AL-MUSTAQBAL UNIVERSITY

COLLEGE OF SCIENCE

MEDICAL PHYSICS DEPARTMENT

FOURTH STAGE

Detection of Ionizing Radiation

Lecture Seven: Semiconductor Detectors

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Semiconductor Ionizing-Radiation Detectors

Functioning of these radiation detectors is based upon the newest technologies. The impact on radiation detection and measurement has been revolutionary because of unique semiconductor properties, especially outstanding energy resolution. New semiconductor detectors continue to be introduced into the market place.

1. Germanium Semiconductor Detectors

There are two main types of germanium semiconductor detectors: Ge(Li) germanium crystal doped with lithium ions to cancel the effect of natural impurities in the germanium crystal, and the more recent (HPGe) high purity germanium crystal in which impurity atom concentration are less than 10^{10} atom/cm^3. The more expensive HPGe detectors have replaced the older Ge(Li) technology since they can kept at room temperature when not in use whereas Ge(Li) crystals must always be kept at liquid nitrogen temperatures (-196 ^{o}C).

Germanium detectors, besides having exceptional energy resolution, are very efficient for detecting photons. Their efficiency ranges from excellent for low energy x-rays too good for medium to high-energy gamma rays over an energy range of 1 keV to 10 MeV. The performance of these detectors is often compared to NaI (Tl) and Cd/Zn telluride (CZT) detectors. Because of the higher atomic number arid larger size, NaI (Tl) detectors often have a higher efficiency for high energy gamma rays than do germanium detectors, but a much poorer energy resolution. The dramatic difference in the energy resolution between NaI (Tl) and Ge (Li) spectrometers is shown in Fig. (4).

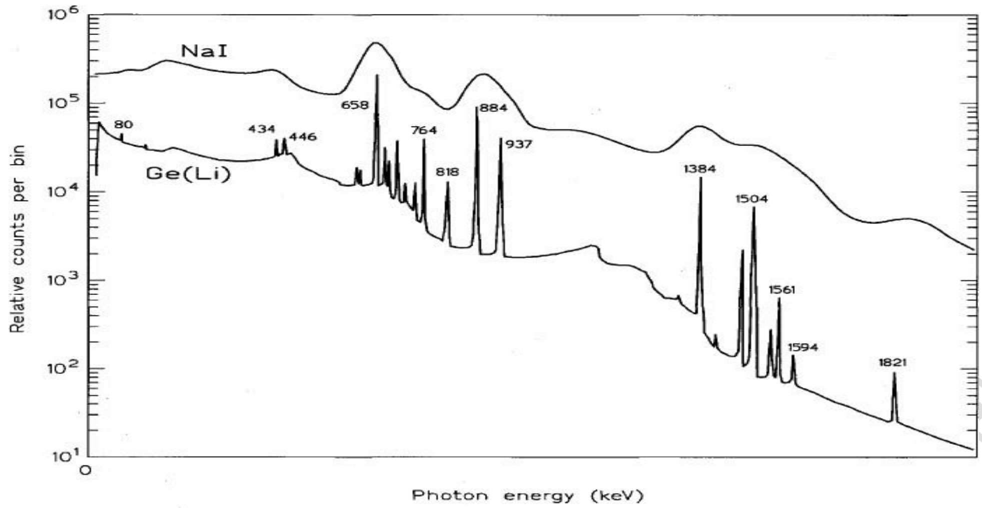

Figure (4) Comparison of the energy resolution of Ge (Li) and NaI (Tl) detectors. The gamma-ray source is a mixture of ^{108m}Ag and ^{110m}Ag

2. Silicon Semiconductor Detectors

Si (Li) detectors with thin entrance windows are commonly used in alpha and beta particle spectrometers. They can be configured to achieve essentially 100% intrinsic efficiency and have excellent resolution. They also offer an inexpensive option for x-ray spectroscopy. Since Si (Li) detectors have a much lower atomic number than CZT. NaI (Tl), and HPGe, their relative efficiency per unit thickness is significantly lower for electromagnetic radiation. However, for x-ray or gamma ray energies less than about 30 keV, commercially available Si (Li) detectors are thick enough to provide performance which is superior to CZT, NaI (Tl), and HPGe. For example, a 3 to 5 mm-thick detector with a thin entrance window has an efficiency of 100% near 10 keV. Based upon the fact that a majority of the applications require a thin window, Si (Li) detectors are often manufactured with very thin beryllium windows.

3. Cadmium Zinc Telluride Detectors

Cadmium zinc telluride (CZT) is a new high-resolution and high-atomic number semiconductor detector material. A reasonable degree of cooling for the detector and the directly coupled preamplifier enhances detector system performance. CZT detectors offer an excellent option for low energy x-ray spectroscopy where cooling is not possible. Keeping the detector and preamplifier at about -30 °C, is adequate to achieve optimum energy resolution. By contrast, HPGe detectors must be cooled at liquid nitrogen temperatures to achieve optimum resolution. These detectors are not available in large sizes. Their small size diminishes the possibility of making detectors with large efficiencies for high-energy electromagnetic radiation. Therefore, the major application is low energy x or gamma-ray spectroscopy.

Personal Detectors

1- Pocket Ion Chamber

Very familiar to radiation workers over many, many years are the self-reading pocket ionization chamber (PIC) and the film badge dosimeter. The pocket ionization chamber is an ion chamber, as described in Section (7-1), in the form of a cylinder about the size of a fountain pen. A charge is placed on the electrodes of the ion chamber and the corresponding voltage is displayed through an eyepiece using an electroscope. As the ion chamber receives radiation exposure, the electrodes are discharged and the voltage change of the electroscope is presented in a reticule scaled to radiation dose or exposure. More commonly, the PIC is sensitive only to gamma radiation. However, neutron sensitive ionization chambers are also used, calibrated in dose equivalent.

2. Film Badge

The film badge consists of a packet of photographic film sealed in a holder with attenuating filters. Ionizing radiation darkens the film, as in the production of an x-ray image. The filtration is designed to render the degree of film darkening as nearly as possible a known function of gamma-ray exposure, independent of the energy of the incident gamma rays. After the badge is carried by a radiation worker for a period of time, the film is processed, along with calibration films with the same emulsion batch exposed to known radiation doses. The worker's radiation dose for the period is assessed and ordinarily maintained in a lifetime record of exposure. In some cases special attenuation filters are used to relate the darkening of portions of the film to beta-particle or even neutron dose. Special badge holders in the form of rings or bracelets are used to monitor the radiation exposure of hands, wrists, and ankles.

3. Thermo luminescent Dosimeter (TLD)

The thermo luminescent dosimeter (TLD) is a solid state radiation detector, whose radiation dose may be gauged by measurement of the release of light upon heating of the detector after exposure. TLDs are inorganic crystals such as LiF or $CaSO_4$ to which impurity elements, or dopants, such as Mg. P, Mn, or Cu are added in small concentrations. The TLD matrix is an insulator but the dopant adds hole and electron with energy levels within the insulator band gap. Upon radiation exposure, traps are filled. They remain filled until the TLD is heated, thereby releasing the trapped charge carriers. Recombination of newly mobile charged carriers leads to light emission. Natural Li, in which the abundance of ^{6}Li is 7.4%, is somewhat sensitive to thermal neutrons. TLD neutron sensitivity may be enhanced by increasing the abundance of the lighter isotope. Similarly, neutron insensitive LiF employs only ^{7}Li. Dosimetry of mixed neutron and gamma-ray radiation may be accomplished by using pairs of neutron-sensitive and neutron-insensitive TLDs.