Silicon Drift Detectors as Tracking Devices

J. Takahashi [a,1] R. Bellwied [b] R. Beuttenmuller [a] H. Caines [c] W. Chen [a] H. Dyke [c] G.W. Hoffmann [d] T. Humanic [c] P. Jensen [d] P. Kuczewski [a] W. Leonhardt [a] Z. Li [a] D. Lynn [a] G. Lo Curto [c] R. Minor [e] J. Schambach [d] R. Soja [a] E. Sugarbaker [c] R.M. Willson [c] S.U. Pandey [b]

[a] *Brookhaven National Laboratory, NY 11973, USA*

[b] *Wayne State University, MI 48201, USA*

[c] *Ohio State University, OH 43210, USA*

[d] *University of Texas, TX 78712, USA*

[e] *Lawrence Berkeley Laboratory, CA 94720, USA*

Abstract

Silicon drift detectors provide unambiguous two dimensional position information for charged particle detection in a single detector layer. Like most other semiconductor technologies Silicon drift detectors are presently used in vertexing detectors. By taking into account the drastic reduction in channel count compared to other silicon based devices this specific technology is also well suited for large coverage tracking detectors. The first larger area Silicon Drift Tracker (6.3cm x 6.3cm) was developed as the inner tracking detector (SVT) of the STAR experiment at the RHIC collider. Advantages and limitations of this detector will be discussed. Recent results of detector performance based on an application in a heavy ion fixed target experiment at the BNL-AGS (E896) are presented.

1 Introduction

To use silicon detectors as tracking devices, it is desirable to cover as large an area as possible while maintaining good position resolution at minimal cost. Traditional position sensing silicon detectors such as microstrip or pixel detectors can provide relatively large area coverage and good position resolution,

[1] jtakahas@rhic.physics.wayne.edu

but the number of readout channels increase quadratically as a function of either requirement. In search for a more cost effective detector that can satisfy both requirements, Silicon drift detectors (SDD's) were originally proposed by P. Rehak and E. Gatti (1).

Silicon drift detectors are charged particle detection devices capable of providing two dimensional position information with a single detector layer and a reduced number of readout channels. Its operating principle is based on creating a drift channel inside a depleted silicon wafer, thus working like a solid-state drift chamber. Figure 1 shows a schematic cross section of the SDD. With an electric field applied by cathodes on both surfaces of the detector, electrons generated by an ionizing particle will be forced to drift from the particle position to the edge of the detector where they are collected by readout anodes. During the drift the charge cloud expands due to diffusion and Coulomb repulsion effects, which leads to charge sharing over many anodes and time pixels. By measuring the drift time together with the distribution of signals along the readout anodes, position information is obtained in both dimensions. Due to the spreading of the cloud over many readout channels, a relatively large readout channel separation (standard pitch is $250\mu m$) will still yield excellent resolution in both coordinates (presently around $20\mu m$).

This remarkable position resolution and high granularity achievable with silicon drift detectors make these devices an excellent choice for high energy and high multiplicity tracking environments. Furthermore, the low input capacitance of the readout anodes (below 1 pF) provides a good signal to noise ratio not only for position measurements but also for energy loss measurements. The measurement of the ionization using relatively thin detector layers can be applied for particle identification without causing large effects of multiple scattering. Finally, studies on SDD's show very good performance characteristics in the event of high radiation levels, in particular when compared to charged coupled devices (CCD) (2).

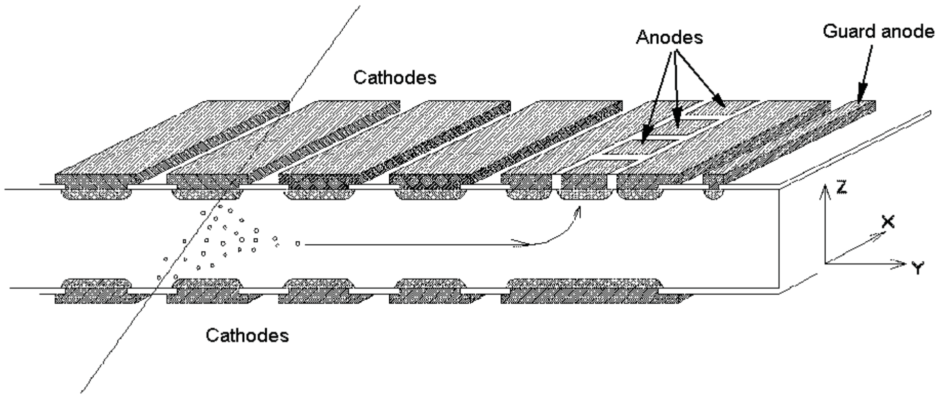

Fig. 1. Schematic view of a silicon drift detector and its operation.

2 The STAR Silicon Vertex Tracker

The Solenoidal Tracker at RHIC (STAR) (3; 4) is an experiment at the Relativistic Heavy Ion Collider (RHIC) designed to search for signatures of the Quark-Gluon-Plasma (QGP) formation. In STAR, a combination of detectors is used to measure hadron production over a large solid angle in an attempt to study several reaction observables in 100 GeV/n Au on 100 GeV/n Au collisions on an event-by-event basis.

The Silicon Vertex Tracker (SVT) of STAR is a semiconductor based tracking detector placed near the interaction point that will complement the outer tracking detector of STAR, the Time Projection Chamber (TPC). The SVT consists of three concentric barrels of position sensing silicon drift detectors. Each single SDD has an area of $6.3 \times 6.3\ cm^2$ and are mounted on long ladder structures with a total of 4, 6 or 7 detectors. These detector ladders are then arranged into three polygon shaped barrels with approximate radii from the interaction point of 6.6, 10.6 and 14.5 cm. A total of 216 wafers is used, leading to a total of 103,680 readout channels. The SVT provides full azimuthal coverage and a span in pseudo-rapidity range of $-1 < \eta < 1$.

The SDD's are produced using a 100 mm diameter, 280 μm thick, neutron transmutation doped N-type silicon wafer with an approximate resistivity of 3 $K\Omega cm$. The detector is divided in two symmetrical halves in which the electrons drift in opposite directions. On both surfaces of the detector, potential defining electrodes are implanted forming a p-n diode type junction with the bulk of the detector. These electrodes are connected in series through implanted resistors that gradually reduce the magnitude of the negative potential from the center of the detector towards the edge where an array of 240 anodes is placed to collect the charge. Characterization measurements of the STAR-SDD performed with laser injection on a test bench demonstrate that the single hit position accuracy is on the order of 25 μm and the double track resolution is on the order of 400 μm. Further details of the detector geometry can be found in references (5; 6).

3 Tracking with Silicon Drift Detectors

The excellent position resolution and high granularity achievable with silicon drift detectors allows tracking at high multiplicity environments. Hence, SDD based tracking devices can be positioned very near the interaction point, which leads to improvements in the global tracking performance of all STAR detector components as well as measurements that are unique to the silicon tracker.

The first obvious advantage is the improvement in the primary vertex position resolution. As an example, in STAR, the extrapolation of the tracks from the TPC detector can resolve the primary vertex position to an accuracy of approximately 500 μm. With the combined tracks of the TPC and the SVT, the primary vertex position resolution is improved to approximately 100 μm.

Another advantage is the extension of the experiment sensitivity to low transverse momentum particles. Most of the collider experiments have tracking devices in magnetic fields with solenoidal topology. In such case, low transverse momentum particles have a very small helicoidal trajectory, thus can only be measured at distances very near the interaction point. In STAR, interesting phenomena such as condensation effects in general and the formation of Disoriented Chiral Condensates in particular require the study of the low transverse momentum region of the charged particle spectrum (7).

The proximity of the tracking device to the primary vertex also improves the acceptance of short-lived particles. Reconstruction of decay vertices reduces the combinatoric background and thus increases the detection efficiency for these particles. Most of the short-lived particles have very low cross sections and the relevant physics topics can only be studied with high statistics. In STAR, the efficiency for detecting short-lived strange hadrons such as K_s^0, Λ, Xi^- and Ω^- is improved greatly due to the tracking in the SVT (8). The relative cross sections of these particles and their anti-particle equivalents are sensitive probes that can be indicative of QGP formation. In addition, the measurement of K_s^0 mesons is very interesting for neutral particle interferometry that can also provide one of the signatures of QGP formation. The two particle Bose-Einstein correlation analysis (HBT) with K_s^0 mesons in STAR is only possible due to the high acceptance achievable with the SVT (9).

4 Recent Application of the SDD in experiment BNL-AGS896

Recently, a set of prototypes of the STAR silicon drift detectors were installed in a relativistic heavy ion, fixed target experiment at the Alternating Gradient Synchroton Accelerator at Brookhaven National Laboratory. It was the first time that this technology was applied to charge particle tracking in a real experimental environment. 15 detector layers, each consisting of a single SVT wafer and its corresponding electronics (10) were assembled in a telescope-like topology inside a 6.2 T magnetic field, very close to the gold target. The detailed setup of E896 has been previously described (11). Results from data analysis show excellent detector performance that includes low noise levels, good position and energy resolution and high track reconstruction efficiency.

Figure 2 shows a typical reconstructed central event projected in the horizon-

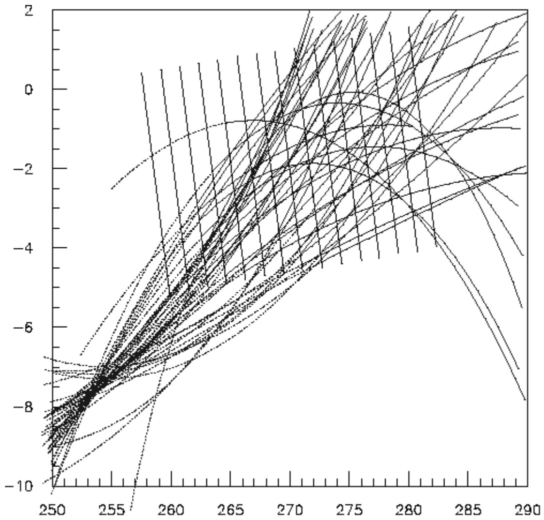

Fig. 2. Reconstructed Tracks in the E896 Silicon Drift Detector array projected in the horizontal plane.

tal plane. The detectors were placed at an angle (approx. 22^o) with respect to the beam direction to maximize coverage in rapidity and transverse momentum space. An average multiplicity of 70 tracks per event and an occupancy of 2.3% were measured, which is very comparable to the anticipated occupancies at RHIC. Figure 3a shows a dE/dx plot used for particle identification for the ongoing spectra analysis of primary particles (π,K,p). Figure 3b shows a preliminary result of the invariant mass spectrum for reconstructed Λ-particles. This demonstrates nicely that even in such high track density environment it is possible to reliably reconstruct secondary vertices.

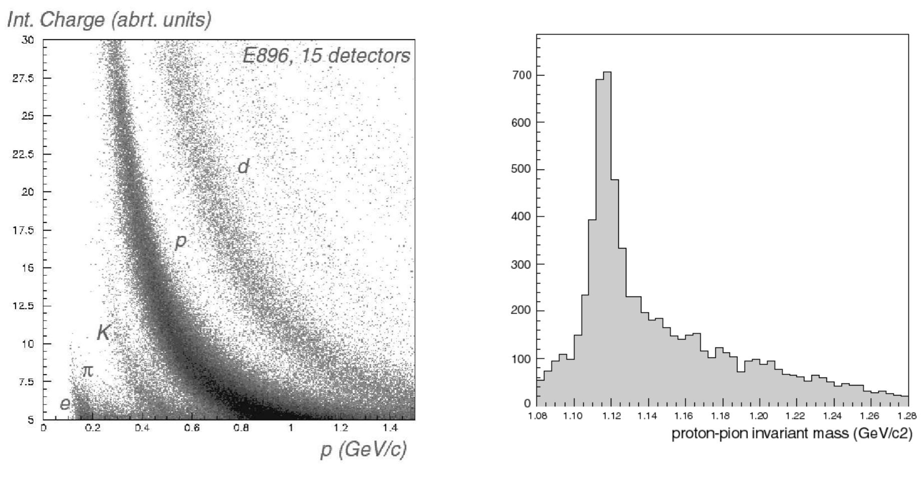

Fig. 3. (a) dE/dx as a function of particle momentum measured with the E896 Silicon Drift Detector Array. (b) Λ invariant mass spectrum based on secondary decay vertices reconstruction (preliminary result).

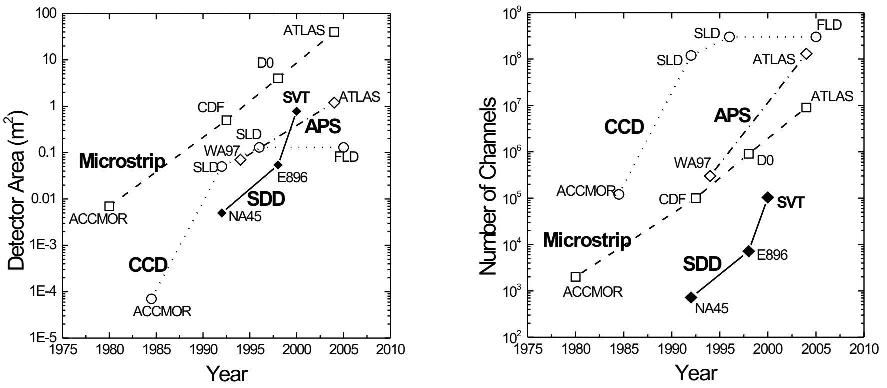

Fig. 4. Time development of area coverage (a) and number of channels (b) of leading edge vertex tracking detectors, according to the main technologies, Microstrip, CCD, Active Pixel and Silicon Drift detectors. Information extracted from (13)

5 Future Application

The goal of the present research and development on silicon drift detectors is the extension of its application towards a full semi-conductor based tracking device, in which pairing this technology with gas drift detectors like a TPC is no longer required. To utilize any semiconductor technology as tracking devices, it is necessary to cover as large area as possible with cost effective granularity. Figure 4a summarizes the area coverage of vertex and tracking detectors according to the main technologies developed in the last two decades. Silicon drift detectors have comparable area coverage to active pixel detectors and CCD based detectors, however the number of readout channels is an order of magnitude smaller, as demonstrated in figure 4b. Compared to microstrip detectors, silicon drift detectors have the advantage of no ambiguity in the position information, which facilitates tracking with single detector layers.

Recently, a first study of a possible design of an independent SDD tracking detector for future high-energy collider experiment was presented (12). This study was based on the progress and the success of the STAR-SVT project.

6 Summary and Conclusions

The extensive characterization tests, the recent experimental results and the development of the SVT tracker for STAR show that silicon drift detectors have matured into a reliable technology that can be commercially produced and assembled into cost efficient, large coverage detector systems. Taking into account the superior resolution achievable with any silicon detector compared to gaseous tracking detectors, its utilization as the main tracking device in high energy and heavy ion collider experiments should be considered in the future.

A first step towards an integrated tracking system was achieved using silicon drift detectors in the BNL-AGS heavy-ion experiment E896. Results show good detector performance and the analysis of the data shows interesting prospects for relevant physics topics in nuclear physics.

As a next step the SVT, a large area silicon drift detector based tracking and vertexing device for the STAR experiment at RHIC will be completed and installed by the end of this year.

7 Acknowledgments

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