§1. Development of Wide Band and Compact X-ray Spectrometer

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A wide band and compact X-ray spectrometer has been developed to measure simultaneously the Kα X-ray transition array from Fe ionization stages and to evaluate the charge state distribution in the plasma center. Although analysis of the charge state distributions of impurity ions can determine the transport coefficients, the Fe Kα X-ray line measurements became also important for understanding detailed processes on the ionization and recombination of highly ionized ions.

The spectrometer consists of a Johan-type quartz (2023) crystal (2d=2.7498Å) with a curvature radius of 2R=630mm and a back-illuminated CCD detector (Andor model DO420-BN)[1)] in Fig.1. The spectrometer was installed at #1-O port on the LHD. A wide band energy range of 6.4-6.75keV can be obtained with high brightness and high temporal resolution, which enable us the measurement of Kα transitions. Time-developed Fe Kα spectra have been measured with a time interval of 10ms in the full binning mode of the CCD. Figure 2 shows typical example of Fe Kα spectrum. We have been clearly observed the charge states distribution from Fe irons of FeXXI (C-like) to FeXXV (He-like). The observed energy resolution of the spectrometer has been calculated using the He-like Fe Kα resonance line and estimated to be 4eV at 6.7keV as a value of FWHM.

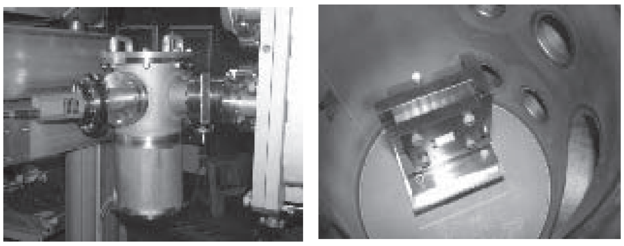

Fig.1 Photographs of (a: left) wide band and compact X-ray spectrometer and (b: right) Johann-type curved crystal set in crystal holder on rotary stage.

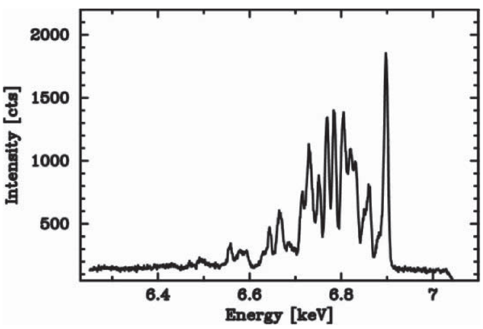

Fig.2. Typical example of Fe Kα spectrum observed with new spectrometer using quartz (2023) crystal.

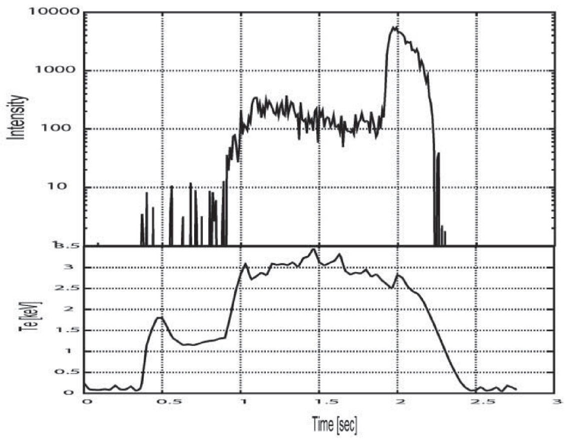

Fig.3 Time evolution of He-like Fe line intensity (top) and electron temperature (bottom). Fe-coated carbon pellet is injected t=1.8s. (shot number #84625, B=2.769T,R_{ax}=1.254)

The time behaviors of He-like Fe line intensity and electron temperature are shown in Figure 3. The electron temperature is measured with Thomson scattering diagnostic. It should be noticed that the vertical axis is logarithmic. The temperature dependence of the Fe Kα lines is very strong. In this shot, a carbon pellet ($0.9mm^{\phi}\times 0.9mm^{L}$) coated by iron with a thickness of 13μm is injected using an impurity pellet injector to confirm the brightness of He-like Fe line and to test the signal responce. The pellet with a speed 200m/s is ablated at the plasma center of the LHD. The pellet was injected at t=1.8s in Fig.3. A small time delay is seen between the pellet injection and the rapid rise of the x-ray signals. It means the ionization time needed for developing the change states of iron up to He-like ions in addition to the ablation time τ_d of the pellet. The line intensities slowly decrease with a decay time of 0.4-0.6s after reaching the maximum values. This decay time indicates a confinement time of iron ions in the plasma center, typically defined by the diffusion coefficient *D*. In this case the value of *D* is estimated to be 0.12-0.18m^2/s at d=0.4-0.6s, which is in good agreement with the past work[2)].

The results presented verified the high brightness of the crystal spectrometer designed for this work, which is extremely useful for our future study, not for the transport study of the laboratory plasmas but also for the transient process on the ionization and recombination and atomic physics related to the astrophysical plasmas.

1) I.Sakurai, Y.Tawara, C.Matsumoto et al., Sci. Instrum. **77**, (2006) 10F328.
2) H.Nozato et al., Phys. Plasma 11,(2004), 1920