DETECTION OF CHARGED PARTICLES WITH SILICON DETECTORS

A) DESCRIPTION OF SILICON CHARGED PARTICLE DETECTOR

The silicon charged particle detector is a wafer of silicon having surface contacts forming a p-n junction. These contacts may be surface barriers (thin metal layers) as in the case of Surface Barrier Detectors or may be junction (doped) contacts as in the modern high-performance Passivated Implanted Planar Silicon (PIPS) detector. A bias voltage is applied in the reversed direction to establish an electric field across the device.

The reverse bias acts to form a depletion region in which there are no free charges. To function as a particle detector, this depletion region should be thicker than the penetration range of particles being detected (about 32 microns for 6 MeV alpha particles in silicon).

In the detection process the particle is stopped in the depletion region, forming electron-hole pairs in the process. The energy necessary to form a single electron-hole pair depends on the detector material, but is essentially independent of the energy of the incoming particle; the number of electron-hole pairs ultimately formed is thus directly proportional to the energy of the stopped particle. The electric field in this region sweeps the electrons to one terminal and the holes to the other. It is this charge pulse that is integrated in a charge sensitive preamplifier to yield the observed voltage pulse.

The thickness of the depletion region depends upon the applied bias voltage, so that higher voltages give a thicker region, capable of stopping more energetic particles. The capacitance of the detector depends upon the thickness of the depletion region and the area of the wafer, so detector bias will affect the capacitance (and response) of the detector.

The noise level of charge-sensitive preamplifiers is usually given by the manufacturer as a certain value of zero input capacitance. The noise level increases with capacitance, and this rate of increase is also specified. The detector capacitance is reduced at higher voltages, so that the lowest noise and best solution are obtained at higher voltages within the recommended range. At voltages above the recommended by the manufacturer, the reverse leakage current will likely increase, causing excessive noise and a loss of resolution.
B) BIAS VOLTAGE AND DETECTOR RESPONSE

1) Connect the apparatus as shown in Figure 1. Evacuate the chamber. After pumping the chamber for about 2-3 minutes, set the detector bias voltage to the recommended value for that particular detector (refer to attached detector specifications).

![Figure 1 Electronics Setup](image_url)

2) The pulses from the amplifier are fed to a Multichannel Analyzer (MCA) card installed in the computer. The MCA is basically a pulse height analyzer which converts the analog pulses to digital values and sort them into the corresponding channels according to their heights. Hence, the resulting spectrum is a plot of pulse intensity against channels.

3) The amplifier gain has been set such that the alpha pulses are collected around the middle of the spectrum.

4) Refer to appendix A for a guide to the MCA-3 software.

5) Collect a pulse height spectrum of the $^{241}$Am source for a duration of say, 200 sec.

6) Highlight the ROI for the alpha peak. Note the peak channel and FWHM (in channels).

7) Determine the resolution in keV using the following formula

$$\text{Resolution} = \frac{\text{FWHM} \times \text{Energy of the source}}{\text{Peak Position}}$$

The alpha particle energy is 5.298 MeV for $^{210}$Po and 5.477 MeV for $^{241}$Am. ($^{241}$Am also has a weaker peak at 5.435 MeV).
8) Repeat the experiment for bias voltages of 2, 4, 6, 8, 12, 16, 24, 32 and 60 volts. Print out the spectra and determine the peak position and resolution.

9) Repeat for \(^{210}\text{Po}\).

10) Make a graph of the peak position vs. voltage, as in Figure 2, noting that the position changes more at low bias than at high bias.

![Figure 2: Peak Position vs. Bias Voltage](image)

The large shift at lower voltage is due to incomplete charge collection. The electron-hole pairs recombine before they are swept out of the depletion region if the voltage is too low. Also the change in detector capacitance vs. bias is greatest at low bias.

Another effect at low voltage is that the depletion region is smaller and the incident alpha particle may pass through it before it is stopped. Then not all of the alpha particle energy is deposited as electron-hole pairs in the depletion region, and a smaller pulse is obtained.
C) ENERGY CALIBRATION AND RESOLUTION

1) Collect the spectrum separately for $^{210}$Po and $^{241}$Am using the same recommended bias voltage for the detector.

![Figure 3: 241Am and 210Po Spectra](image)

The energy calibration of the range below the two alpha peaks will not be very accurate if the two peak positions alone are used to plot the energy calibration graph as the energy separation between the two peaks is only 180 keV. Channel zero of the MCA does not necessarily correspond to zero energy, so it cannot be used as a point on the calibration curve. However, it is relatively easy to determine the analyzer zero with a pulser.

2) Disconnect the BNC T-joint from the output of the amplifier and connect it to the pulser’s ‘Norm out’ BNC socket. Turn on the pulser and set the polarity switch to ‘positive’.

Set the pulser at some dial setting, such as 1.00 volt. Use the oscilloscope to confirm the amplitude. Collect this pulse signal on the MCA and record the channel number of the peak. Repeat for 2, 3, 4 & 5 volts. Make a graph of pulse voltage vs. peak channel number. The point at which the straight line intersects the x-axis, as in Figure 4, is the zero of the analyzer. This channel may be used as zero energy on an energy calibration curve.

3) Plot the energy calibration graph. Use the gradient (keV/channel) to determine the resolution of the 2 alpha peaks.
D) MEASUREMENT OF THE ACTIVITY OF THE ALPHA SOURCE

The surface barrier semiconductor detector has an efficiency of 100% for alpha particles that strike the active area. Since the alpha particles are emitted randomly in all directions from a source, the total number of alpha particles emitted can be determined by comparing the solid angle subtended by the detector to that of a sphere whose radius is equal to the source-detector distance.

The fraction of alphas detected is

\[ \frac{A}{4\pi r^2} \]

where \( A \) is the area of the detector (usually specified by the manufacturer) and \( r \) is the source-detector distance. For the Model SPD-50-17-I00AM detector, \( A = 50 \text{ mm}^2 \).

To determine \( r \) accurately, the exact position of the detector when \( r = 0 \) has to be obtained first. This is done by raising the stage till it touches the bottom of the detector. Note the scale reading.

Place the $^{210}\text{Po}$ (or the $^{241}\text{Am}$) source in the chamber and evacuate. Turn on the detector bias to the recommended operating voltage. Collect a spectrum for at least 500 sec.

Determine the total number of alphas particles detected (i.e. net counts under the ROI) and calculate the activity of the source by dividing the number of alphas per second detected by the fraction \( A/4\pi r^2 \). Calculate the source strength in $\mu\text{Ci}$ by using $1 \mu\text{Ci} = 3.7 \times 10^4$ disintegrations per
second. This number will not agree with the strength given on the source because of the half-life of $^{210}$Po, which is only 138 days.

\[
\begin{align*}
^{241}\text{Am} & \quad t_{1/2} = 0.145 \times 10^{11} \text{ sec} \\
^{210}\text{Po} & \quad t_{1/2} = 0.120 \times 10^8 \text{ sec}
\end{align*}
\]

E) ALPHA PARTICLE RANGE AND ENERGY LOSS IN AIR

1) Switch off the vacuum pump.

2) Place the $^{241}$Am alpha source at 1 cm from the charged particle detector. Close the chamber door and set the detector bias to the recommended operating voltage.

3) Collect a spectrum of alpha particles for a duration of 100 sec at atmospheric pressure and the chamber door closed. Note the net counts under the ROI and the peak position.

4) Repeat for equal times at distances of 1.5, 2, 2.5, 3 cm, etc. When the net counts begin to decrease rapidly, make measurements in steps of 1 mm until less than 20 counts are obtained.

5) Make a graph of the alpha energy and the counts vs. the distance between the source and the detector. The range of the alpha particles in air is taken to be the point at which the intensity has fallen to half the value of the shoulder. Plot a graph of the energy loss in air vs distance.

CAUTION

Alpha-particles emitters are particularly dangerous radioactive materials. They can cause damage to tissue, particularly if ingested.

Refer to the PIPS Detector Instructions before handling or using the detector.
PIPS Detector Instructions

HANDLING

The PIPS detector should be handled with care. The implanted face contact, while not as fragile as an evaporated gold contact, is nevertheless very thin as it must be in order to achieve high efficiency and good resolution for alpha particles. Do not touch the surface with anything that might cause scratches or abrasion.

OPERATION

The PIPS detector has implanted, passivated contacts which are protected from the environment so there is little risk of microplasma breakdown upon application of bias. However, if the detector has been stored in humid conditions, it should be kept in vacuum for a short while to remove excess condensation before applying bias.

Alpha resolution is measured using a point source at least one detector diameter away from the detector face. Resolution will not be as good with the source closer because of the more acute angle of particle travel through the entrance window.

REFERENCES


Revised Feb 2013
MCA-3 SOFTWARE GUIDE

I. DATA ACQUISITION

a) Click “DATA OPERATIONS” icon
   i) Enter spectrum title as: C:\MCA3\data\Spectrum Name

Note: Make sure the file format has been selected as either "ASCII(ASC) or GANAAS(SPE)"

b) Click “RANGE... PRESET” icon
   i) Set range to 256
   ii) Enable REALTIME PRESET checkbox
   iii) Enter the data acquisition preset time

c) Click “DISPLAY OPTIONS” icon
   i) Select “SPLINE I” for type

d) Start acquisition by clicking ‘start’ button

e) Stop acquisition by clicking ‘stop’ button

II. REGION OF INTEREST (ROI)

a) Press the right mouse button and drag it to define the region of interest

b) Click “CREATE NEW ROI” icon to mark the defined ROI

c) Goto “REGION” menu and select “FIT” to obtain ROI details.

III. PRINTING OF SPECTRUM

a) Go to “FILE” menu and select “SETUP PRINTER”
   i) Change orientation to “Landscape”

b) Next select “PRINT” from “FILE” menu
   i) Click “ADD” tab
   ii) Click “OK” to print.

IV. SAVING OF SPECTRUM

a) Go to “FILE” menu and click “SAVE”