3.5

Department of Advanced Accelerator Technologies

The Department of Advanced Accelerator Technologies (AAT) has been carrying out advanced research in the field of accelerator and related science in a strategic manner at KEK. It supports R&D efforts that are not limited to one institute or laboratory in KEK. According to the research strategy described in the "KEK Roadmap 2013" [1], three project offices, the Linear Collider Project Office, the ERL Project Office, and the Detector Technology Project (DTP) Office, were in operation in FY2015. Additionally, the Advanced Laser Science Project was supported by the AAT.

Linear Collider Project Office

The International Linear Collider (ILC) is a next generation high energy physics collider, for which the center-of-mass energy of electron and positron beams is 500 GeV at the initial stage, and can be upgraded to 1 TeV in the future. R&D and design work for the ILC have been carried out with global cooperation since the Global Design Effort (GDE) was set up by the International Committee for Future Accelerators (ICFA). The GDE published the ILC Technical Design Report (TDR) in June 2013, after which the global coordination for the ILC design and R&D works under the ICFA was succeeded by the Linear Collider Collaboration (LCC). Meanwhile, after the discovery of the Higgs particle at CERN in the summer of 2012, the high energy physics community in Japan proposed to host the ILC in Japan as a global project in October 2012.

The preparation for the ILC was subsequently included in the five-year research strategy plan, the “KEK Roadmap 2013” [1], which was established in May 2013. The preparation and promotion for the ILC project have been continued worldwide. Progress in the accelerator design integration work and various R&D efforts after the ILC-TDR completion were disclosed in the “ILC Progress Report 2015,” published by the LCC in July 2015 [2]. At KEK, the “KEK-ILC Action Plan” was released in January 2016, which summarizes the studies on the organization, the technical issues, and the human resources necessary in the ILC preparation phase [3].

The ILC design study and R&D work were carried out at the Linear Collider Project Office at KEK. In particular, the main focus was on the following research areas: superconducting RF (SRF) technology, nano-beam technology, accelerator design integration (ADI), and civil engineering in FY2015. The R&D on the SRF technology was conducted at the Superconducting RF Test Facility (STF) and the Cavity Fabrication Facility (CFF) at KEK, and a summary on the STF-2 project during FY2015 is reported in the Research Highlights 4.11 of this report. Progresses in the ADI and civil engineering works were made in the framework of the LCC through a series of meetings and workshops.

The Accelerator Test Facility (ATF) is KEK’s unique facility for R&D on nano-beam technology. Research at the ATF was essential in producing the ILC-TDR. After completion of the TDR, further study has been pursued to demonstrate the primary R&D goal of a beam size of 37 nm at a beam energy of 1.3 GeV at the final focusing point in the ATF, which corresponds to a beam size of 5.9 nm at an expected ILC energy of 250 GeV. By FY2015, a beam size of 41 nm, very close to the goal, was achieved. Furthermore, the beam position stabilization at the final focus point reached 67 nm, with a successful feedback system operation established with the same optics as those of the ILC beam delivery system. Further efforts to improve the feedback system are in progress, including incorporation of the dynamic wake field effect from beam line components, as well as feedback against ground vibrations. These works have been carried out in cooperation with various laboratories and universities worldwide, within the global ATF collaboration.

ERL Project Office

The ERL Project Office has been carrying out R&D to validate the feasibility of future light sources based on the Energy Recovery Linac (ERL). For this purpose, KEK has constructed and operated the Compact ERL (cERL), a test ground for ERL technologies.

In FY2014, cERL was successfully commissioned with beam conditions of 100 μA and 20 MeV. Additionally, the Laser Compton Scattering (LCS) X-ray beamline was completed and the production of the LCS was demonstrated, thanks to the collaboration between KEK and the Japan Atomic Energy Agency (JAEA). The targets of the cERL in FY2015 were as follows. The first was a higher beam current operation (up to 1 mA), the second concerned beam development to maintain a small emittance during operation, and the third was the development of bunch compression systems by using the arc section. Details on the R&D achievements at cERL are described in the Research Highlights 4.13 of this report, including LSC experiments and development of a high-power THz radiation source.

The beam tuning for higher beam current operation was started in February 2016. A 1.3 GHz beam repetition rate with 0.7 pC/bunch was used to achieve a current of 0.9 mA without any beam-loss problem. Following this success, 1 mA current operation under a 162.5 MHz beam repetition rate with 5 ~ 6 pC/bunch was also demonstrated without any serious beam loss. This means that a 10 mA CW operation at a 1.3 GHz beam repetition rate is feasible presently at the cERL.

Table 1. Tentative emittance measurement at cERL.

Bunch Charge	Normalized Emittance (horiz./vert.) [mm·mrad]
0.02 pC	0.14 / 0.14
0.5 pC	0.27 / 0.17
7.7 pC	1.5 / 1.1 (tentative)

Low emittance is a key feature of the ERL. The normalized emittance of the recirculation loop is measured using a conventional Q-scan method. Table 1 lists a tentative result of the emittance measurement for several bunch charge conditions. At a bunch charge of 7.7 pC, normalized emittances of 1.5 mm·mrad and 1.1 mm·mrad were obtained in the horizontal and vertical directions, respectively. These values were obtained during a limited operational time.

The short bunch length is also a key feature of ERL. The bunch was compressed in the first arc section and decompressed in the second arc section with the combination of off-crest acceleration in the main linac and non-zero longitudinal dispersion (R56). In summer 2015, four sextupole magnets were installed to correct the second-order energy dependent path length. A coherent transition radiation (CTR) monitor with Al target was installed after the first arc section to make a compression tuning. After tuning, the bunch length can be estimated as about 150 fs. Further experiments are required for a quantitative discussion about bunch lengths in the future.

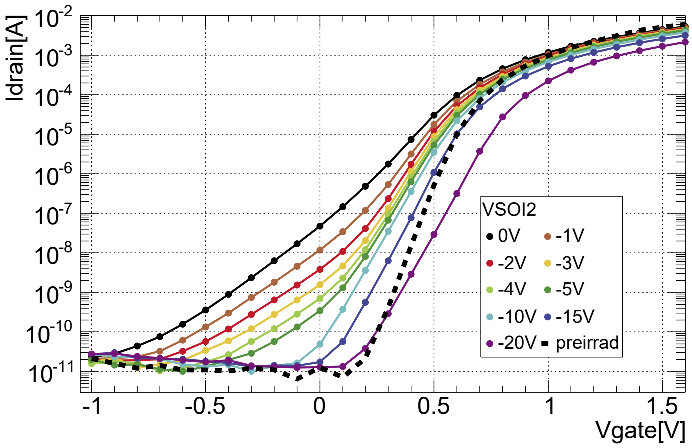

Fig. 1. I-V curves of the SOI test FET. The dotted curve represents the I-V behavior before irradiation. After a 2000 kGy exposure to radiation, the curve shifts to the black line. Application of a compensating voltage (V_SOI) brings the curve gradually back and finally to the purple line at 20 V close to the pre-irradiated level.

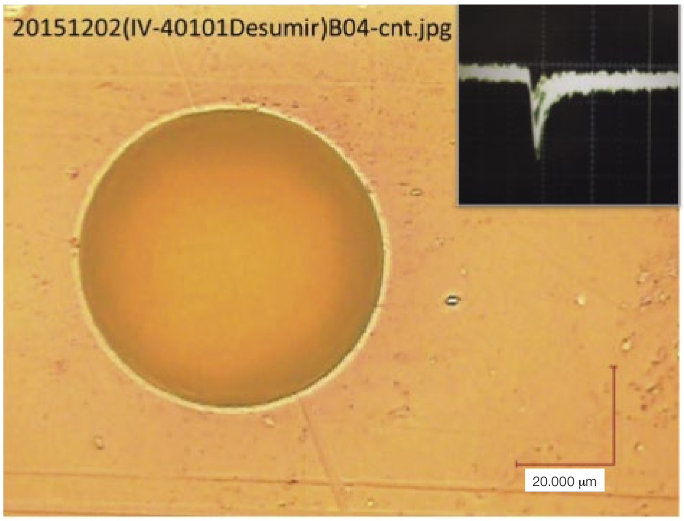

Fig. 2. Microscope image of the new GEM film. The laser-etched hole of 70 µm is clearly visible. Inset shows an oscilloscope trace observed for 5.9 keV X-rays.

Technologies developed at cERL are applicable to a wide range of science and innovation topics. Examples of such are future light sources other than ERL such as X-ray Free Electron Laser (XFEL), medical imaging, and semiconductor lithography. Discussions on such potential applications are under way with researchers from other institutes and universities, as well as the industry.

Detector Technology Project Office

Detector technologies are a key to the success of research carried out at KEK, from particle and nuclear physics projects to materials and life sciences. High-performance detector and sensor technologies developed for these projects can be applied to other areas of science, as well as for medical and industrial uses. Under the DTP Office's authority, seven R&D projects are currently under way, with the respective missions as described below. 1) Silicon-On-Insulator (SOI) pixel sensor, 2) Superconducting device detector (SCD), 3) Liquid noble gas Time projection chamber (LiqTPC), 4) Micropattern gas detector (MPGD), 5) Fast scintillation detector (FSCI), 6) Application specific integrated circuit (ASIC) development, and 7) CO_2 cooling. Here, three selected topics are highlighted among a great number of excellent outcomes provided by the DTP in FY2015.

For the SOI project, there was remarkable progress during a steady R&D phase, in which practical methods to enhance the radiation tolerance of the sensors fabricated using SOI technology. As shown in Fig. 1, the radiation effect observed in the I-V behavior of a Field Effect Transistor (FET) can be dramatically compensated by applying voltage to a newly implemented second SOI layer. In addition to this new compensation, a new device process optimization in doping level was developed to reduce the radiation effect itself substantially. Those measures combined enable the SOI sensors to function up to 200 kGy with high performances superior to other types of detectors. Being confident in a higher radiation tolerance for the coming years, a great effort is given to develop applications in various fields.

The MPGD group has been working for several years on developing a micro pattern film for a gas electron multiplier (GEM) using a conducting non-metal film to realize a non-sparking stable MPGD. In FY2015, successful film development was achieved using a conducting polymer PEDOT fixed with melamine resin, on which multiple 70 µm diameter holes are etched by an excimer laser. The overall hole shape is satisfactory, as shown in Fig. 2, and can hold sufficient high voltages to generate signals. A very clear signal can be observed for a 5.9 keV X-ray, showing a rather good energy resolution and indicating a good uniformity. This is the first demonstration of a non-metal GEM radiation detector working in practical conditions.

The FSCI project aims at developing a fast nanosecond scintillator with a large content of heavy elements to detect either MeV-gamma rays or high-energy X-rays. A nanosecond response of scintillation is also helpful to handle X-rays reaching $>10^7$ s^{-1}. Using a fast photon sensor with high counting rate, a time resolved high energy X-ray measurement is possible. To demonstrate the capability of the proposed detector concept, the system was constructed with a plastic scintillator containing lead nano particles connected with a high-speed silicon avalanche photodiode. In the test, using 67.41 keV X-rays from Photon Factory (PF), consecutive pulses separated

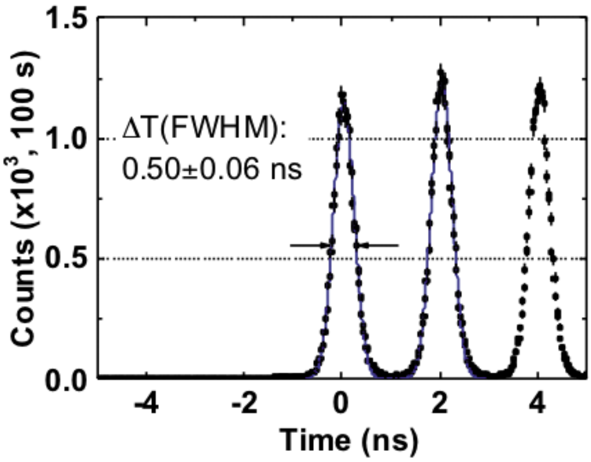

Fig. 3. Pulse train of X-rays, recorded in the PF beam line by the demonstration prototype for FSCI.

by 2 ns were successfully observed, which correspond to the beam bunches of the PF ring with a timing resolution as high as 500 ps at the FWHM, as displayed in Fig. 3.

Advanced Laser Science Project

A novel acceleration method was demonstrated to generate a very high acceleration gradient, up to 50 GV/m [4]. There are acceleration schemes driven by high intensity laser or by high intensity beam. As per the novel acceleration scheme, the Laser Plasma Wakefield Acceleration (LWFA) and Dielectric Laser Acceleration (DLA) are driven by high intensity laser, and the Beam Driven Plasma Wakefield Acceleration (PWFA) and Dielectric Wall Accelerator (DWA) are driven by high intensity electron beam.

The objective here is to perform the proof experiment of the post acceleration, which is so-called afterburner on these novel acceleration schemes, using the existing high quality electron beam with multi GeV electron energy, and a 4-stage bunch compression system as shown in Fig. 4.

In the Advanced Laser Science Project, KEK is collaborating with the University of Tokyo, Nagoya University, and Osaka University for the LWFA. It is also collaborating with the University of Tokyo for the DLA and National Institute of Advanced Industrial Science and Technology (AIST) for the DWA. Through these collaborations, a 10 TW Ti: Sapphire laser for LWFA and DLA was moved from the University of Tokyo to the power supply room next to LINAC's third switch yard in FY2012, and was reconfigured in collaboration with Nagoya University in FY2014, as shown in Fig. 5.

The laser transportation line to the LINAC beam line was already installed in FY2015, and the plasma chamber with a

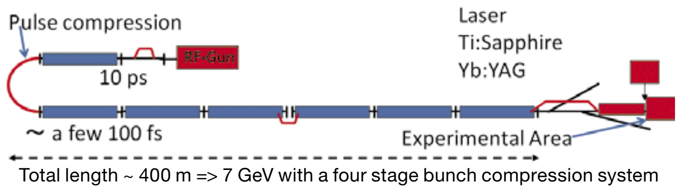

Fig. 4. Facility concept of Ultra High Intensity Beam-Laser Complex using the existing KEK LINAC.

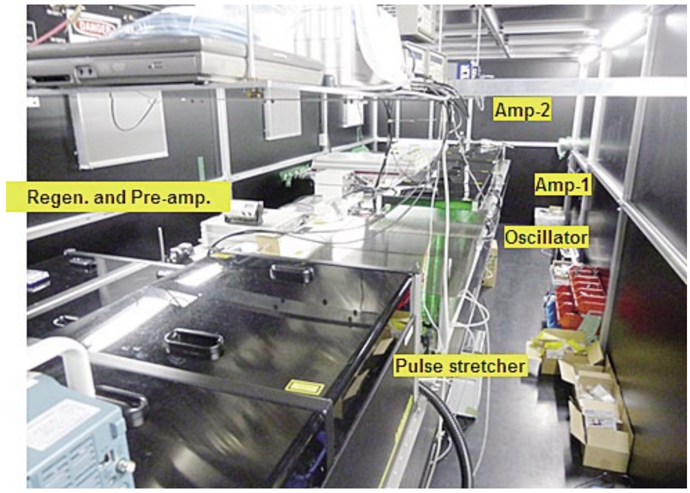

Fig. 5. The 10 TW Ti: Sapphire laser for LWFA.

new small compressor chamber will be installed in the near future. Later, the afterburner experiment will be commenced according to the LINAC beam time.

Development of a high intensity laser is in progress, in collaboration with the Institute for Molecular Science (IMS) and Hamamatsu Photonics K.K.. The high intensity Yb-doped thin disk laser is currently the best candidate for the low density plasma LWFA.

References

[1] KEK Roadmap 2013, http://www.kek.jp/en/About/Roadmap/.

[2] Linear Collider Collaboration, The International Linear Collider Progress Report 2015, KEK-2015-004 and the other ten laboratory institutional documentation numbers, https://cds.cern.ch/record/2059240?ln=en

[3] KEK-ILC Action Plan, http://www.kek.jp/en/NewsRoom/Release/KEK-ILC_ActionPlan_160106-EN.pdf.

[4] W. Leemans *et al.*, Phys. Rev. Lett. **113**, 245002 (2014).