTRODUCTION

The Thomson scattering system for the Advanced Toroidal Facility[1] (ATF) can provide a 2-D profile of the electron density and temperature by shot-to-shot horizontal translation of the vertically directed ruby laser beam coupled with a repointing of the viewing optics.[2] A sketch of the Thomson scattering system is shown in Fig. 1. The viewing optics relay the scattered laser light onto an image plane, which is coupled via fiber-optic bundles to 15 spectrometers. Each spectrometer has from five to eight output channels, depending on the particular grating used. The output of the spectrometer channels is coupled via optical fibers to an array of approximately 105 photomultiplier tubes. The task of maintaining a fully calibrated system in the face of time-varying tube gains and quantum efficiencies can be quite time consuming. The viewing optics track the laser beam by means of the set of rotating and translating mirrors shown in Fig. 2. The complex shape of the ATF vacuum vessel means that the different scattering positions in the plasma have varying levels of vignetting and reflected stray light. Thus, an absolute (density) calibration is required for each viewing position to account for these variations.

I. CALIBRATION TECHNIQUES

The standard laser Thomson scattering calibration technique involves the convolving of density and wavelength response calibrations.[3] This usually includes an *in situ* Rayleigh scattering from neutral gas for an absolute density calibration at the laser wavelength. In order to perform this calibration, one spectrometer channel must be tuned to the ruby wavelength (normally rejected by the spectrometer and additional filters). In addition, a spectral calibration is required to determine the relative wavelength channel responses for the combination of collection optics, spectrometers, and associated detectors. This technique uses a National Bureau of Standards (NBS) traceable tungsten calibration lamp and a white reflective plate[4,5] to create a spatially extended source with a broad spectrum. Substitution of this source in the viewing optics path, at the location of the first mirror shown in Fig. 2, allows spectral calibration of all the components except the vacuum window. The multiple-calibrations method involves a considerable amount of time and effort in 2-D scattering systems because of the large number of spectrometers and detectors and the large range of scattering and collection angles.

An alternative technique employing a tunable dye laser is proposed.[3] During Rayleigh scattering calibration, the dye laser can be substituted for the ruby beam. Rayleigh scattering measurements at a high repetition rate (1–10 Hz) are made while the dye laser output wavelength is scanned over the full wavelength range of the spectrometers. This allows a complete characterization of the scattering geometry and the various spectrometer spectral and intensity responses. Translation of the beam (in the same manner as the ruby beam) provides this calibration at each spatial location. This method also accounts for long-term changes in the transmission and spectral properties of the vacuum window caused by sputtering of materials during plasma operation. The complete calibration can be done without a vacuum opening or disassembly and retuning of any of the viewing optics components. All of the unique dye laser calibration properties listed above should result in improved accuracy by reducing systematic and random errors and the need to make assumptions about window transmission as a function of wavelength, angle, or time.

The characteristics of the dye laser beam must be similar to those of the ruby beam in order to obtain an accurate calibration. The beam divergence must be small enough that all of the Rayleigh scattered light will be collected by the viewing optics. In our case this requires a beam divergence of less than 500 μrad. A laser pulse time less than or equal to the

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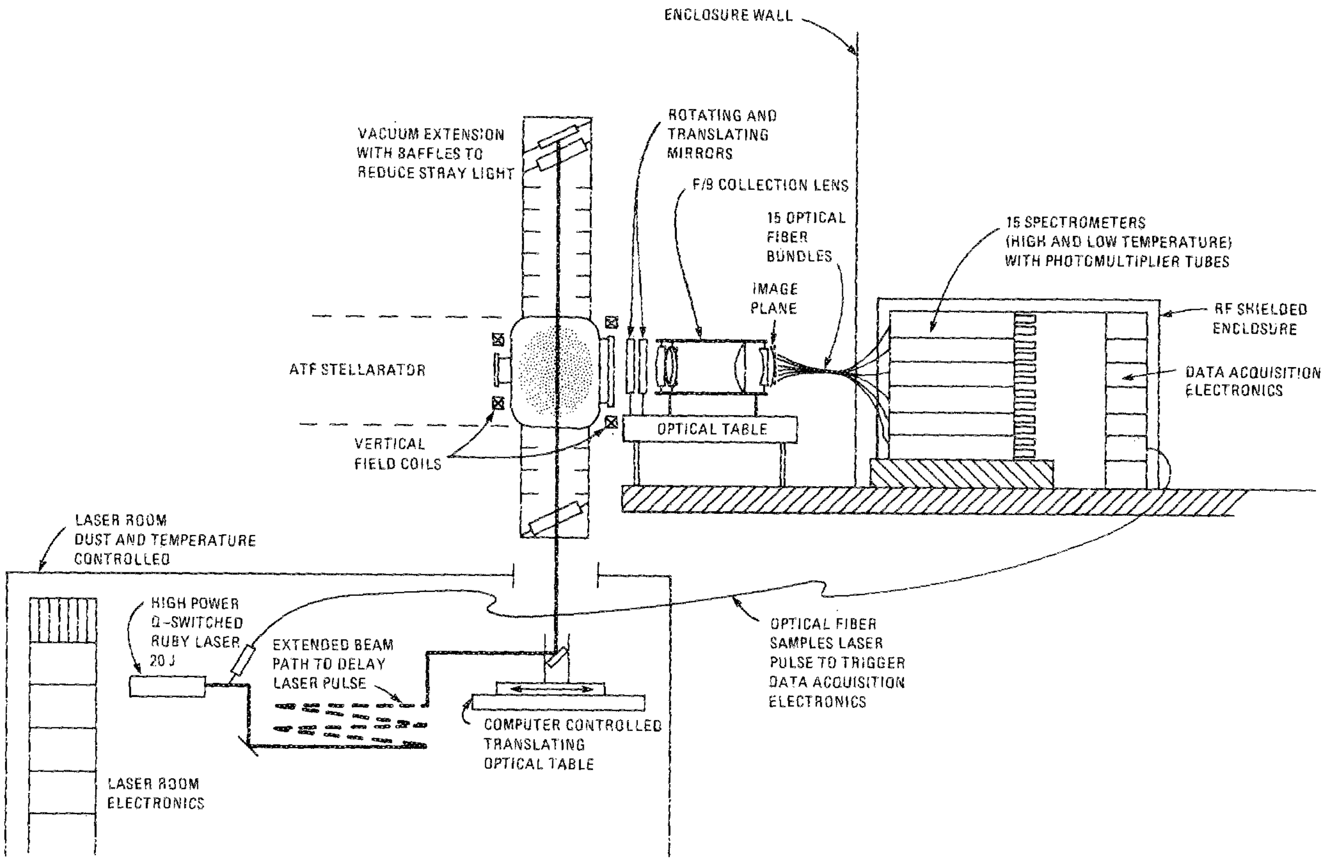

FIG. 1. ATF Thomson scattering system outline. The dye laser will be substituted into the input beam path just in front of the mirror which is mounted on the translating optical table.

ruby pulse (20–30 ns) is desired so that no changes need to be made to the phototube gating electronics timing (100-ns gate). In our system the ruby beam energy and divergence are routinely monitored on each laser pulse with a joule meter and photodiodes for all Rayleigh (and Thomson) scattering measurements. This will also be required for the dye laser calibration. The spectral response of the joule meter used (Laser Precision Rj-7000) is constant to within 0.2% over our range of wavelengths (690–850 nm). The overall calibration of the joule meter (NBS traceable) is easily maintained to within $\pm 5\%$. In addition, the polarization of the dye laser should preferably be the same as that of the ruby in order to simplify the comparison of Rayleigh scattered signals from the two lasers.

With our system, typical Thomson scattered spectra ($n_e = 1.0\times 10^{13}$, $T_e = 300$ eV) produce a minimum signal of ten photoelectrons per channel. Ruby laser Rayleigh scattering measurements typically produce 100 photoelectrons per channel. The restricted viewing angle, limited access to the ATF device, and measurement on the red side of the spectrum result in an overall collection efficiency (detected photoelectrons) for scattered light of 0.24% for our arrangement. Thus Rayleigh scattering provides approximately 200 detected photoelectrons per joule per Torr H_2 (800 per joule per Torr N_2) in the narrowest spectrometer channel. A 40-mJ dye laser pulse will result in a minimum measurement of 80 photoelectrons with a 10-Torr H_2 backfill in the ATF vacuum vessel. With a 1-Hz (limited by data acquisition)

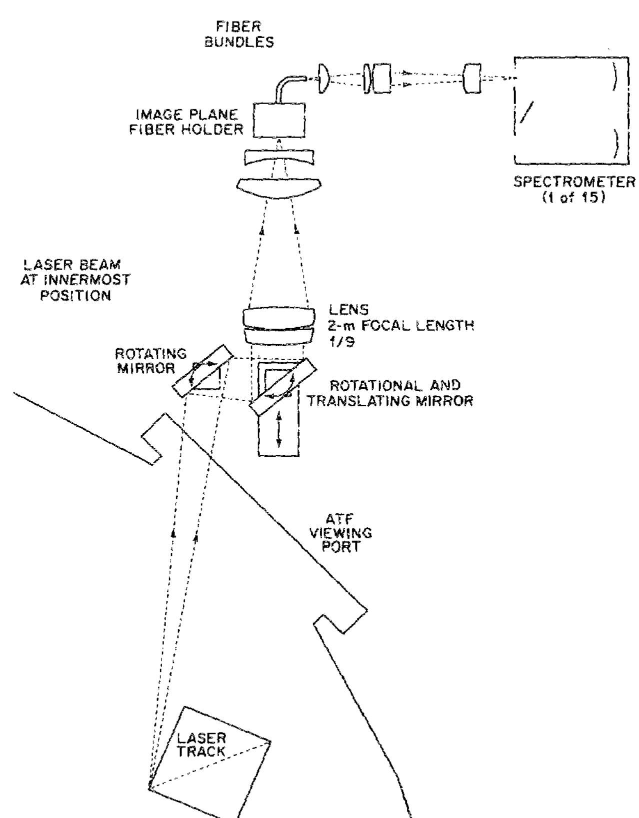

FIG. 2. Viewing optics layout. No changes to the viewing optics are required to perform a calibration with the dye laser.

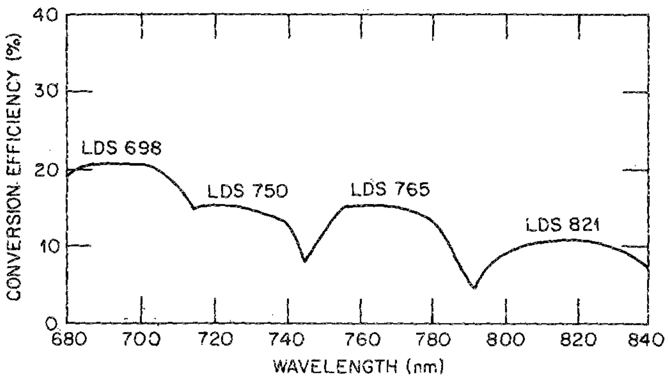

FIG. 3. Output conversion energies of laser dye cell as a function of wavelength with a doubled Nd : YAG pump.

repetition rate, a complete calibration can be accomplished in less than one day. This compares favorably with the standard technique, which requires approximately one week for a full 2-D calibration.

II. DYE LASERS

We will use a Quanta Ray doubled Nd : YAG laser to pump the dye laser. The dye laser has a divergence of approximately 400 μrad, and with a pulse length of 5 ns the repetition rate is 10 Hz. The dye laser output efficiency as a function of wavelength is shown in Fig. 3. Four different dyes are required to cover a band from 680 to 840 nm. Throughout most of the band, the dye laser output is greater than 40 mJ when pumped with the nominal 400-mJ doubled Nd : YAG laser. This will allow Rayleigh scattering with good statistics at a fill pressure of 10 Torr of H_2.

A conceptually simpler and less expensive approach will also be investigated. The ruby laser beam (at reduced energy) can be used to pump a dye cell that is placed directly in the ruby beam path. This can produce a beam of essentially the same diameter and divergence as the input ruby beam with a pulse length of approximately 5 ns. The dye cell arrangement can be quite inexpensive. The disadvantage of this arrangement is that wavelengths shorter than approximately 720 nm cannot be produced with the ruby laser pump (unless the ruby output is doubled). This would preclude calibration on the blue side and for the first channel on the red side of a typical fusion plasma Thomson scattered spectrum. In conclusion, we feel that the simplicity, speed, and expected improved accuracy of the dye laser calibration technique make it well worth investigation. We expect to report comparisons of this technique with the traditional method in the near future.

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