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FINAL

PROGRESS REPORT

# MEASUREMENT OF IMPURITY ION DENSITIES AND ENERGIES IN THE DIVERTOR AND EDGE REGIONS OF ALCATOR C-MOD TOKAMAK

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## DISCLAIMER

# Introduction

We are investigating impurity production and transport in the divertor and edge regions of the Alcator C-Mod tokamak through spectroscopic techniques. Our emphasis is on the low ionization states found in the edge and divertor regions which are indicative of the physical processes related to impurity generation and particle and energy transport in this region. We are using a high-resolution visible/ultraviolet spectrograph capable of measuring the Doppler shifts associated with neutral and ion flows and the Doppler broadening associated with neutral and ion temperatures.

# Objectives

There were three primary objectives for the fifth year of this investigation. First, we had planned to begin data acquisition with the University of Maryland 2.0-meter high-resolution spectrometer during periods of Alcator C-Mod operations. This was of greatest importance in the ongoing experimental program. Second, we had planned to bring into operation the spatially-resolved tangential-viewing fiber optics system. This allows for simultaneous ion velocity and ion temperature measurements in the outer scrape-off layer region. Third, we had planned to begin studying impurity flows in the divertor and scrape-off layer. We had hoped to study Doppler shifts and widths to determine flow velocities and temperatures as well as Zeeman shifts to localize the emission in the magnetic field.

# Results

## Instrumentation and Data Acquisition

The University of Maryland 2.0 meter high-resolution spectrograph was placed into operation for the November 1995 to February 1996 run period and recorded nearly 65,000 spectra. It was routinely used to monitor the hydrogen to deuterium ratio during ion cyclotron (minority) RF heating and to monitor $D_{alpha}$ emission. Data was

recorded simultaneously through five fibers viewing the plasma in the divertor, at the midplane, and from the top of the machine both parallel and perpendicular to the magnetic field lines. Doppler shifts of neutral deuterium lines were observed at times during the discharge. Doppler broadening measurements were also made during the discharge.

A five-fiber optical periscope was designed and constructed to view the outer edge of the plasma (approximately) tangent to the magnetic field lines. This was placed into operation for the August to September 1996 run period. It is being used to measure parallel flows in the outer scrape-off layer. Approximately 15,000 spectra were taken during this run period. Doppler shifts were also observed during this run period from various views.

**Analysis**

The initial results from the high-resolution spectrograph include observations of Doppler shifts and Doppler broadening of neutral deuterium lines. Flows into the divertor of $0.2 \times 10^6 cm/sec$ were recorded during RF heating. Flows in the main chamber of $1.4 \times 10^6 cm/sec$ were recorded at times early in the discharge. Doppler widths of neutral deuterium were measured which correspond to neutral temperatures of 2 eV in the divertor and 7 eV in the edge region.

We have developed a code to calculate the Zeeman pattern of particular transitions from two electron ions in an arbitrary magnetic field. We will use this code, along with the magnetic field measurements, to simulate the expected lineshape for the various lines of sight. The variation of the Zeeman pattern along the line of sight must be considered in extracting flows from the Doppler shifts of spectral lines. The code will integrate this calculated Zeeman pattern along the line of sight to be compared with measurements. This analysis will be extended to transitions from one electron ions, as well as other transitions as necessary.

There was a significant reduction in carbon and oxygen emission and an increase in boron emission as a result of the boronization of C-Mod. This result has a very important impact on our diagnostic and we have already shifted our emphasis from impurities of carbon and oxygen to boron. Transitions of B I-IV have been identified and experiments are planned to search for a B V (n=6-7) line in the upcoming campaign. This B V transition will be important for the planned charge exchange recombination spectroscopy (CHERS) diagnostic to be installed on Alcator.

We have recently presented two papers at conferences, which will be published in the conference proceedings. We presented an invited talk at the 10th APS Topical Conference on Atomic Processes in Plasmas (in San Francisco) in January 1996. The talk was titled *Lineshape Measurements of Visible Light Emission from the Alcator C-Mod Tokamak* and discussed density measurements and isotope ratio measurements. We also presented a talk at the 13th International Conference on Spectral Line Shapes (in Firenze, Italy) in June of 1996. The talk was titled *Profiles of High Principal Quantum Number Balmer and Paschen Lines from Alcator C-Mod Tokamak Plasmas* and compared theoretical calculations and experimental measurements of line widths of high-n Balmer and Paschen series lines. A preprint of these two papers is available.

We have collaborated with a group in Marseille, France (through Dick Lee at LLNL) who have calculated the Stark broadening line shapes for the Balmer and Paschen series lines that we use as a density diagnostic in C-Mod. The preliminary results of this collaboration were presented at the Line Broadening Conference mentioned above. We have had correspondences with researchers at PPPL and University of Texas reguarding their existing and planned upcoming collaborations. We have had discussions with Dr. Charles Skinner at PPPL concerning the Zeeman patterns of the $D_\alpha$ transition that is measured with the Fabry Perot interferometer. We have also been in contact with Dr. Bill Rowan from the University of Texas because of our experience with remote access to diagnostics. We feel that both of these groups enhance our collaboration and plan to continue to work with them.

# APPENDIX

## PUBLICATIONS

1. B.L. Welch, H.R. Griem, J. Terry, C. Kurz, B. LaBombard, B. Lipschultz, E. Marmar, and G. McCracken, "Density measurements in the edge, divertor and X-point regions of Alcator C-Mod from Balmer series emission", Phys. of Plasmas **2** (11), 4246 (1995).

2. J.A. Goetz, et al., "Comparison of Detached and Radiative Divertor Operation in Alcator C-Mod", Phys. of Plasmas **3** (5), 1908 (1996).

## INVITED PRESENTATIONS

1. B.L. Welch, H.R. Griem, J.L. Weaver, J.L. Terry, R.L. Boivin, B. Lipschultz, D. Lumma, E.S. Marmar, G. McCracken, and J.C. Rost, "Line shape measurements of visible light emission from the Alcator C-Mod tokamak", APS 10th Topical Conference on Atomic Processes in Plasmas, San Francisco, Calif. (1996).

2. J.A. Snipes and the Alcator Group, "Characteristics of high-confinement modes in Alcator C-Mod", Bull. Am. Phys. Soc. 1803 (1995).

3. R.S. Granetz and the Alcator Group, "Disruptions and Halo Currents in Alcator C-Mod", Bull. Am. Phys. Soc. 1804 (1995).

## CONTRIBUTED PRESENTATIONS

1. B.L. Welch, H.R. Griem, J.L. Weaver, J.U. Brill, J.L. Terry, B. Lipschultz, D. Lumma, G. McCracken, S. Ferri, A. Calisti, R. Stamm, B. Talin, R. W. Lee, "Profiles of high principal quantum number Balmer and Paschen lines from Alcator C-mod tokamak plasmas", Proceedings of the 13th International Conference on Spectral Line Shapes, Firenze, Italy (1996).

2. B.L. Welch, J.U. Brill, H.R. Griem, J.L. Weaver, J.L. Terry, M. Greenwald, B. Lipschultz, E. Marmar, and J. Rice, "High-Resolution Visible/Ultraviolet Measurements from the Alcator C-Mod Tokamak", Bull. Am. Phys. Soc. (To be presented 1996).

3. J.L. Weaver, B.L. Welch, H.R. Griem, J.U. Brill, J.L. Terry, B. Lipschultz, D. Pappas, and S. Wolfe, "High Resolution Measurements of Zeeman Patterns in Vislible/Near Ultraviolet Spectra from the Alcator C-Mod Tokamak", Bull. Am. Phys. Soc. (To be presented 1996).