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The development of the soft X-ray diagnostic with CsI:Tl scintillator usable in high neutron flux enviroments

高中性子束環境下で使用可能なCsI:Tlを用いた軟X線検出器の開発

Takahiro. Bando[1], Satoshi. Ohdachi[1,2] and Yasuhiro. Suzuki[1,2]

坂東隆宏, 大舘暁, 鈴木康浩

[1]*Graduate University for Advanced Studies, 322-6 Oroshi-cho, Toki 509-5292, Japan*

[1] 総合研究大学院大学, 岐阜県土岐市下石町３２２−６

[2]*National Institute for Fusion Science, 322-6 Oroshi-cho, Toki 509-5292, Japan*

[2] 核融合科学研究所, 岐阜県土岐市下石町３２２−６

In the Large Helical Device (LHD), semiconductor based detector arrays for the soft X-rays (SX)) emission has been used for studying MHD instabilities [1]. However, the semiconductor device is expected to be damaged in high neutron flux environments in the coming deuterium plasma experiments in LHD. In order to measure SX in such environment, a CsI:Tl scintillator based diagnostic have been developed. Though the CsI:Tl is sensitive to neutrons and gamma-rays as well, the effect can be reduced if the very thin CsI:Tl foil (50 micro meter) is used.

1. Introduction

From the multi-channel soft X-ray emission measurement, the deformation of the flux surface can be measured effectively. Therefore, this kind of measurement is quite useful for studying the spatial structure of the MHD instabilities. Semiconductor based detectors have been used mainly for this purpose in hydrogen experiments in LHD. Experiments using deuterium will start in the near future.

We have been developing another type of diagnostic using scintillator suitable for deuterium experiments. Soft X-ray lights are converted to visible light by the scintillator. The light are then guided to a remote location and measured there. CsI:Tl, having high conversion efficiency, will be used as the scintillator since it is reported that there is little effect of neutron flux exposure due to its high atomic numbers[2].

2. Hardware

The schematic view of the detection system is shown in Fig.1(A). It essentially is a pinhole camera with scintillator screen. The SX emission from plasma go through the pinhole, and enter the CsI:Tl scintillator put on fiber optic plates (FOP). The SX lights are converted to visible light there and the light is converged by lens and leaded to the optical fibers. The light is then transferred and detected by the avalanche photo diode(APD) array set in a neutron and γ ray shielding box far from LHD. The slight lines are shown in Fig.1(A).

The size of the pinhole is 2mm × 6mm. Three of fiber optic plate with scintillator (FOS) J6673-01, made by HAMAMATSU Photonics, is used. Each effective area of FOS is 47mm × 7mm. The thickness of CsI:Tl layer is 50μm. C12703 APD modules, made by HAMAMATSU Photonics are used for the detector. The upper frequency limit for the APD module is about 70kHz. The thickness of Be foil to cut low energy photon is 50μm. At the initial stage, 6ch are installed will be extended to 13ch.

3. The estimation of the incident power to CsI due to each radiation

The amplitude of scintillation light of CsI:Tl is proportional to the sum of the incident power to CsI:Tl. Therefore, here, to estimate the effect of neutron flux and γ ray to signal, the incident power to CsI viewed from one optical fiber channel is estimated. The amount of Tl in CsI is few, so the power is estimated for only CsI.

The neutron flux and γ ray particle fluence in the place on the diagnostic have been calculated with a transport code, DORT [3]. DORT is a code that calculates flux and influence of particles which are produced by collisions with other particles or interactions between with mediums in one or two dimension. The condition of this calculation is that the core plasma temperature is 9.46keV and the line average plasma density is $2.5\times 10^{19}m^{-3}$. Almost all neutrons occur collisions between part of plasma and energetic particles of neutron beam, so the amount of neutron flux don't much depend on plasma parameters here. Two of NBI are injected. One is a perpendicular injection, which energy is 14MW, the other is a tangential injection, which energy is 18MW. And also, the result of this condition is the maximum of them in deuterium plasma experiments.

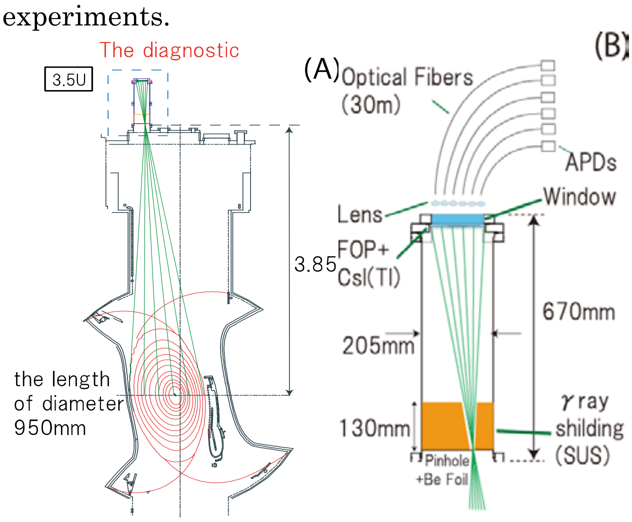

Fig.1. Cross sectional view at a poloidal section of 3.5 U port of LHD(A). Sight lines are shown as green lines. Schematic diagram of the diagnostic is shown in (B).

3.1 *The incident power due to bremsstrahlung*

Here, it is assumed that almost SX is due to bremsstrahlung. The result is evaluated as $E_{SX} = 7.5 \times 10^{-8}$ W.

3.2 *The incident power due to γ rays*

The power is given by

$$E_\gamma = \int S\,\phi\big(1 - \exp(-\lambda l)\big)d\varepsilon\ [\mathrm{W}]. \qquad (2)$$

This eq.2 shows that a process that γ rays are absorbed by CsI. $\phi[m^{-2}s^{-1}]$ is given by the result of DORT. And we assume the existence of γ ray shielding of Stainless, which thickness is 10cm. So, the power is estimated as $E_\gamma = 1.03 \times 10^{-8}$ W.

3.3 *The incident power due to neutron flux*

The power is given by

$$E_n = \frac{VN}{2}\int \sum_{i=Cs,I} E_i\,(\varepsilon)\sigma_i(\varepsilon)\phi(\varepsilon)d\varepsilon\ [\mathrm{W}]. \qquad (3)$$

Here, E_i J $(i = Cs, I)$ means the incident energy due to a neutron, σ_i m^2 $(i = Cs, I)$ means the elastic cross sections of Cs or I, ϕ $m^{-2}s^{-1}$ means the energy spectrum of neutron flux, given by DORT in Fig.1(A). The result is $E_n = 4.79 \times 10^{-10}$ W.

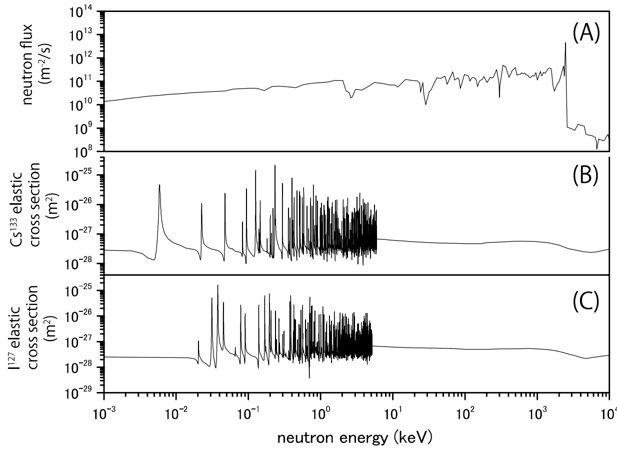

Fig.2. Fig. (A) shows neutron flux calculated by DORT. Figures (B) and (C) show the cross sections of Cs^{133} and I^{127}, respectively

3.4 Conclusions

Fig.3. shows a summary of the absorbed power, Energy from the SX emission of one order larger than other contribution. It is also noted that SX emission might be increased by a factor of 10 from the contribution of the recombination radiation. So, this diagnostic will work in deuterium plasma experiments.

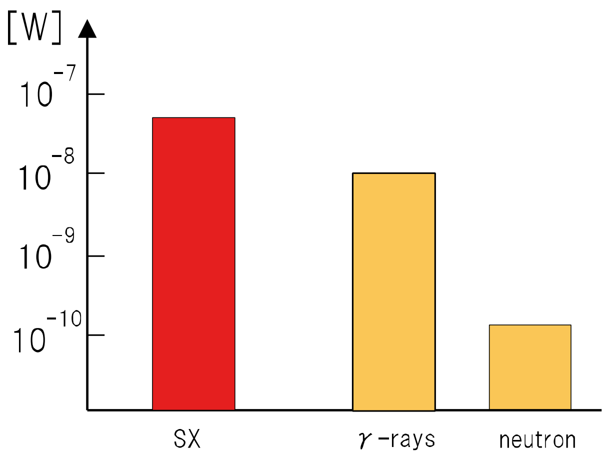

Fig.3. Incident power from SXs, γ rays and neutrons onto one channel is shown.

References

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