Development of Strip-type Low-Gain-Avalanche Detectors

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Motivation/Application

• A detector for tracking in HL-LHC
• Reduction of fake tracks with precision space-time (4D) info.
  – For the barrel region, strip detector is a cost-effective solution.

ATLAS: High Granularity Timing Detector (HGTD)

Barrel: overlap of tracks
Space-time tracking layer(s)

Forward: highly collimated jets

interaction region: \( 2\sigma_z = 15 \text{ cm} = 500 \text{ ps} \)
in HL-LHC, max. 200 interactions at a collision

\( \Delta t = 10 \text{ ps} \Leftrightarrow \Delta z = 3 \text{ mm} \)
Motivation/Application II

• Application to medical instrumentation
  – Positron Emission Tomography (PET)
  – A novel detection element, replacing conventional scintillator crystals
  – Similar application as in the “barrel” region, with $\gamma$ detection

Coincidence in space-time

• Precision space info.
  – high resolution in “line of sight”
  – $\Delta x \sim 20 \mu m$

• Precision time info.
  – reduction of fake lines
  – $\Delta t \sim 10$ ps = $\Delta r \sim 3$ mm
  – which may reduce a requirement for photon energy measurement

Figure [Wikipedia]
LGAD: Strip Sample

- **Geometry**
  - Strip pitch: 80 µm
  - Readout metal: DC-coupled (although AC should be possible)
  - Opening (30 µm wide) in the metal for laser injection

- **Density of p+ gain layer**
  - 4 densities: A, B, C, D as
  - 2 Active thicknesses: 50, 80 µm

**Traditional**

Signal: mirror current of drifting carriers (e, h) to n++ in the bulk

**LGAD**

Signal: mirror current of drifting carriers, multiplied at the n++-p+ junction, drifting away in the high electric field in p+ layer
Gain Measurement with Laser

- **Irradiation with neutrons**
  - TRIGA reactor of JSI, with V. Cindro et al.
  - Supported by the H2020 project AIDA-2020, GA no. 654168
  - Fluences: 0.3, 1.0, $3 \times 10^{15}$ 1-MeV n$_{eq}$/cm$^2$

- **Infrared laser (Nd:YAG)**
  - $\lambda = 1064$ nm
  - Focused at surface, collimated to $2 \times 2$ $\mu$m$^2$
  - uniform $e$-$h$ generation in depth, mimicking the traverse of charged particle
Responses to Laser

S. Wada et al.,
HSTD11 (2017)

- At the center of strips (bottom figs.) – observed gain both before and after irradiation, as expected.
- At the interstrip (top figs.) – no gain before irrad. as expected; non-zero gain after irradiation, surprising, but, in retrospect, confirming “charge multiplication”

Before irradiation

After irradiation of $1 \times 10^{15}$ $n_{eq}/cm^2$
How to Make a Usable Device?

• Present sample:
  – No gain in the interstrip region, although a small gain has appeared after irradiation.
  – As is, it is not usable, with a design as same as the conventional strip sensor (narrow strip with wide interstrip region)

• Improvement(?):
  – “AC LGAD” might be a way to go for (see other talk)
  – Here, we pursue to introduce gain in the interstrip region before irradiation.
  – In the next slides we show how, with TCAD simulations...
TCAD Simulations – Strips in General

- A few factors that are affecting electric field
  - Guard band (GB): usually $n^+$ implantation, noted as GB($n^+$)
  - Extended Al (XA)
  - Staggering of $n^{++}$ and $p^+$ layers
Electric Field and Flow lines

- **Case 2.0 — as is, No GB(n⁺)**

Carries drifting along these flow lines will not go avalanche, except ...

- A corner of n⁺⁺ electrode with E>300 kV/cm may have become effective to go avalanche after irradiation.

Avalanche breakdown field – 300 kV/cm
Electric Field and Flow lines

- Case 1.5 – as is, with GB(n+)

- GB(n+) suppresses a region with $E > 300$ kV/cm at a corner of n+ electrode, making the device safer for micro-discharge breakdown.

Avalanche breakdown field – 300 kV/cm
A Proposed Solution (?)

- **Case 3.1** – GB($p^+$), No XA, width $p^+ \sim n^{++}$$

*Geometry*

Carries drifting towards the corner along flow lines (not drawn) will go avalanche

- GB($p^+$), no extended Al, same width of $n^{++}$ and $p^+$ enhance electric field along the edge of $n^+$ electrode to have $E > 300$ kV/cm, making the $n^{++}$ electrode sensitive to avalanche in all faces.

Avalanche breakdown field – 300 kV/cm
Summary

• We have evaluated strip-type LGAD (DC-coupled), by implementing high density p⁺ gain layer in the conventional strip structure.
• The strip region where the gain layer is showed gain of ≥10, before and after irradiation to neutrons, as expected.
• The interstrip region did not show gain, before irradiation as expected, showed small gain after irradiation, a confirmation of “charge multiplication”.
• We have pursued and propose a design to introduce gain in the interstrip region before irradiation, verified with TCAD simulations.
• A next step is to fabricate a device.
Backup
• Case 2.3 – GB(p+(5e14)), No extended Al

2018/2/20 Y. Unno
• Case 3.0 – GB(p+(5e14))-XA, n+ side-smearing(1 nm)

2018/2/20 Y. Unno
• Case2.05 – No GB, No extended Al (XA)