Characterization, time resolution and proton hardness of IHEP-NDL LGAD sensors

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Introduction

• Why timing and LGAD?
  Future particle physics experiments can benefit from high-precision timing information in many aspects of 4D tracking, pile-up rejection, particle identification.

A High-Granularity Timing Detector (HGTD) is proposed and being developed for the ATLAS Phase-II upgrade, to mitigate the pile-up effects in High-Luminosity LHC (HL-LHC). **Low gain avalanche diode (LGAD)** is the best candidate for HGTD and 4D detector.

• Why irradiation hard?
  - The silicon detectors in high energy collider HL-LHC will be exposed in high hadron fluences. Radiation-resistant detectors play a key role in the flavor physics of CEPC. Higher radiation level damaging the time resolution of the detector is becoming a serious problem.

IHEP-NDL LGAD sensor

• LGAD sensor developed by the Beijing Normal University Novel Device Laboratory (NDL) cooperated with IHEP.
• n-on-p type with different volume resistivity: BV60 and BV170.
• 2x2 pads, pad size 1.3x1.3mm², total size 3.2x3.2mm².
• The physics thickness is 300μm, epitaxial layer is 33μm.
• Current-voltage (I-V) and capacity-voltage(C-V) curves are measured at room temperature.

![LGAD structure](image)

![Detector read-out board developed by UC Santa Cruz](image)

- Double-side conductive tape to mount the LGAD on test board
- Aluminum wire connecting LGAD to input amplifier on test board
- Laser testing system:
  - Picosecond laser: wave length 1064 nm, pulse width 7.5 ps
  - Oscilloscope: sampling rate 40GS/s, Band width 2.5GHz

![Laser test for time resolution](image)

- Time resolution expression of LGAD sensor: $\sigma_t^2 = \sigma_{T}^2 + \sigma_{time\, walk}^2 + \sigma_{Landau\, noise}^2 + \sigma_{signal\, distortion}^2 + \sigma_{jitter}^2$
- For the time resolution test by laser, the first 4 terms are small enough to neglect, and the test is effect of jitter term.
- Jitter vs. bias voltage

Test Beam

• Desy test beam facility
• Electron/positron beams: 5GeV
• The hit positions from beam are recorded with 6 mimosa plates with 18.5um x 18.5um unit pixel size
• DUT: NDL sensor
• Time resolution needs to be obtained by combining different measurements
• Calculation method.

\[
\sigma_t^2 = \frac{\sigma_{I1}^2 - \sigma_{I2}^2}{2}
\]

Proton irradiation hardness

• China Institute of Atomic Energy (CIAE) in Beijing
• 100 MeV proton synchrotron
• Irradiation was carried out on July 9
• 5 fluence points were chosen: 7E14, 1E15, 2E15, 3E15, 4.5E15
• sensor: 18 HPK, 4 CNM, 55 IHEP-NDL
• Beam current: 100nA (~1-2%)
• Beam area: 2.5cm X 2.5cm
• Temperature: below 0°C

![Proton irradiation hardness](image)

- depled voltage vs. fluence
- foot voltage vs. fluence
- doping profile vs. fluence

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