Upgrade of pixel sensor telescope for the characterization of ALPIDE sensor

J Kaewjai¹, C Kobdaj¹ and K Kittimanapun²

¹ School of Physics, Institute of Science, Suranaree University of Technology, Nakhon Ratchasima, Thailand
² Synchrotron Light Research Institute, Nakhon Ratchasima, Thailand

E-mail: jetnipit.kaewjai@cern.ch

Abstract. A Large Ion Collider Experiment (ALICE) is an experiment station at CERN that detects quark-gluon plasma, a state of matter thought to have formed immediately after the big bang. A plan was proposed to upgrade the particle detector in the Inner Tracking System (ITS) of ALICE by 2020. In the upgrade, new silicon sensor technology, the Monolithic Active Pixel Sensor (MAPS), will be used to replace the ITS. The new sensor is called ALICE PIxel DEtector (ALPIDE). This project focused on the characterization of ALPIDE sensors with a new version of a pixel sensor telescope using the 1.2 GeV electron beam at the Synchrotron Light Research Institute Beam Test Facility (SLRI-BTF). Seven ALPIDE sensors were lined up as a stacked sensor to perform a test using the electron beam at SLRI-BTF. The previous version of the telescope could only characterize the middle area of the sensor; however, the new sensor telescope can be used to characterize edges and corners of the sensor. This advantage provides us with a complete view of the detection efficiency in all sections of the ALPIDE sensor. The detection efficiency of the sensor will be investigated and analyzed by EUTelescope software.

1. Introduction

A Large Ion Collider Experiment (ALICE) is developing a significant upgrade of its apparatus; the complete installation of the upgrade is planned during the Long Shutdown 2 (LS2) of the Large Hadron Collider (LHC) in 2020. The Inner Tracking System (ITS) upgrade [1] includes 1. development of an elaborate parameter measurement technique for the collision, 2. upgrade of readout time capability, and 3. adjustment of the detector layout. TowerJazz 180 nm CMOS technology has been proposed to replace the current ITS with a Monolithic Active Pixel Sensor (MAPS); this is an image sensor that integrates both the readout electronic and silicon parts on a single sensor unit.

Suranaree University of Technology (SUT) and Synchrotron Light Research Institute (SLRI) have collaborated to conduct research on the characterization of these sensors using the electron test beam at the Synchrotron Light Research Institute Beam Test Facility (SLRI-BTF). The SLRI-BTF is a part of the SLRI accelerator complex [2], and the characterization of the MAPSs with a 1.2 GeV electron beam was conducted here [3].

To characterize sensors [4] with an electron test beam, a pixel sensor telescope consisting of testing and tracking sensors was constructed and set up at the end station of the SLRI-BTF. This is used to measure the hit positions created by particles on its path and reconstruct the trajectory of particles. Using reference trajectories from the tracking sensors, one can calculate...
the positions the particle passes through a device under test (DUT) and consequently measure and characterize the sensor response. In this work, details of the design and setup of the beam telescope based on the MAPS characterization at SLRI-BTF are presented. The commissioning results of the beam telescope with the 1.2 GeV electron beam are also shown and discussed.

Prototypes of pixel sensors used for the ITS upgrade [5] have been tested in many facilities around the world. CERN PS and CERN SPS use pions with energies of 6 GeV and 120 GeV, respectively. Rez (Prague) uses protons with an energy of 0.03 GeV. Frascati BTF, DESY, Pohang, and SLRI-BTF use electrons with energies of 0.5 GeV, 5 GeV, 0.06 GeV, and 1.2 GeV, respectively. For sensor characterization using electrons, the results obtained at DESY with the 4–6 GeV electron beams are similar to those obtained at SLRI-BTF with 1 GeV electron beams [6]. Therefore, the results obtained by the SLRI can be considered useful. The advantages of the SLRI-BTF is that a considerable amount of time is available for sensor characterization.

Table 1. Electron beam Parameters for high-energy beam transport line (HBT).

| Beam parameters          | Value                        |
|--------------------------|------------------------------|
| Energy                   | up to 1.2 GeV                |
| Energy spread            | -0.05% at 1 GeV              |
| Current                  | 10 mA                        |
| Pulse duration           | 8.5 ns                       |
| Bunch length             | 0.5 ns                       |
| Repetition rate          | 0.5 Hz                       |
| # of electron per spill  | $10^8$                       |

2. Synchrotron Light Research Institute - Beam Test Facility
2.1. Experimental setup
SLRI-BTF is an experiment station used for testing properties of sensors; it is located in basement of the SLRI accelerator building next to the vertical bending magnet, as illustrated in figure 1. The area of the experiment station is 3.5-m×3.5-m×3-m and this area is reserved for the installation of the detector and tested instrumentation including a local computer, power supply, and the electron beam for the detector system. The components of the SLRI-BTF includes 1. electron gun for producing electrons, 2. a tungsten target that controls the electron intensity by varying the depth of the tungsten target manipulator, and 3. electron beam test station [7]. Table 1 summarizes the properties of the SLRI electron beam.

2.2. Current pixel telescope
The pixel sensor telescope installed currently at the SLRI-BTF experiment station has been used to investigate the efficiency of the MAPS. The first version of the telescope was characterized and studied with a 1 GeV electron beam at SLRI. The telescope consists of seven planes of the prototype ALICE PiXel DEtector (pALPIDE) as references. The ALICE Pixel Detector (ALPIDE) is used as the DUT. The spacing between each plane is 20 mm. Communication between the telescope and the PC is conducted via 3.0 USB ports. All sensors are powered on by the Hameg Power Supply HMP2030.
Figure 1. Location of the beam test facility at SLRI.

3. Upgrade of pixel sensor telescope

3.1. Trajectory prediction

Prior to the construction of the new pixel telescope, a telescope optimizer was used to predict the trajectory of particles to the pixel sensor telescope. Additionally, the telescope optimizer makes it easy to specify a suitable boundary for the experiment. The telescope optimizer calculates the trajectory of particles using the Monte Carlo (MC) method. The track position establishes the trajectory of particles that move through the pixel sensor telescope [8]. The track position determines whether a charged particle has traversed the material; in this case, many small random deflections will be observed. This is called multiple scattering [9]. Multiple scattering affects the energy loss of a particle in a matter and the deflection direction of an incident particle. The interaction mechanism depends on the momentum, energy, and charge of an incident particle.

The calculation boundary is input by the telescopic parameters. The spacing between the reference planes is 20 mm, and the spacing of between the DUT and the reference planes is 40 mm. The spatial resolution of all planes is 5 µm and the material budget ($x/X_0$) per layer is 0.5 %. Figure 2 shows the general track position and figure 3 shows the track position calculated using the MC method. The green line indicates the particle trajectory obtained using the real values from the MC method. The black lines indicates the possible trajectories of particles moving through the pixel sensor telescope.
3.2. Modification of telescope setup
This work focuses on the characterization of ALPIDE sensors with the new version of the pixel sensor telescope using the 1.2 GeV electron beam at SLRI. A diagram of the new sensor telescope is shown in figure 4. The new sensor telescope consists of seven planes of ALPIDE sensors. The chip is placed in the middle plane (the DUT) while the other planes are the reference planes. The telescope is upgraded so that it can move the DUT plane along the x-direction (left–right) and the z-direction (up–down). It has a resolution of 0.1 mm, and a 10 mm stage (range in the vertical and horizontal directions). The new pixel sensor telescope is currently being constructed at the SLRI-BTF.

![Figure 4. Layout of the second version of the telescope (left: concept, middle: schematic, right: real).](image)

![Figure 5. Sensors are investigated with the 1.2 GeV electron beam at SLRI.](image)

With the current telescope, only two regions on a center of a sensor (shaded area in figure 5) can be measured; the telescope cannot be used to characterize other areas. However, the competence of the new telescope enables other sections of the sensor in the DUT to be measured such as its edges and corners. This advantage provides us with a complete view of the detection efficiency in all sections of the ALPIDE sensor. Thus, the new pixel sensor telescope can determine the complete quality of the ALPIDE sensor.

4. Conclusion
This work aimed to characterize the ALPIDE sensor by using the new pixel sensor telescope. This characterization will provides a complete view of the detection efficiency in all sections of the sensor. A telescope optimizer was used to specify the suitable boundary of the pixel sensor telescope. Additionally, the telescope optimizer can predict the particle trajectory. Currently, the optimal boundary conditions are being applied to the new pixel sensor telescope that is being constructed at the SLRI-BTF.

References
[1] Abelev B et al 2014 J. Phys. G. 41 8
[2] Kittimanapun K, Chanlek N, Klysubun P, Krainara S and Supajeerapan S 2016 IPAC2016 MPIK002 2539–41
[3] Kittimanapun K, Chanlek N, Klysubun P, Krainara S and Supajeerapan S 2017 IPAC2017 MOPIK015 528–30
[4] Cavicchioli C et al 2014 Nucl. Instrum. Methods Phys. Res. 765 177–82
[5] Mager M 2016 Nucl. Instrum. Methods Phys. Res. A 824 434–38
[6] Aglieri G et al 2013 JINST 8 C12041
[7] Kittimanapun K, Chanlek N, Klysubun P, Krainara S and Supajeerapan S 2019 Nucl. Inst Methods Phys. Res. A 930 105–11
[8] Mager M 2016 The telescope optimiser Retrieved from http://mmager.web.cern.ch/mmager/telescope/tracking.html
[9] Scandale W et al 2017 Nucl Instrum. Methods Phys. Res. B 402 291–5