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Radiation Monitoring with CVD Diamonds and PIN Diodes at BaBar

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The BaBar experiment at the Stanford Linear Accelerator Center has been using two polycrystalline chemical vapor deposition (pCVD) diamonds and 12 silicon PIN diodes for radiation monitoring and protection of the Silicon Vertex Tracker (SVT). We have used the pCVD diamonds for more than 3 years, and the PIN diodes for 7 years. We will describe the SVT and SVT radiation monitoring system as well as the operational difficulties and radiation damage effects on the PIN diodes and pCVD diamonds in a high energy physics environment.

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1. Introduction

The Babar experiment [1] at the Stanford Linear Accelerator Center uses a radiation monitoring and protection system, SVTRAD [2], to protect the Silicon Vertex Tracker [3] from radiation damage. The SVT, centimeters from the beam pipe, is highly susceptible to radiation damage. The goal of the SVTRAD system is to monitor the total integrated dose received by the SVT, as well as protect it from large radiation bursts that could cause permanent damage to the Silicon.

The SVTRAD system consists of 12 Hamamatsu S3590-08 silicon PIN diodes (1x1 cm^2 x 300μm) and two polycrystalline chemical vapor deposition (pCVD) diamonds (1x1 cm^2 x 500μm). The diamonds were installed in August 2002. The PIN diodes were installed in 1999. The PIN diodes are arranged in two rings at the forward and backward sides of the inner most layer of the SVT. Each ring consists of six diodes, three diodes on the east side of the detector and three on the west side occupying the top, middle and bottom plane of the ring. The two diamonds are located at the backward side mid planes only due to space constraints. The diodes are reversed biased at 50V while the diamonds are biased at 500V. Both are readout via a custom-built, DC-coupled boards. The total current through the sensors is measured at a sampling rate of 10kHz. The currents consist of a predominantly large leakage current and small radiation-induced current. At each beam loss, the leakage current is calibrated for a baseline. During operation, the leakage current is corrected for temperature variations and subtracted from the total current to obtain the radiation-induced component. When radiation currents go above predefined thresholds, the boards issue a beam dump. The SVTRAD system furthermore provides background quality feedback to machine operators for an improved detector and data taking environment.

2. Dose Rate Monitoring and Protection

The SVT has received a total dose of approximately 3.7 MRad in the mid-plane. The total radiation budget is 5MRad. We should reach this budget in 2008 at the end of running. To limit excess or unnecessary dosage, a ten-minute-timer is incorporated. When the dose rate goes above 100mRad/s for more than one minute, an alarm is sent to the beam operators notifying them. If these conditions persist for more than ten minutes, the beams are dumped. Typical dose rates of up to 50mRad/s are seen while running at a luminosity of 12.0×10^{33} cm^{-2} sec^{-1}.

The SVTRAD system also exercises 2 types of beam aborts for fast, "acute", radiation bursts. If the dose rate exceeds 1.25 Rad/s and integrates to 5 Rads (Type-A abort), or if the dose rate exceeds 400 Rad/s (Type-B abort), the beams are dumped. These thresholds are relaxed when the SVT bias voltage is turned off during beam fills. Figures 1 and 2 show a snap-shot of radiation levels during two beam aborts.

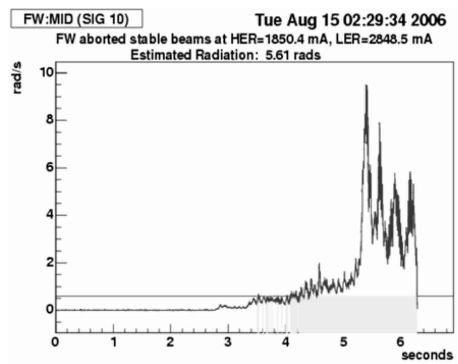

Figure 1. Radiation levels during Type-A beam abort.

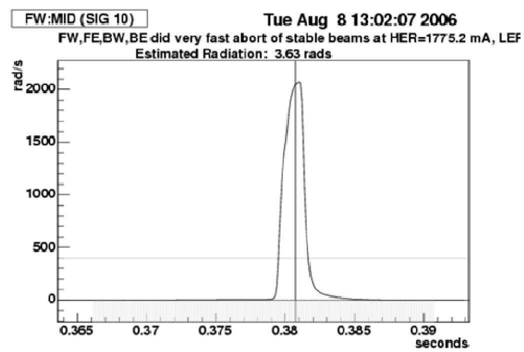

Figure 2. Radiation levels during Type-B beam abort.

The leakage currents of the PIN diodes have increased considerably due to the total integrated dose. Table 1 lists the typical signal and leakage currents of the mid-plane diodes and diamonds. The leakage current of the diodes has increased by a factor of a thousand since the start of BaBar. The PIN diodes have become increasingly difficult to operate because of the radiation damage. In particular, the backward west mid-plane diode has been replaced by a diamond for dose rate monitoring. As total integrated dose increases, dose rate monitoring by the PIN diodes will no longer be reliable.

The radiation hardness of the pCVD diamonds is a great feature compared to silicon diodes [4,5]. After almost a total accumulated dose of 1.875 MRads, the leakage current remains less than a couple of nA. The signal of the diamonds is not dominated by leakage current as is the case for the diodes. Unlike the diodes, the diamonds do not suffer from leakage currents due to temperature variations.

	Total Accumulated Dose	Typical Signal Currents	Typical Leakage Currents
BW-MID Diode	3.675 MRad	≈ 10 nA	≈ 3000 nA
BE-MID Diode	1.935 MRad	≈ 4 nA	≈ 1300 nA
FW-MID Diode	2.900 MRad	≈ 8 nA	≈ 1800 nA
FE-MID Diode	2.860 MRad	≈ 6 nA	≈ 2000 nA
BW-MID DM	1.875 MRad	≈ 5 nA	≈ 0-2 nA
BE-MID DM	0.795 MRad	≈ 2 nA	≈ 0-2 nA

Table 1. Typical signal and leakage currents of mid-plane diodes and diamonds.

3. Trickle Injection Monitoring

The SVTRAD system continues to improve. Recently trickle injection monitoring has been incorporated. Prior to March 2004, beams were filled into the machine while the detector was ramped down. When the beam currents were topped off, injection would stop while the beams were coasted allowing the detector to ramp up for data taking. The beams are no longer filled and coasted. Instead, beams are continuously injected/trickled while the detector stays ramped up and taking data [6]. Clean injections are required for healthy data taking conditions. Trickle injection monitoring is used by machine operators to monitor trickle injection quality as well as identify poor data taking conditions.

Trickle injection monitoring is accomplished by measuring the dose associated with each injection shot. Both electron and positron injections are monitored. Figure 3 shows the signal from two injection pulses. The typical signal pulse is 10ms wide. The dose from the pulse is measured over 10 ms. Then the following 10 ms after the pulse is measured and subtracted from the pulse dose to give the total injection dose. The typical dose from trickle injection is 0.02 mRad per injection shot for electrons and 0.01 mRad per injection shot for positrons at typical injection rates of 5-10 Hz.

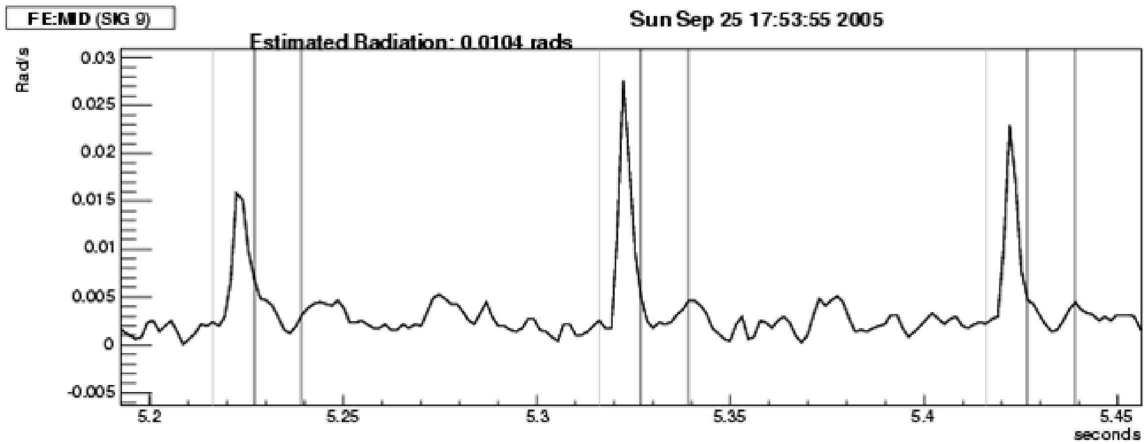

Figure 3. Trickle injection pulses.

4. Conclusions

The pCVD diamonds have performed outstandingly at BaBar. PIN diodes have been augmented by CVD diamonds due to the increasing operational difficulties caused by radiation damage. The diodes have shown large increases in leakage currents due to radiation damage, while the diamond leakage currents have not changed since installation in August 2002. They have proved to be a viable alternative to silicon PIN diodes. The SVTRAD system has continued to improve beam condition monitoring with the newly implemented trickle injection monitoring.

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