Measurement of the thickness of a uniform metal layer using alpha spectroscopy

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(Dated: 12 October 2003)

The thickness of the unresponsive layer of silicon on a surface barrier detector was undetectable. Alpha particles passed through the layer at normal incidence and at 60° with respect to the plane of the detector. Electronic drift obscured the difference between the two measured energies. The minimum detectable thickness of silicon for the system is (70 ± 8) μg/cm^2, or (30 ± 3) μm. Future experiments using this technique will require precise and highly stable data acquisition systems.

INTRODUCTION

The Coulomb-nuclear interference polarimeter at the Brookhaven Alternating Gradient Synchrotron employs silicon microstrip detectors to measure the energy of carbon nuclei which the polarized proton beam deflects from a 150 Å carbon sheet [1]. The polarization of the beam determines the asymmetry between the deflection to the left and to the right. In general, a charged particle produces an electron-hole pair per 3.6 eV of energy deposited in the silicon [2, 3]. An unresponsive dead layer of silicon coats the surface of these semiconductors. Although charged particles lose energy in the dead layer, they do not produce electron-hole pairs with a detectable current. Because carbon nuclei exhibit high energy loss in matter [4], the thickness of the dead layer must be known precisely in order to measure precisely the polarization of the beam. Knowing the thickness of the dead layer permits reconstruction of the full energy of the carbon nuclei.

EXPERIMENTAL PRINCIPLES

An Ortec® EB-022-450-100-S silicon surface barrier detector serves as a prototype detector for the proposed technique of measuring the thickness of the dead layer. A particle detector measures slightly less energy than expected for an ejected particle in a nuclear decay because the particle loses energy in the dead layer. Particles from a source oriented at an angle α with respect to the plane of the detector travel through an effective path length a factor of $(\cos\ \alpha)^{-1}$ longer than particles from an overhead source.

A 40 μg/cm^2 layer of gold coats the Ortec® detector in addition to the layer of unresponsive silicon. E_0 is the energy of the incident alpha particle, and t_{Au} and t_{Si} are respectively the thicknesses of the gold and silicon layers. $E(\alpha)$, the measured energy for any angle α, and $\Delta E(\alpha)$, the difference in measured energy between particles from angled and overhead sources, are given by

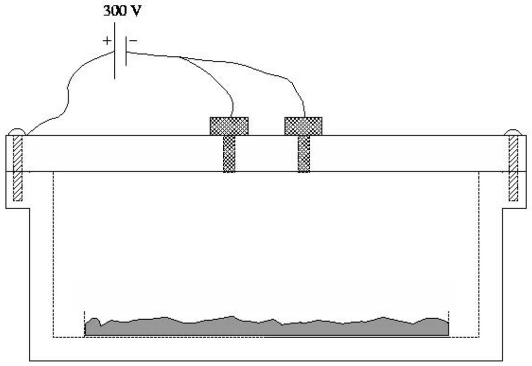

FIG. 1: The canister containing the ^{228}Th compound.

$$E(\alpha) = E_0 - \frac{t_{\mathrm{Au}}}{\cos\ \alpha}\frac{\mathrm{d}E}{\mathrm{d}x}\bigg|_{\mathrm{Au}} - \frac{t_{\mathrm{Si}}}{\cos\ \alpha}\frac{\mathrm{d}E}{\mathrm{d}x}\bigg|_{\mathrm{Si}} \quad (1)$$

$$\Delta E(\alpha) = \left(\frac{1}{\cos\ \alpha} - 1\right)\left[t_{\mathrm{Au}}\frac{\mathrm{d}E}{\mathrm{d}x}\bigg|_{\mathrm{Au}} + t_{\mathrm{Si}}\frac{\mathrm{d}E}{\mathrm{d}x}\bigg|_{\mathrm{Si}}\right] \quad (2)$$

where $(\frac{\mathrm{d}E}{\mathrm{d}x})_{\mathrm{Au}}$ and $(\frac{\mathrm{d}E}{\mathrm{d}x})_{\mathrm{Si}}$ are the stopping powers for alpha particles in gold and silicon respectively. Because $\Delta E \ll E$, all stopping powers are evaluated at E_0.

This technique actually measures the quantity in square brackets in Eq. 2. The experiment can not measure t_{Au} and t_{Si} independently. However, t_{Si} may be isolated if another method accurately determines t_{Au}. t_{Si} may be measured directly with an uncoated detector.

PROCEDURE

^{212}Pb provides an excellent spectrum of alpha particles. An aluminum cylinder at -300 V rests over a ^{228}Th compound. The flat end of the cylinder collects ^{220}Rn nuclei, a decay product of ^{228}Th. ^{220}Rn quickly decays to ^{212}Pb, which has a 10.6 h half-life. The cylinder is a portable source of 6.051 MeV, 6.090 MeV, and 8.785 MeV alpha particles. Figure 1 shows ^{212}Pb collection, and Fig. 2 depicts the complete decay chain of ^{228}Th.

Many tabulations of stopping powers for different materials are available [5, 6]. They provide values for the

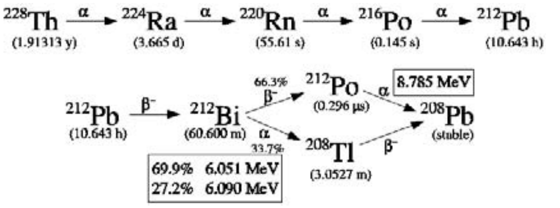

FIG. 2: The decay chain of ^{228}Th. Numbers in parentheses are half-lives; percentages are branching ratios; and energies are alpha lines [7].

parameters in the above equations. For the 8.785 MeV alpha particles, $(\frac{dE}{dx})_{\mathrm{Si}} = 422\ \mathrm{MeV} \cdot \mathrm{cm}^2/\mathrm{g}$ and $(\frac{dE}{dx})_{\mathrm{Au}} = 176\ \mathrm{MeV} \cdot \mathrm{cm}^2/\mathrm{g}$.

The plugs were disconnected from high voltage and removed from the ^{228}Th container. An aluminum arc positioned them directly over the surface barrier detector at $\alpha = 60°$ with respect to the normal to the plane of the detector (Fig. 3). Aluminum paddles (not shown) alternately blocked each source so that particles from only one source reached the detector. A brass disc with a 2 mm × 10 mm slit just over the surface of the detector collimated the alpha particles. The detector was reverse-biased at 225 V, and a thermocooler cooled the detector to reduce the leakage current to 0.11 μA, a noise reduction technique [2]. The electronic pulse from each alpha particle passed through a shaping pre-amplifier and a spectroscopy amplifier with a gain of 13.0. A discriminator triggered a QDC to measure the charge contained in the pulse. That charge is proportional to the energy of the alpha particle.

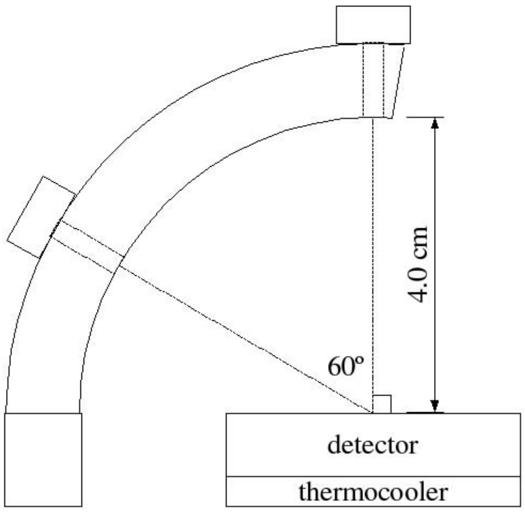

FIG. 3: The source mount and detector assembly.

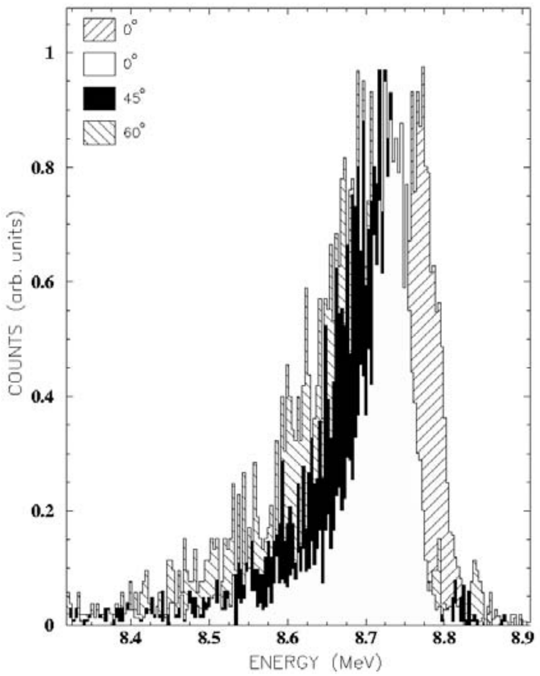

FIG. 4: Alpha spectra through 400 μg/cm^2 Ag foil. The shaded 0° peak was recorded 37 hours after the unshaded 0° peak.

ELECTRONIC PRECISION

This experiment requires high quality electronics. The pre-amplifier, spectroscopy amplifier, and QDC must have exceptional precision and stability. Additionally, the QDC must have excellent resolution. Specifically, to measure t_{Au} to within 10% assuming $t_{\mathrm{Si}} = 0$ the QDC must be sensitive to (8×10^{-3})% signal shifts, corresponding to 0.7 keV shifts at 8.8 MeV.

This experiment's electronics failed to approach the stability required to measure the thickness of the silicon dead layer. The QDC could resolve 3.46 keV per channel. Without electronic drift, it would be sensitive to a peak shift from the gold alone. However, the mean position of a peak drifted by as much as five channels per hour. Because counting rates never exceeded 100 per minute, the time scale of electronic drift exceeded the time scale required for reasonable statistics acquisition.

A silver foil helped test the validity of the experiment's principle and the functionality of the equipment. The foil is effectively a thick dead layer, measured on a microbalance to be 400 μg/cm^2, roughly ten times as thick as the gold coating on the detector. The foil covered the slit in the collimator. Alpha spectra from ^{212}Pb sources at 0° and then 45° were measured. The next day, fresh sources at 60° and again at 0° provided additional spectra. Unfortunately, the foil was wrinkled and dotted with pinholes. The subsequent non-uniform thickness causes wide peaks. Figure 4 displays all four renormalized spectra. Although the mean positions of the peaks decrease with increasing source angle, the results are not reproducible. The repeated measurements with sources at 0°, taken 37 hours apart, are separated by (9 ± 1) QDC channels, or (31 ± 3) keV. The wide drift disallows quantitative measurements of the thickness of the foil.

RECOMMENDATIONS

This experiment fails not in principle but in implementation. Although the data acquisition system provided 8.785 MeV alpha peaks with as small as 21 keV widths at half-maximum, the electronic instability obscured the data beyond usefulness. The channel shift observed in the 0° peak with silver foil corresponds to (70 ± 8) μg/cm^2, or (30 ± 3) μm, of silicon. The detector cannot observe thinner layers of silicon with the current electronics. The (31 ± 3) keV error on the position of each peak yields 124 keV as the peak shift required for accuracy to within 25%. This shift corresponds to 700 μg/cm^2 of gold or 290 μg/cm^2 of silicon. Future experiments to measure the thickness of a dead layer on a surface barrier or microstrip detector must incorporate highly stable, precise electronics with excellent resolution. Fission fragments would cause greater peak shifts than alpha particles due to their higher energy loss in matter, but the feasibility and safety of such an experiment is highly questionable.

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