§2. Energy Resolved X-ray Video Camera System in LHD

Arai, Y., Miyoshi, T. (High Energy Accelerator Research Organization, KEK), Tsuru, T. (Kyoto Univ.), Ono, Y. (Univ. Tokyo),
Tsukada, K. (Nagoya Inst. of Technology),
Sudo, S., Nakanishi, H., Muto, S., Tamura, N., Ito, Y., Nishimura, R. (Grad. Univ. Advanced Studies)

To study impurity behavior in magnetically confined plasma by injecting tracer-encapsulated solid pellet (TESPEL), new kind of X-ray detection system is required. The detector must measure the radial profiles of time-resolved soft X-ray spectra emitted from high temperature plasmas in LHD. The plasma emits strong soft X-ray 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 emitted from the impurities such as ionized argons and transition metals.

In the third fiscal year, we measured soft X-ray by using a Silicon-on-Insulator pixel detector (SOIPIX) installed at 7-O horizontal port in LHD. The SOIPIX has both thick high-resistive radiation sensor and CMOS readout circuit in a single chip[1, 2]. The signal is read out at the rate of 520 ns/pixel. The detector used at the port has 256×256 pixels of 14 μm square. The thickness of the sensor is 300 μm to obtain the X-ray in the range from 1.0 keV to 10 keV, effectively. The data and control signals are transferred through an Ethernet I/F consisting of an on-board FPGA. The detector is cooled to less than 0 °C to reduce leakage current. Completed SOI detector chamber is shown in Fig. 1.

In the present research, the soft X-ray emitted from LHD is measured by means of an in-vacuum-pinhole camera to obtain the X-ray distribution. The pinhole is a diameter of 100 μm at a 200-μm-thick stainless plate. The plate is manually movable in the vertical direction. The precision of the motion is about 10 μm. Additionally, the SOI chamber was modified in this year to be adjustable in the horizontal direction. The precision is about 100 μm. The X-ray through the pinhole and a 250-μm-thick beryllium filter is measured with the SOIPIX. The beryllium filter separates vacuum system between LHD and the detector system, and also reduces the flux of low-energy X-rays. For example, the transmission rate of argon K_α (E = 3.2 keV) and iron K_α (E = 6.7 keV) emitted from high temperature plasma are 18.4 % and 85.4 %, respectively. The distances between the pinhole and the plasma center (R_{ax} = 3600 mm), the pinhole and the sensor are 16.9 m and 65.5 mm, respectively. The sensor is 437 mm higher than LHD equator. At the plasma center the sensor approximately covers a 0.8-m-square region.

The measurement of an X-ray image has been tried at the last cycle (18th LHD experimental campaign). Figure 2 shows the two images, one (to the left) obtained from a long pulse heated plasma of approximately 40-minutes pulse duration (LHD#124530) in FY2013, and the second (to the right) obtained from a long pulse heated plasma of approximately 10-minutes pulse duration (LHD#131052) in FY2014. The total exposure time of the SOIPIX is 12.139 sec. The square frame indicates the whole region covered with the sensor. In the present measurement, the position of the sensor was perfectly adjusted. Eventually, the detector system was completed within these three years except the cooling system. Temperature was reached to below -50 degree in the initial test setup, but after several modifications of the chamber system the temperature can be reached only -7deg. We realized that the further optimization of the cooling system is needed.

In the final year, small Pulse height Analyzer (PHA) was also introduced in the SOI chamber system, and the system can calibrate the X-ray count rate during the LHD operation. Eventually, more stable data, such as time dependence and total number of photons, are measured.

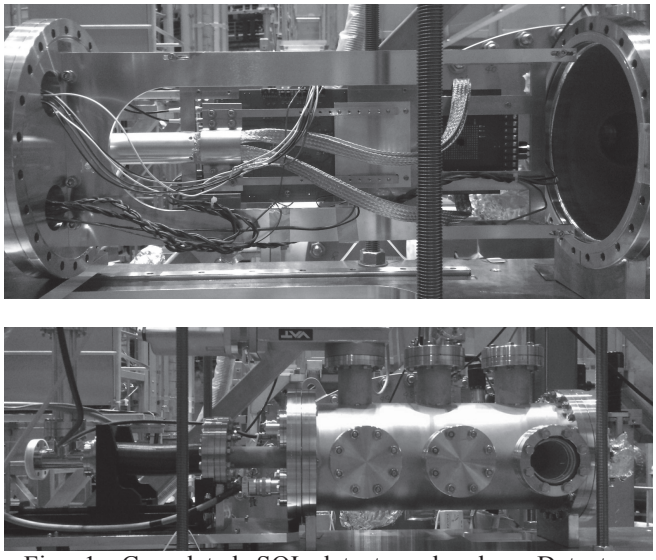

Fig. 1. Completed SOI detector chamber. Detector frame with a cooling arm (top) and closed chamber (bottom)

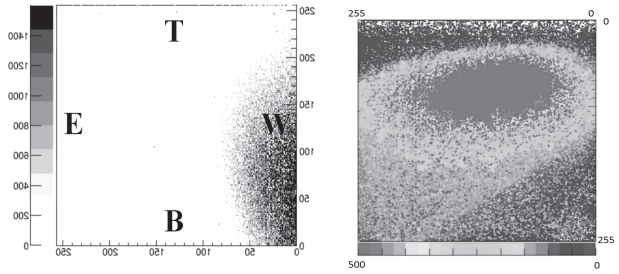

Fig. 2. LHD plasma X-ray images taken with the SOIPIX camera system (left: in FY2013, right: in FY2014). The vertical and horizontal axes are corresponding to the Z and toroidal direction of the plasma, respectively. The signs of “T”, “B”, E”, and “W” mean the top, bottom, 6-O side, and 8-O side of the sensor. At the sensor the X-ray image of LHD plasma is reversed due to the pinhole camera.

1) Y. Arai, *et al*., Nucl. Instr. and Meth A. Vol. 636, Issue 1, Supplement, pp. S31-S36. DOI:10.1016/j.nima. 2010.04. 081.
2) Y. Arai, 'Progress on Silicon-on-Insulator Monolithic Pixel Process', PoS(Vertex 2013)021, http://pos.sissa.it/archive/conferences/198/021/Vertex2013_021.pdf