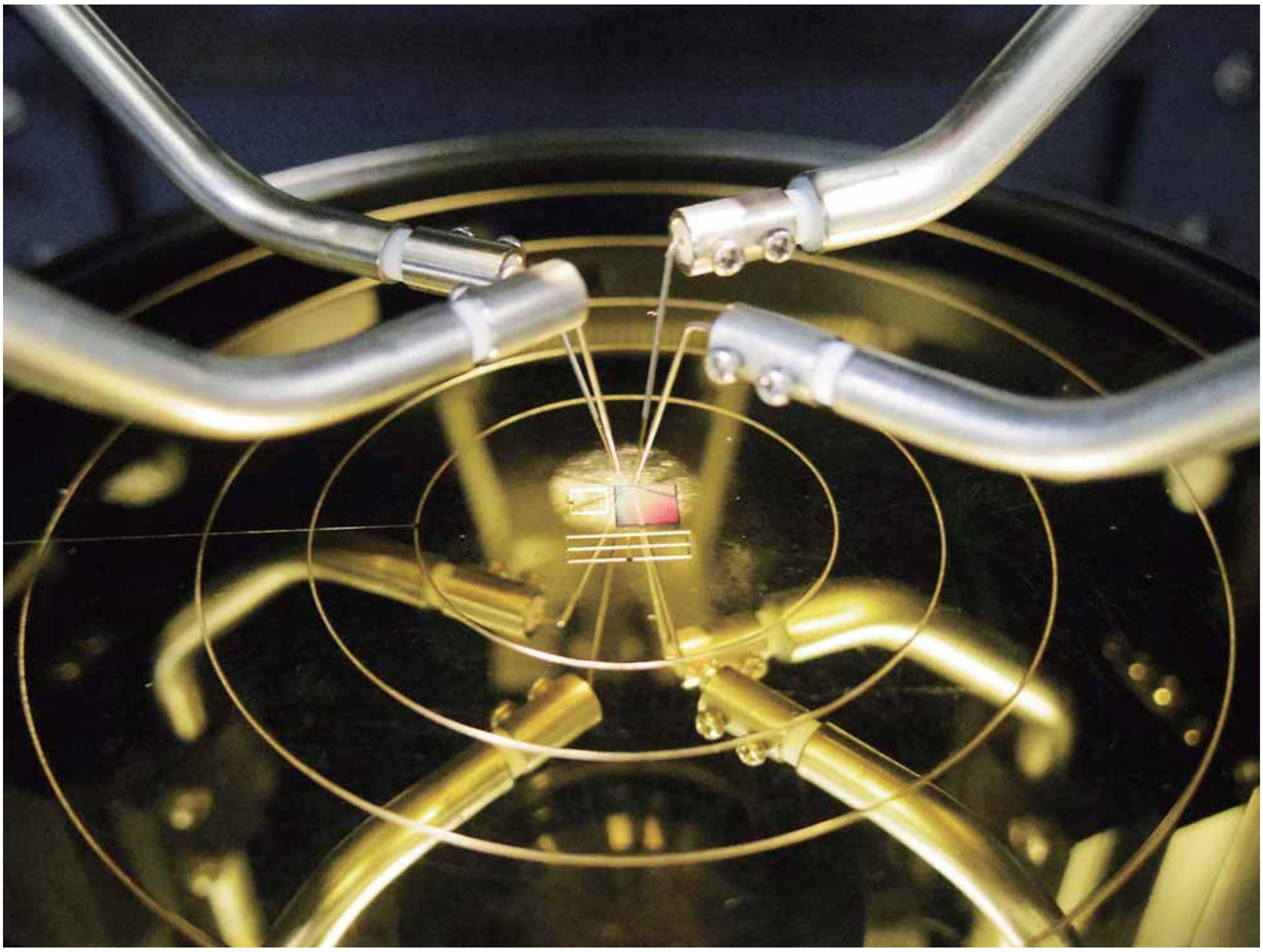

3.5 Department of Advanced Accelerator Technologies

The Department of Advanced Accelerator Technologies (AAT) has been promoting R&D activities in selected topics according to the KEK's research strategy. There was reorganization within AAT in FY2016. In FY2015, three project offices, the Linear Collider project office, the ERL project office, and the Detector Technology project office used to be in operation. In FY2016, however, technological developments of the accelerator and detector of the linear collider were carried out in the framework of the IPNS, ACCL, and ARL, instead of AAT, to enable this R&D work to be more effectively coordinated over the institute and laboratories. The Advanced Laser Science Project, which was supported by AAT up to FY2015, is now a project in ACCL. In FY2016, there also was a revision in the strategy of photon science in KEK to follow the "KEK Project Implementation Plan (KEK-PIP)" [1], which was intended to drive projects described in the "KEK Roadmap 2013" [2]. The research activity in the ERL (Energy Recovery Linac) project office in FY2016 was focused on making the ERL technology industrially applicable.

Reformation of ILC promotion activity

KEK reformed the organization of the International Linear Collider (ILC) project in April 2016. ILC is a next generation high energy physics collider where electrons and positrons will be accelerated in a linear tunnel from opposite directions and will collide with unprecedented energy to explore laws of physics at the highest energy. The technical developments and design works have been carried out within a worldwide framework. The International Committee for Future Accelerators (ICFA) set up the Linear Collider Board (LCB) and the Linear Collider Collaboration (LCC) to promote linear collider projects worldwide. The Japanese high energy physics community released a statement in October 2012 to express its intention to host ILC in Japan as a global project. This proposal was welcomed by the worldwide high energy physics community as shown, for example, in the statements by ICFA on ILC [3]. In Japan, the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) set up the ILC Advisory Panel in May 2014, and various issues related to hosting ILC in Japan have been investigated by the panel.

At KEK, R&D for the ILC project had been carried out under the linear collider project office at AAT for a long time. The planning office for the ILC was established in February 2014. Since the roles of the two offices somewhat overlapped, and the ILC project was entering an important phase toward its realization, KEK decided to restructure the framework for the promotion and R&D activities of the ILC project. On the one hand, all project promotion efforts would be set by the ILC planning office headed by the KEK director general. On the other hand, R&D of accelerator and detector technologies and ILC design works would be carried out within the framework of the institutes and laboratories of KEK, namely, IPNS, ACCL, and ARL. Since coordination is needed for these technical works, an ILC R&D project leader was assigned to lead the joint teams working on the ILC technical developments. In this annual report, accelerator and detector developments for ILC are included separately in each institute/laboratory report.

ERL Project Office

The ERL project office was established in 2006 to progress R&D of the ERL accelerator technology from the viewpoint of a future light source. With this future light source, two outstanding features such as coherent light and femtosecond short pulse are important for material science studies. To realize these features, low emittance of less than 1 mm·mrad, and a short electron bunch width of ~100 fs of the electron beam should be milestones of the R&D activities.

In FY2015, a beam current of 1 mA was successfully achieved at Compact ERL (cERL), and the beam normalized emittance at 7.7 pC/bunch was demonstrated as 1.5 mm·mrad (horizontal) and 1.1 mm·mrad (vertical). Furthermore, the bunch compression was achieved as ~150 fs using a combination of off-crest acceleration in the main linac and non-zero longitudinal dispersion (R56), and also by correction of the second order energy dependent path length by means of sextuple magnets.

In FY2016, however, the synchrotron radiation community decided to choose the 3 GeV storage ring as the light source instead of the 3 GeV ERL, because there was still much R&D to be done to realize the 3 GeV ERL light source. The KEK roadmap was revised accordingly. Subsequently, R&D of cERL as a future synchrotron radiation facility was stopped. On the other hand, the technologies developed with the cERL will have industrial applications such as an Extreme Ultraviolet-Free Electron Laser (EUV-FEL) light source, a security system for nuclear material based on gamma ray production by means of laser Compton scattering, and a high resolution medical X-ray imaging system. In KEK-PIP, the “Industrial application of ERL technology” is listed as one of the projects conducted using the general funds of KEK with efforts being made to obtain external funding. In an industrial setting, it is much more important to establish low emittance operation (~1 mm·mrad) at a high bunch charge (60 pC/bunch).

At the end of FY2016 (March 2017), KEK operated cERL to demonstrate this low emittance operation. Subsequently, the normalized emittance was demonstrated as 2.4 mm·mrad (horizontal) and 1.4 mm·mrad (vertical) with 40 pC/bunch. Figure 1 shows the experimental emittance data using the slit scanning method. The obtained value does not completely coincide with the expected value; nevertheless, these efforts are important to realize the industrial applicability of ERL technology.

Detector Technology Project Office

The KEK Detector Technology Project (KEKDTP) office is now focusing on six R&D projects to enhance the level of advanced detector technologies at KEK, to establish it as a world leading accelerator laboratory.

In FY2016, the Silicon-On-Insulator (SOI) pixel project moved to the stage of practical use. The SOI photon imaging array sensor (SOPHIAS) detector developed for X-ray imaging by the RIKEN group was used in several beam lines at SPring-8 facility. The X-ray SOI pixel (XRPIX) detector developed for X-ray astronomy by a Kyoto University group achieved the highest ever energy resolution of 400 eV for an X-ray with an energy of 13.95 keV by lowering the noise level to around 10 electrons at a temperature of −60 °C.

To use the SOI detector in high energy particle accelerator experiments, radiation hardness is an important factor. The SOI project group has succeeded in enhancing radiation hardness by introducing double SOI wafer technology, with the remaining issue of drain current decrease of PMOS (P-type metal-oxide semiconductor) transistor, as indicated in the left plot of Fig. 2. Further analysis identified that the

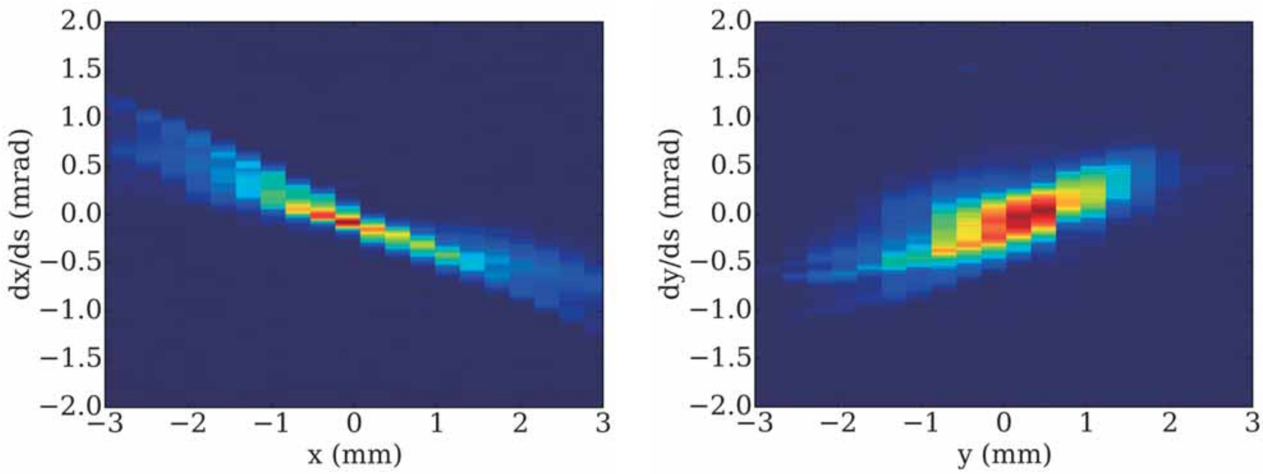

Fig. 1. Emittance measurement experimental data at the condition of 40 pC/bunch by using slit scanning method on (a) horizontal direction and (b) vertical direction, respectively.

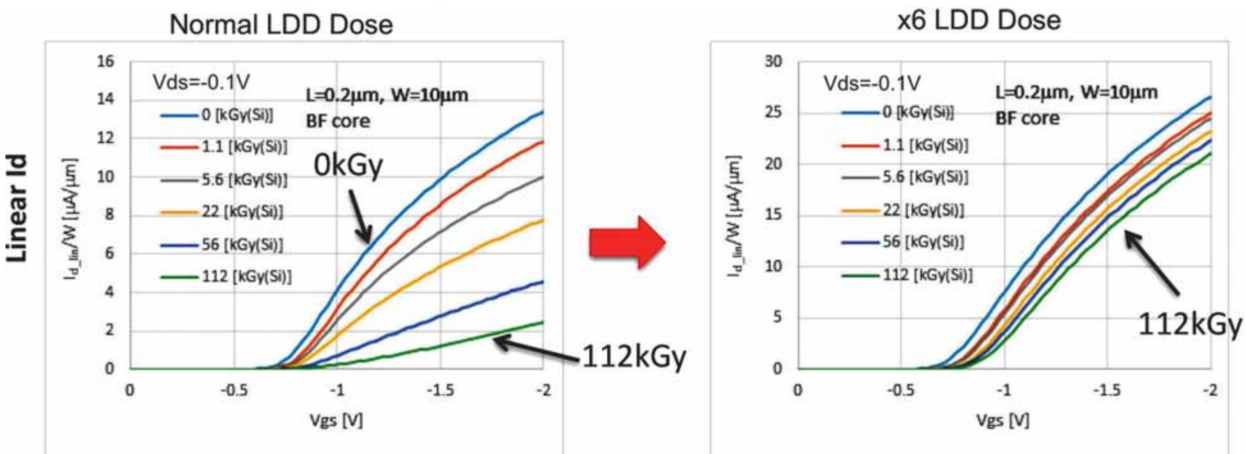

Fig. 2. Drain current decrease by irradiation. (Left) normal LDD dose case. (Right) six times higher LDD dose case. The effect of the irradiation is very much reduced.

dose of LDD (Lightly Doped Drain) region of the transistor is a key parameter for the radiation effect, and it was successfully demonstrated that the six times higher LDD dose could recover the drain current, as shown in the right plot of Fig. 2.

The R&D project in fundamental technologies to realize a large Liquid Argon Time Projection Chamber (LArTPC) detector has made good progress with the development of an ionized charge signal readout system including a high voltage system and argon purification system. In FY2016, the project group successfully developed charge signal readout electronics (analog amplifier application-specific integrated circuit, ASIC), which can be operated at a cold temperature. The group plans to verify the functionality of the signal readout electronics at a large scale engineering prototyping detector (CERN WA105). It will be commissioned shortly in the context of the worldwide cooperative R&D effort. A high voltage system is also being intensively developed for extremely long drift distance using a small setup at KEK as well as by simulation to understand the electric field formation in the Time Projection Chamber (TPC).

The goal of the CO_2 Cooling project is to develop cooling systems for advanced detectors using two phase CO_2 as the

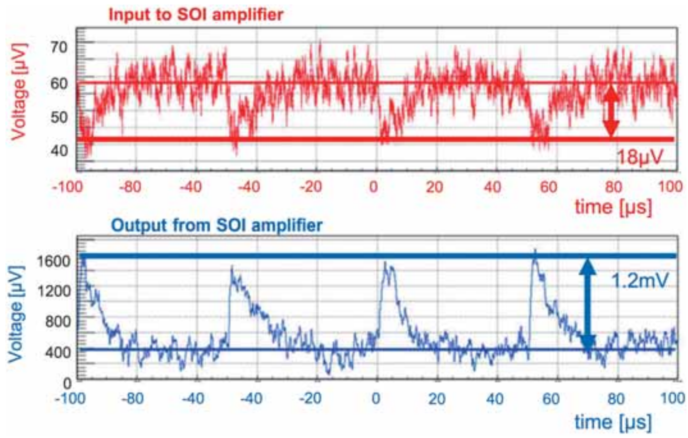

Fig. 3. The signal from Nb/Al-STJ to the SOI amplifier (upper) and the amplified output (lower).

coolant. This will realize more efficient and stable cooling with less material inside the detectors. At KEK, a unique system using a gas compressor for circulation of the CO_2 coolant is being developed. After completion of a proof-of-principle system, the group developed an automatic pressure control system, which precisely stabilized the temperature of two-phase CO_2 for detector cooling. A CO_2 dryer system using a molecular sieve was also added to the cooling system.

In FY2016, the Superconducting Detector (SCD) project developed a cryogenic detector system composed of a Nb/Al Superconducting Tunneling Junction (STJ) sensor with an amplifier circuit formed using fully depleted SOI technology. The system was cooled down to 0.3 K, and visible light pulses with a wavelength of 465 nm were irradiated onto STJ. Figure 3 shows the pulse signals obtained. The group successfully detected the amplified STJ signals at the cryogenic temperature. Furthermore, it succeeded in reducing the leakage current in the STJ made of Hf down to 8% of the previous sensor by depositing a thin Al layer on the HfO insulator, and detecting the pulse signals of visible light.

One of the tasks for the detector technology project is to promote its achievements toward users outside the fields of particle and nuclear physics of which development of the user-friendly Micro Pattern Gas Detector (MPGD) system is an important goal. In FY2016, the group developed the system with new DAQ software in which all service connections were integrated conveniently at one side. Gas tightness and circulation inside the chamber were also improved significantly for easier operation. Simpler and easier DAQ software was developed with several user-friendly options. The MPGD systems using Gas Electron Multiplier (GEM) foil for a neutron detector are used in several beam lines in the Materials and Life Science Experimental Facility (MLF) of J-PARC, at Hokkaido University and Kyoto University, as well as at the Rutherford Appleton Laboratory in the UK because of its reliability and high performance in spatial and timing resolution.

References

[1] KEK Project Implementation Plan (KEK-PIP), http://www.kek.jp/en/About/Roadmap/.

[2] KEK's Roadmap (5-Year Plan) 2013, http://www.kek.jp/en/About/Roadmap/.

[3] ICFA statements, http://icfa.fnal.gov/wp-content/uploads/ICFA_Statement.pdf (February 2014); http://icfa.fnal.gov/wp-content/uploads/ICFA_Statement_20140706.pdf (July 2014).