PIN Photo-diodes as Radiation Detectors in Accelerator Applications.

L. Mondragón–Contreras[1, 2], F.J. Ramírez-Jiménez[1], E.F. Aguilera-Reyes[1], C.E. Ojeda-Nava[3]

[1] Instituto Nacional de Investigaciones Nucleares, ININ, México
[2] Instituto Tecnológico de Toluca, México
[3] Universidad Autónoma del Estado de México

Email contact of main author: luis.mondragon@inin.gob.mx

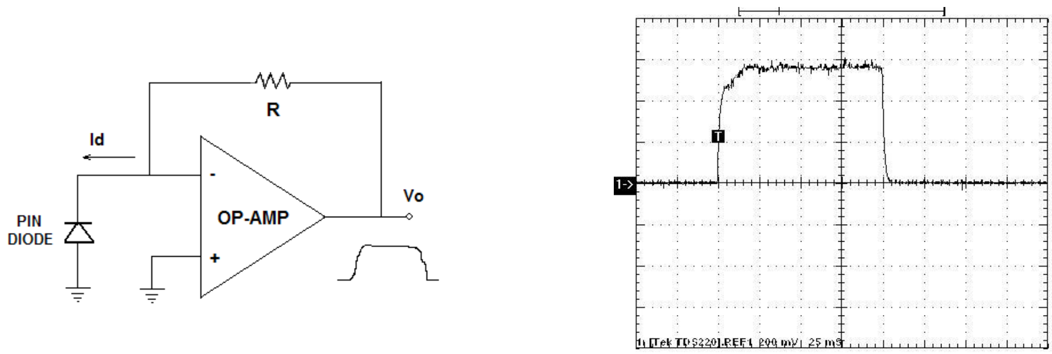
ABSTRACT. We have been using PIN photo-diodes originally suited for light detection as radiation detectors in several applications: photon monitoring in X-ray machines in industrial and medical applications, X-ray spectroscopy for identification of radioactive materials and XRF, and charged particle spectroscopy. The versatility of these devices as radiation detectors has led us to apply it in several accelerator experiments. This work presents an overview of the results obtained in several experiments: the measurement of charged particles up to 12 MeV in a Tandem accelerator, the measurement of the Bremstralung radiation obtained in an experimental electron accelerator in the range from 70 keV to 470 keV, the direct measurement of the intensity of the electron beam; also the application of PIN photo-diodes in the measurement of the intensity of photons in lineal accelerators used in radiotherapy up to 18 MeV. The front end conditioning electronics associated with the detectors is also described for every application: low noise charge sensitive preamplifiers and current amplifiers are used. The PIN diodes are a good choice for radiation detection in several accelerator applications with the advantage of a good position resolution due to its small size, good sensitivity for different radiation fields and low cost, and can be used to build a wide variety of detection systems around accelerator experiments.

1. Introduction

PIN photo-diodes are specially designed for light detection in the range from infrared to ultraviolet, however this kind of diodes have been used as radiation detectors with success in many applications in physics research [1], we have been using low cost selected devices in applications such as: photon monitoring in X-ray machines in industrial and medical applications [2], X-ray spectroscopy for identification of radioactive materials and XRF [3], and charged particle spectroscopy [4]. The PIN photo-diode used in all the reported experiments is an OPTEK OPF420, its active area is 1 mm^2 and its thickness is around 150 μm.

In the condition where the X-ray field from an X-ray machine is strong, the PIN diode can be used in photovoltaic mode as radiation detector, as shown in FIG. 1.a), in this condition, the PIN diode response to the X-rays is directly proportional to its intensity, considering that the X-ray intensity is defined as: $I_x = \frac{N_p\, E_p}{A}$, where: N_p is the number of photons per second (s^{-1}), E_p is the photon energy (keV) and A is the considered area. The electric current Id, generated in the diode due to the X-ray interaction with its detection volume, is related with the X-ray intensity. The kind of response obtained, Vo, is shown in FIG. 1.b), this signal has the information of the exposure time set in the machine and the intensity of the X-rays, the settings used in the X-ray machine in this example were: 50 kV and 100 mA-s.

X-ray spectroscopy can be made with PIN photo-diodes, in this application the diode is reverse biased to get the maximum depletion volume, a charge sensitive preamplifier must be employed [5], see FIG. 2.a). The size of the fast charge pulses generated in the detector, Qi, is proportional to the energy of the X-rays. Si-Li detectors are normally used to get the best results in X-ray analysis due to its good energy resolution, typically 180 eV, and good efficiency in the energy range from 1 kev to 100 keV, nevertheless there are special PIN diodes, commercially available and suitable for X-ray detection, these detectors have some nice advantages over the Si-Li detectors mainly regarding the size and compactness, also they have the advantage that no liquid nitrogen is required for its operation.



a) *b)*

FIG. 1. a) PIN diode in photovoltaic mode connected to a current amplifier. b) Voltage signal obtained at the output of the current amplifier for an X-ray beam from a high frequency X-ray machine, the settings in the oscilloscope are: 200 mV/div and 25ms/div.

FIG. 2.b) shows a comparison of the spectra obtained with a PIN diode and a Si-Li detector in a multichannel analyzer for an Am-241 X-ray source. Of course the best resolution of the Si-Li detector is shown, but also the great accuracy in the position of the peaks for the PIN diode spectrum is noticed.

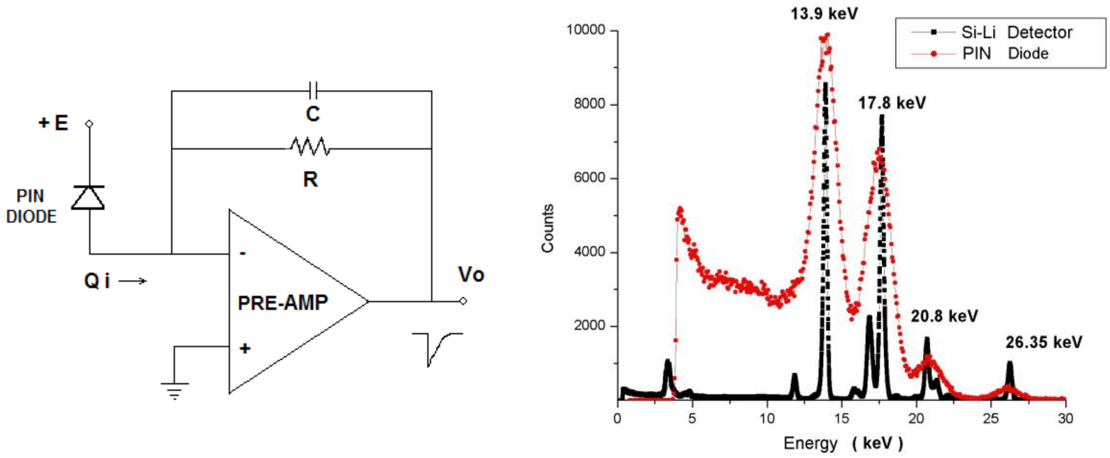


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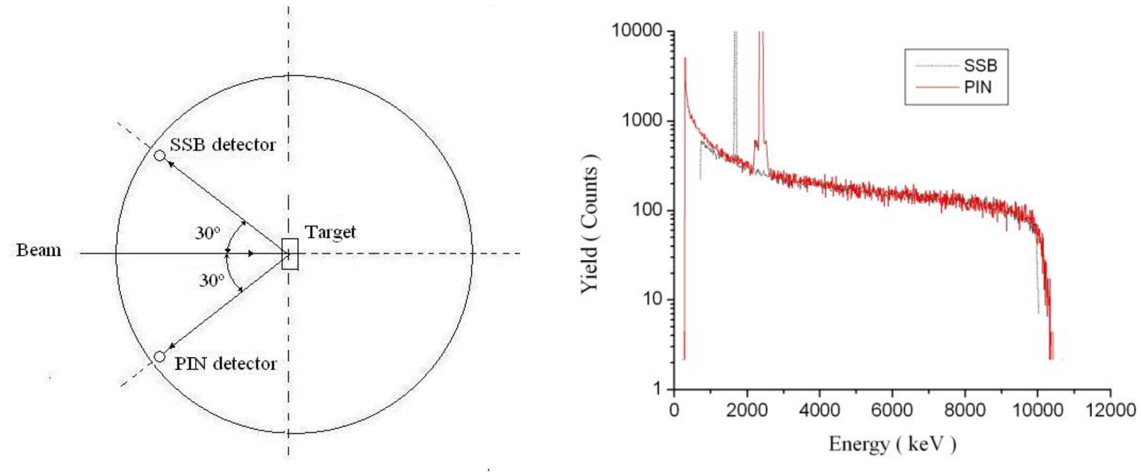
FIG. 2. a) PIN diode biased and connected to a charge sensitive preamplifier. b) Comparison of the spectra obtained with a PIN diode and a Si-Li detector for an Am-241 X-ray source.

The versatility of low cost PIN photo-diodes as radiation detectors has led us to apply it in several experiments around particle accelerator. In the next paragraphs, we present an overview of the results obtained in several experiments: the measurement of charged particles up to 12 MeV in a Tandem accelerator, the measurement of the Bremstralung radiation obtained in an experimental electron accelerator in the range from 70 keV to 470 keV, the direct measurement of the intensity of an electron beam; also the application of PIN photo-diodes in the measurement of the intensity of photons in lineal accelerators, LINAC, used in radiotherapy up to 18 MeV.

2. Detection of Charged Particles in a Tandem Accelerator

PIN photo-diodes were used in several Rutherford backscattering, RBS, experiments realized in a Tandem accelerator, in fact, its behaviour as charged particle detectors was compared with the results obtained at the same time with a Silicon Surface Barrier detector, SSB. For this application, the glass window was removed from the PIN photo-diode detector to permit the direct interaction of the particles with the sensitive area. A charge sensitive preamplifier similar to the one shown in FIG. 2.a) was used. The set-up of the experiment is shown in FIG. 3.a), the beam was obtained from a Tandem accelerator with an accelerating voltage of 12 MV. A ^{12}C beam hits a Ta target and backscattered particles are detected by a SSB detector and a PIN photo-diode, both detectors are placed symmetrically at the same angle. FIG. 3. b) shows the RBS spectra, after correction by solid angle considerations. Both spectra agree with the simulated values. The peaks in the low energy region correspond to test signals applied to the respective preamplifiers that are used as reference.



a) *b)*

FIG. 3. a) Set-up used in the RBS experiment. b) RBS spectra obtained with the PIN diode and a SSB detector.

The importance of these results is that the test provides information of the detection capability of both detectors in all the energy range, from low energies up to the maximum energy applied, as shown in FIG. 3.b).

3. Detection of Bremstralung Radiation in an Electron Accelerator

The experimental Pelletron electron accelerator built at ININ provides electron beams of several μA´s and energies from 70 keV to 1 MeV, bremstralung radiation is also produced.
An X-ray monitor made by using the configuration of FIG. 1.a) was used in this experiment. The X-ray monitor is placed in front of the accelerator beam as shows in FIG. 4; the distance from the electron beam output to the detector is 5.5 cm. There is a Ti window and an aluminum plate at 3.8 mm whose purpose is to stop the pass of electrons to the monitor; this

plate can be removed at will depending of the kind of radiation that wants to be measured. The preamplifier output is connected to a 4 digits digital voltmeter to get the reading of the X-ray monitor.

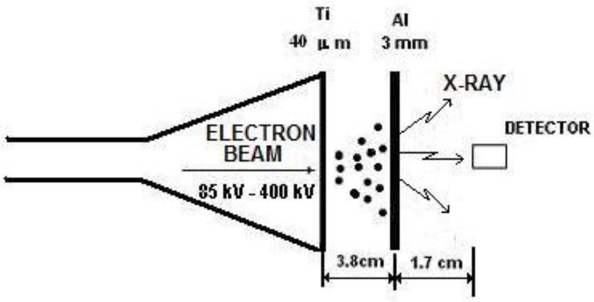
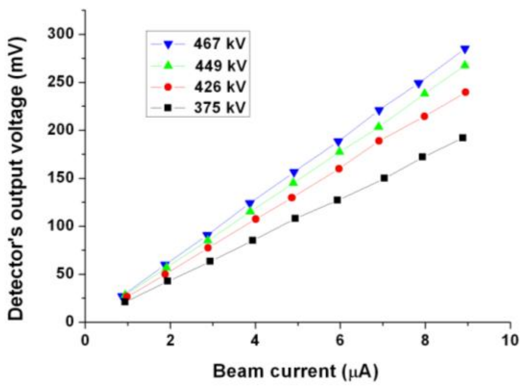
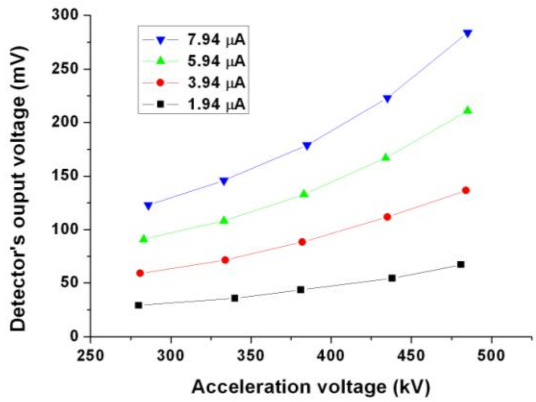


FIG. 4. Set up used in the measurement of electrons and bremstralung radiation with a PIN photo-diode detector.

The response of the X-ray monitor to different conditions is shown in FIG. 5, the aluminum plate was placed to prevent that electrons could reach the detector. Fig. 5.a) shows the linear dependence of this response with the beam current in the range from 1 µA to 9 µA, the acceleration voltage was varied from 375 kV to 467 kV.





a) b)

FIG. 5. a) Response of the X-ray monitor with respect to the beam current. b) Response of the monitor with respect to the accelerating voltage.

Fig. 5.b) shows the non linear dependence with the accelerating voltage in the range from 270 kV to 480 kV. In this experiment we are studying the dose rate of bremstralung radiation present in several conditions around the accelerator.

3.1. Monitoring the Intensity of the Electron Beam

If we remove the aluminum plate shown in the FIG. 4, the electrons will reach the detector, and direct measurement of the intensity of the electron could be determined in the monitor. FIG. 6 shows the signal generated during an irradiation at 300 kV and an electron beam of 2 µA. The beam was on during 20 s, then interrupted 18 s and started again, an intentional reduction in the beam current is shown at the end of the irradiation. A determination of the electron beam stability can be done with the monitor.

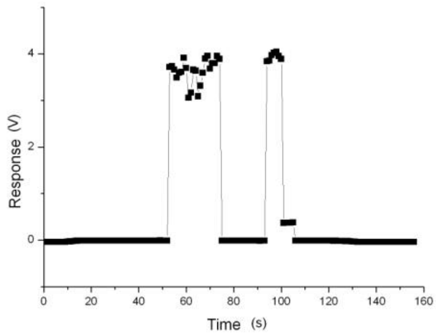
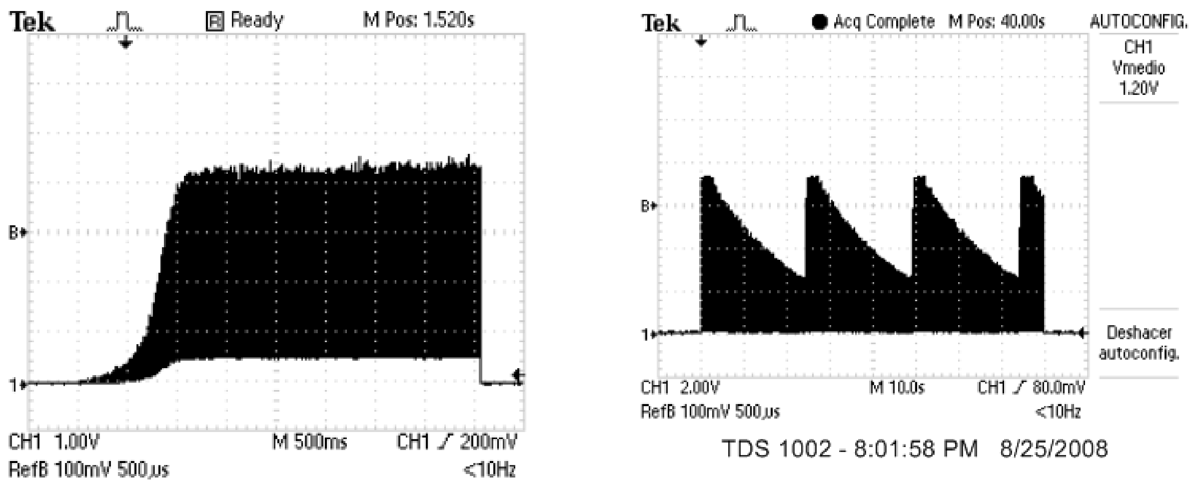


FIG. 6. Output signal of the PIN diode monitor for electrons.

4. Monitoring the Intensity of Photons in Lineal Accelerators

A monitor made by using a configuration similar to the one sown in FIG. 1.a) was used to detect the intensity of photon radiation in LINAC used in hospitals for radiotherapy [6] for energies from 6 MeV to 18 MeV. The monitor is placed in front of the accelerator beam at a distance of 100 cm from the focal point in a field of 10 cm×10 cm. FIG. 7.a) shows the signal obtained at the output of the monitor as seen in an oscilloscope after an irradiation in an Elekta 51-02 LINAC. FIG. 7.b) shows the signal obtained when a Varian LINAC was used.



a) *b)*

Fig. 7.- Signals obtained at the output of the monitor. a) For an Elekta 51-02 LINAC with an energy of 6 MeV, dose of 20 MU. The settings of the oscilloscope were: Vertical scale = 1 V/div, Horizontal scale = 500 ms/div, trigger= single shot .b) For a Varian LINAC with an energy of 6 MeV, dose of 400 MU, the settings are: 2 V/div, 10 s/div.

The PIN photo-diode monitor provides information about the energy conversion method employed in the LINAC, as seen in FIG:7 and could be used for example in the detection of any transient failure in the operation of the LINACs. At the moment we are using it in studies to evaluate the delivered dose rate under different conditions.

5. Conclusions

PIN photo-diodes are a good choice for radiation detection in several accelerator applications with the advantage of a good position resolution due to its small size, good sensitivity for different radiation fields and low cost. As shown in this paper, PIN diodes can be used as basis to build a wide variety of detection systems around accelerator experiments both in spectroscopy as in monitoring applications.

6. References

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