TIME-RESOLVED SPECTRA IN THE 5-330 Å REGION EMITTED FROM THE PLT AND TFTR TOKAMAK PLASMAS*

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1. INTRODUCTION

The analysis of impurity radiation from Tokamak plasmas is one of the most important diagnostics, allowing the measurement of the impurity concentrations, radiation losses and particle transport studies. This study requires simultaneous time-resolved observation of spectral lines from many ionization states for each element. The most intense and important lines are the He and H-like resonance transitions of Oxygen and Carbon and $\Delta n = 0, 1$ transitions of highly ionized metallic impurities. These emmissions have been recorded on PLT and TFTR tokamaks by means of a soft X-ray multichannel spectrometer (SOXMOS).

2. SOFT X-RAY MULTICHANNEL SPECTROMETER

The basic instrument is a high resolution, interferometrically adjusted, 2m extreme grazing incidence (between 89.3° and 87.5°) duochromator, built by Schwob and Fraenkel at the Hebrew University of Jerusalem (Filler et al. 1977). It is equipped with two interchangeable gratings: 2400 l/mm and 600 l/mm. With the less dispersive grating used in the present work, the instrument covers the 5-330 Å spectral range. In the multichannel version (Schwob et al. 1983) one of the 2 channel electron multipliers is replaced by a 50mm long, funneled MgF_2 coated microchannel plate (MCP). This detector is interferometrically adjusted and can be moved along the Rowland Circle. The MCP is associated with a phosphor screen image intensifier and coupled by a flexible fiber optic conduit to a 1024-element photodiode array. The photodiode array is controlled and read out via an optical multichannel analyzer. The instrument offers a simultaneous coverage of 20 Å at short wavelength (Al XIII lines at 7 Å were clearly observed) and 70 Å at the long wavelength limit. A high spectral resolution: 0.12 Å FWHM at 20 Å, with a low background over the whole range covered, has been achieved. This allows a good line separation and accurate line brightness measurements.

3. IDENTIFICATION OF Ag XXIX-XXXIV LINES IN THE 50-80 Å RANGE

Silver has been introduced in the PLT tokamak plasma by a laser blow off technique (Marmar et al. 1975). The target plasma parameters were $n_e(o) \sim 3.10^{13}$ cm^{-3} and $T_e(o) \sim 2.5$ keV, and the particle injection occurred during the steady-state phase of the

*Work supported by U.S. DOE Contract No. DE-AC02-76-CHO-3073.
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https://doi.org/10.1017/S0252921100085638 Published online by Cambridge University Press

ohmically heated tokamak discharge. Spectra emitted by silver ions belonging to NiI-NaI like sequences have been recorded between 25-150 Å. The present work discusses only the 50-80 Å range where a very large number of lines originating from $3p^6 3d^k$ - $3p^5 3d^{k+1}$ and $3p^k$ - $3p^{k-1} 3d$ transitions are emitted within many ionization states.

The brightest lines in this domain are classified in the present work (Fig. 1). They belong to KI, ArI, ClI, and SiI like ions. These ions have relatively simple ground configurations and the number of high intensity lines emitted within transitions between the low lying excited levels and the ground state is small. Identifications are based on comparison of the experimental data with extrapolated energy level values along the isoelectronic sequences from Z = 20 to Z = 42 elements (Stratton et al. 1983, Finkenthal et al. 1984). It is important to mention that in tokamak spectroscopic experiments the assignment of a line to a given ionization state can be inferred from its time behavior and the radial position of the emitting ion in the plasma.

4. FIRST SPECTROSCOPIC OBSERVATIONS ON THE TFTR TOKAMAK

The Tokamak Fusion Test Reactor (TFTR) in Princeton is (together with the JET in Europe) the largest operating tokamak. The plasma diameter is varying from 82 to 166 cm, plasma currents of 1-1.4 MA and discharge duration of about 4 seconds were obtained. The chord integrated electron density is $1-3 \times 10^{13}$ cm^{-3} and central electron and ion temperatures, without auxiliary heating, are 2-3 keV.

Understanding the origin and the behavior of the impurities in this experiment is of paramount importance for its success. A few examples of spectroscopic analysis of the TFTR plasma behavior are presented. The HeI and HI like carbon (introduced from the limiter) and oxygen emission from TFTR has been compared with that of PLT, using the SOXMOS spectrometer. Preliminary results show that the carbon/oxygen concentration ratio inferred from these spectra appears to be similar in the two devices at intermediate densities for TFTR and typically 2:1.

A very interesting example of the importance of spectroscopic observation is illustrated in Fig. 2. In some discharges, during the plasma current ramping phase a very high bolometric signal indicated large radiation losses accompanied by an electron temperature drop. A few such discharges were ended by disruptions. Analysis of spectra recorded by SOXMOS between 25-150 Å showed that a large amount of Zirconium was entering the plasma and radiating strongly as Zr XVI to Zr XXX ions. The time history of the Zirconium emission as presented in Fig. 2 agrees with the bolometer signal, indicating that the strong increase of radiation losses was due to a Zirconium influx. Zirconium has been introduced when the plasma interacted with the Al-Zr gettering system.

The impurity radiation has been studied at two plasma current values as a function of the electron density. Data show that the emission from metallic impurities (Ni and Fe) is decreasing as the gas density increases while Oxygen radiation is enhanced. This correlation between high Z and low Z impurity behavior, which is quite a general feature related to plasma density limits and disruptions will be discussed.

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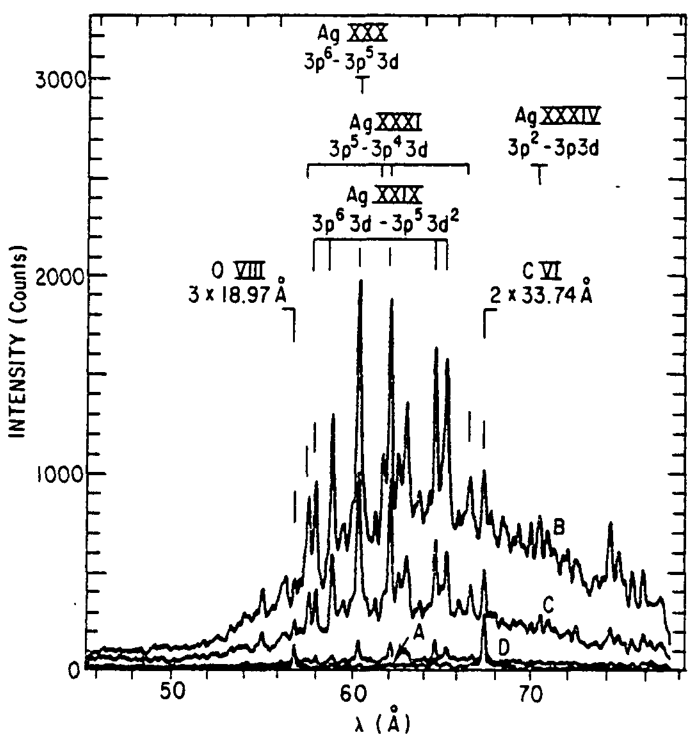

FIG. 1. Spectra from PLT, around 60 Å, showing the silver emission decay after injection:
A. before Ag injection t = 400 ms
B. after Ag injection t = 480 ms
C. at t = 560 ms
D. at t = 640 ms.

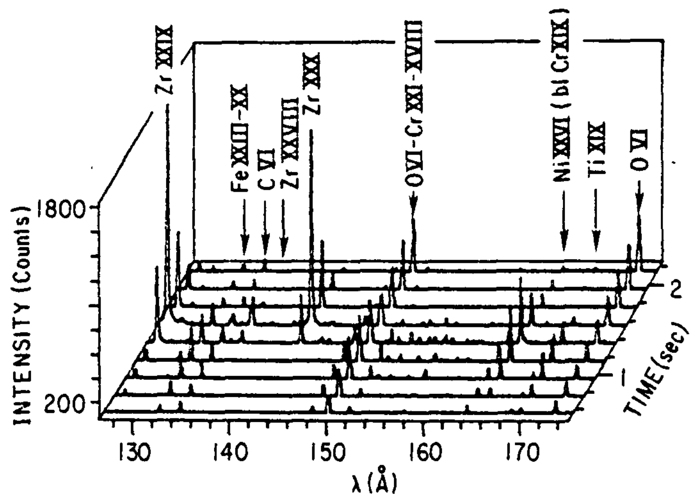

FIG. 2. (a) Time-resolved spectra from TFTR showing Zirconium emission due to plasma-getter interaction.

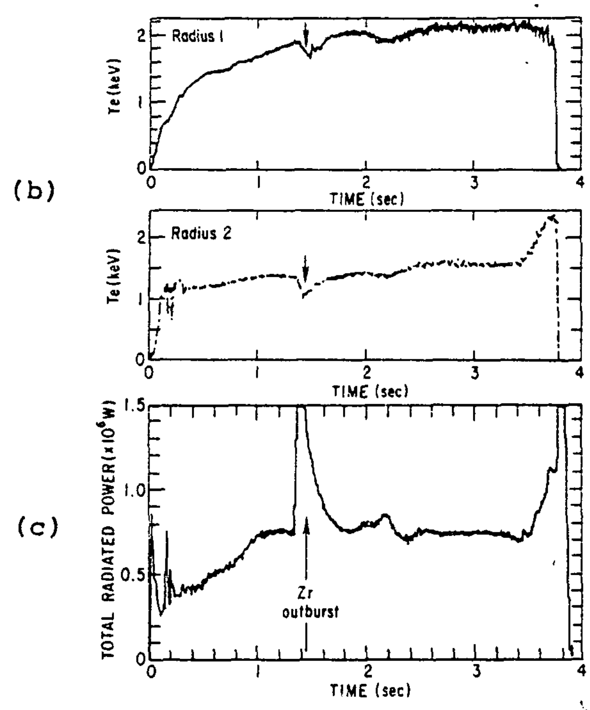

FIG. 2. (b) Electron temperature time histories (at different radii) in TFTR (courtesy of P. Efthimion and G. Taylor), and (c) bolometric signal (courtesy of J. Schivell) showing Zirconium outburst.

https://doi.org/10.1017/S0252921100085638 Published online by Cambridge University Press