Characterization of Low Gain Avalanche Detectors (LGAD) irradiated with protons and neutrons

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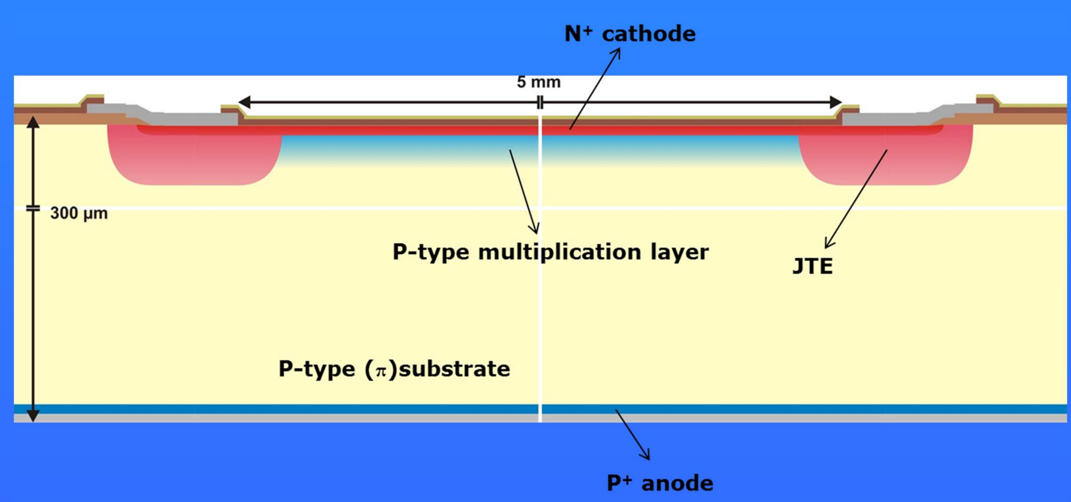
Abstract

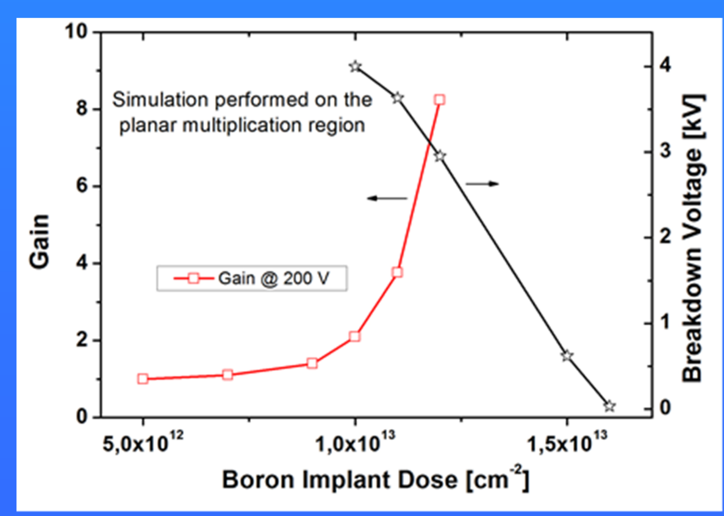
This work reports a new concept of silicon radiation detector with intrinsic multiplication of the charge, called Low Gain Avalanche Detector (LGAD). These new devices are based on the standard Avalanche Photo Diodes (APD) normally used for optical and X-ray detection applications. The main differences to standard APD detectors are the low gain requested to detect high energy charged particles, and the possibility to have fine segmentation pitches: this allows fabrication of microstrip or pixel devices which do not suffer from the limitations normally found in avalanche detectors [1]. In addition, a moderate multiplication value will allow the fabrication of thinner devices with the same output signal of standard thick substrates.

The gain implemented in the non-irradiated devices must retain some effect also after irradiation, with a higher multiplication factor with respect to standard structures, in order to be used in harsh environments such those expected at collider experiments.

Why Low Gain?

- High Gain implies higher levels of multiplication noise (inherent to the stochastic process of multiplication), spoiling the improvement of the Signal to Noise ratio.
- Collection times are increased with gain (more charge to be collected), increasing the trapping efficiency and avoiding the off-setting of the charge loss.
- Avoid cross-talk among adiacent pixels/strips.

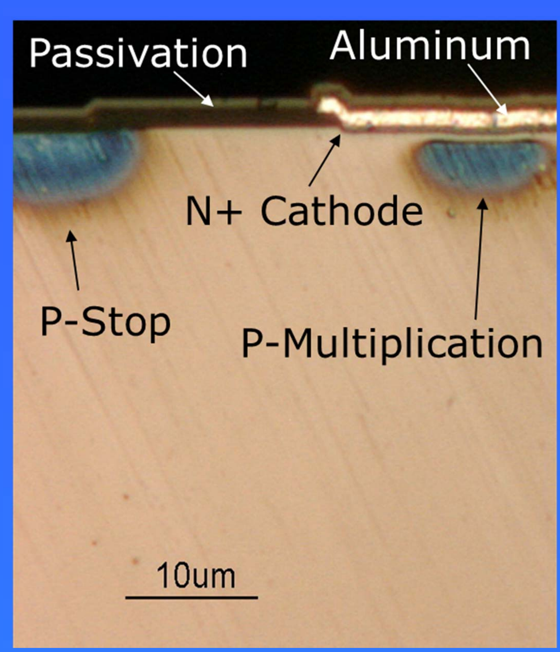


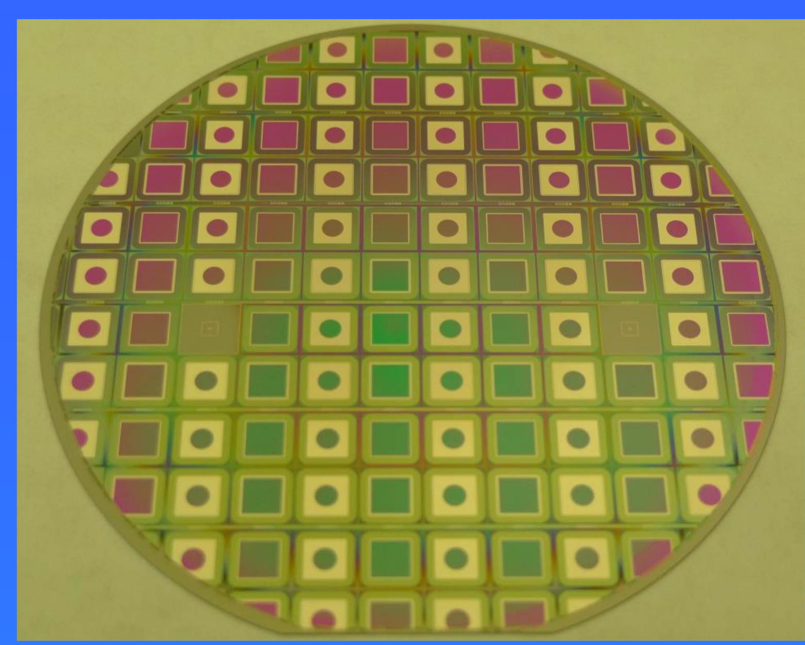


Small modifications in the Boron implant dose (~ 2×10^{12} cm^{-2}) induce great changes in Gain and V_{BD}.

Technology and simulation [2]

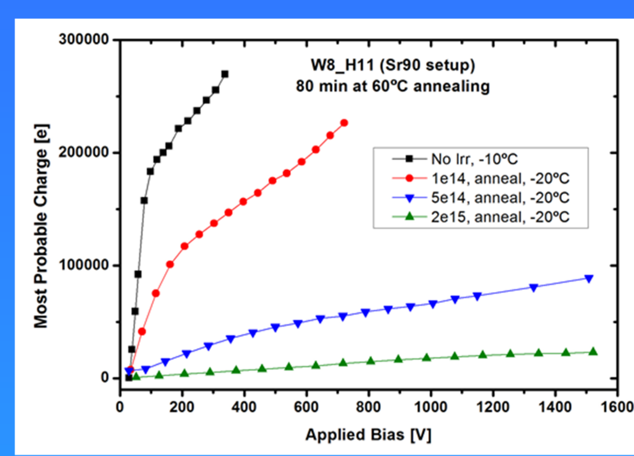
The first LGAD diode detectors were fabricated at CNM-IMB clean room facilities by diffusing a p-type layer just below the n+ electrode. Thus, an $n^+/p/p^-$ junction is created along the center of the electrodes. Under reverse bias conditions, a high electric field region is generated in this localized region, which can lead to a multiplication mechanism for the electrons reaching the n^+ electrode. The objective of the p layer is to enhance the value of the electric field in that region, and its impurity profile will be the main technological parameter to define in order to adjust the gain value.

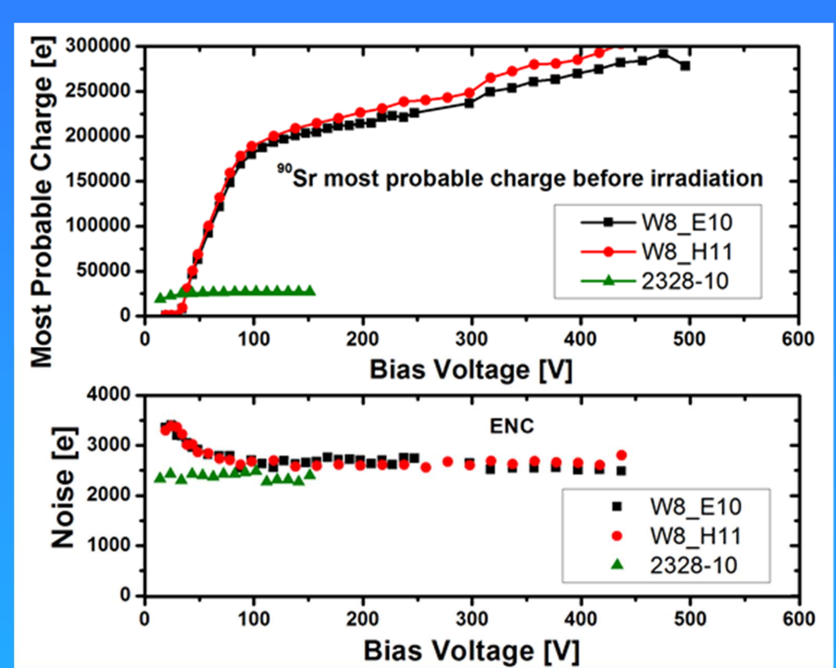


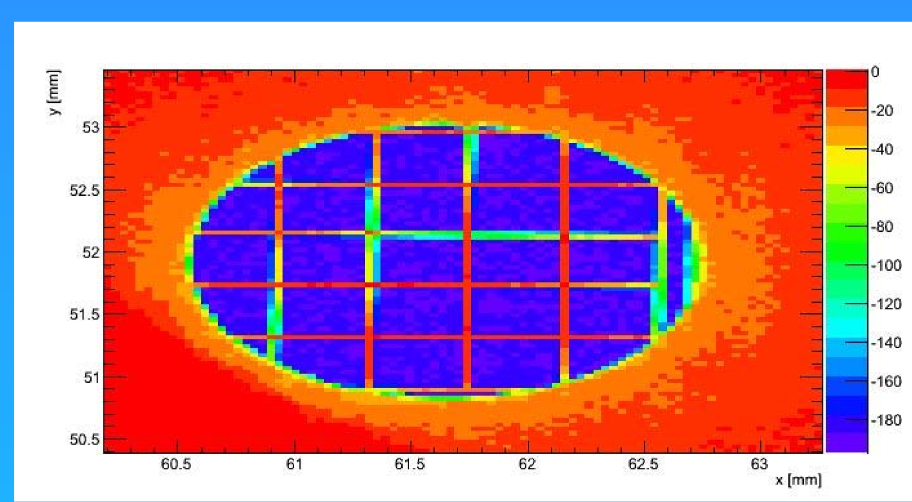


Measurements and irradiations [3]:

- Improvement of signal for a factor 8 at 300 V before irradiation.
- No significant increase of noise – dominated by series noise.
- Laser TCT surface scan shows very good uniformity.
- Detectors irradiated with neutrons in Ljubljana.
- Multiplication decreases significantly with irradiation:
  - this effect is not predicted by simulation anyway the irradiation is known to partially remove the implanted acceptors of the p+ section at the junction.







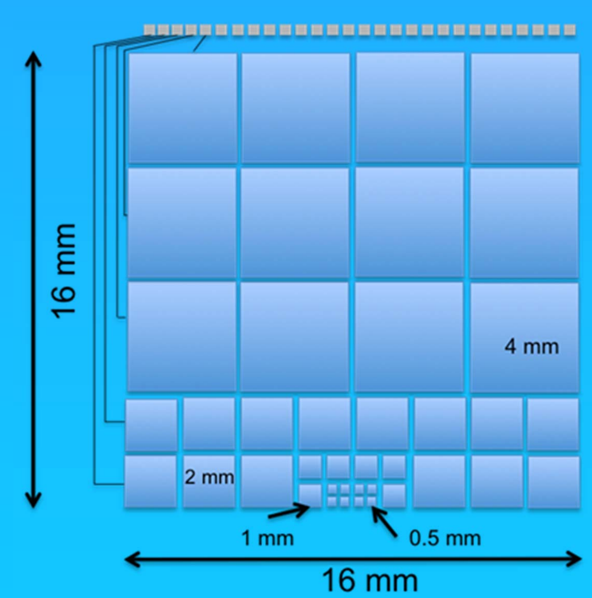
Timing applications [4]:

Very strong interest from LHC experiments: good fit for TOTEM, ATLAS-AFP and CMS-PPS needs.

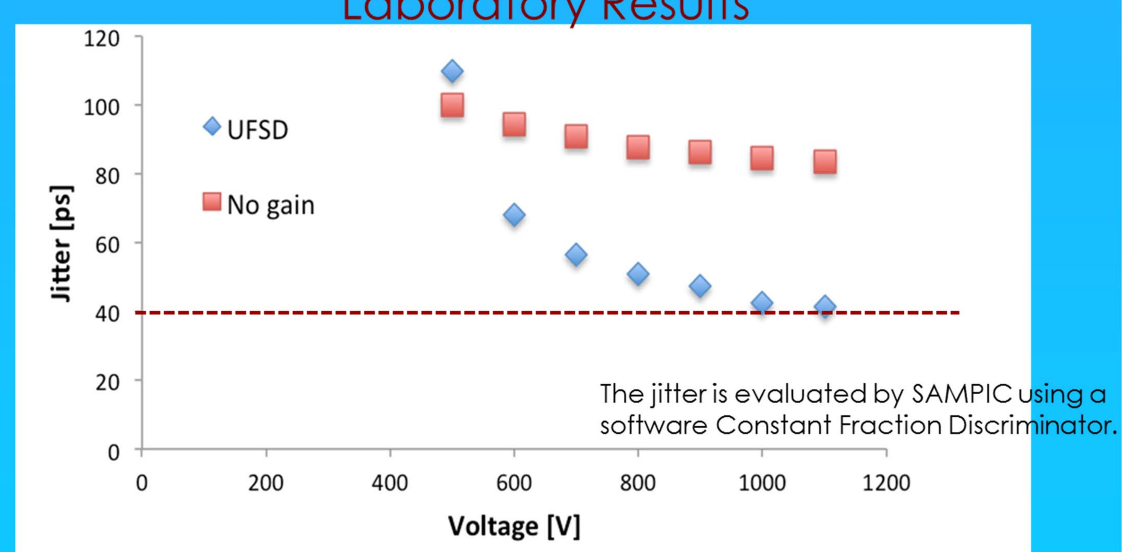
Necessary steps for deployment:

- Need rad-hard version, ~10^{15} n_{eq}/cm^2
- Realization of multipad geometries
- Production of thinner detectors
- Tests with real beams
- Optimized read-out scheme

New fabrication run and design under development in the framework of the CERN RD50 collaboration.



Laboratory Results



References:

1. *I. Tapan et al., "Avalanche photodiodes as proportional particle detectors".*
2. *G. Pellegrini et al., "Technology developments and first measurements of Low Gain Avalanche Detectors (LGAD) for high energy physics applications" NIM A DOI: 10.1016/j.nima.2014.06.008.*
3. *G. Kramberger, et al. "Radiation hardness of Low Gain Amplification Detectors (LGAD)" , 24th RD50 Workshop (Bucharest), 11-13 June 2014.*
4. *N. Cartiglia "Timing properties of UFSD", 24th RD50 Workshop (Bucharest), 11-13 June 2014.*

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