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Energy-Resolved X-ray Imaging by means of SOI Detector in LHD
SOI検出器を用いたLHDに於けるエネルギー分解X線イメージング

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An assembly of silicon-on-insulator pixel sensor has been installed at 7-O horizontal port in Large Helical Device in order to measure x-ray spectrum. The assembly is an in-vacuum-pinhole camera equipped with a cooling system for the sensor. The assembly makes it possible that the soft x-ray emissions from plasmas are observed as energy resolved images.

1. General

The high temperature plasmas emit strong soft x-ray spectra in an energy range from 1.0 keV to 10 keV. The spectra consist of continuum as bremsstrahlung emitted from electrons and K_α lines from the impurities such as ionized argons, and transition metals.

In Large Helical Device (LHD), an assembly of x-ray detector is being developed for the transport study, especially, in high density plasmas where transition metals stay long time around plasma center [1]. The phenomenon have been turned out in an experimental results from pellet injections with an injecting tracer-encapsulated solid pellet (TESPEL) [1]. In the experiment the x-ray spectra have been measured with a pulse high analyzer (PHA) [2]. The phenomenon has been never investigated to obtain impurity transport, since the PHA has only three chords. For the transport study, particularly, to obtain the density dependence of the transport, it is necessary to make more than one order larger numbers of chords for time-resolved x-ray spectra. It is important that the radial profile of time-resolved K_α line gives rise to the diffusion coefficient and the convective velocity profiles of the impurity, separately [2].

2. Assembly of SOIPIX

The assembly has been installed at the 7-O horizontal port. The detector is equipped with a silicon-on-insulator pixel sensor (SOIPIX) [3]. The SOIPIX has both thick high-resistive radiation sensor and CMOS readout circuit in a single chip [4]. The signal is read out in the fast time of less than 1 μs/pixel. The sensor is 264×264 pixels of 14 μm square. The thickness of the sensor is 500 μm to obtain the x-ray in a range from 1.0 keV to 10 keV with high quantum effectively. The data and control signals are transferred through a SiTCP consisting of a FPGA-one-board circuit. The assembly is equipped with a cooling system. The system reduces the thermal noise in the sensor to investigate the photon energy at respective pixel.

The assembly is an in-vacuum-pinhole camera to obtain the x-ray images [5]. The pinhole is a diameter of 100 μm at a 1.0-mm-thick stainless plate. The plate is manually motional in the vertical direction. The precision of the motion is 10 μm. The x-ray through the pinhole and a 250-μm-thickness beryllium filter is measured with the SOIPIX. The filter yields remarkable reduction in an x-ray spectrum due to the strong absorption in the lower energy. The transmissions of highly ionized argon K_α (E = 3.2 keV) and iron K_α (E = 6.7 keV) are 18.4 % and 85.3 %, respectively. The distance between the pinhole and the plasma center (R_{ax} = 3600 mm) is 16.85 m. The distance between the pinhole and the sensor is 65.5 mm. The sensor is 437 mm higher than the LHD equator. At the plasma center the sensor approximately covers 0.8-m-square region.

3. Experimental Results

The measurement of an x-ray image has been tried at the last cycle (17th LHD experimental campaign) [5]. The first image has been obtained from an ICRF heated plasma of approximately 40 minuits heating pulse duration ($T_e^{center} \approx$ 3.0 keV, $n_e \approx 10^{19}$ cm^{-3}). In the present measurement, the relative position of the sensor against the pinhole is fixed in the horizontal direction. From the experimental results, it is suggested that the sensor has horizontally shifted approximately 1.7 mm toward 6-O direction, at which the view frame has approximately shifted 400 mm towards 8-O direction. The pinhole exists at the higher position of 387 μm, at which the center of the view frame is corresponding to be 100 mm higher than the plasma center. In addition, the image is reversed due to the pinhole camera. Accordingly, the x-ray seems to come from the upper and 8-O sides of the 7-O port.

In comparison with the spectra obtained with the Si(Li) PHA at 2-O port, the energy resolutions of SOIPIX is approximately 70 % [5].

The remarkable difference between the PHA and the SOIPIX is the number of chords. The SOIPIX will make it possible that the number of fixed chords is effectively improved to be 32, while that of the PHA is only three. By this fact the impurity transport becomes available in a single shot of LHD. Concerning the estimation of S/N ratio, the readout region is assumed to be reduced to 256×8 per chord. An 8×8 binning mode is also assumed to be chosen. The exposure time is 0.8 ms to obtain 0.1 photon/pixel/readout as photon counting mode. The readout time for a single image is 2.05 ms. Then, the duty ratio is 28 %. Then, the photon number is estimated to be 112/50 ms/chord, while that of the PHA is 200/50 ms/chord.

In the future the readout time will be improved to be the faster time of 0.5 μs/pixel. The S/N ratio per chord will become approximately 90 % in comparison with the PHA.

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