Temperature measurements on CHS with a multi-layer mirror soft X-ray spectrometer

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1. INTRODUCTION

The multilayer mirror (MLM) soft X-ray spectrometer has the potential of measuring the electron temperature (Te) with high spatial and temporal resolution. Presently, the other diagnostic that is capable of measuring electron temperature with high resolution is correlated radiometry of electron cyclotron emission (ECE). Using such a diagnostic system, fluctuations with a relative level below 1% has been measured[1]. However, in low density plasmas the measurement of T_e using ECE is difficult. In addition, the estimation of the emissive point for each cyclotron frequency is complicated in helical systems because of its magnetic configuration. The MLM soft X-ray spectrometer has the potential as an alternative diagnostic for temperature measurement in such conditions.

MLM based soft X-ray monitors have already been used for impurity measurement in tokamaks such as Alcator-C-Mod[2], TEXT[3] and Phaedrus-T[4]. MLM's have distinct advantages over other optical elements as they are compact and have high throughputs.

An MLM based polychromator has been used to estimate the electron temperature of the Phaedrus-T tokamak plasma[4] from the observed impurity line ratio. In this paper, we present preliminary experimental results obtained using a fully calibrated MLM soft X-ray spectrometer that we have developed and installed on the Compact Helical System (CHS) .

2. DESCRIPTION OF THE DIAGNOSTIC

The MLM is a dispersive optical element, which has a high reflectivity in the soft-X ray range. Two types of calibration are necessary to use it for temperature measurement:

1)reflectivity of the mirror as a function of the incident energy and angle,

2) sensitivity of the detectors (PIN diodes).

Both of these calibrations were carried out at the KEK Photon Factory (Tsukuba, Japan). The energy range of calibration was from 300 eV to 1200 eV. The reflectivity of the mirror was found to increase with photon energy from 3% (at 300 eV) to about 25% (at 1050 eV). Figure 1 shows the reflectivity as a function of the incident soft X-ray energy. Each peak in the figure shows the signal at a fixed reflection angle. Thus the width of a peak represents the energy resolution. The FWHM increases from 8.9eV(E=335.3eV) to 29.2eV (E= 1050eV). A 20 channel PIN diode array[5] coupled with a pre amplifier was used to detect the reflected rays. The diodes were found to have almost 100 % efficiency for creating electron-hole pairs in this energy range.

A schematic diagram of the experimental arrangement is shown in Fig.2. The collimated light from the plasma passes through an 8 μm thick Be filter and strikes the MLM. The filter rejects

visible light and background radiation. The reflected light obeying the Bragg law of reflection ($m\lambda = 2d\sin\theta_{inc}$) strikes the 20 channel PIN diode array. The signal is then amplified and digitized. The MLM used for the diagnostic was fabricated at Osmic, Inc. The high Z layer is made of tungsten and the spacer is silicon . The total number of layers is about 200 and the 2d value (twice the thickness of one bilayer) of the mirror is 6.76 nm.

3. EXPERIMENTAL RESULTS

CHS[6] is a low aspect ratio($A_p =5$) heliotron/torsatron device with a major radius of 1.0 m. In these experiments, plasma was produced by ECH or ion Bernstein wave (IBW) heating and then heated by neutral beam injection (NBI). Figure 3 shows the time evolution of the soft X-ray signal along with some other plasma parameters, viz. IBW and NBI powers, diamagnetic energy, radiation power and density. The soft X-ray signal increases gradually during NBI and abruptly drops off once the NBI is turned off.

To obtain the soft X-ray energy spectrum , various correction and calibration factors (i.e. the amplifier gains, the reflectivity and energy width of the MLM, and the transmissivity of the Be filter) have to be taken into account. The fits were calculated using the least square method. The electron temperature is then derived from the slope of the spectrum. The errors in the calibration factors lead to a systematic error in the temperature. An error of about 30% enters into the calculation from the error of the calibration curve. Another 18% results from the finite width of the calibration curve and the transmissivity of the Be filter. These errors result in a error of about 5% in the temperature. The noise level decreases with averaging time (upto1 ms), and its effect on temperature is negligible. As shown in Fig.4 some peaks are observed in the spectrum around the energies 730 eV, 850 eV and 1160 eV. The effect of these peaks on the temperature determination is also shown in the Fig.4.

In CHS, sawtooth oscillations in the soft X-ray signals are observed in neutral beam heated plasmas and they are correlated with burst event recorded by the magnetic pickup coils. The oscillations were observed in all the energy channels of the spectrometer and were in phase but only very small oscillations in the temperature was evident. This suggests that the oscillations are mainly due to oscillations in the density and/or impurity content of the plasma.

For NBI heated plasmas, the soft X-ray signal bear some relation with the stored energy and the magnitude of the toroidal field. However, a clear relation with the radiation power could not be determined.

Figure 6 shows the time evolution of the electron temperature determined from the MLM spectrometer and the central electron temperature determined from the Thomson scattering system. Though the two signals show correlation yet the absolute value of the temperature determined from MLM spectrometer is much lower than that determined from the Thomson scattering system.

4. DISCUSSION AND SUMMARY

A MLM soft X-ray spectrometer has been installed on CHS with the aim of measuring fast changes in the electron temperature. However, as seen in the Fig.6, the temperature determined from the soft X-ray spectrometer is much lower than that from Thomson scattering. Although some uncertainties enter into the calculation of the spectrum, these cannot account for the large discrepancy between the two measurements. Another possible source of discrepancy may be that this spectrometer measures the soft x-ray profile not only from the center but also from the edge. Thus the measured temperature is lower than the central temperature. Additionally, the transmissitivity of the be-filter rises steeply in the present calibrated energy range. These effects will be reduced at higher energies where the contribution from the low temperature edge is

small and the transmissivity of the Be-filter becomes flat. We plan to increase the energy range of calibration in order to measure higher energy range in the near future. All in all, at this preliminary stage of our analysis, we can find no satisfactory explanation for the difference inthe two temperatures. It is speculated that the energy range measured by the present set-up is highly contaminated by impurity lines. A more reliable use of this spectrometer may be to detect impurity line emission from the plasma with a time resolution of about 0.1 ms.

5. ACKNOWLEDGEMENT

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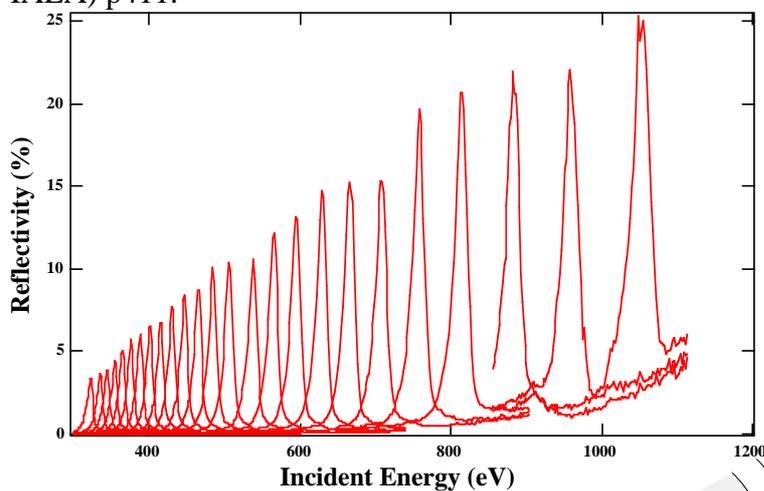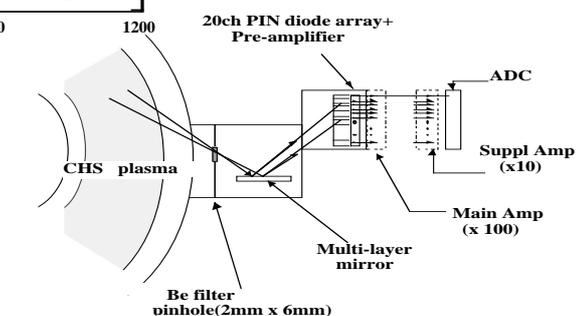
Fig.1.Reflectivity of the MLM versus the incident photon energy (eV).

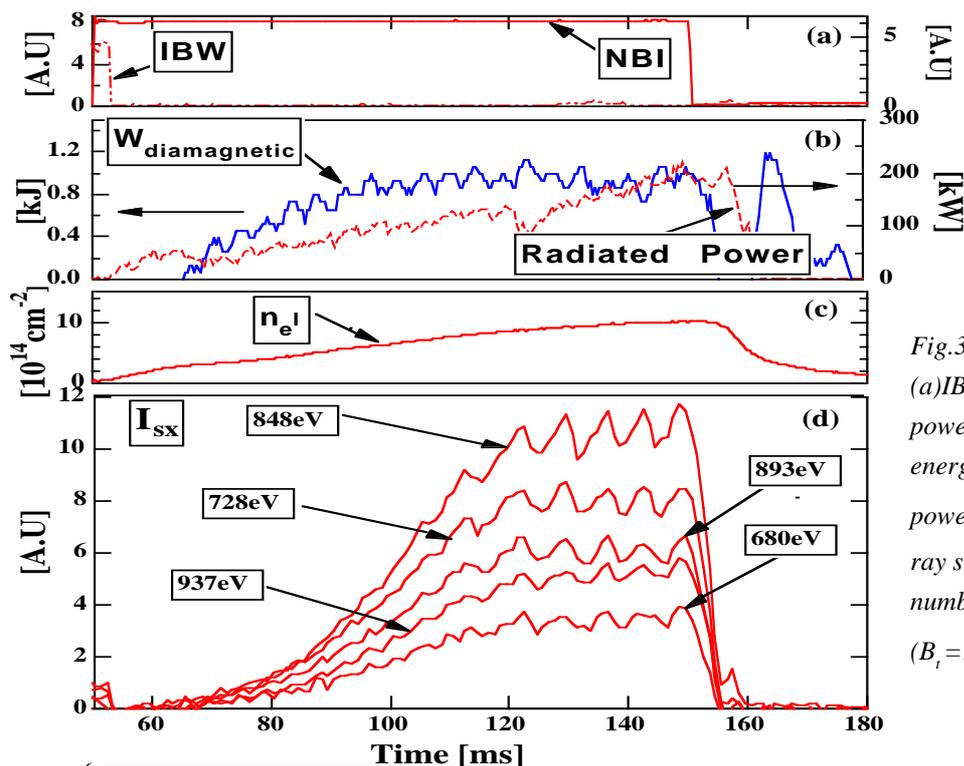Fig.2 Schematic diagram of the experimental set-up of the MLM spectrometer.

Fig.3.Time evolution of (a)IBW and NBI powers.(b)Diamagnetic energy and radiated power. (c) $n_e l$. (d) soft X-ray signal of shot number# 76981 $(B_t = 1.4 T)$.
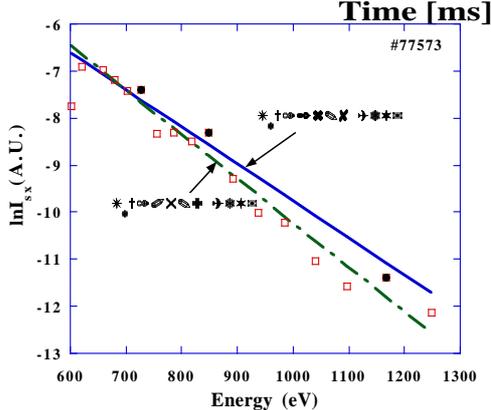

Fig.4. Spectrum of the soft X-ray signal. The solid line is the fit of the spectrum for all channels including the peaks. The dashed line is the fit without the peaks. The filled squares mark the channels with peaks.
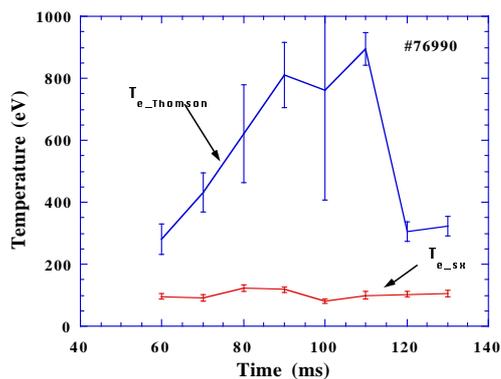

Fig.6 Time evolution of the electron temperatures measured by soft X-ray measurement and Thomson scattering measurement.
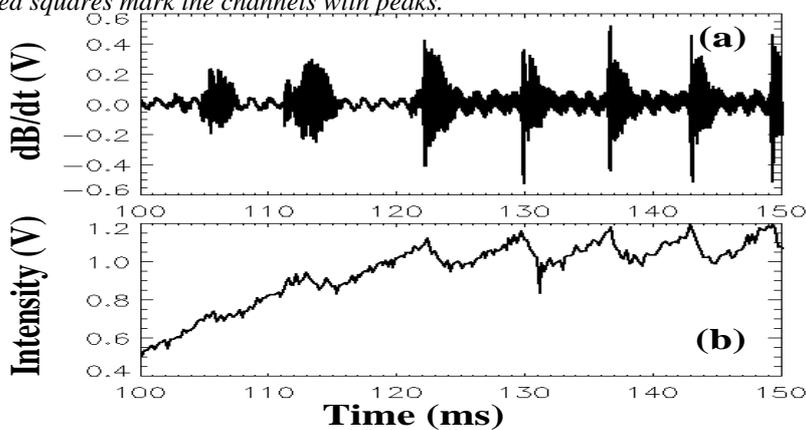

Fig.5 Time evolution of (a)the magnetic fluctuations during a burst and (b) the oscillation in the soft X-ray signal.

496