Testing a diamond detector for use in DAPPER

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As compared to silicon detectors diamond detectors have a higher displacement energy, which makes them more radiation hard, their signals have faster rise time, and their large band gap keeps their dark current low even at higher voltages. The combination of good energy resolution, excellent time resolution and improved radiation hardness make diamond detectors attractive as a potential ΔE detector for beam identification. Known disadvantages of diamond detectors are their higher cost, small single crystalline size and larger pulse height defect than their silicon counterparts [1]. Additionally, there is some evidence that diamond detectors' large radiation hardness as compared to silicon diminishes for lower energy beams [2-4].

If the diamond detector exhibits high radiation hardness along with sub 3% FWHM energy resolution for incident particle rates of 10^5 pps it would make an excellent beam purity detector for the DAPPER array (Detector Array for Photons Protons, and Exotic Residues). The measurement of the ^{60}Fe's photon strength function is hampered by the presence of cobalt contamination present in the ^{59}Fe secondary beam. A ΔE measurement of the beam before it reaches the CD_2 target would allow for the cobalt contamination to be gated out. The limited data on the performance of the diamond detectors at various rates of low energy heavy ion beams motivated this study to see if the detectors could operate in this capacity.

The diamond detectors were characterized using sources and then used in beam experiments consisting of both low and high rates of low energy heavy ions. The energy resolution of the detector was monitored closely, as a representative of the radiation hardness, as well as other effects like pulse-height defect and polarization.

In order to test the characteristics of diamond detectors at high beam rates, a test was done using a 4.5 mm x 4.5 mm 20 µm thick single crystalline chemical vapor deposited (sCVD) diamond detector supplied by Applied Diamond, Inc. A beam of ^{78}Kr accelerated to 7.5 MeV/u impinged the diamond detector and a ^{39}K beam contaminant was used as a calibration point. In this test, two preamps were used in order to monitor both the event rate and energy resolution of the detector. An Ortec 412 preamplifier was used to monitor the resolution of the detector via the alpha particles from a ^{228}Th source placed near the detector during low beam rates. In order to monitor the high ^{78}Kr beam rates on the detector, a Caen 1425 preamplifier was used due to the signals fast rise and fall times. The energy resolution and polarization effects at various applied voltages were investigated at low and high beam rates. After the ^{78}Kr beam test, a lab test was done using a ^{228}Th source, and a 300 µm Dual-Axis Duo-Lateral (DADL) detector in order to characterize the variance of the permanent damage across the area of the diamond detector.

When the diamond detector was subjected to a modest rate of ^{78}Kr it began to exhibit signs of polarization. This affect was previously demonstrated with a strong ^{90}Sr positron source in [5] with scCVD diamond detectors. This polarization effect has been shown to be reduced by increasing the electric field via the applied voltage on the detector. This relationship is shown in Fig. 1. At 430 pps on the diamond biased to 28 V (1.4 V/µm), there is a stable response of the ^{78}Kr peak position (shown by the

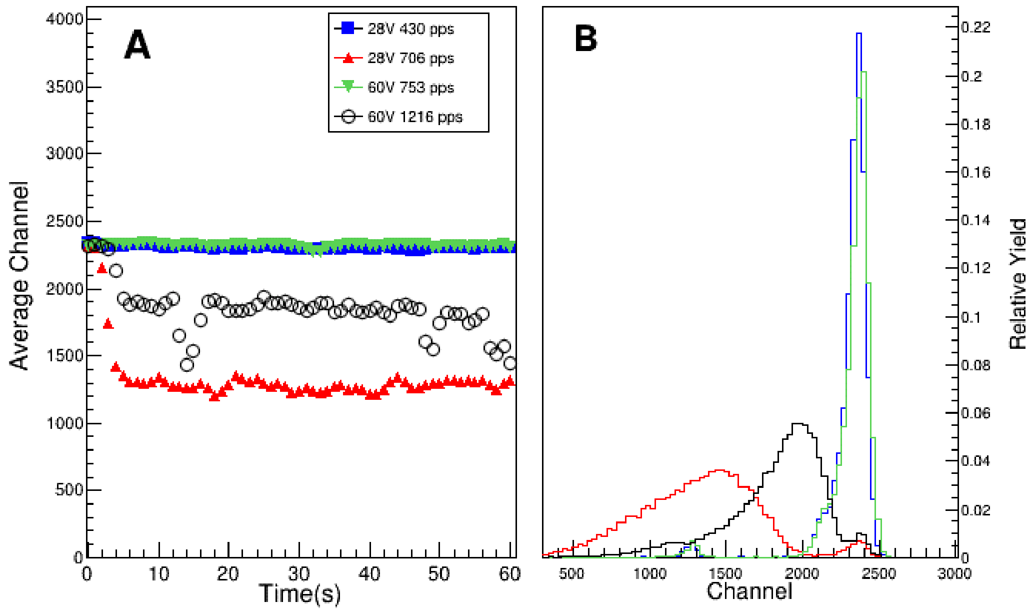

Fig. 1. The average channel number observed in the diamond detector as a function of time. At 28 V the diamond detector has a stable response at 430 pps (blue squares), but at 706 pps (red triangles) it shows a degradation in pulse height until it plateaus at a new equilibrium value, though with much larger fluctuations. Increasing the voltage to 60 V makes the diamond response stable again even at 753 pps (green point-down triangles). However, when the beam rate was subsequently increased to 1216 pps (black open circles), degradation in pulse height was seen again. B). The spectrum observed in the diamond for the same runs as in A). When the pulse height degraded, the energy resolution also suffered.

blue squares). When the beam rate is increased to 706 pps, the polarization effect begins to affect the electric field in the detector resulting in the degradation of the pulse height to a new equilibrium (red triangles) until the applied voltage is increased to 60 V (3 V/µm). At this higher voltage, the pulse height is stable even at 753 pps. However, once again an increase in the beam rate to 1216 pps (black circles) results in the polarization of the detector. When attempting to increase the voltage on the detector past this point, evidence of dielectric breakdown was observed.

After the completion of the high rate beam tests, the long term effects of the high rate on the performance of the sCVD diamond detector was investigated using a ^{228}Th source. Prior to the beam run, an alpha spectrum was taken at 4 V in order to get pristine data (Fig. 2 blue curve). After the ^{78}Kr beam an alpha spectrum was taken with the same detector and same electronics test at both 4 V and 40 V (green and black curves respectively). A significant decrease in energy resolution is observed in the alpha source data indicating permanent damage had been done to the detector, with the increase in voltage giving a modest improvement. The diamond DADL telescope test showed that this degradation in the energy resolution is not primarily due to differences in the charge collection efficiency (CCE) across the area of the diamond.

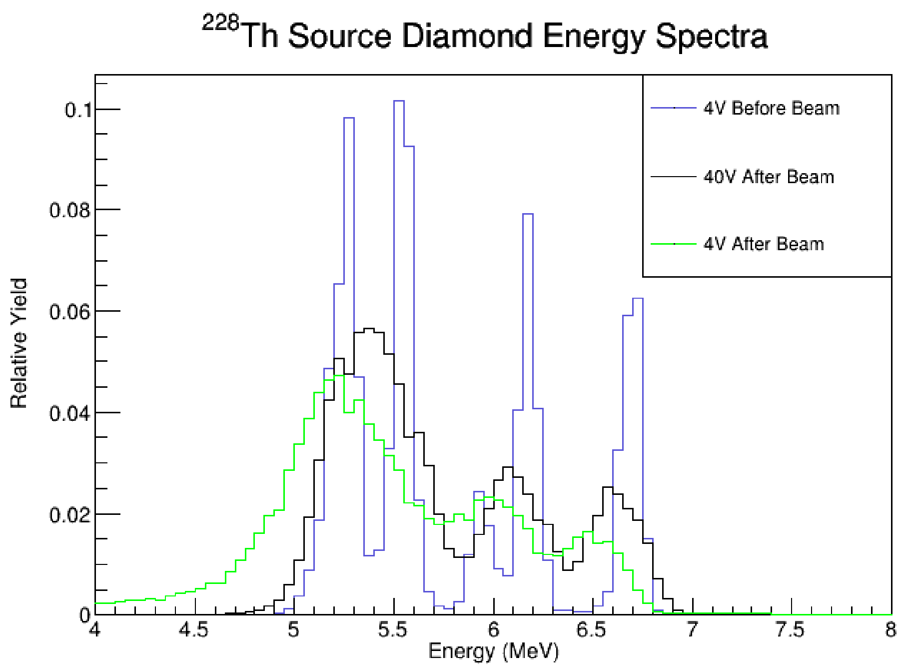

Fig. 2. ^{228}Th alpha spectra in Diamond-DADL telescope configuration. Black is the ^{228}Th spectra with the diamond biased to +40 V while in green it is biased at +4 V. In blue is the same detector biased at +4 V before the experiment.

sCVD diamond detectors have been shown to possess energy resolution sufficient for isotopic resolution up to magnesium [6]. In addition, they can simultaneously provide excellent energy resolution and timing resolution. However, they are small and expensive. Their radiation hardness appears to be superior to silicon detectors for minimally ionizing particles, however this advantage appears to diminish for higher Z beams. The strong polarization effects seen with the ^{78}Kr indicates that energy resolution quickly degrades somewhere in the 1000pps region, depending upon the voltage per micrometer that can safely be applied to the diamond detector. Diamond detectors appear to suffer from a similar issue to gas filled detectors when the rate of the charge put into them becomes too high. This means that the diamond detector will most likely perform poorly as a ΔE beam purity detector for high mass beams. This makes the diamond detector unsuitable for implementation into the DAPPER array.

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