Traditional versus PIN Diode Geiger Counter

Bernd Laquai 4.9.2012

The traditional Geiger counter

Traditionally a Geiger counter was a detector for weak ionizing radiation containing a so-called Geiger-Muller tube. This tube was invented by the German physicist Hans Geiger together with his PhD student Walther Muller in 1928. The tube is a special variant of a gas ionization chamber.

Radioactivity causes a nuclear radiation that is able to ionize gas atoms or in other words it causes the separation of atoms into positively charged ions and negatively charged electrons. These charged particles are much easier to detect than the nuclear radiation itself. The detection of electrically charged particles is achieved when they are accelerated in opposite directions in an electrical field and then are captured with electrodes while measuring the resulting current in the electrodes used for generating the electrical field.

Geiger and Muller used a very thin conducting wire in their detector tube. Due to the small circumference of the wire the electrical field strength becomes very high and accelerates the charged carriers massively as they approach the wire such that they are able to cause a further ionization when they collide with further atoms in the vicinity of the wire. This causes an avalanche of charged carriers (collision ionization) which in turn yields a strong current impulse (spike), which when amplified causes a click in a loudspeaker. To have a Geiger-Muller tube working correctly an electrical voltage of a few 100Volts is required to produce the appropriate electrical field. This however is sufficient to easily detect even the radiation of naturally radioactive substances.

Geiger Counters on the basis of semiconductors

In general today, instruments that detect nuclear radiation based on ionization are called Geiger counters mostly when they also are able to produce the characteristic clicking noise from individually disintegrating atoms in a loudspeaker even when they are not based on a real Geiger Muller tubes. In the modern radiation measurement technology it is often the fact that the current spike causing the click does not reflect the energy emitted during a single disintegration due to the uncontrolled avalanche effect. Therefore other methods are preferred for quantified measurements of radiation.

On this webpage a semiconductor detector is preferred because it does not require the dangerous high voltage necessary for the electrical field to achieve ionization. This is considered to be an advantage particularly for educational experiments with students.

Indeed it is a general property of a semiconductor that absorbed radiation causes the ionization of the crystal atoms even at very low voltages of a few volts. The effect of the ionization is similar as in a gas ionization chamber and can be detected as a current flow. This is effect was productized in a large scale in photovoltaic modules for solar radiation. The energy of radiation from naturally radioactive material however is much smaller, such that the induced current flow needs to be amplified massively to detect it. Whereas the current flow induced by direct solar irradiation on a solar module is in the range of Amperes, the disintegration of Uranium atoms in naturally appearing minerals causes short current spikes in the Nano-Ampere range only.

There are also semiconductor sensors that multiply the ionized carriers of an incoming radiation quantum (avalanche photo detector, APD) much like the Geiger-Muller tube. However, these detectors are expensive and difficult to control. In contrary, good and cheap low-noise amplifiers are available today that can amplify Pico- and Nano amperes sufficiently to detect them with a sufficient signal to noise ratio. These amplifiers are the key for the do-it-yourself construction of a Geiger counter using a low cost standard photo diode.

PIN-Diode Counter

Everybody who attended school should know the photoelectric effect. Radiation from visible or invisible sources is able to break out electrons from specific materials that can be detected as a current. The resulting electrical energy of the emitted electrons is equivalent to the energy of the radiation quants reduced by the material’s specific electron binding energy. A silicon photo or solar cell uses exactly this phenomenon. In the PN-junction of a silicon photo cell charge carriers (electrons and holes) are generated in a similar way as soon as the incident radiation quants reach a certain minimum energy (when it is used for generation of electrical energy it is called the photovoltaic effect).

In order to make a photo cell used for signal processing (in contrast to a solar cell) extremely sensitive to very weak radiation of low frequency a further undoped zone (a so-called intrinsically conductive I-zone) is added to the PN-diode to obtain a PIN-diode. Such a photo detector is therefore called a PIN-photo detector. These kinds of photo detectors are used in large amounts for optical fiber data transmission for the telephone network and for the Internet on transoceanic and terrestrial long haul connections. At the receiver side of such connections the arriving laser radiation is very weak too.

When a voltage is applied in reverse direction to such a PIN diode, space charge region which is free of carriers widens up strongly across the I-zone and as soon as a radiation quantum strikes this region a pair of carriers (electron and hole) is generated ionizing the affected atom of the crystal. The current pulse from the generated charge carrier pair is only a few Nano amperes. For silicon this ionization is only possible for wavelength below about 1100nm (minimum energy related to the electron binding energy). The wavelength corresponding to the energies of nuclear radiation are much shorter, therefore a PIN photo detector is always able to detect radioactivity.

On the other hand specific materials, primarily plastics, shield the nuclear radiation quite well. Therefore the material used as transparent window in the housing of a photo detector is crucial to its sensitivity. As an example highly energetic alpha radiation is shielded already completely by a thin plastic foil. Therefore a PIN detector embedded in a plastic housing does not detect alpha radiation in a meaningful way.

However, since radioactive disintegration happens always in decay chains, the alpha decay of a parent nucleus generates a daughter nucleus that disintegrates further again in its own way and may emit beta or gamma radiation even when the parent decay is a pure alpha emitter. Therefore a beta and gamma sensitive PIN detector in a plastic housing is still a good detector for radioactivity even when quantitative information on alpha radiation can't be obtained directly.

As a conclusion, even though the PIN detector counters presented on this webpage are easy to be constructed with do-it-yourself methods, they are only suitable for qualitative detection not for measurement in the sense of exact radiation measurement techniques. Therefore the presented counters are rather detectors not measurement instruments.