LOW- INTENSITY PULSED BEAM GENERATION SYSTEM USING THE OPU LINAC

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Abstract

Ultra low intensity electron beam irradiation system have been developed by the use of the electron linear accelerator at Radiation Research Center of Osaka Prefecture University (OPU Linac). The energy and the pulse width of the beams are about 4-12MeV and 0.5-4μs, respectively. The minimum beam charge obtained was estimated to be about several aC/pulse. The lower limit was determined mainly by dark current of the accelerator emitted probably from near the electron gun.

INTRODUCTION

A beam pulse of an ordinary electron linear accelerator is composed of about 10^{13}electrons. The irradiation effects by such huge radiation are considered to be macroscopic and statistical. In some cases of delicate experiments, the radiation is too intensive, e.g. for energy spectroscopy, transient analysis and single event study. We have attempted to develop an ultra low intensity electron beam system for these investigations by modifying an electron linear accelerator. The minimum beam charge has been achieved to be about several aC/pulse for the present. The final aim of this attempt has not been achieved yet which is a generation of single electron pulsed beam.

These electrons generated from a linac are basically mono energetic, controllable, collimated and synchronized with the time base of the accelerator, which are more favourable features compared with these of β-ray sources. The low intensity electron beam, therefore, are considered to be suitable for the evaluation of response of radiation detectors[1], study on single event phenomenon of semiconductor devices and biological objects. In the following sections of this paper, the generation systems of the ultra low intensity electron beam developed are introduced, and the investigation on the dark current of the accelerator which was harmful for the system are also described.

BEAM MODULATION

In the ordinary operation of an accelerator, any technical difficulty does not put on the weakening beam current. However, the weakening to about ten orders of magnitude smaller compared with the original beam is considered to be difficult in technical. Additionally, the measurement of such weak beam pulse is also difficult[2]. In this study, the following modulation methods were used for generation of the ultra low intensity beam.

A) Weakening the electron gun: The cathode emission can be reduced by decrease of cathode temperature. The method is very effective, however, the dark current of an accelerator becomes to be problem for the ultra low intensity beam system.
B) Shortening the grid pulse of the electron gun: This is a popular method for beam modulation. However, under the influence of the grid emission, the attenuation factor is not so much.
C) Shortening the RF pulse: The acceleration period is shortened by this operation. Degradation of energy spectrum is apprehensive in the case of extremely short RF pulse.
D) Beam attenuation by using a narrow slit: The attenuation factor is restricted by the spatial limits. In the case that the gap of the slit is extremely narrow, the component of the shallow scattered electrons on the slit surface increased in the beam extracted and degrades the quality of the beam.

We used mainly the method A. However, only by the use of this method, the limit of the beam weakening was about several fC/pulse. It was considered to be caused by dark current of the accelerator. In this study, the energy spectrum and the pulse shape of the dark pulse were also measured, and the origin of the dark current was investigated.

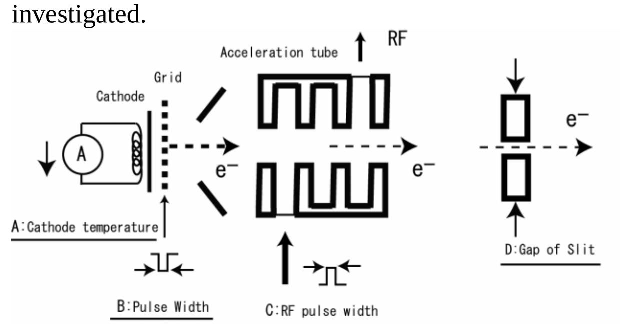

Figure 1: Modulation methods for beam weakening.

EXPERIMENT

Figure 2 shows an experimental layout for the ultra low intensity electron beam extraction. The water cooled slit was set in the middle of the beam line and interrupted the beam. The attenuation factor of the slit was measured in the case of the normal current beam and estimated about 1/350. The pre- adjustment of the beam was performed under the condition that the electron beam was bent downward at a point upstream from the slit. The accelerator parameter was modified to obtain the stable beam with intended energy. Next, the beam was weakened by temperature control of the cathode of the electron gun. The beam charge was adjusted to the intended value. After verifying the stability of the beam, the beam was returned to straight line. The beam weakened flew to the target distant about 10 m from the slit.

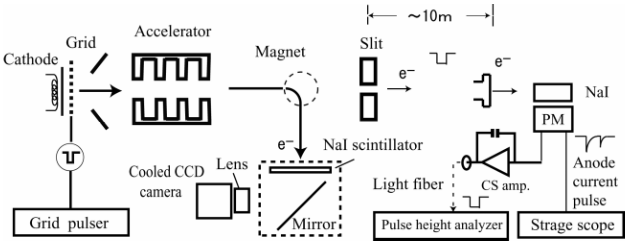

Figure 2: Layout of ultra low intensity beam experiments.

Beam Profile Monitor

A two- dimensional beam profile monitor for the ultra low current beam was developed by the use of a high sensitivity radiation imaging system. The schematic diagram of this system is shown in the middle of Fig.2. The system consists of a cooled CCD camera and a NaI(Tl) scintillator (1mm x 50mm ∅), and set in the dark box. The system was capable of on- line beam profile monitoring for ultra low intensity beam. Fig.3 shows the images obtained by the beam profile monitor. The profiles for Fig.3(a) ,(b), (c) were obtained by single pulse irradiation. Only for the weakest beam (Fig.(d), 3.3fC) could not obtained clear image for single pulse, and the image was obtained by image accumulation of 300 pulses. The charge distribution of the 3.3fC beam (Fig.3(d)), seen as the slight elliptic 5mm∅beam, is almost the same with that of 11pC beam.

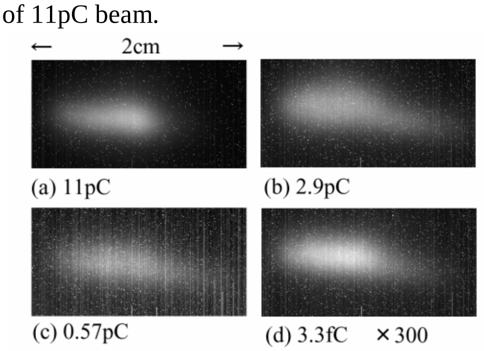

Figure 3: Beam profiles obtained by the cooled CCD system.

Ultra Low Intensity Beam

Next, the beam was weakened further by shortening the RF pulse and detected by the NaI(Tl) scintillator (2inch x 2inch ∅). The results are shown in Fig.4. The pulse height distribution moved to lower side (left side) by shortening the RF pulse width. Finally, the distribution was settled as shown in Fig.4(b). The distribution shown in Fig.4(a) was considered a complex spectrum piled up by many responses of the electrons. The fluctuation of the pulse height is mainly caused by the fluctuation of the number of electron detected. On the assumption that the fluctuation is obeyed by a Poisson distribution, the right peak was estimated to be composed by about 40 electrons and the left peak was by about 16 electron responses. The latter value was equivalent to the charge value of 2.5aC. The spectrum in Fig.4(b) was considered to be composed by single electron pulse, which was different from our expectation. The spectrum of electron beam had to be mono energetic basically, while the spectrum measured was shaped exponential distribution. The cause of this discrepancy has been under investigation now. We roughly supposed that was caused by dark current of the accelerator and incomplete acceleration due to the extremely shortened RF pulse.

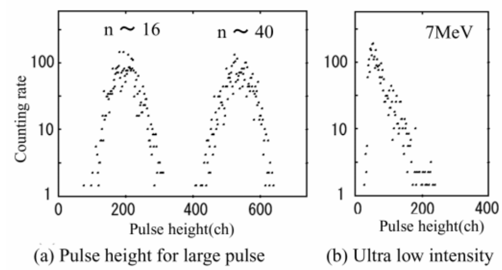

Figure 4: Pulse height distribution of NaI(Tl)scintillator for low intensity electron beam.

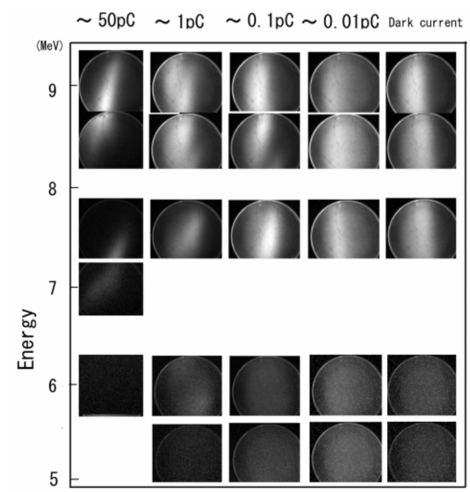

Figure 5: Brightness distribution of low intensity beam profile corresponding to the energy spectrum.

Energy Spectrum

The CCD beam profile monitor developed was capable of measuring low intensity beam under fC/pulse by the condition that the measuring time was long enough. By the use of this monitor, the energy spectrum of the ultra low intensity electron beam was measured. Figure 5 shows the results. These images were obtained with the condition that the current of the analyzing magnet was changing respectively. The vertical axis of the figure indicates the energy and the vertical distribution of the brightness is considered to correspond to the energy spectrum of beams. The figure also shows changes of the energy spectrum accompanied with weakening the beam.

The spectrum for the beam lower than 0.01 pC/pulse seems to be broad compared with that of 50 pC/pulse. The former spectrum was almost the same as the dark current spectrum.

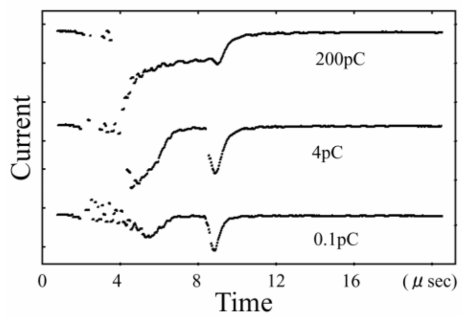

Figure 6: Change of pulse shape by changing the beam intensity

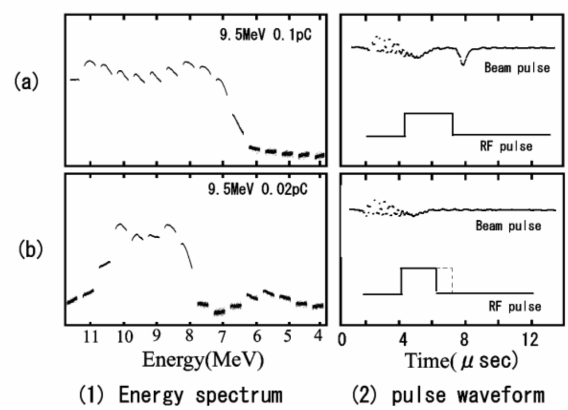

Figure 7: Change of pulse shape and the energy spectrum by changing the pulse width of RF pulse.

(a) Before shortening of RF pulse
(b) After shortening of RF pulse

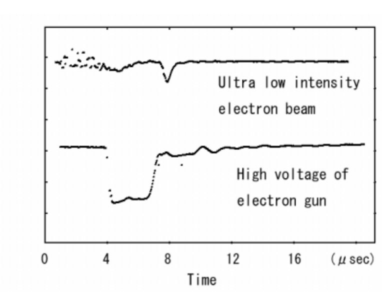

Figure 8: Pulse shape of ultra low intensity electron beam and the high voltage of the electron gun.

Pulse Shape Measurement

The pulse shape of the low intensity beam was measured by the use of the NaI(Tl) scintillator (2inch x 2inch ∅). The low intensity beam pulse injected directly to the NaI scintillator and the pulse shape of the anode current pulse of the photo-multiplier was measured by a storage scope. Figure 6 shows results. The pulse shape was observed to split into two pulses in the case of ultra low intensity. The pulse height of later pulse did not change by the temperature control of the cathode while the former pulse changed.

Dark Current

Next, the beam was weakened further by shortening the RF pulse width. Figure 7 (a) shows the energy spectrum and pulse shape of the original beam. On the other side, Figure 7 (b) shows the results of the beam weakened, where the later pulse of the double pulse disappeared. The energy spectrum of the ultra low intensity was broad extremely (Fig. 7(a1)). Unexpectedly, the energy spectrum of the beam weakened by RF pulse shortening was improved (Fig. 7(b1)). This fact indicates that the energy spectrum of the later pulse was broad. Simultaneously, the later pulse of the double pulse was considered to be a main part of dark current of the electron linac.

The fact that the dark current pulse could be eliminated by shortening RF pulse indicates that the RF pulse was not the cause of the dark current. In the other words, the dark current was not emitted from the upstream region of acceleration cavity by the RF field emission. The region of the electron gun was most probable for the generation area of the dark current. In the OPU linac, the pulsed high voltage has been applied on the electron gun. Figure 7 shows the pulse shape. The dark current pulse started at the end point of the extraction pulse. The dark current may be considered to be emitted from the tip of the anode electrode of the gun by the field emission in the condition of transiently applying reverse voltage. However, any traces of over shooting wave form did not appear in Fig.7. On the whole, the origin of the dark current is unknown until now.

CONCLUDING REMARKS

Ultra low intensity electron beam system has been developed by the use of an electron linac. The minimum charge has been about several aC/pulse. The dark current of the accelerator determined the lower limit. The detailed mechanism of the dark current is not yet known. The generation point is considered probably near the electron gun. On the whole, the major response of dark current could be reduced by the pulse width control of RF pulse.

REFERENCES

[1] R.Taniguchi et.al. “Response Evaluation of Radiation Detectors by Using Ultra Low Intensity Electron Beam”, Proc. of 20th workshop on radiation detectors, KEK, Japan (2006) in press.

[2] S.Okuda et.al. “Low Intensity Electron Beam Monitoring and Beam Application at OPU Linac” contribution to this conference.