

SILICON DETECTOR DEVELOPMENT FOR CE-35

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The p-p scattering experiments with the Wisconsin Atomic Beam Source presently mounted in the A-section (see elsewhere in this report) all require detection of the recoiling protons. The CE-01 detector, consisting of a ΔE scintillator, a wire chamber pair and a stopping detector (Ref. 1), is used to detect the forward scattered proton, whereas 8 silicon strip detectors are used to detect the recoil proton. The recoil detectors are mounted alongside the polarized target cell (Fig. 1). They are 1-mm thick with an active area of 4 cm by 6 cm and have 28 strips per detector. Presently, the detectors are used to observe elastically scattered recoil protons of energies between 0.5 MeV and 20 MeV. The detectors stop protons with kinetic energies up to 12 MeV. Thick detectors were chosen to obtain large signals for the punch-through particles. The capability to detect recoil protons of more than 20 MeV kinetic energy will become more important as the incident energy is increased from 200 MeV to 500 MeV during future experiments.

During the startup phase of CE-35 (Ref. 2), the first experiment to use the detectors, it was noticed that the detectors could barely be biased up to their nominal depletion voltage. The nominal depletion voltage (typically 100 V) had been determined by Micron Semiconductors (the supplier) via a measurement of the detector capacitance as a function of the bias across the detector. For a fully depleted detector the capacitance remains constant even if the bias across the detector is further increased. Ideally, one would run the detectors at about 20% overbias to be insensitive to small changes in bias that result when the leakage current changes. For example, a change in the leakage current of $0.5 \mu\text{A}$ results in a drop of the detector voltage by 12 V in our case, since the input resistance of the preamplifier is $24 \text{ M}\Omega$. During running we found that the detectors broke down even for a small overbias on the order of 10 V. In order to stay safely below the breakdown point, we operated the detectors at a bias just at the depletion point. As a result, the punch-through branch of the kinematic locus for pp elastic scattering events was considerably broadened (angles $\geq 14^\circ$ in Fig. 2). For some detectors the broadening appeared to be a discrete locus rather than a uniformly smeared band. When we analyzed only events in this so-called "ghost locus", we found that they corresponded to protons that had hit close to the central region, i.e. in the vicinity of strip no. 14, of the detector.

In an attempt to understand and possibly eliminate the problem, offline tests with silicon detectors of 300 μm , 500 μm and 1000 μm thickness were conducted. An ^{241}Am alpha source was mounted in front of the strip side of the detector and the resolution and peak position were measured as a function of the bias across the detector. Figure 3 shows

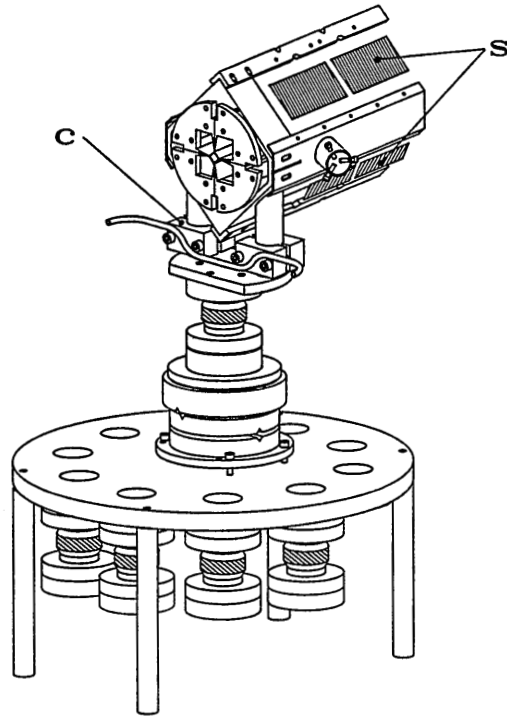


Figure 1. Cell and detector support structure. Copper clamps (C) are used to cool the silicon detectors (S) to 0 °C.

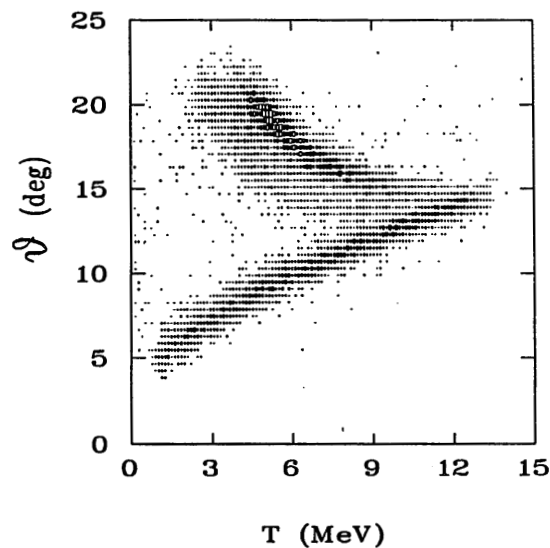


Figure 2. Scattering angle of the forward going proton as a function of energy deposited in the silicon detector at 200 MeV. The angle has been reconstructed using the wire chambers of the CE-01 detector. The voltage across the silicon detector was 107 V, its nominal depletion voltage is 110 V.

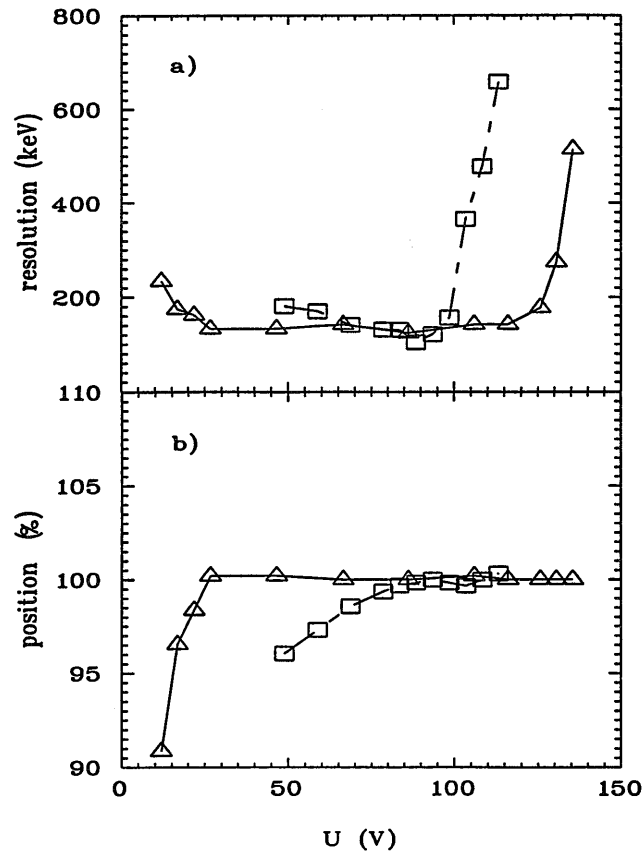


Figure 3. Energy resolution (a) and peak position (b) as a function of voltage across the detector, measured with a ^{241}Am source. The dashed line and square symbols correspond to a $1000\mu\text{m}$ thick detector, the solid line and triangular symbols correspond to a $300\mu\text{m}$ thick detector. The peak position is expressed as a relative shift compared to the position at full depletion.

the result of such a measurement for 300 and $1000\mu\text{m}$ detectors. For biases higher than the nominal depletion voltage the resolution deteriorates due to an increase of detector noise (Fig. 3a). For biases lower than the nominal depletion voltage the peak position shifts (Fig. 3b) due to a decrease in active thickness of the detector. Given the two constraints that the peak position should be stable and the resolution at least 150 keV, the operating range of the $1000\mu\text{m}$ detector is less than 10 V.

Since the leakage current is expected to decrease with lower temperature of the detector, cooling of the detectors to 0°C was introduced. The copper clamps used to cool the support structure of cell and detectors are shown in Fig. 1. As cooling liquid we used a mixture of alcohol (65%) and water (35%). It was found that cooling the detectors does not increase the bias at which the detector resolution deteriorates. However, cooling stabilizes the bias across the detector. This is because the actual bias on the detector depends on the leakage current, which in turn changes with temperature. Since this makes possible maintenance of the optimum bias immediately below the onset of detector noise, it was decided to cool the detectors during future operation.

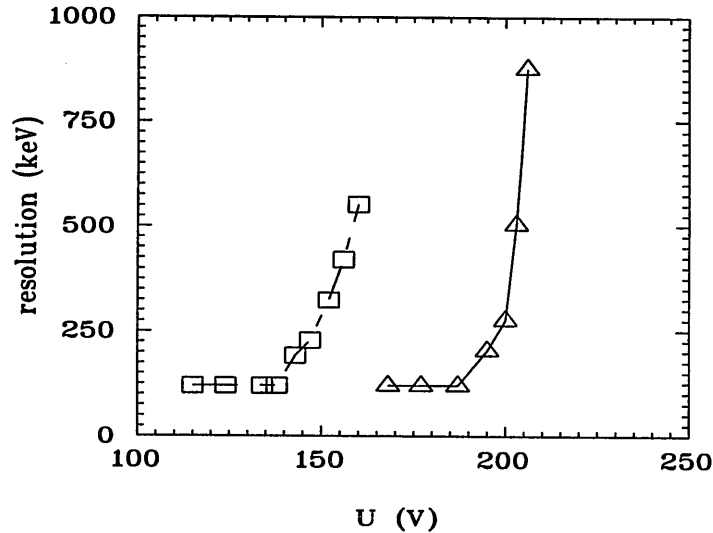


Figure 4. Effect of a guard ring on the upper limit of detector bias. The dashed line is without guard ring, the solid line is with guard ring. The measurement is done with a $500\mu\text{m}$ thick detector, see text for details.

In order to investigate the behavior of silicon detectors of different types, we made the same measurement of resolution as a function of detector bias for a $300\mu\text{m}$ thick detector and a $500\mu\text{m}$ thick detector. We found that the onset of detector noise occurs within $\sim 20\text{ V}$ at the same voltage independent of detector thickness, but, since the thinner detectors deplete at lower bias, the operating window is wide enough for slightly overbiased operation of the thinner detectors. Fig. 3 shows a direct comparison with the $1000\mu\text{m}$ thick detector.

It was pointed out to us (Ref. 3) that the breakdown of the detectors is caused by surface currents around the edges of the detector. The onset of these surface currents occurs at approximately the same bias for all detectors. Small differences (on the order of 20 V) are possibly due to surface contamination. A ring (typically etched on the strip side of the detector) remedies the shortcoming of the thicker detectors by limiting the active volume of the detector to a region away from the edge. The guard ring is operated at approximately half the bias across the detector. Using a $500\mu\text{m}$ thick detector with guard ring, we also compared the detector performance with and without guard ring. If the bias is applied to the back side of the detector, a detector without guard ring can be simulated by grounding the guard ring together with the strips. The resolution as a function of the detector bias for a $500\mu\text{m}$ thick detector with and without guard ring is shown in Fig. 4. The bias on the detector can be increased by $\sim 50\text{ V}$ if it is operated with the guard ring. We found that the energy resolution does not depend critically on the bias at the guard ring. As soon as the guard ring was biased higher than a certain threshold (typically 10 V), a sudden decrease in detector noise was observed. Further increase of the bias on the guard ring did not improve the energy resolution significantly.

Since the existing 1-mm thick detectors cannot be supplemented with guard rings after manufacturing, we decided to investigate the possibility of using the two outermost strips (no. 1 and no. 28) as "partial" guard ring. To test this scheme strips 1 and 28

were connected to a separate power supply and biased at half the bias across the detector. Then, the resolution as a function of the detector bias was measured. We found that the detectors can be overbiased by approximately 20 V (about half as much as for a complete guard ring). Despite the decrease in active surface we decided to run strips 1 and 28 as "guard strips" during future runs.

The observation that the events in the "ghost locus" are central hits on the face of the detectors has an explanation: according to the manufacturer (Ref. 4), the resistivity of the raw silicon material is often lower in the interior region of the crystal and thus across the wafer from which the detector is manufactured. As a consequence, the central region of the detector depletes fully at a higher bias, which in turn leads to the "ghost locus" if the detector is run at or slightly below its nominal depletion voltage.

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4. C.D. Wilburn, Micron Semiconducters, private communication.

TEMPERATURE SENSITIVITY OF SURFACE CHANNELS ON HIGH-PURITY GERMANIUM DETECTORS

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Introduction

Problems relating to the intrinsic surface of germanium detectors have been recognized from the beginning of their use. Surface states invariably lead to the nominal intrinsic surface having some degree of n- or p-typeness; this slightly conducting layer is called a "surface channel".¹⁻⁴ The typeness of the surface channel is not related to the typeness of the bulk germanium from which the detector is fabricated. These surface channels cause distortions in the electric field near the surface. Some of the charge from photon interactions occurring in these affected regions reaches the surface, then slowly migrates to a contact. When the charge movement is sufficiently slow, the charge will not reach an electrical contact within the integration time of the amplifier. Consequently, only a partial signal, whose magnitude depends on the location of the photon interaction, will be observed. The depth of the affected region usually varies greatly from one electrical contact to the other, and is on the order of 1 mm from the surface.^{3,4} The presence and