THE PROTON ENGINEERING FRONTIER PROJECT: STATUS AND PROSPECT OF PROTON BEAM UTILIZATION*

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Abstract

A 100-MeV, 20-mA high intensity proton linac is to be constructed in 2012 by the PEFP (Proton Engineering Frontier Project) of the Korea Atomic Energy Research Institute, which was started in 2002 with three main objectives; development of high intensity proton linac, development of proton beam utilization technologies, and industrialization of developed technologies. Proton beams with variable energy and current can be provided to the users from various research and application fields such as nano-, bio-, semiconductor-, space-, radiation-, environment-technologies and medical- and basic sciences, etc. through 10 targets rooms, which are assigned specific application fields to meet various user's beam requirements. Following a brief introduction to the accelerator development, multiple beamline development and the construction works, we will review the achievements of our user program which have been operated over the past 8 years to cultivate and foster proton beam users and beam utilization technologies in diverse R&D fields. In addition, we will discuss the perspectives of the beam utilization in conjunction with design and construction of user facilities.

ACCELRATOR AND USER FACILITIES

100-MeV Accelerator

The 100-MeV linac is composed of a 50-keV injector, a LEBT, a 3-MeV RFQ, 20-MeV DTL, a MEBT, 100-MeV DTL, beam dump, and Klystrons. Its Specifications are summarized in Table 1 [1]. As shown in Figure 1, the low-energy part, 20-MeV linac, was completed in 2005 and beam service with 20-MeV proton beam was started in 2007 with the limited operating conditions. Several hundreds of samples from various application fields, nano-, bio-, and medical sciences, have been irradiated every year.

Table 1: Specifications of the PEFP's 100-MeV Linac

Extraction Energy (MeV)	20	100
Peak Beam Current (mA)	20	20
Max. Beam Duty (%)	24	8
Avg. Beam Current (mA)	4.8	1.6
Pulse Length (ms)	2	1.33
Max. Repetition Rate (Hz)	120	60
Max. Avg. Beam Power (kW)	96	160

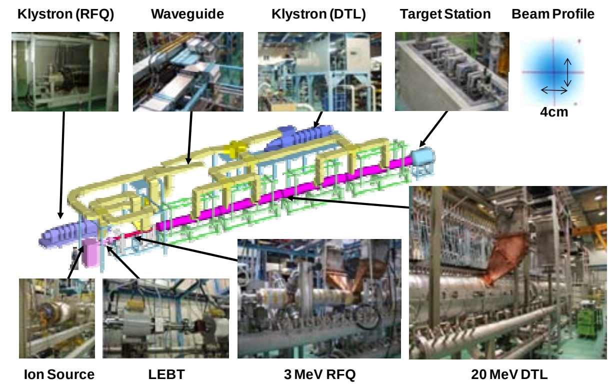

Figure 1: 20-MeV Proton Accelerator.

User Facilities

The user facilities for 20-MeV and 100-MeV proton beam were composed of 10 target room and connected 10 treatment rooms. Each target rooms and treatment rooms are assigned for specific application fields. And the irradiation conditions are also decided according to the users' requirements from diverse application fields. The schematics of the user facilities are shown in Figure 2. And irradiation conditions of 10 target rooms, optimized to the specific application fields, are summarized in Table 2 [1].

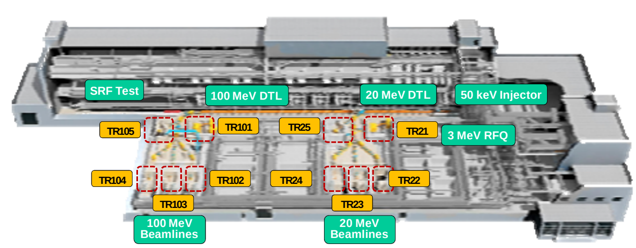

Figure 2: Layout of the Accelerator and User facilities.

Table 2: Specifications of the User Facilities

(a) 20-MeV User facilities

Beam Line	Application Field	Rep. Rate	Avg. Current	Irradiation Condition
TR21	Semiconductor	60Hz	0.6mA	Hor. Ext. 300mmØ
TR22	Bio-Medical Application	15Hz	60μA	Hor. Ext. 300mmØ
TR23	Materials, Energy & Environment	30Hz	0.6mA	Hor. Ext. 300mmØ
TR24	Basic Science	15Hz	60μA	Hor. Ext. 100mmØ
TR25	Radio Isotopes	60Hz	1.2mA	Hor. Vac. 100mmØ

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(b) 100-MeV User facilities

Beam Line	Application Field	Rep. Rate	Avg. Current	Irradiation Condition
TR101	Radio Isotopes	60Hz	0.6mA	Hor. Ext. 100mmØ
TR102	Medical Research (Proton therapy)	7.5Hz	10μA	Hor. Ext. 300mmØ
TR103	Materials, Energy & Environment	15Hz	0.3mA	Hor. Ext. 300mmØ
TR104	Basic Science Aero-Space tech.	7.5Hz	10μA	Hor. Ext. 100mmØ
TR105	Neutron Source Irradiation Test	60Hz	1.6mA	Hor. Vac. 100mmØ

BEAM UTILIZATION

Every target rooms are assigned to specific application fields as mentioned above. The irradiation systems should be designed to meet the requirements of the users from prospective applications fields. In this section, we will show and explain the representative examples of the expected application fields for each target rooms.

Semiconductor (TR21)

Protons can make large number of defects inside the semiconductor passing through it, lose their energies by the interactions with atoms, and finally be stopped in specific range depending on their energies. Using these characteristics, we can improve the properties of power semiconductor devices, such as FRD (Fast Recovery Diode), IGBT (Insulated Gate Bipolar Transistor), BJT (Bipolar Junction Transistor), etc. The defects made inside the semiconductor by proton beam play roles of recombination centers, reduce the minority carrier lifetime, and contribute to the improvement of the speed and power consumption properties as shown in Figure 3. The reverse recovery time, minority carrier lifetime was reduced to 1/35 by proton beam irradiation compared to original one [2-4].

(a) (b) (c)

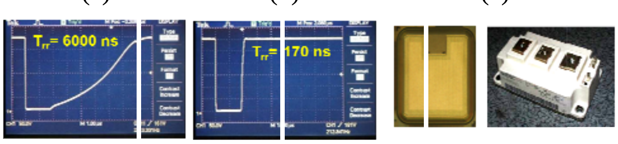


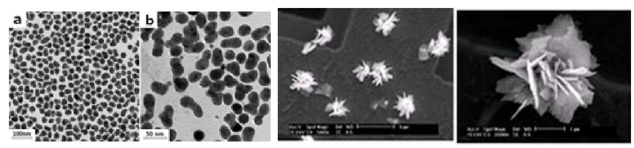
Figure 3: Reverse recovery time (a) without proton beam irradiation (b) with proton beam irradiation of (c) a 600-V and 5-A IGBT.

By using proton beam, we can fabricate SOI (Silicon On Insulator) or GOI (GaAs On Insulator) wafers and thin layer of compound semiconductor in the range from several tens-nm- to several μm-thickness. The thickness of the thin layer can be simply controlled by changing incident proton energy. Proton atoms stopped in a specific depth of semiconductor wafer, will be changed to the hydrogen gas bubble by heat treatment following the proton beam irradiation process. By using low energy proton beam less than 20 MeV, can be utilized for micro-machining of the semiconductor and TLA (Thin Layer Activation).

For these kinds of applications, irradiation area should be larger than 6”. For mass production and high economics, the higher flux is the better considering total dose range is 1E+15~5E+17/cm^2.

Materials, and Nano Sciecnes (TR23 & TR103)

Metal nano particles, silver, gold, and platinum, can be synthesized by using proton beam irradiation instead of the chemical process. These metal nano particles can be utilized as catalyst materials for fuel cell and as pharmaceuticals for medical applications. The silver nano particles synthesized with different conditions are shown in Figure 4 [5-6]. The size and shape of the nano particles are dependent on the irradiation conditions and composition ratio of the silver aqueous solutions.



(a) (b)

Figure 4: Silver Nano Particle Synthesized by Proton Beam Irradiation; (a) Continuous Beam, (b) Pulsed beam.

Aero-Space Applications and Nuclear Physics (TR104)

Increasing the interest on the space radiation, the necessity of space radiation simulation facility also has been increased accordingly. The NASA has been operating the Space Radiation Laboratory at the BNL and many institutes have their own facilities to test the device and materials for space applications. Recently the interests are extended to the biological effects on the human and animals, test facility for space application became essential one to promote the R&D of the satellite and space technologies. These facilities can be utilized for nuclear physics, performance test and calibration of the radiation detectors.

The Figure 5 shows that test results of the control board for the satellite developed by the private company and to be exported to abroad.

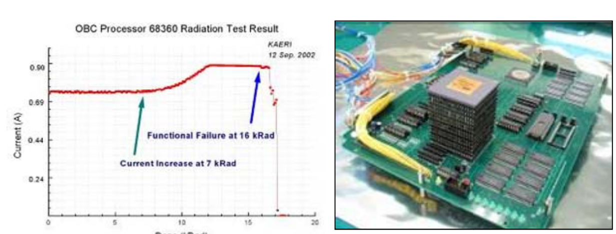


Figure 5: (a) Radiation Test Results of (b) OBC Processor.

Bio- & Medical Sciences (TR22 & TR102)

The photon, X-ray and gamma-ray, have been to be used for the development of valuable new genetic resources, plants, vegetables, flowers, micro-organism, and animal, for a long time. Proton became another effective tool for these application because of the higher LET value compared to photon.

For the medical applications, radio-biological effects on the animal and human cell is highly be interested to identify the mechanism of proton therapy. Figure 6 shows that proton beam inhibits the development of the trunk of zebrafish [7]. The TR102 is assigned to these kinds of experiments. New radiation therapy techniques, for example, PIRT (Proton Induced radiation Therapy) can be studied using these facilities.

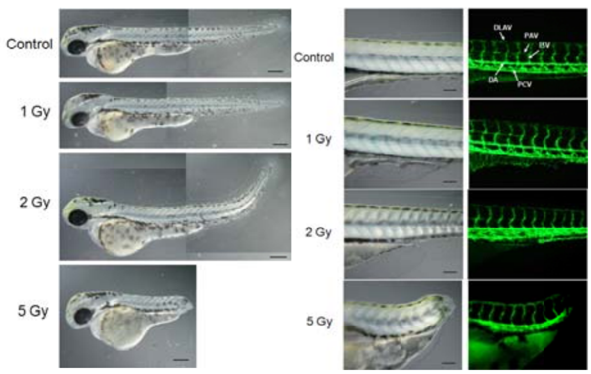


Figure 6: Development of the Trunk of the Zebrafish According to the Irradiation Doses.

RI Production (TR25 & TR101)

New RIs could not be produced by existing domestic proton accelerators can be produced by using PEFP 100-MeV proton linac. Sr-82, Cu-67, and Ge-68 are very attractive RIs and the need of Sr-82 was increased rapidly during last 2-3 years. Sr-82 can be used for the diagnostics of cardiac decease using PET instead of Tc-99m using SPECT.

Low Energy Neutron Source (TR105)

We have made a plan to develop a LENS (Low Energy Neutron Source) to study the physics concerned with key components, target, reflector, and moderator, to promote the R&D of neutron beam applications, and to cultivate the potential users. Thermal and fast neutron can be provided by using this facility and the energy of the fast neutron will be controlled by the discrete proton energy incident to the target.

USER PROGRAM

As a result of the last 8-year operation of the user program, the potential users for proton beam were increased to 736 from 131 institutes and samples more than 1,500 are irradiated ever year by using 20-MeV linac and available domestic facilities. The statistics of users and irradiated samples are shown in Figure 7 and Figure 8.

The distribution of users according to application fields are displayed in Figure 9. Users from nano-, medical-, bio-technologies, and nuclear physics occupied more than 50% of total number of users.

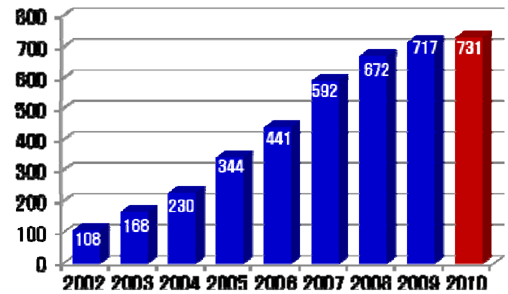


Figure 7: Integrated Number of Users.

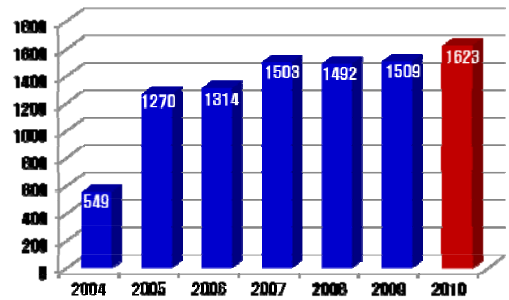


Figure 8: Annual Number of Irradiated Samples.

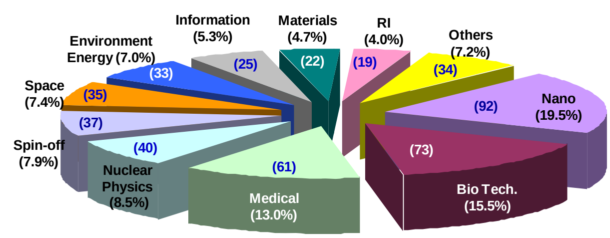


Figure 9: Distributions of Users According to Application Fields.

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