Simulation of the Influence of JTE and p-Stop Geometry on the Breakdown Voltage of Long RSD/LGAD Sensors

Authors: Violetta Maier, Nikolay Atanov, Alexandr Putilin et al.

1. RSD-LGAD Sensor Concept

Modern detector systems for particle physics, such as the Outer Tracker (OTK) of the future Circular Electron-Positron Collider (CEPC), aim to improve both time and spatial resolution while reducing the amount of material in the detector and simplifying its readout electronics. One possible approach is the use of large-area RSD-LGAD sensor strips. Such sensors can provide particle position information using multiple adjacent readout pads. Increasing the strip length and the number of strips per module allows a larger area to be covered with fewer readout channels.

A conventional LGAD matrix consists of discrete n^{++} cathodes separated by edge-termination structures, such as the Junction Termination Extension (JTE) and p-stop. These structures introduce insensitive dead regions between pixels, thereby reducing the fill factor. AC-coupled RSD-LGAD sensors (here after referred to as AC-LGADs) (Fig. 1, left) [1] address the dead-region problem by employing a continuous n^{+} layer. In an AC-LGAD, the metal readout electrodes are electrically isolated from the resistive layer by a thin dielectric passivation layer, providing capacitive coupling to the readout electronics. These structures have demonstrated promising performance, as reported in [2], achieving a time resolution of 25-30 ps and a spatial resolution of 10 µm. Further improvements in signal shape and time and spatial resolution may be achieved using DC-coupled RSD-LGAD sensors [3, 4]. In a DC-RSD LGAD, the dielectric layer beneath the electrodes is absent. The metal pads form a direct electrical contact with the resistive layer, providing DC coupling [3] (Fig. 1, right).

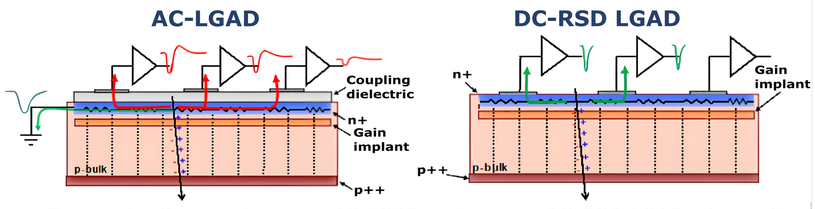


Figure 1 *- Schematics of an AC-LGAD (left) and a DC-RSD LGAD (right) [3]*

One of the key characteristics of a semiconductor sensor is its breakdown voltage. A higher breakdown voltage extends the sensor's operating range and enables stable operation at higher bias voltages. Therefore, achieving a high breakdown voltage while maintaining a simple sensor structure is highly desirable. In this work, the influence of structural parameters on the breakdown voltage of a DC-RSD LGAD was investigated. Thestudy was first performed for a structure with a length of 400 µm, followed by an investigation of the effect of the most influential parameter on the breakdown voltage of a longer structure.

2. DC-RSD LGAD 2D Model

There are many ways to arrange electrodes on the sensor surface. These configurations are described in detail in [2, 3, 5]. In this work, we consider a 2D model of a strip DC-RSD LGAD sensor implemented in Synopsys Sentaurus TCAD, based on the structure of the AC-coupled RSD-LGAD sensor described in [5]. We assume continuous strips with a large width in the cross-section (Fig. 2), ranging from 400 µm to one centimeter.

- passivation surface layer (oxide).

- resistive layer (n^{+} type doping, N=1 x 10^{18} см$^{-3}$).

- gain layer (p - type doping, N = 1 x 10^{16} см$^{-3}$).

- p^{-} epitaxial layer (p^{-} type doping, N=1 x 10^{12} см$^{-3}$).

- anode (p^{++} type doping, N = 1 x 10^{19} см$^{-3}$).

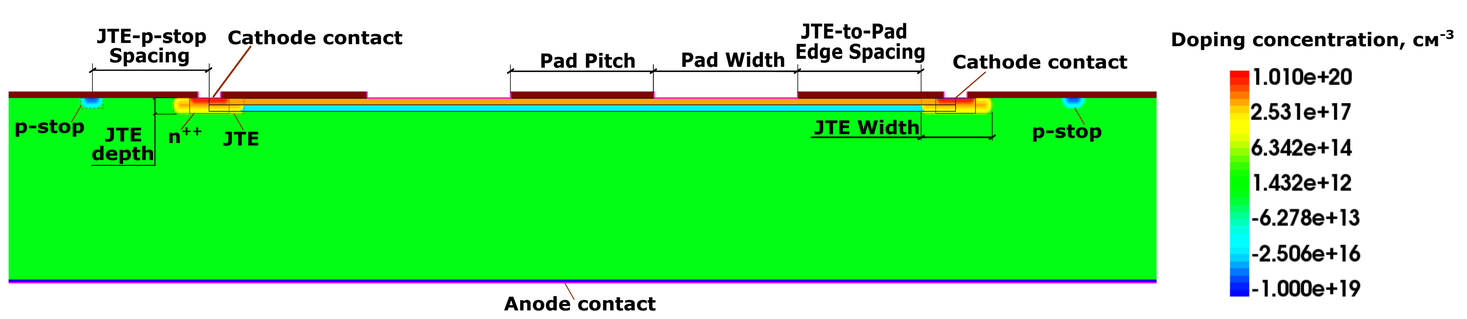


Figure 2 *- 2D Structure of the DC-RSD-LGAD Sensor*

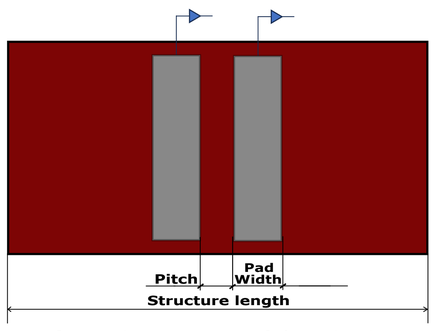


Figure 3 *- Top View of the DC-RSD LGAD Sensor*

The length of the structure means the dimension illustrated in Figure 3.

3. Tasks

The main objectives of this study are:
1. To investigate the dependence of the breakdown voltage on the width of the Junction Termination Extension (JTE) in a DC-RSD LGAD sensor with a structure length (Fig. 3) of 400 µm.
2. To evaluate the influence of the JTE depth on the breakdown voltage at the same structure length.
3. To determine how the distance between the JTE and the p-stop region affects the breakdown voltage.
4. To investigate the influence of the electrode pad width on the breakdown voltage.
5. To evaluate the effect of the pad pitch on the breakdown voltage.
6. To determine how the distance between the JTE edge and the electrode pad edge affects the breakdown voltage.
7. To identify the geometrical parameter with the greatest influence on the breakdown voltage and investigate its effect in a longer sensor structure.

4. Method for the Breakdown Calculation

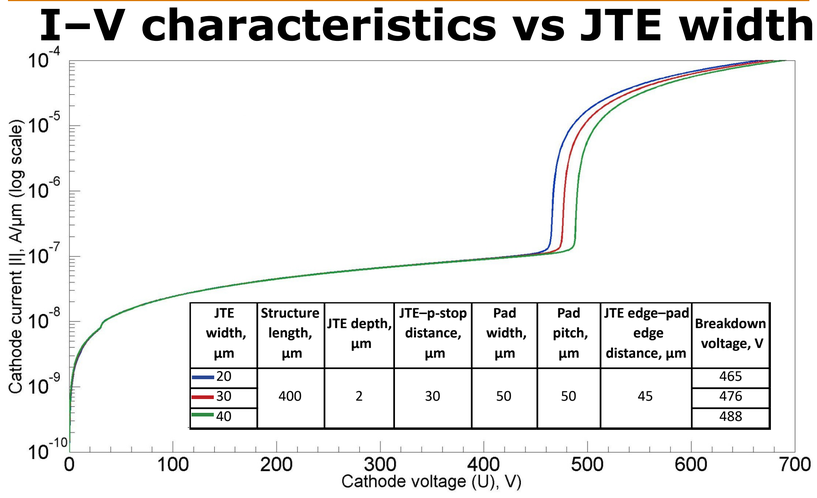
The breakdown voltage was determined as the maximum of the second derivative of the logarithm of the current with respect to voltage:

$$\frac{d^2(\ln I)}{dU^2}$$

The voltage at which this curve reaches its maximum is taken as the breakdown voltage.

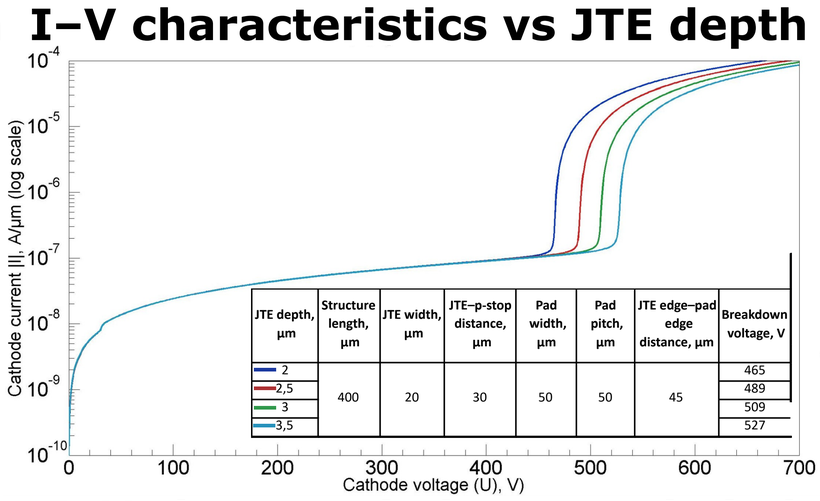
5. Results

I–V characteristics vs JTE width



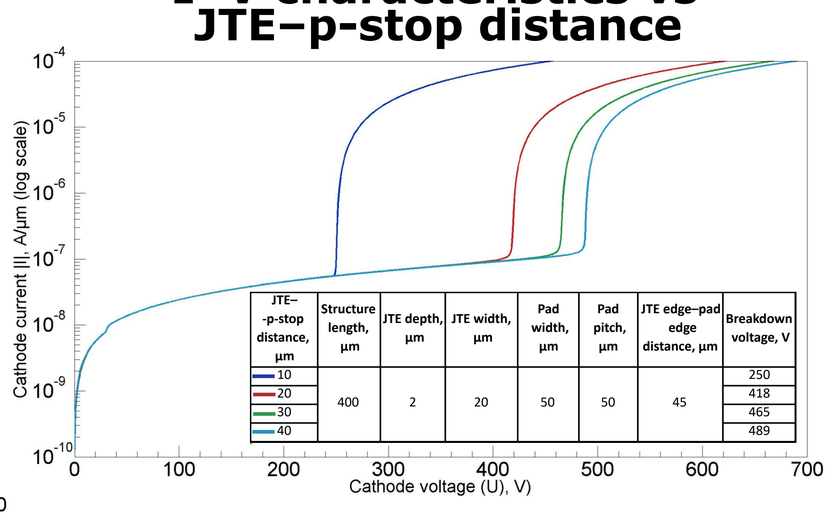
JTE width, µm	Structure length, µm	JTE depth, µm	JTE–p-stop distance, µm	Pad width, µm	Pad pitch, µm	JTE edge–pad edge distance, µm	Breakdown voltage, V
20	400	2	30	50	50	45	465
30							476
40							488

I–V characteristics vs JTE depth



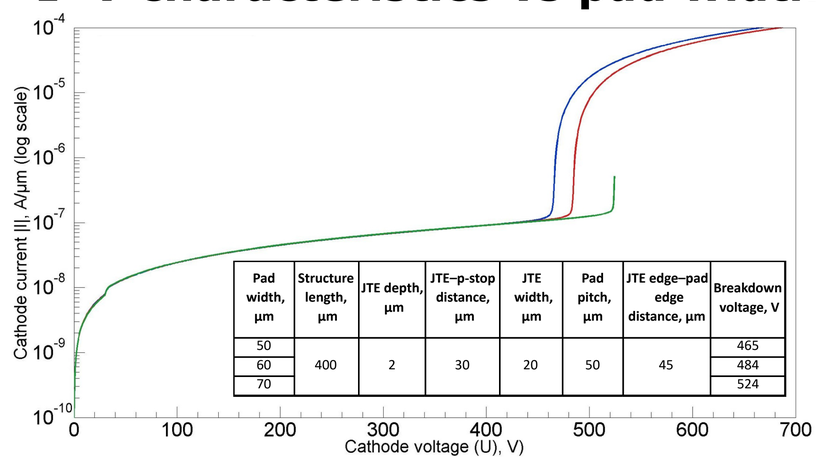
JTE depth, µm	Structure length, µm	JTE width, µm	JTE–p-stop distance, µm	Pad width, µm	Pad pitch, µm	JTE edge–pad edge distance, µm	Breakdown voltage, V
2	400	20	30	50	50	45	465
2,5							489
3							509
3,5							527

I–V characteristics vs JTE–p-stop distance



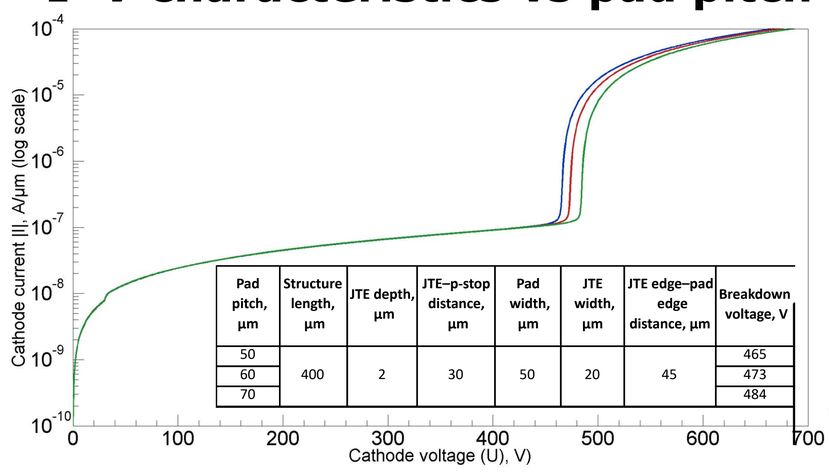
JTE– -p-stop distance, µm	Structure length, µm	JTE depth, µm	JTE width, µm	Pad width, µm	Pad pitch, µm	JTE edge–pad edge distance, µm	Breakdown voltage, V
10	400	2	20	50	50	45	250
20							418
30							465
40							489

I–V characteristics vs pad width



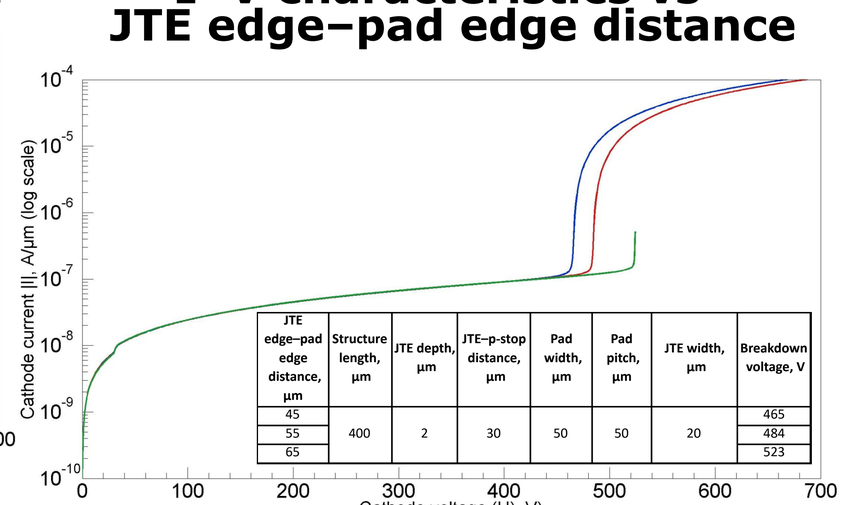
Pad width, µm	Structure length, µm	JTE depth, µm	JTE–p-stop distance, µm	JTE width, µm	Pad pitch, µm	JTE edge–pad edge distance, µm	Breakdown voltage, V
50	400	2	30	20	50	45	465
60							484
70							524

I–V characteristics vs pad pitch



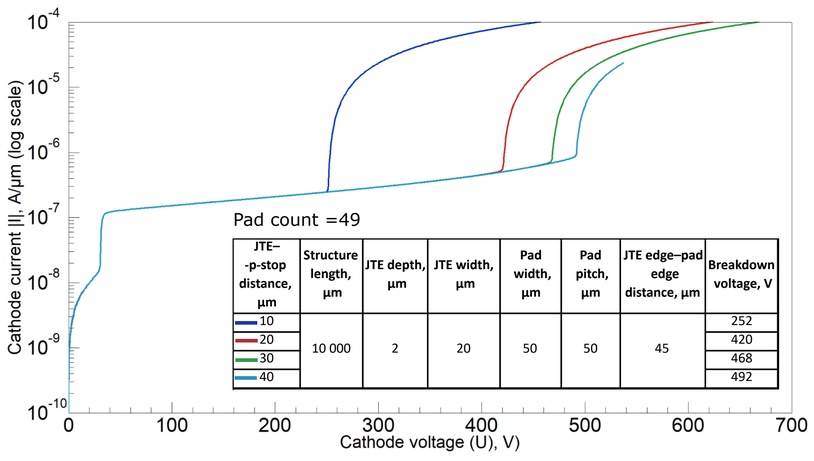
Pad pitch, µm	Structure length, µm	JTE depth, µm	JTE–p-stop distance, µm	Pad width, µm	JTE width, µm	JTE edge–pad edge distance, µm	Breakdown voltage, V
50	400	2	30	50	20	45	465
60							473
70							484

I–V characteristics vs JTE edge–pad edge distance



JTE edge–pad edge distance, µm	Structure length, µm	JTE depth, µm	JTE–p-stop distance, µm	Pad width, µm	Pad pitch, µm	JTE width, µm	Breakdown voltage, V
45	400	2	30	50	50	20	465
55							484
65							523

I–V characteristics vs JTE–p-stop distance



JTE– -p-stop distance, µm	Structure length, µm	JTE depth, µm	JTE width, µm	Pad width, µm	Pad pitch, µm	JTE edge–pad edge distance, µm	Breakdown voltage, V
10	10 000	2	20	50	50	45	252
20							420
30							468
40							492

6. Conclusions

1. The breakdown voltage increases with increasing values of all investigated geometrical parameters within the studied ranges.
2. The distance between the JTE and p-stop regions has the strongest influence on the breakdown voltage. Increasing this distance from 10 to 40 µm raises the breakdown voltage from approximately 250 to 489 V. However, the increase becomes progressively smaller at larger distances.
3. The JTE depth also has a significant effect on the breakdown voltage. Increasing the depth from 2 to 3.5 µm raises the breakdown voltage from 465 to 527 V. The incremental increase in breakdown voltage decreases as the JTE depth increases.
4. The pad width and the distance between the JTE edge and the pad edge have comparable effects on the breakdown voltage, increasing it by approximately 59 V and 58 V, respectively, over the investigated ranges.
5. The JTE width and pad pitch have the weakest influence among the investigated parameters, with breakdown voltage increases of approximately 23 V and 19 V, respectively.
6. For the 10,000 µm-long structure, the breakdown voltage increases from 252 V at a JTE–p-stop distance of 10 µm to 492 V at 40 µm. This trend is consistent with the results obtained for the 400 µm-long structure, suggesting that the influence of the JTE–p-stop distance persists in longer sensors.

7. References

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5. X. Zhang et al., "Design of AC-coupled low gain avalanche diodes (AC-LGADs): a 2D TCAD simulation study," J. Instrum., vol. 17, no. 09, p. C09014, 2022.