Fermi National Accelerator Laboratory

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Performance of a Silicon Microstrip Detector in a High Radiation Environment *

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The performance of a silicon microstrip detector has been studied in a high rate environment using electron, pion, and proton beams. The pulse height, time response, and leakage current have been studied as a function of particle fluence up to a total integrated flux of about 4×10^{14} *protons/*cm^2.

Silicon microstrip vertex detectors are a major new component of Fermilab experiment 789[1], designed to study the rare decays of the B and D mesons in a very high radiation environment. Several other experiments are also using silicon detectors as precision tracking devices. There are also several proposals to use silicon detectors for central tracking at the SSC. The radiation levels in these experiments will be very high and it is important to understand the performance of these detectors and their associated electronics in such an environment. Because of these proposals, in recent years there has been a lot of activity studying radiation damage to particle detectors[2].

We have studied the performance of a silicon microstrip detector (SMD) at the Los Alamos Meson Physics Facility to determine the effects of high fluxes of ionizing radiation. The details of this measurement will be published in a forthcoming publication[3]. A high intensity 0.8 GeV proton beam was used to study the effects of radiation damage on pulse height, timing resolution and leakage current. The detector was exposed for several different periods, at rates varying from 10^8 to 10^9 proton/sec/cm^2 over several hours, up to a total integrated flux of 4×10^{14}. In the pion test channel (beam momentum ranging from 500 to 700 MeV/c^2), rate effects on the pulse height and timing resolution were studied.

The SMD, build by Micron Semiconductors, was 5 cm $\times$ 5cm, approximately 300 micron thick, and made of N-type silicon with ion implanted P type strips at 50 micron pitch. Eight strips in the central region of the detector were instrumented with Fermilab ASIC preamplifiers. These preamps are a bipolar-current amplifying type developed on an ASIC by the Research Division[4] at Fermilab. The outputs of these preamps were digitized using CAMAC based ADC's, TDC's, and scalers. The ADC gate and TDC start were provided by the accelerator beam gate. The time interval between beam pulses was 360 ns and each beam spill lasted for 625μs at 60 Hz. The duty factor of the accelerator was about 3% with an average silicon strip occupancy of about 10%. Five strips throughout the detector volume were also instrumented to measure any increase in leakage current due to radiation damage. All the other strips were grounded.

The proton beam was monitored throughout the run with a beam profile monitor which recorded the beam spot size and position, and an ion chamber which measures the beam intensity. Eight 1 cm $\times$ 1 cm aluminum activation foils were also placed over the active area of the detector to determine the total integrated flux seen at different locations on the detector. The fluence varied from 10 Mrad at the center of the detector to 100 Krad at the top and bottom.

The pulse height and time response of the detector, generated by the beam gate "Start", and the discriminated silicon "Stop" were monitored throughout this measurement. A sharp reduction in proton peak pulse height was observed between 5.5×10^{12} and 1.4×10^{13} protons/cm^2. The loss in the amplitude of the proton pulse height could be recovered by increasing the bias voltage. Further reduction in pulse height was observed at higher fluences. Some of this loss in pulse height is also due to a reduction in preamp gain caused by a high level of leakage current. The silicon output was DC coupled to the preamp input. Radiation damage to the preamp at its location, about 24$''$ from the beam axis, was very small. The loss in amplification of the preamp due to radiation damage was measured to be about 10% for a fluence of 10^{13} protons/cm^2 on the preamplifier. At present, we are attempting to correct our silicon pulse height data for the gain loss due to the increase of leakage current. An increase in charge sharing between adjacent strips was observed at higher fluences. No significant change in the time response of the detector occured as a result of the irradiation. Hence there was no severe degradation of the drift time within the silicon, or of the shape of the leading edge of the pulse.

An increase of two orders of magnitude in the reverse bias current was noted after irradiation of the central strips. Fig. 1 shows the increase of the leakage current as a function of bias voltage at different particle fluences. The damage constant (α = Increase in leakage current/Particle fluence) calculated at 90 V bias voltage and 20^o C from this data is 1.8×10^8 nA/cm, which is in good agreement with other measurements[5]. At a particle fluence of 3.75×10^{14} the SMD exhibits a resistive characterstic rather than a diode characterstic. During the irradiation a large increase in the leakage current was observed when the detector bias was on, compared to when it was off. This rapid increase in the bias-on leakage current decayed at a faster rate than the annealing rate for radiation induced leakage currents measured with the bias off. This effect is believed to be due to the buildup of charge at trapping centers in the SiO_2 layer.

After the proton beam exposure, the detector was transfered to a temperature controlled box to study the dependence of the leakage current on temperature and to study annealing at room temperature. The leakage current as a function of bias voltage at different temperatures is shown in Fig. 2. There is an order of magnitude drop in leakage current for every 20^{o} C drop in temperature. The leakage current of the detector was also monitored to study room temperature annealing. A 50% decrease in the leakage current was noted after 120 days. The annealing rate seems to decrease as a function of time. The room temperature annealing data is shown in Fig. 3.

Summary

In conclusion, we observe that irradiation causes a Silicon Microstrip detector's performance to degrade due to an increase in leakage current, which is roughly proportional to the fluence. After irradiation the SMD required a higher bias voltage for full charge collection. The leading edge of the silicon pulse is uneffected by radiation. Such detectors can be operated successfully above 10^{13} minimum-ionizing particles/cm^2, perhaps even up to 10^{14}. We also find that cooling apparently is more effective method than annealing for continuing to use a radiation damaged detector.

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References

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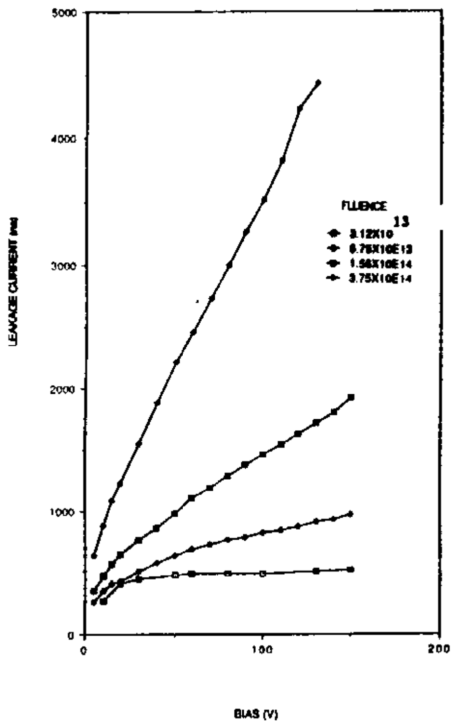

Fig. 1. Leakage current dependence on the bias voltage at several fluences.

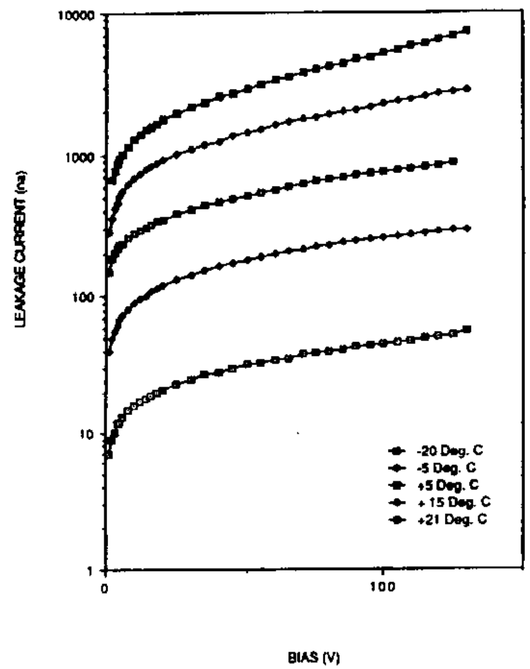

Fig. 2. Temperature dependence of the leakage current after irradiation.

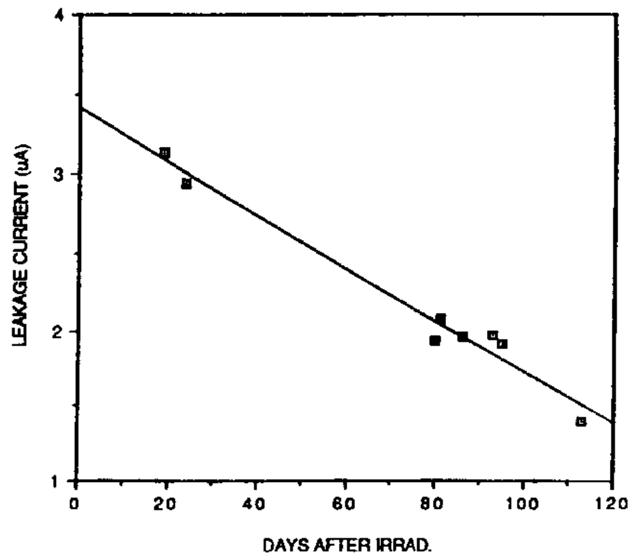

Fig. 3. Leakage current as a function of time elapsed after the exposure at 20° C temperature and 90 volts bias.