Electron Injection in Silicon Drift Detectors

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Abstract

We have examined the electron injection process in the silicon drift detectors that will be a part of the STAR experiment. Electron injection can be used to calibrate the temperature sensitive detectors. We found that appropriate biasing increases the likelihood that an injector will work. Injection characteristics such as well recovery time, signal evolution after a bias is applied, and lateral nonuniformity of injected charge were observed.

1 Introduction

The capabilities of Silicon Drift Detectors (SDD's) include excellent spatial resolution, large particle occupancy, and a relatively small number of electronic readout channels [1]. This makes them very well suited for use in the STAR experiment at the Relativistic Heavy Ion Collider (RHIC). The main physics goal of the STAR (Solenoidal Tracker at RHIC) experiment is the collision of heavy nuclei in order to provide sufficient energy density to cause a transition to a color deconfined, chirally symmetric quark and gluon plasma [2].

SDD's consist of (6X6) cm^2 of single-crystal silicon that is 300 μm thick. A total of 441 cathode strips along the top and bottom of the silicon wafer bias the detector negatively from the center of the detector. Generally, the center cathode is at -1500 V and the outermost cathodes are at 0 V, with the voltage increasing in several volt increments as one moves away from the center of the detector. The bias serves to deplete the bulk silicon and establish a constant electric field pointing away from the 240 collector anodes at either side of the detector. When an ionizing particle passes through the detector, the electric field causes the electron cloud released by the particle to drift toward the collector anodes. The position of the particle can then be determined by charge sharing among the anodes and the drift time of the cloud.

For a constant electric field, the velocity of the electron cloud is directly proportional to the field. However, the velocity also varies according to temperature (approximately $\mathrm{T}^{-2.4}$). This makes the detectors very sensitive to small (.1 K) changes in temperature. Therefore, on-line calibration is desirable.

This can be accomplished with electron injectors. Injectors are metallic gates that are deposited on the silicon dioxide present between cathode strips. The

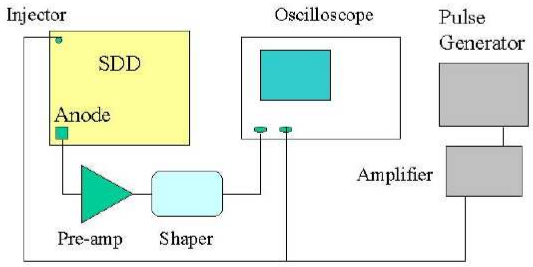

Figure 1: Block diagram of experimental setup

positive charge of the Si-SiO_2 interface creates a potential well at the surface below the injectors [3]. Electrons are trapped in this well. If a negative pulse is sent through the injector, the potential is changed and electrons can escape into the bulk of the silicon, where they behave like ones released by a particle. Thus, injectors can theoretically be used to calibrate for drift velocity. We have determined a way to improve the often inconsistent injection process and also observed the potential well recovery time, time dependence of the signal, and lateral uniformity of injection.

2 Experiment

2.1 Biasing

Figure 1 illustrates the experimental setup. Pulses from a pulse generator were amplified and sent into the injectors. The charge resulting from each pulse was collected by the anodes, then sent into a pre-amplifier and shaper. A Tektronix TDS 640A Digitizing Oscilliscope was used to examine the outputs of 2 anodes at a time.

Initially, pulse amplitude and width were varied at each injector. Table 1 shows that 3 injectors worked at some combination of pulse amplitude and width. Previous investigation has determined that the height of the potential well is about 20 V [4]. The observation that even 40 V pulses often did not create a signal suggests that at some injectors either a potential well did not exist or the well was actually deeper than 40 V.

The next step was injector biasing. Biasing was accomplished with a 5 MΩ potentiometer attached to higher and lower resistors on the external voltage divider board that is used to place the cathodes at incremental potentials. As indicated in Table 1, 4 injectors that previously were not working were able to inject after appropriate biasing. Biasing also decreased the minimum pulse height needed to create a signal from 10-15 V to as little as 2 V. A possible explanation for these observations is that biasing controls the height of the potential well and can even create a well if one does not exist. Figure 2 illustrates

Injector #	SI97#06	#673	S15
1	0	before	0
2	after	after	-
3	after	before	before
4	after	0	-

Table 1: A summary of which tested injectors worked. A "before" indicates that the injector worked before biasing. An "after" indicates that the injector worked only after biasing. A "0" indicates that the injector never worked. Dot injectors that could not be tested are marked with a "-".

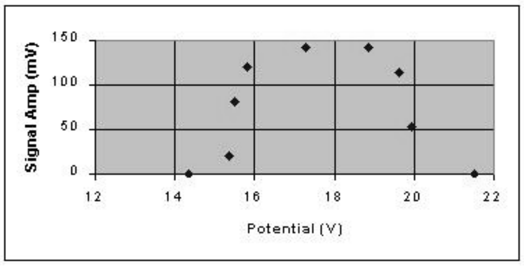

Figure 2: Signal amplitude as a function of injector potential for a constant pulse. All potentials are measured with respect to an adjacent cathode. The leftmost point on the plot is at the unbiased potential.

the effect of biasing on an anode signal for a constant pulse height and width.

It is important to note that the signal produced by an injector at one pulse height and injector bias would generally not be the same as in another detector. This nonuniformity has to do with the fabrication process of the detectors. For example, on one detector an injector only injected between 10-12 V (with respect to a nearby cathode), while on another detector the same injector worked over a range of 8-14 V. Even though the injection characteristics of different detectors were often qualitatively similar, few quantitative generalizations can be made.

2.2 Well Recovery Time

With more working injectors, other injection characteristics could be studied. One such characteristic is well recovery time. After each pulse, a finite time is required for the wells to be replenished. If the well is pulsed before this, the signal will be diminished. The effect of decreasing the time between pulses is seen in Figure 3. An exponential of the form $y = A * (1 - e^{-t/\tau})$, where τ is a measure of the well recovery time, was fitted to the graph. A value of approximately 150 μs was obtained for τ. Again, different injectors yielded similar curves, but with different values.

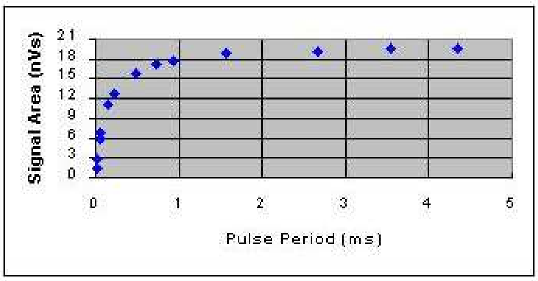

Figure 3: Signal area for various times between pulses

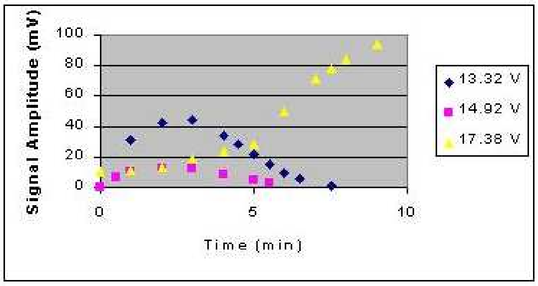

Figure 4: A comparison of the signal evolution for an injector placed at various potentials

2.3 Time Dependence of Signal

Injectors that only worked with an appropriate bias exhibited another type of time dependence. It was found that the size of the signal from a constant pulse changes from its value when the bias was originally applied. It generally takes between 5 to 100 minutes for the signal to reach a final, steady-state value. Furthermore, as Figure 4 shows, the final value of the signal depends on what potential the injector was placed at. The signal amplitudes from 13.3 V and 14.9 V biases initially grow but decay to 0 within 10 minutes. The signal amplitude from a 17.4 V bias continues to grow and does not reach a final value until well past the time scale of Figure 4. When the potential is removed, the signal gradually relaxes to its original size. These findings are difficult to explain, but may have to do in part with the time required to equilibriate the surface charges trapped in the SiO_2 layer. This 100 minute time scale coincides with the well known time scale required for surface currents in oxide layers to reach a steady state after a voltage is applied.

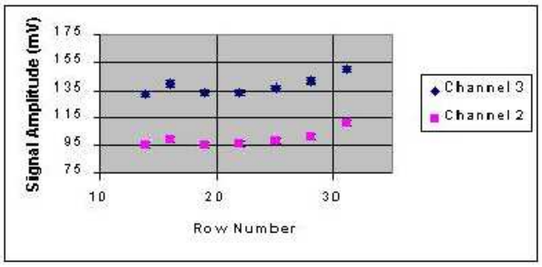

Figure 5: Signal amplitude vs anode row number. Two anodes in each row were examined. Each channel corresponded to a different pre-amp and shaper, which accounts for the difference between the two channels.

2.4 Lateral Nonuniformity of Signal

The variation in signal between anodes for a constant pulse was also studied. Figure 5 shows the observed signal amplitude variation between anodes. These results agree with previous ones [4]. A small (.01 μs) but significant drift time variation was also obtained. The light from a GaAs laser diode was then focused close to the pulsed injector and the signal from the laser was measured at 2 anodes that had displayed a drift time difference. Again, there was an approximately .01 μs time difference between the signals at the two anodes. We therefore think that the drift time difference was probably due to either the properties of the bulk material itself or the electronics, and not the injection process.

3 Conclusions

We determined that appropriate biasing increases the likelihood that injectors will work. We also observed several properties of the injection process. Our work suggests that although this process is not completely understood, electron injection is a viable means to calibrate the detectors.

4 Acknowledgment

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