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GENERAL ATOMICS

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ABSTRACT

Local details of the edge current profile can have profound effects on the stability and ultimate performance of many advanced tokamak (AT) modes.[1–3] This is true for both bootstrap and externally driven currents that may be used to tailor the edge shear. Absent a direct local measurement of j(r), the best alternative is a determination of the poloidal field. On the DIII–D tokamak[4] we are using precision polarimetry of an injected lithium beam (LIBEAM)[5] to make measurements of the necessary precision in the region of interest (ρ = 0.7–1.1). Combined polarimetry/spectroscopy of the various Zeeman-split 2S-2P lithium resonance line components gives direct information on the local magnetic field components. Because of the negligible Stark mixing of the relevant atomic levels, this method of determining j(r) is insensitive to the large local electric fields typically found in enhanced confinement (H–mode) edges, and thus avoids an ambiguity present in motional Stark effect (MSE) measurements of B.[6,7] Beam intensities and energy are suitable for measurements in the edge region of even high-density discharges. Key issues for utilizing this technique include good beam quality, an optimum viewing geometry, and a suitable optical pre-filter to isolate the polarized emission line. Details of the existing DIII–D diagnostic are presented. We also discuss details of the analysis necessary to determine the field component from these measurements, and our plans for future improvements to the system.

I. INTRODUCTION

At present, the performance of “advanced” modes of tokamak operation is set more by the stability limits of various modes (peeling, ballooning, and kink) than by transport considerations.[8,9]. The avoidance and extension of these limits to further improve the plasma performance requires careful tailoring of the plasma pressure and current profiles. This in turn places a premium on precise measurement of these parameters. Measurement of the current density profile through the use of hydrogenic beams and the motional Stark effect (MSE)[10] has played a key role in the understanding and development of these advanced operational modes. However, since the polarization of the Stark-split emission manifold is determined by the electric field in the rest frame of the beam, complication occurs for most advanced tokamak modes, where substantial intrinsic radial electric fields are found to be coexistent with the high gradients that are often formed by the transport barriers.[11,12] In this case it is quite difficult for a simple MSE-style measurement to distinguish between the intrinsic (E_r) and motional ($v \infty B$) Stark terms without such complications as multiple views, multiple beam injection angles, multiple beam energy components, etc. This is of particular import for studies of the edge bootstrap current on DIII–D where small poloidal magnetic field changes (~1%) need to be resolved in the presence of large (~ 100 kV/m) electric fields associated with high-performance H–modes.[13] As an alternative measurement for this edge region, we have deployed a diagnostic based on the Zeeman effect in the lithium 2S-2P resonance transition. In this case, because of the wide separation of the atomic levels there is no Stark mixing and the polarization and splitting of the resonance emission is strictly due to the local magnetic field.[14] To make the measurement we take advantage of (1) the known polarization state of emission of the various Zeeman components as well as (2) the known angular distribution of fluorescence emission for various views relative to B.

II. NEUTRAL LITHIUM BEAM AND POLARIZATION OPTICS

Figure 1 shows the deployed beam system, which is basically the resurrected LIBEAM system.[5] Details of the system and installation are reviewed in Reference 7. To optimize radial resolution and sensitivity to the poloidal field, we have chosen radial injection and vertical viewing. This implies we must analyze both the circular (equivalent to emission along the field direction) and linear (emission perpendicular to the field direction) polarization in order to precisely determine the magnetic field direction and components.

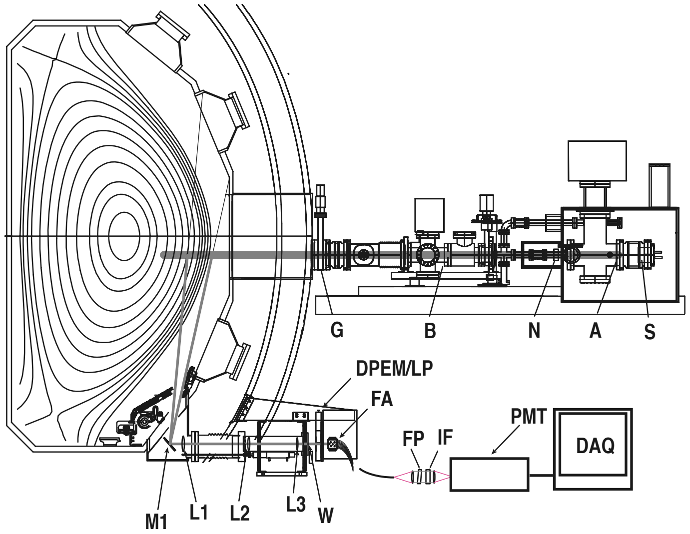

Fig. 1. Neutral lithium beam system and viewing optics system on DIII–D for the Zeeman polarization diagnostic. Beam parameters: 30 keV, 10 mA, 1–2 cm diameter. Radial resolution 5 mm. All lenses are SFL6 (low Verdet constant) glass and the polarization-maintaining mirror has a special coating compatible with extended vacuum exposure and high (350°C) temperature. Dual PEM fundamental frequencies are 23 and 20 kHz. Fiber array allows up to 32 radial channels to be observed simultaneously.

A substantial amount of effort went into the design of the optical system. Design features include low Verdet constant glasses, polarization maintaining mirrors, and an insertable diagnostic polarizer. A dual photoelastic modulator (PEM) is mounted immediately outside of the vacuum window and is used to modulate the polarization state of the emitted light. Lock-in detection is then used to determine the input polarization state. In-vessel tests of the optics after the 2000 experimental campaign revealed no large systematic variations of the measured polarization due to the various elements, and only minor (~1 mm) spatial shifts of the 32 viewing locations. We believe we have a robust set of optics with good fidelity for polarization determination.

III DETECTION AND POLARIZATION ANALYSIS

Due to the relatively small separation of the Zeeman states for typical DIII–D discharge conditions, a premium is set on efficient narrow band spectral filtering of the line profile to isolate one of the σ components. A prototype filterscope employing a tilt-tuned Fabry-Perot etalon and lithium line filter serves to isolate the proper component, depending on the line broadening that is actually present due to beam thermal spread, finite viewing angle, etc. To accurately determine the ratio of circular to linear polarization using modulation techniques requires lock-in measurements at four different frequencies (fundamental and first harmonic of each of the two PEM resonant frequencies). To avoid deploying and tuning 128 separate analog lockin amplifiers, increases in computer speed and memory have allowed us to pursue true digital lock-in techniques to extract all four required frequency components in near real-time. This technique relies on off the shelf PC/PCI hardware and is scaleable to many channels. Two big advantages of this approach are (1) the elimination of analog noise during the reference mixing and (2) digitizing the PEM reference frequencies allows us to avoid error due to frequency drift. The system is presently capable of doing eight separate channels simultaneously using a single PC and PCI DAQ board at digitization rates up to 1 MHz for the full DIII–D shot length.

IV. INITIAL RESULTS

Figure 2 shows the beam fluorescence collected at several radial locations inside the plasma, spanning the approximate range $0.7<\rho< 0.995$. The signal levels are reasonably consistent with beam penetration modeling. These signals represent the total line intensity and are not polarization resolved. Figure 3 shows the measured circular polarization for a channel looking near the edge ($\rho=0.91$) after the Fabry-Perot was tuned to the wavelength appropriate for the doppler shifted $\sigma+$ component. The overall polarization was small (~1%). We believe this is due to excessive energy spread in the beam, which increases the overlap of the doppler-broadened π and σ states. Despite the small level of polarization, the digital lock-in technique is still capable of accurately extracting the polarization components. The ratio, which is roughly proportional to the poloidal field, is seen to increase with the current ramp, then decrease possibly due to current diffusion.

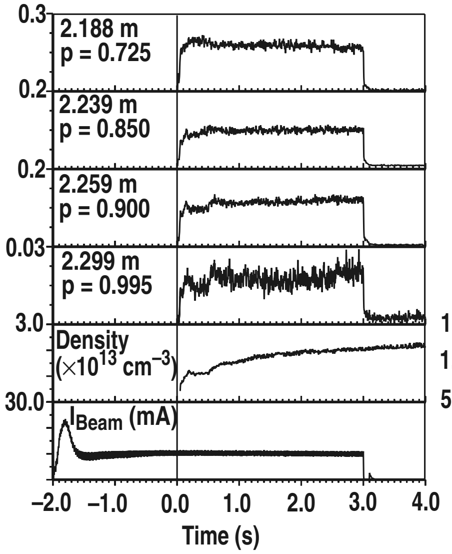

Fig. 2. Lithium beam fluorescence versus radius for DIII–D shot 107208. Plasma density was ~2.5∞10^{13} cm^{-3}. Beam is turned off at 3.0s.

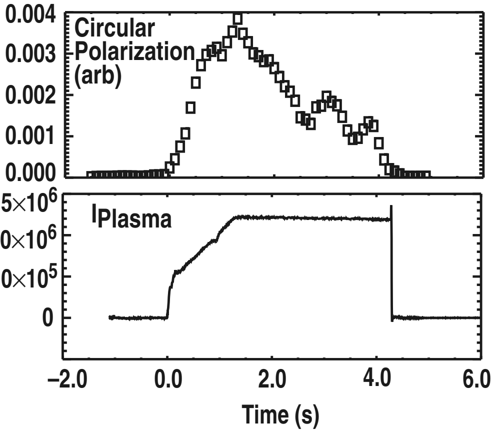

Fig 3. Polarization data for a single channel at $\rho=0.91$, for DIII–D shot 107805. Also shown is the total plasma current. Beam is turned off at 4.0 s.

V. SUMMARY AND FUTURE WORK

Deployment of the neutral beam accelerator and the associated polarization optics on DIII–D is essentially complete, and we have tested a few channels of the digital lock-in/data acquisition system. In the near future we plan to improve the beam energy resolution to increase the measurable polarization fraction. We will increase the number of detection channels to the full complement of 32. In addition, we will continue to search for improved spectral resolution elements such as Lyot filters to improve on the Fabry Perot performance, as well as improving the computer control of various aspects of the experiment including PEM, detector, and beam control. Our ultimate goal is to have the resolved field components input directly as constraints to EFIT, similar to the existing MSE data.

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