PHGN 326

Experiment 4:

Energy loss of alpha particles

PURPOSE

The purpose of this experiment is to familiarize you with the use of silicon charged-particle detectors.

APPLICABILITY

Semiconductor charged-particle detectors have been used extensively in experimental nuclear research since the 1960's.

These detectors can be used through an extensive range of energies. These include 20-keV electrons on one end of the spectrum and 200-MeV heavy ions on the other. The inherent resolution of these surface-barrier detectors is surpassed only by magnetic spectrometers. The detector output pulses rise rapidly and hence are well suited for fast (~1 ns) timing with coincidence circuitry or time-to-pulse-height converters.

The efficiency of these detectors for their active volume/area is essentially 100%, and their energy vs pulse-height curves are linear over a rather impressive range. It is fortunate that they also have good long-term pulse-height stability. This is particularly noticed when they are contrasted with scintillation counters, gas proportional counters, or ionization chambers. Finally, their small size and compactness make them easily adaptable to almost any type of counting geometry.

For further general information see the handout on solid state detectors.

ALPHA SOURCES

Caution! Alpha sources offer a potential personal contamination problem. Never touch the face of a source with your fingers. Most alpha sources are electrodeposited into platinum blanks. The actual radioactive source is usually a spot about 1 mm in diameter, and it has been deposited in the geometrical center of the disk. If you look carefully, you may be able to see the deposited spot. Always handle an alpha source by the edge of the mounting disk under the supervision of the instructor.

SURFACE-BARRIER DETECTORS

There are three main parameters that define a silicon surface-barrier detector: resolution, active area, and depletion depth. The ORTEC model numbers reflect each of these three parameters in that order. The R-016-050-100 detector for example is a style R (Ruggedized) detector with a resolution of 16 keV FWHM for ^{241}Am alphas, an area of 50mm^2, and a depletion depth of 100μm.

Since the shape of the detector is a circular disk, its active area defines the diameter of its faces. At any given distance from the source a larger area will subtend a larger angle and thus intercept a greater portion of the total number of alpha particles that emanate from the source.

The depletion depth is synonymous with the sensitive depth of the detector. For any experiment the depth must be sufficient to completely stop all the charged particles that are to be measured, and its ability to do this is dependent upon both the energy and the particle type. Note that a 5.5-MeV alpha is completely stopped with about 27μm of silicon. Since natural alphas are usually less than 8 MeV in energy, a 50-μm detector is adequate to stop all natural alphas.

Procedure

1. Build a vacuum system with detector on one end and a port for a radioactive alpha source on the other. Measure the distance (40-50 cm). Connect vacuum gauge, turbo pump/ roughing pump combination (through valve) and needle valve for venting.
2. We will be using two types of radioactive nuclei as alpha sources: 210-Po (Polonium) and 244-Cm (Curium). To get all necessary information about the alpha energies emitted by these nuclei use the worldwide web. Go to http://nucleardata.nuclear.lu.se/nucleardata/toi. Print out all the information about these nuclei.
3. Build in detector and 244-Cm source (under supervision of the instructor). Connect and plug in vacuum gauge. Close needle valve and evacuate system with roughing pump (to about 75 mTorr).
4. Connect: preamplifier to detector feedthrough; preamp output E to oscilloscope; preamp power to the outlet at the back of the amplifier. Power up the NIM bin. Describe and sketch the signal you see on the oscilloscope. Risetime, falltime, noise.
5. In order to shape and amplify the signals further for our data acquisition, we connect the preamp output to the amplifier input. Select the correct polarity on the polarity switch. Connect the unipolar output to the oscilloscope. Describe and sketch the signal: risetime, falltime, noise level. What changes with using the gain switches and shaping time switch?
6. Connect the high voltage cable to the 0-500 Volt output on the NIM HV power supply. Monitor the electronic noise level of the amplifier signal on the oscilloscope while you slowly turn the voltage up to +40 V. Describe what you see. Adjust the gain to a signal of 6 V for the highest alpha energies.

7. Startup the MCDWIN data acquisition program on the PC. Connect the unipolar output of the amplifier to the ADC/MCA input; the oscilloscope to the bipolar output. Start the data acquisition and take a spectrum of the 244-Cm source signal. Save and print.

At this point you will see one broad peak (extending to low energies), where we should see two narrow peaks (see 244-Cm data sheets). The reason for this is, that this strong 244-Cm source is protected by a thin metal foil (of unknown thickness and composition). In this foil the alpha particles loose energy. This means that for an accurate energy calibration and resolution determination of our detector, we need to change to a windowless alpha source.

8. Turn off high voltage and NIM bin power supply. Close valve to roughing pump and open vent valve. Get the instructor for radioactive source change.
9. Evacuate vacuum system. Turn HV and NIM bin back on. Monitor oscilloscope (via bipolar output) and start the ADC/MCA.
10. Calculate the anticipated countrate under the assumption of a source strength of 0.1 μCi using the following equation:

It was mentioned earlier that surface-barrier detectors are essentially 100% efficient for their active area.

$$\text{activity (alpha per s)} = \left(\frac{\Sigma_\alpha}{t}\right)\left(\frac{4\pi s^2}{\pi r^2}\right),$$

where

s = distance from source to detector,

r = radius of the detector (cm),

t = time in seconds,

Σ_α = counts in spectrum

1 μCi = 3.7 x 10^4 disintegrations/s. Remember that the half-life of ^{210}Po is 138 days. If the instructor gives the activity of the source when it was made, a correction will have to be made for its present activity.

11. Run this measurement for ~ ½ hour, compare the result to your calculation.
12. Compare the position of the 210-Po peak to the peak of 244-Cm. Do a rough energy calibration and calculate the energy the alpha particles from the 244-Cm source loose in the protection foil.
13. For the measurement of the energy loss of alpha particles in air, we need to mount again the stronger 244-Cm source. We now know the energy of the alpha particles it emits. Repeat the steps above for the source change.
14. Determine the peak position and FWHM for the 244-Cm source at the following pressures: vacuum, 2.5 Torr, 5 Torr, 7.5 Torr, 10 Torr, 15 Torr, 20 Torr. Close the valve to the pumps and use the needle valve.
15. Compare the results for the energy loss to theoretical calculations or tabulated data.

Calculations of energy loss are quite cumbersome and not very exact. The normal way to find energy loss data is to use an appropriate computer program like the SRIM code. This code uses both theoretical calculations and experimental data to generate its values. Attached is an output file from this code. Calculate the absorber (air) thickness for your experiment and do a comparison with the SRIM code, which is installed on the PC. Display a comparison between measurement and calculation in a diagram.

EXTRA: If you have an hour or more left at the end of the laboratory day: explore electronic noise in the detector with turbo pump and ventilator. For this purpose, connect the preamp output directly again to the oscilloscope and startup the turbo pump. Make notes on special observations on noise frequency and magnitude.

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SRIM version ---> SRIM-2000.40
Calc. date ---> November 20, 2001
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Target = Helium in Nitrogen (gas)
Density = 1.2500E-03 g/cm3 = 5.3741E+19 atoms/cm3
Target is a GAS
======= Target Composition ========

Atom Name	Atom Numb	Atomic Percent	Mass Percent
N	7	100.00	100.00

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Disk File Name = Helium in Nitrogen (gas)
Stopping Units = eV / (1E15 atoms/cm2)

Ion = Helium [2] , Mass = 4.003 amu

Ion Energy	dE/dx Elec.	dE/dx Nuclear	Projected Range	Longitudinal Straggling	Lateral Straggling
1.00 MeV	4.487E+01	4.797E-02	5.00 mm	270.56 um	335.52 um
1.10 MeV	4.350E+01	4.426E-02	5.42 mm	278.65 um	341.66 um
1.20 MeV	4.211E+01	4.111E-02	5.85 mm	286.95 um	347.81 um
1.30 MeV	4.074E+01	3.840E-02	6.30 mm	295.51 um	354.01 um
1.40 MeV	3.941E+01	3.605E-02	6.77 mm	304.34 um	360.31 um
1.50 MeV	3.814E+01	3.399E-02	7.24 mm	313.46 um	366.74 um
1.60 MeV	3.693E+01	3.216E-02	7.74 mm	322.88 um	373.33 um
1.70 MeV	3.577E+01	3.053E-02	8.25 mm	332.60 um	380.09 um
1.80 MeV	3.469E+01	2.907E-02	8.78 mm	342.64 um	387.04 um
2.00 MeV	3.268E+01	2.655E-02	9.88 mm	379.94 um	401.59 um
2.25 MeV	3.049E+01	2.399E-02	11.35 mm	437.41 um	421.07 um
2.50 MeV	2.858E+01	2.190E-02	12.93 mm	495.04 um	442.12 um
2.75 MeV	2.691E+01	2.017E-02	14.60 mm	553.16 um	464.82 um
3.00 MeV	2.544E+01	1.870E-02	16.38 mm	611.95 um	489.21 um
3.25 MeV	2.415E+01	1.745E-02	18.25 mm	671.50 um	515.31 um
3.50 MeV	2.299E+01	1.636E-02	20.22 mm	731.87 um	543.14 um
3.75 MeV	2.196E+01	1.540E-02	22.29 mm	793.08 um	572.68 um
4.00 MeV	2.102E+01	1.456E-02	24.45 mm	855.13 um	603.91 um
4.50 MeV	1.920E+01	1.313E-02	29.08 mm	1.09 mm	671.72 um
5.00 MeV	1.789E+01	1.198E-02	34.10 mm	1.31 mm	746.42 um
5.50 MeV	1.677E+01	1.101E-02	39.46 mm	1.52 mm	827.36 um
6.00 MeV	1.579E+01	1.020E-02	45.17 mm	1.73 mm	914.25 um
6.50 MeV	1.494E+01	9.509E-03	51.23 mm	1.94 mm	1.01 mm
7.00 MeV	1.418E+01	8.908E-03	57.61 mm	2.15 mm	1.10 mm

Multiply Stopping by	for Stopping Units
5.3741E-04	eV / Angstrom
5.3741E-03	keV / micron
5.3741E-03	MeV / mm
4.2994E-02	keV / (ug/cm2)
4.2994E-02	MeV / (mg/cm2)
4.2994E+01	keV / (mg/cm2)
1.0000E+00	eV / (1E15 atoms/cm2)
8.6993E-02	L.S.S. reduced units

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