RADIATION-SHIELDED DOUBLE CRYSTAL X-RAY MONOCHROMATOR FOR JET

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Abstract

A double crystal X-ray monochromator for absolute wavelength and intensity measurements with very effective shielding of its detector against neutrons and hard X-rays was brought into operation at JET. Fast wavelength scans were taken of impurity line radiation in the wavelength region from about 0.1 nm to 2.3 nm, and monochromatic as well as spectral line scans, for different operational modes of JET.

1. Introduction

Soft X-ray plasma spectroscopy is a well established technique which provides a range of diagnostic information relating to the concentration, transport and temperature of impurity ions [1,2]. A high temperature plasma, producing a significant rate of DT fusion reactions, as anticipated in the latter phases of JET operation (active phase) will produce high fluxes of neutrons and γ-rays. The need to provide good shielding of the detector while covering a wide spectral range, places severe constraints on the design of an active phase crystal spectrometer. This required the development of a new high precision crystal-drive mechanism, and special techniques to evaluate the suitability of crystal diffraction properties over a larger surface area [3,4]. Shielding is achieved by placing the instrument outside the JET torus hall and by using two crystals in the parallel (non-dispersive) mode. For this device input and output beams are fixed for all wavelengths, allowing a labyrinth radiation shield to be built around the optical path between the small penetration in the JET biological shield and the detector (Fig. 1).

2. The active phase double crystal monochromator

The crystals are mounted via rotary tables to linear displacement tables, and their trajectories necessary to maintain the Bragg condition are controlled by a fast digital servo system [3]. It is necessary that the crystals be kept parallel to well within their diffraction profiles, which is achieved by the control system to about 6 arc sec. in the full Bragg angle range from 26^o to 60^o. The resolving power is $\lambda/\Delta\lambda = (1/\Delta\Theta) \cdot tan\Theta$ where the angular width $\Delta\Theta$ is defined mainly by remotely interchangeable coarse $(1/\Delta\Theta = 600)$ and fine $(1/\Delta\Theta = 5000)$ gridded collimators. The sight-line contains a

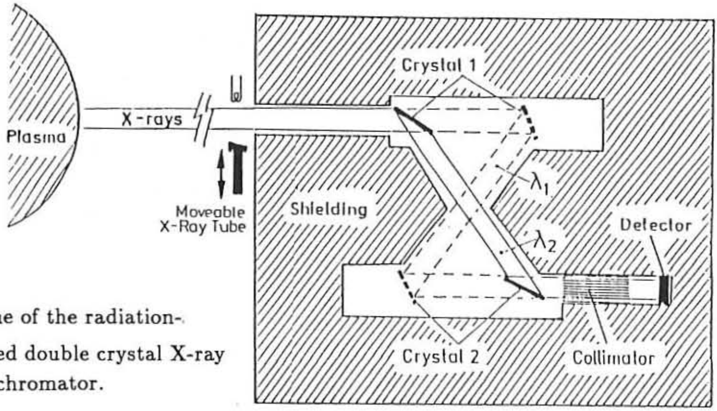

Fig. 1 Scheme of the radiation-shielded double crystal X-ray monochromator.

remotely deployable calibration source which, together with the high resolution angle encoders and the fine collimator, allows absolute wavelength calibration and Doppler line-profile and line-shift measurements.

Absolute intensity measurements are performed using the throughput relation: $N = IF_c\chi\Delta\Theta R_{cc}P_{cc}\eta/\omega$, where N is the counts integrated in a spectral line of intensity I (photons $m^{-2}s^{-1}sr^{-1}$), F_c the projected crystal area, χ the acceptance angle perpendicular to the plane of dispersion, $\Delta\Theta$ the collimator acceptance angle, R_{cc}, P_{cc} the double crystal integrated and peak reflectivities, respectively, ω the crystal rotational velocity and η the combined efficiency of detector and windows. The luminosity of the system is typically about $10^{-9}sr \cdot m^2$.

The detector is a multiwire gas proportional counter (MWPC) with thin polymer window for which the gas pressure, high voltage, and pulse height window can be controlled automatically to suit the observed wavelength range. This gives a high quantum detection efficiency (QDE) and allows background rejection and selection of the desired diffraction order by pulse height analysis. The 48 anodes are connected into 8 groups, each with its own signal processing chain, which allows signal-plus-background count rates of $\sim 10^7s^{-1}$ without serious pile-up. All instrument and vacuum system functions can be controlled automatically by the JET control and data acquisition system (CODAS).

3. Examples for the operational modes of the active phase double crystal monochromator

The double crystal monochromator can be operated in different modes: Broad band spectra can be taken covering the Bragg angle range from about 26^o to 60^o in a time of about one second. With crystals like Topaz(303), LiF(220), Gypsum, TℓAP and KAP, as applied so far, the wavelength range from about 0.12 nm to about 2.3 nm was covered. An example of such a broad-band spectrum taken with TℓAP crystals is given in Fig. 2, showing some Ne-like Ni lines and some members of the oxygen Lyman

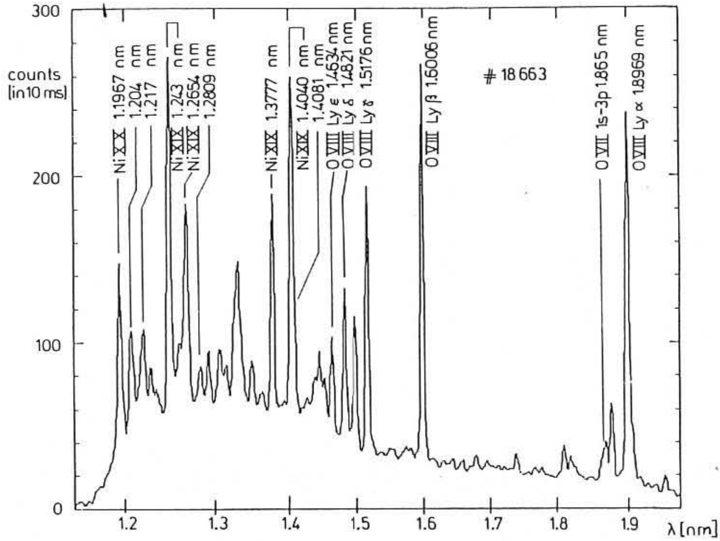

Fig. 2 Broad band spectrum obtained using TℓAP crystals covering the wavelength range from 1.13 nm to 1.95 nm with Ne-like Ni lines and the Lyman series of oxygen

series. Since the absorption in the thin foil (which separates the monochromator from the torus vacuum) increases with wavelength the count rate ratios do not directly reflect the line intensity ratios. Another mode is the repetitive scan of a smaller wavelength interval. An example of a line scan is given in Fig. 3. It is a scan of the profile of a certain spectral line performed many times throughout the discharge in order to follow the time behaviour of the line width and its intensity. This figure shows that the sensitivity of the monochromator is good enough to reveal the different behaviour of O and Ni. Fig. 4 gives as an example for the fourth operational mode, the monochromatic time behaviour of the Fe XXV line obtained from laser ablation of Fe into the JET discharge [5].

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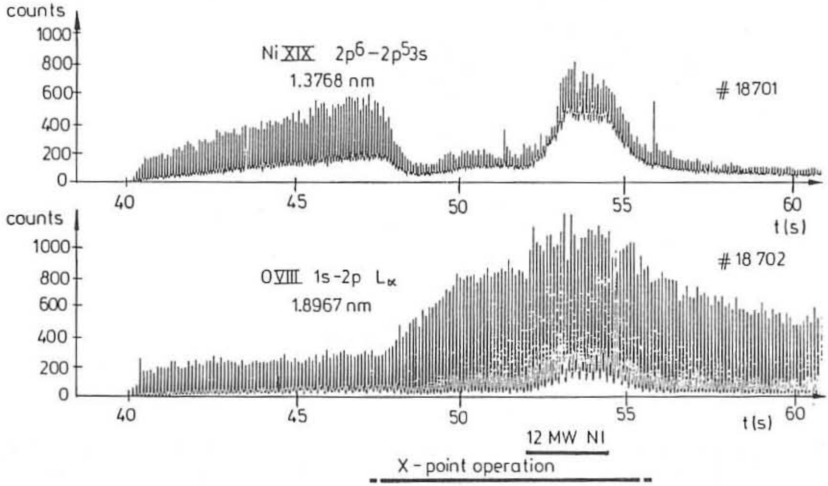

Fig. 3 Line scans for Ne-like Ni (above) and Oxygen Lyman α throughout two consecutive discharges at JET

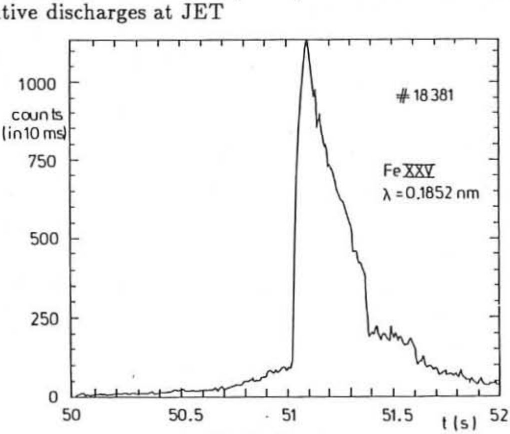

Fig. 4 Time behaviour of He-like Fe line from laser ablation of Fe.