UNIVERSITY OF CALIFORNIA SANTA CRUZ OFFICE OF RESEARCH

Deep Junction Low Gain Avalanche Detector

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BACKGROUND

The development of Low-Gain Avalanche Detectors (LGADs) that make controlled use of impact ionization has led to an advancement in the use of silicon diode detectors in particle detection, particularly in the arena of ultrafast (~10 ps) timing. For what are today considered to be “conventional” LGADs, the high fields needed to induce the impact ionization process lead to breakdown between the separated n-p junctions that are used to simultaneously deplete the sensors and establish the readout segmentation. As a result, working devices have included a Junction Termination Extension (JTE) that provide electrostatic isolation between neighboring implants, but at a cost of introducing a dead region between the sensor segments that is insensitive to the deposited charge from an incident particle. The width of this dead region is 50 µm or more, making conventional LGAD sensors inefficient for granularity scales much below 1mm. On the other hand, demands from the particle physics (4D tracking) and photon science (high frame-rate X-Ray imaging) communities call for granularity at the 50 µm scale. Thus, there is great interest in overcoming the current granularity limits of LGAD sensors. There are several ideas, under various levels of development, that have been proposed to circumvent the JTE limit

AC-coupled (“AC-LGAD”) LGADs eliminate the need for the JTE by making use of a completely planar (non-segmented) junction structure, and then establish the granularity entirely through the electrode structure, which is AC-coupled to the planar device through a thin layer of insulator. Since charge is not collected directly by the electrodes, there is a point-spread function that relates the signal location to the pad (electrode) response that is a property of the effective AC network formed by the highly doped gain layer just below the insulating layer and the electrode structure. Prototype devices exhibit good response and timing characteristics.

Inverse (“ILGAD”) LGADs also eliminate the need for the JTE by making use of a planar junction structure. In this case, the electrode structure is placed on the side of the device opposite the junction. Prototypes with appealing signal characteristics have yet to be produced. In addition, the manufacture of these devices requires processing on both sides of the sensor, which is significantly more difficult than the single-sided processes used for conventional and AC LGADs.

Trench-isolated (“TI-LGAD”) LGADs attempt to replace the JTE with a physical trench etched around the edge of the detector segment, which is then filled with insulator. This approach is very new, and its proponents hope to be able to use it to reduce the dead area between segments to as little as 5 µm. First prototypes are just recently available and are under study. Much work remains to be done to show that this approach will produce a stable sensor, and to see how small the dead region can be made.

TECHNOLOGY DESCRIPTION

This device solves the problem of granularity limits on Low-Gain Avalanche Detectors (LGADs) by burying a planar, highly-doped diode junction several microns below the surface of the device. This allows for a high-field region in the area of the junction that produces the gain characteristic of LGADs, but then allows for a low-field region in the area close to the surface readout structure. This allows for the elimination of the Junction-Termination Extension structure, which limits achievable granularity, employed by conventional LGADs and thus allows for a much higher degree of granularity - a development required for application in several different scientific areas.

The Deep Junction (“DJ-LGAD”) structure is shown below:

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OTHER INFORMATION

KEYWORDS

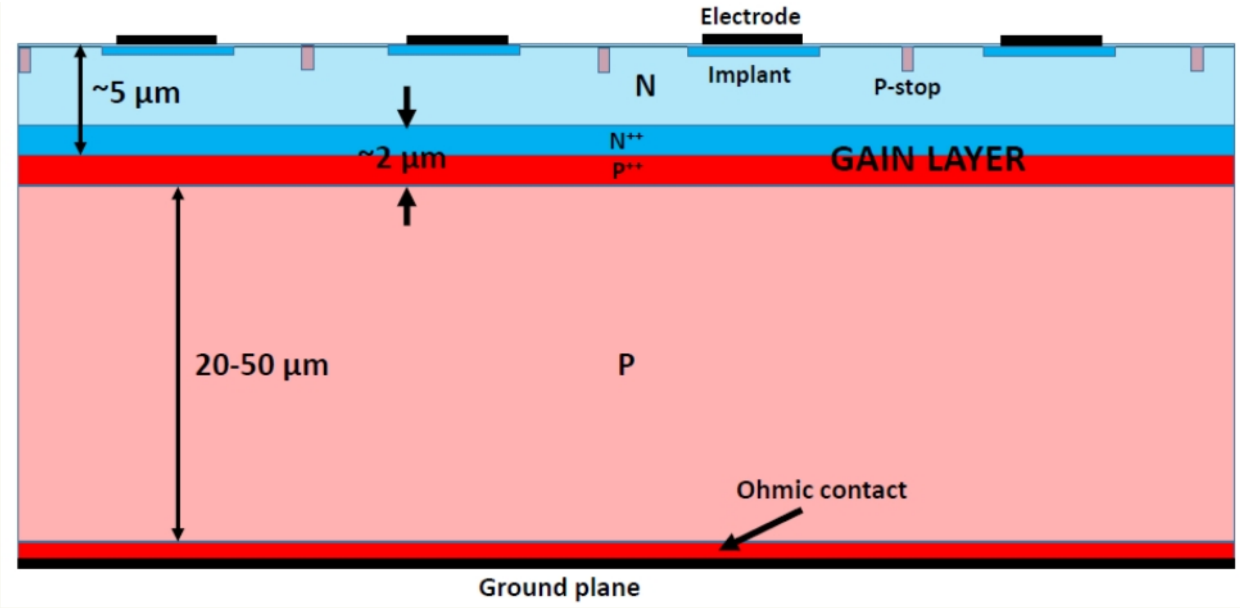
Avalanche Detector, Low-Gain Avalanche Detector, Particle Physics tools, Silicon diode detector, Particle Detection, Reduced Junction Termination Extension

CATEGORIZED AS

- **Optics and Photonics**
  - All Optics and Photonics
- **Sensors & Instrumentation**
  - Physical Measurement
  - Scientific/Research

RELATED CASES

2019-978-0, 2015-655-0



The need for the JTE might be avoided if the high-field region needed to induce impact ionization, and thus gain, is separated from the readout structure. This has been achieved by moving the diode junction away from the upper surface of the device, where the segmentation is imposed, and then burying it a few microns into the device. The key benefit of burying the entire junction, rather than just the highly-doped P++ region, is that upon depletion, this establishes a field in the region of the junction that is similar to that of a parallel-plate capacitor. Due to the resulting two planes of high charge density of nearly equal, but opposite sign, the field in the region of the junction is high, inducing the limited and controlled impact ionization that is characteristic of LGADs, but outside the highly-doped junction region the fields are much lower. In addition to the use of the buried junction to localize the high-field region and isolate it from the readout structure, this device is unique it that it uses the full junction, rather than just the P++ doped area, for the gain layer (i.e., the gain layer is composed of both the deep blue and deep red sections above, rather than just a deep red section).

APPLICATIONS

- Particle Physics
- Photon detection
- High frame rate X-ray imaging

ADVANTAGES

- Highly granular silicon diode systems
- Fewer complex segmentation techniques
- Removal of constraints on the granularity of LGADs while maintaining the properties of internal gain, timing resolution and repetition rate

INTELLECTUAL PROPERTY INFORMATION

Country	Type	Number	Dated	Case
United States Of America	Issued Patent	11,923,471	03/05/2024	2019-978
European Patent Office	Published Application	EP 4052304	09/07/2022	2019-978

Additional Patent Pending

RELATED MATERIALS

- A new approach to achieving high granularity for silicon diode detectors with impact ionization gain - 01/02/2021

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