Performance tests of large pitch silicon strip sensors for the LHCb inner tracker

P. Sievers¹

*Physik-Institut Universität Zürich, Winterthurerstr. 190, CH-8057 Zürich,
Switzerland*

On behalf of the LHCb Inner Tracking Group²

Abstract

Different multi-geometry silicon prototype sensors were designed and produced for the LHCb Inner Tracker. Silicon ladders have to be 22 cm long and the pitch of the sensors should be as large as possible in order to reduce costs of the readout electronics. Major design criteria are material budget, short shaping time in the order of 25 ns and a moderate spatial resolution of $80\,\mu\text{m}$. Sensors should be as thin as possible in order to minimize the multiple scattering of particles in the detector. The electrical characteristics of the sensors are presented. Laboratory and test beam results on resolution, signal-to-noise and efficiency are discussed. It has been found that the efficiency, especially in the inter-strip gap, is very sensitive to different tested geometries. Based on the results the decision will be made which geometry will be implemented in the final sensors for the LHCb Inner Tracker.

1 Introduction

High particle rates severely constrain the technology choice for tracking detectors designed for application at the LHC collider. In the LHCb Inner Tracker [1] charged particle densities can attain $10^6\text{ cm}^{-2}\text{s}^{-1}$. The decisive factors for choosing silicon strip sensors for the LHCb Inner Tracker are their capability to cope with high occupancies, their reliability and radiation tolerance. The silicon sensors designed for the LHCb Inner Tracker have to withstand an expected fluence of $5\cdot 10^{13}\text{ cm}^{-2}$ of charged hadron particles after 10 years of operation. In contrast to many silicon strip applications a moderate

¹ E-mail: sieversp@physik.unizh.ch.

² <http://lhcb.web.cern.ch/lhcb-track/html/innertracker.htm>

spatial resolution of $80\text{ }\mu\text{m}$ is sufficient for the Inner Tracker since the momentum resolution of the tracking system is dominated by multiple scattering. In addition, the pitch of the sensors should be as large as possible in order to reduce costs of the readout electronics. This suggests the use of sensors with a large readout pitch of typically $240\text{ }\mu\text{m}$.

In order to avoid pile-up of consecutive bunch crossings at LHC the shaping time of the front-end electronics has to be in the order of 25 ns (FWHM). The basic units of the Inner Tracker will consist of either 110 mm (one sensor) or 220 mm (two sensors) long silicon ladders. The combined requirements of the fast shaping, thin sensors and long readout-strips with accordingly high capacitive load seen by the fast front-end electronics restrict the attainable signal-to-noise performance of the ladders. However, a high charge collection efficiency (CCE) over the full sensor has to be reached to ensure an efficient tracking performance. Therefore, the sensor strip geometry has to be carefully chosen in order to optimize this performance.

Two different multi-geometry prototype sensors have been developed for the LHCb Inner Tracker. A p^+n technology has been chosen to keep production costs at a tolerable level as it is the most common production method. Due to the requirement of minimized material mass involved in the Inner Tracker the sensors were produced from $300\text{ }\mu\text{m}$ and $320\text{ }\mu\text{m}$ thick wafers, respectively. All prototype sensors were capacitively coupled (AC) in order to decouple the front-end amplifier inputs from the leakage current of the sensor.

2 First prototypes

First studies on signal-to-noise, resolution and charge collection efficiency for wide-pitch silicon sensors were performed using multi-geometry prototype sensors from SPA Detector in Kiev/Ukraine [2]. These sensors were produced in single-sided p^+n technology from $300\text{ }\mu\text{m}$ thick $4''$ wafers. Strips are 66.6 mm long and have a constant pitch of $240\text{ }\mu\text{m}$. Three different ratios of strip width over pitch of $w/p=0.2, 0.25, 0.3$ were implemented on each sensor. C-V curves of the sensors indicate a full depletion voltage of about $50\text{--}70\text{ V}$ and the total strip capacitance was measured to be about $1.3\text{--}1.7\text{ pF/cm}$. The total strip capacitance is here defined as the sum of the capacitance to the backplane and capacitance to the adjacent strips. Unfortunately, these prototype sensors exhibited a very low break down voltage of about $110\text{--}130\text{ V}$.

2.1 Test beam measurements

Two ladders of these prototype sensors were evaluated in a test beam performed in the T7 beam line at CERN using a 9 GeV π^- beam [3]. One ladder was equipped with one sensor the other with three, the latter resulting in a total strip length of 20 cm. The sensors were read out using the HELIX128 chip [4]. The shaping time of about 70 ns does not fit the requirements of LHCB, but the noise performance of the HELIX chip is similar to that of the final readout chip. A beam telescope allowed a precise measurement of the ladders resolution and signal-to-noise performance.

The obtained spatial resolution was $50\text{ }\mu\text{m}$ which is better than the design value for the LHCB Inner Tracker. However, a significant charge loss in the inter-strip gap of the sensors was observed which directly translates into an efficiency loss for the long ladder at fastest shaping in that region, as indicated in figure 1. The efficiency loss depends on ratio w/p and decreases towards higher w/p values, where charge collection seems to be more effective. Figure 2 shows the efficiency of the long ladder for different bias voltages. The efficiency loss in the middle of the inter-strip gap decreases for higher bias voltages. Therefore, strong overbiasing of the sensors may help to overcome this problem that we interpret as due to a region of low electric field in between the strips. Unfortunately, higher bias voltages could not applied to the prototype sensors because of their early junction breakdown.

Fig. 1. Efficiencies of the 20 cm long ladder for the different $w/p = 0.2, 0.25, 0.3$ regions. The efficiencies are shown as function of the track position in between two strips for fastest (filled dots) and for a slower (open squares) shaping time. The bias voltage was 90 V.

Based on the results obtained in this test beam the sensor specifications were reviewed. Since it has been found that the efficiency, especially in the inter-strip gap, is very sensitive to ratio w/p new multi-geometry prototype sensors were ordered.

Fig. 2. Efficiencies of the 20 cm long ladder as function of the track position in between two strips for the $w/p=0.2$ region and different bias voltages of 80 V, 90 V and 100 V. Data was taken with slow shaping.

Overall dimensions		110 mm $\times$ 78 mm				
Active area		108 mm $\times$ 75.6 mm				
region	strip No.	pitch [μ m]	number of strips	p^+ width [μ m]	AC Al width [μ m]	w/p
A	1-64	198	64	50	58	0.252
B	65-128	198	64	60	68	0.303
C	129-192	198	64	70	78	0.354
D	193-272	237.5	80	70	78	0.295
E	273-352	237.5	80	85	93	0.358

Table 1

Sensor geometry of Hamamatsu prototype sensors.

3 Full-sized multi-geometry prototype sensors

New 6" multi-geometry prototype sensors were manufactured according to specifications of the LHCB Inner Tracker group by Hamamatsu Photonics, Japan [5]. They have a physical dimension of 110 mm $\times$ 78 mm as foreseen for the final detector, a thickness of 320 μ m and consist of five regions with different strip geometries. Two different pitches of 198 μ m and 237.5 μ m respectively were implemented on the sensor. In addition the width of the p^+ strips is varied. Table 1 summarizes the geometry parameters of the prototype sensor.

3.1 Sensor test results

In figure 3 the leakage current is shown as function of the bias voltage. No breakdown up to 300 V was observed. The bias voltage was not increased above 300 V. Because of the moderate radiation damage expected in the LHCB Inner Tracker operation voltages above this voltage will not be necessary.

Fig. 3. Leakage current of Hamamatsu prototype sensors as function of the biasing voltage. The measurement was performed at room temperature.

The signal-to-noise ratio degrades with higher load capacitances resulting from long sensor ladders. Therefore the knowledge of the total strip capacitance is of utmost interest. The C-V-curve was measured for all sensors indicating a full depletion voltage in the order of 60 V. The total capacitance at full depletion voltage can be expressed as a linear function of the ratio w/p as illustrated in figure 4. A linear fit yields $C_{tot} = (1.02 + 1.65 \cdot w/p)$ pF/cm, which is in agreement on a 15% level with previous measurements on the first prototypes [2].

3.2 Electronics

The Hamamatsu prototype sensors were connected to the BEETLE v1.1 read-out chip [6] fabricated in radiation hard $0.25\,\mu\text{m}$ technology. This chip is custom developed for the LHCb vertex detector and the Inner Tracker. It integrates 128 channels with low-noise charge-sensitive preamplifiers and shapers followed by an analogue pipeline with a maximum latency of 168 sampling intervals. The rise time of the shaped pulse is in the order of 25 ns pursuant to the requirements of LHC.

A front-end hybrid in a four layer copper on polyimide technology³ was designed to house three BEETLE v1.1 chips. In order to match the different pitches of readout chip and prototype sensors a pitch adapter⁴ made of thin

³ Manufactured by Andus electronic, Berlin Germany.

⁴ Manufactured by Siegett TFT(www.siegett-tft.de), Hermsdorf Germany.

Fig. 4. Total strip capacitance per unit length as function of the ratio strip width to strip pitch (w/p). Different markers refer to different sensors. The line is an averaged linear fit.

film ceramics was designed.

3.3 Test beam results

In total three test ladders were assembled, where two ladders were equipped with two sensors and one ladder with one sensor. The large surface of the sensors allowed a functionally test of the ladders in a cosmic ray setup. In May 2002 two sensor ladders, a long and the short one, were then installed at the X7-CERN test facility and operated in a 120 GeV charged π beam. The BEETLE signal was scanned varying the trigger delay in steps of 5 ns while the latency of the BEETLE was kept constant. The delay scan for the short ladder is illustrated in figure 5. S/N-values of 13.7 and 9.8 at a bias voltage of 120 V are obtained for the short and the long ladder, respectively. The maximum of a Landau was used to define the most probable value of the S/N-ratio. The analysis of the test beam data is still ongoing.

The results of this test beam will provide the basis of the decision for the final strip geometry for the LHCb Inner Tracker.

Fig. 5. Left: pulse shape scan of the short ladder. S/N is shown as function of the trigger delay. Right: S/N -ratio of region C (see table 1) for the long ladder at a bias voltage of 120 V.

4 Conclusion and outlook

At a strip pitch of $240\text{ }\mu\text{m}$, a spatial resolution is obtained that outperforms the requirements for the LHCb Inner Tracker. For the first prototype sensors it has been found that the efficiency is very sensitive to the ratio w/p and to the bias voltage. The tests of these prototypes were severely limited by their early HV breakdown. The measurements of the electrical characteristics of new full-sized prototype sensors are very promising. The decision which strip geometry will be finally implemented in the LHCb Inner Tracker sensor will be based on the results of the test beam performed with the new sensors. A technical design report for the silicon Inner Tracker is going to be submitted by end of this year.

References

- [1] P. Sievers, The LHCb Silicon Inner Tracker, Nucl. Instru. and Meth. A 485 (2002) 23-26.
- [2] F. Lehner et al., Description and Characterization of Inner Tracker Prototype Sensors, LHCb-2001-036.
- [3] C. Bauer et al., Test Beam Results on Inner Tracker Silicon Prototype Sensors, LHCb-2001-135.
- [4] <http://wwwasic.kip.uni-heidelberg.de/~trunk/projects/Helix/>
- [5] F. Lehner et al., Description and Evaluation of Multi-Geometry Silicon Prototype Sensors for the LHCb Inner Tracker, LHCb-2002-038.
- [6] Niels van Bakel et al., The Beetle reference manual, Version 1.0, LHCb-2001-46.