26th EPS Conf. on Contr. Fusion and Plasma Physics, Maastricht, 14 - 18 June 1999 ECA Vol.23J (1999) 769 - 772

Development of Spectrally Selective Ultra Soft X-Ray Tomography System for TEXTOR

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Introduction. Impurity transport is a crucial process determining such basic problems in fusion plasma physics as energy confinement and radiative edge cooling [1, 2]. A comprehensive study of impurity transport, based on the full set of experimental data, will enable to understand transport mechanisms. A successful approach to this fundamental problem may be based on a tomographic study of the distribution of ions in the plasma with sufficient spatial and time resolution. A tomography of multicharged ions assumes multi-chord detection of radiation of certain ionic species. Here we report on development of a novel instrumentation for spectrally selective, time resolved plasma emission tomography in the range 0.1–4 keV at TEXTOR. The technique is intended for reconstruction of distributions of local emission coefficients for impurity ions at particular ionization stages.

Technique. The experimental approach is associated with the use of miniature wavelength resolving pinhole cameras, equipped with advanced soft x-ray multilayer mirrors and CCD-based detectors. Each instrumentation module (Fig. 1, 2) contains a MLM/pinhole camera, which creates a spectrally selective x-ray image of a plasma poloidal cross-section.

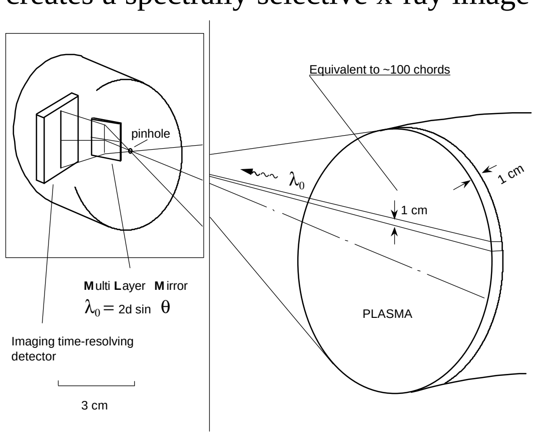


Fig. 1. Scheme of MLM/pinhole imaging camera

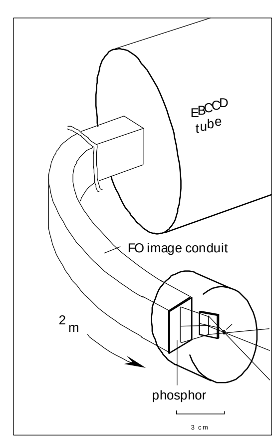


Fig. 2. Optical components and detector

The x-ray image is converted to a visible one in a phosphor layer deposited on the entrance surface of a fiber optical image conduit, transmitting the image to a remote detector.
The necessary selectivity is achieved due to the use of a high-resolution MLM [3,4]. Table 1 contains parameters of typical MLMs, developed for the pilot imaging module. To provide radiation collection from a plain cross-section, the MLM is made with variable period.

Table 1. Typical parameters of multilayer mirrors optimized for specific spectral intervals

Ion	λ nm	Structure	Period nm	Grazing angle,deg	Reflectivity %	Resolution $\lambda/\Delta\lambda$
Ne X	1.21	W-Si	2.2	16	13-14	90-100
Ne IX	1.35	W-Si	2.2	18	11-12	90
O VIII	1.90	W-Si	2.2	25	6	75-80
O VII	2.16	Cr-Sc	2.0	32	5-7	120-130
C VI	3.37	Cr-Sc	2.4	43-45	5-7	100-140
C V	4.03	Cr-Sc	3.0	40-43	5	100-120
Ar XIV	2.74	W-Si/Si	2.5	33-35	5-6	60-70

An electron-bombarded CCD (EBCCD) camera is used as a 2D, time resolving detector, recording the images at a 50 Hz rate during the whole plasma discharge. The camera provides a high signal-to-noise noise ratio due to acceleration of electrons up to 10 keV, combining it with excellent imaging qualities. The camera is compact and can be easily protected from EM fields. Fig. 3 contains a scheme of the camera tube.

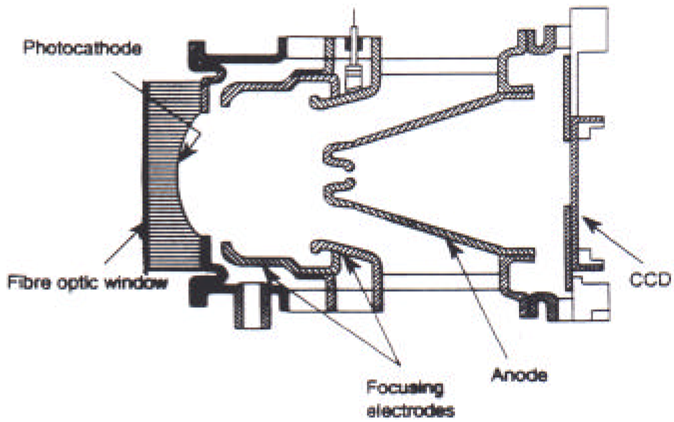
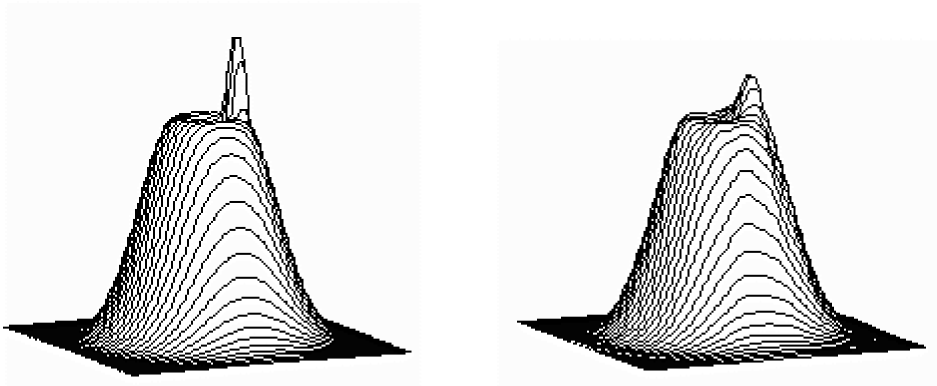


Fig.3. EBCCD tube cross-section

A comprehensive work on optimization of characteristics of x-ray phosphors in the whole spectral range of interest, in particular below 1 keV, is in progress.
PC-based control and read-out electronics and software are developed for the system of 6 imaging modules. Analysis of intensity distribution in the images will result in determination of radiation integrals along multiple directions, and subsequent tomography reconstruction of

emission coefficient distributions. Data on electron temperature and density will be needed for reconstruction of ion distributions.

Tomography. The instrumentation developments are supplemented by numerical simulations of imaging experiments using known and new tomography algorithms [5,6]. The phantoms library includes smooth hollow profiles, additions as highly localized disturbances, models for axially symmetrical and asymmetrical distributions. As an example, Fig. 3 shows a model reconstruction using the maximum entropy algorithm [7].



a b

Fig. 3. (a) Exact model of an intensity distribution with a local disturbanve
(b) Tomogram reconstructed with maximum entropy algorithm for 5 projections,
100 chords in each projection

Pilot experiments. Essential parameters of the instrumentation were tested in experiments with a pilot single imaging module at RTP and TEXTOR. The imaging module installation at TEXTOR is shown in Fig. 4. Ions of intrinsic and seeded impurities (OVIII, OVII, CVI, CV, NeX, NeIX, Ar XV) were detected under various experimental conditions, including deuterium neutral beam injection. As an example, Fig. 5 contains time resolved poloidal cross-section RTP plasma images in spectral lines of Ne IX (1.35 nm, 1.16 nm, 1.10 nm) and Ne X (1.21 nm), seen on a background of numerous lines of Fe ions.

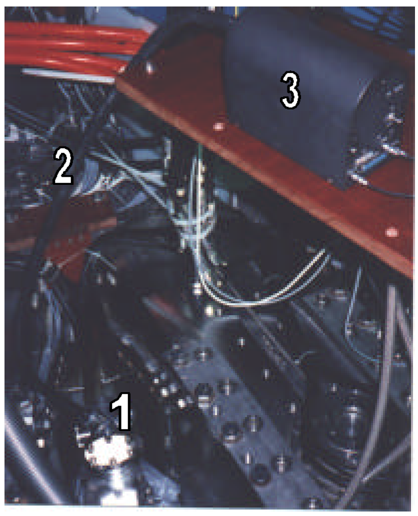


Fig.4. Pilot imaging module at TEXTOR: 1 - MLM/pinhole camera,
2 - fiber image conduit, 3 - EBCCD camera (magnetic shield removed)

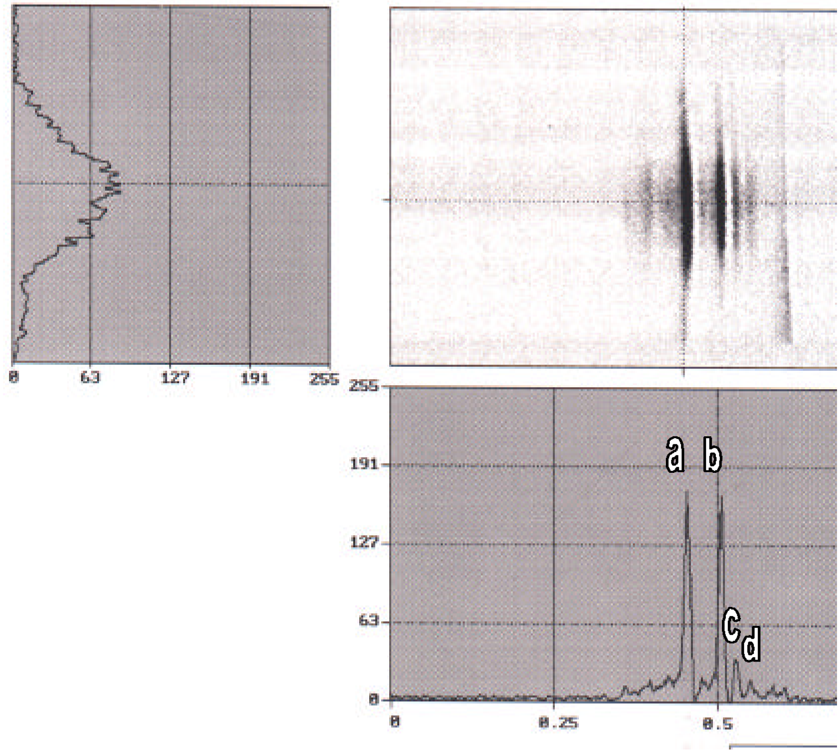


Fig. 5. Time resolved (20 ms) images of RTP tokamak poloidal plasma cross-section in spectral lines of Ne IX (a - 1.35 nm, c- 1.16 nm, d - 1.10 nm) and Ne X (b - 1.21 nm). Ne X (1.35 nm) image intensity profile is shown.

Conclusions. The pilot ultra-soft x-ray tomography instrumentation module has been developed and tested under real experimental conditions at the RTP and TEXTOR tokamaks. The results have proved applicability of the main concept as well as of specific technical solutions. The computer tomography developments are expected to be suitable for the future work on reconstruction of distributions of plasma emission coefficients.

Acknowledgements. This work is performed under the Euratom-FOM association agreement with financial support from Euratom and NWO.

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