Update on proposal RD50-2023-03: Deep Junction LGAD

1° DRD3 Workshop (2024, CERN)

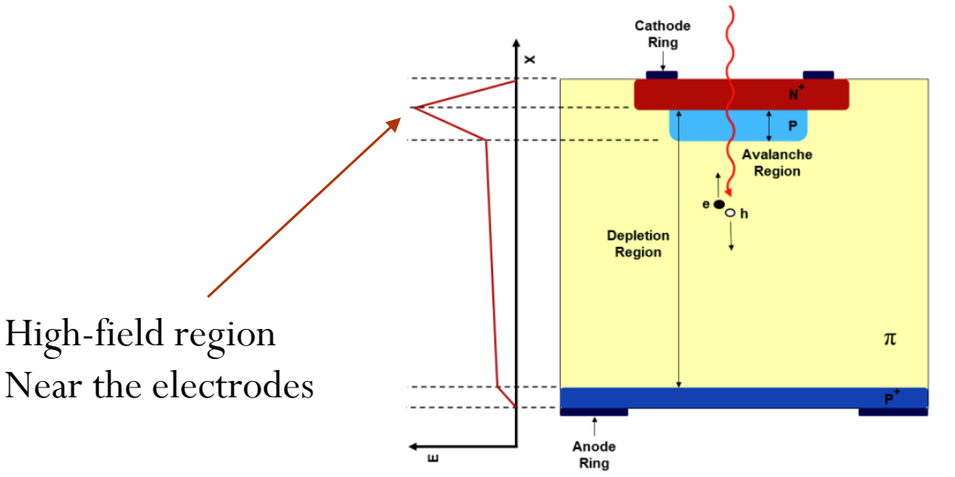
Dr. Simone M. Mazza (SCIPP, UC Santa Cruz)
On behalf of the 13 institutes involved

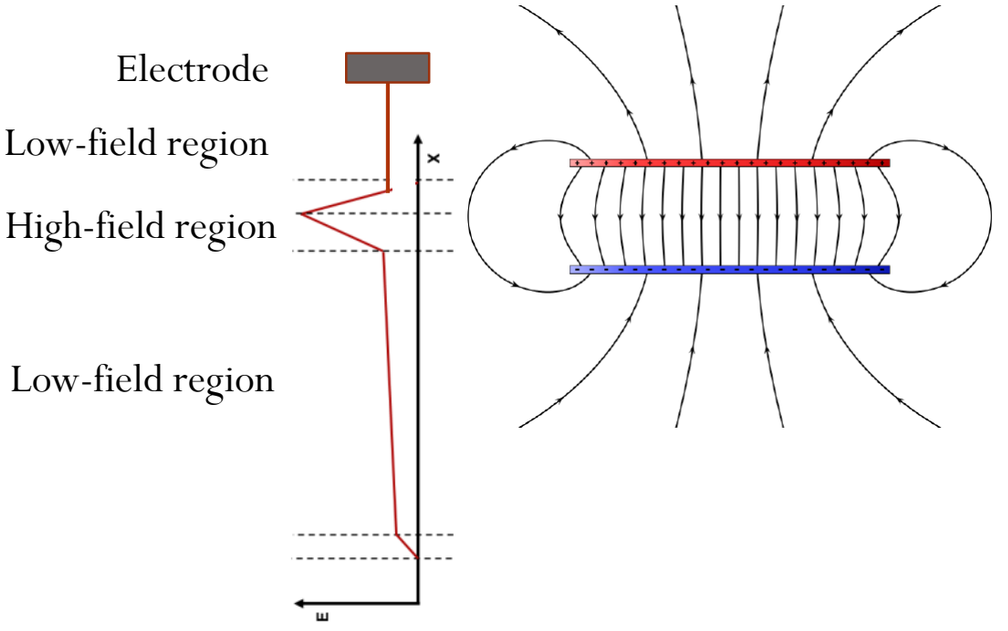
A new approach: deep junction

- Granularity limit is caused by high field near the electrodes
  - **What if the field is kept low while maintaining gain?**

- Basic inspiration is that of the capacitive field:
  - Large between plates, but surrounded by low-field region beyond the plates
- Use symmetric P-N junction to act as an effective capacitor
- Localized high field in junction region creates impact ionization
- Bury the P-N junction so that fields are low at the surface, allowing conventional granularity

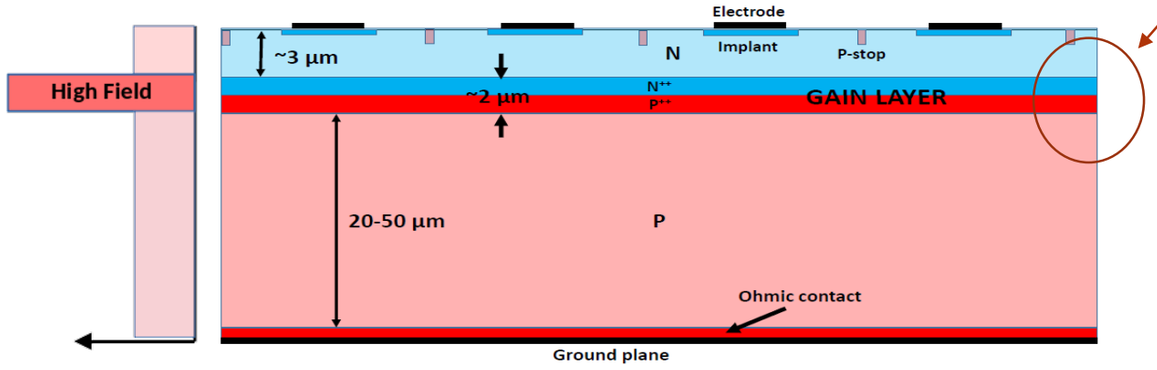
- → **"Deep Junction" LGAD (DJ-LGAD)**
- Concept presented first at TREDI 2020
- Prototype results presented at previous RD50 workshop
- Project approved after RD50 workshop last year

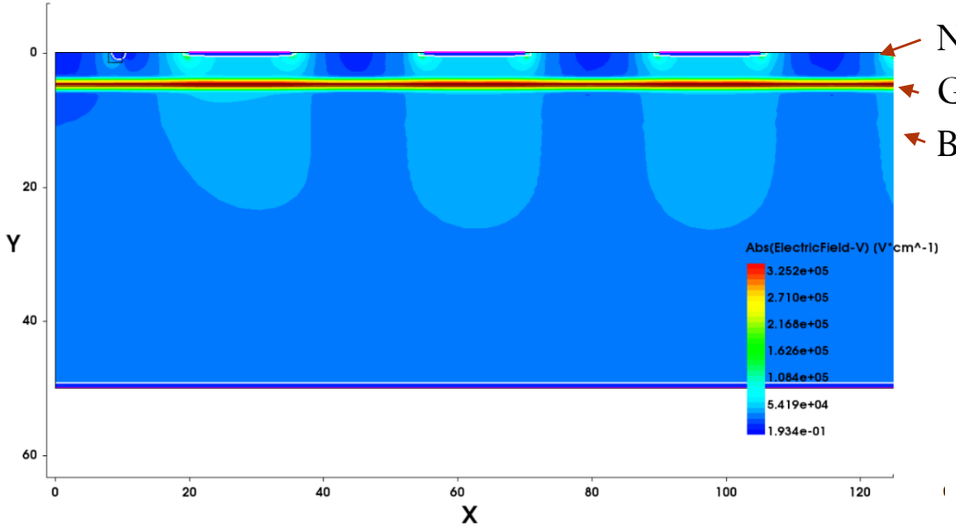




DJ-LGAD

Termination of the gain layer was studied in the first production





- **P++ gain layer is paired with a N++ layer that lowers the field**
  - Junction is buried ~5 um inside the detector
- Tuning of N+ and P+ parameters important
  - Low field outside of the electrodes while maintaining sufficient gain
  - No need for a JTE
  - Different termination of the gain layer designed
- DJ-LGAD design studied with TCAD Sentaurus
  - First production in collaboration with BNL and CACTUS completed and results presented
- Ongoing project at FBK for production using epitaxial growth

Fabrication of DJ-LGAD in RD50

- Fabrication within RD50 of DJ-LGAD at FBK (providing in-kind contribution)
  - Project cost ~100k
  - 12 participating institutions

Project cost	
Starting wafers (40 epitaxial wafers)	3.800 €
Fabrication of both short loops (deep junction and trench)	8.000 €
Epi growth for short loop (external service)	9.600 €*
High energy implantation for short loop (external service)	3.000 €
Photolithographic masks (for trench short loop and sensor batch)	7.200 €
Wafer processing for sensor batch	43.000 €
Epi growth for sensor batch (external service)	9.600 €*
High energy implantation for sensor batch (external service)	3.000 €†
SIMS	4.800 €
On-wafer electrical measurements	7.200 €
Dicing	2.400 €
Total Cost	101.600 €

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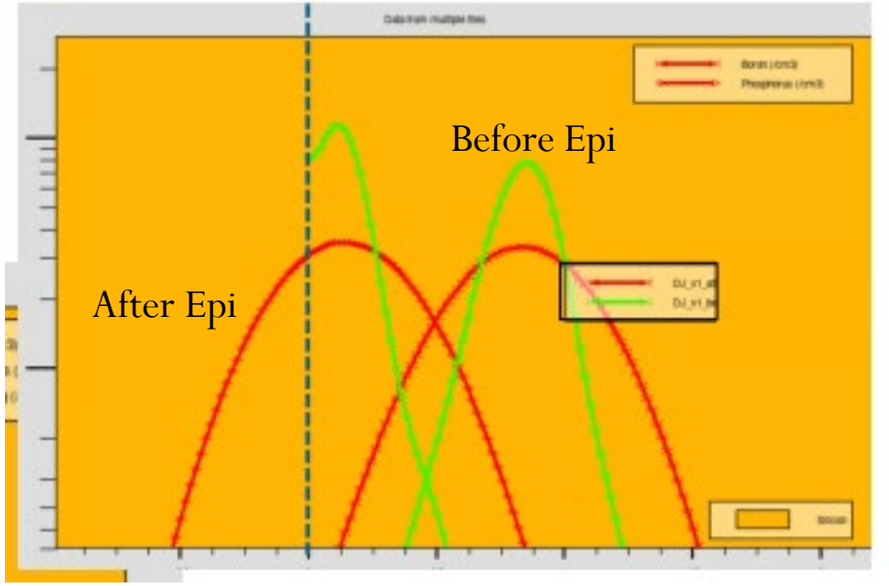
Institutes	1. University of California Santa Cruz (S.M. Mazza, B. Schumm) 2. FBK (M. Boscardin, M. Centis Vignali, G. Paternoster) 3. CERN (M. Moll, V. Kraus, M. Wiehe, M. Fernandez Garcia, N. Sorgenfrei) 4. UNM (S. Seidel, J. Si, R. Novotny, J. Sorenson, H. Farook, A. Gentry) 5. KIT (M. Caselle, A. Dierlamm) 6. PSI (J. Zhang, A. Bergamaschi, M. Carulla) 7. HEPHY (T. Bergauer, A. Hirtl, M/ Dragicevic) 8. UCG (G. Lastovicka-Medin, V. Backovic, I. Bozovic, J. Doknic) 9. Nikhef (M. van Beuzekom, F. Filthaut, M. Wu, H. Snoek) 10. UZH (B. Kilminster, A. Macchiolo, M. Senger) 11. IHEP Beiking (Z. Liang, M. Zhao, Y. Fan) 12. Manchester (O.A. De Aguiar Francisco, E. Ejopu, M. Gersabeck, A. Oh)
Total project	101.600 €
RD50 request	50.000 €

Project status

- The project started somewhat slowly due to patenting issues and setting up the CERN order to start gathering funds
  - Institutes are now being invoiced
- We're now in the process of doing the first short loops to study the effect of gain layer implantation and Epitaxial growth
- Due to Epi temperature issues with outgassing and diffusion to understand
- Sending out test implanted wafer soon for Epitaxial growth
  - Next: SIMS to understand the doping profile change
- Support from UCSC and KIT on TCAD simulation to understand the sensor behavior after diffusion

Activity	Institutes	Duration
Short loop for deep junction	FBK	6 months†
Short loop for trench filling	FBK	3 months
Simulation and detector design	FBK, UCSC (partially parallel to short loops)	3 months
Batch production	FBK	9 months†
On-wafer testing	FBK	2 months
Electrical characterization	UCSC, HEPHY, CERN, UNM, KIT, Nikhef, UZH, IHEP, Manchester	2 months
Functional characterization	UCSC, HEPHY, CERN, UNM, KIT, PSI, UCG, Nikhef, UZH, IHEP, Manchester	4 months
Sensor irradiation	UNM	TBD
Post-irradiation characterization	UCSC, CERN, UNM, UCG, Nikhef, UZH, IHEP, Manchester	4 months

Table 1: Time allocation for project activities. † Note that these times are susceptible to the lead time for external services.



Conclusions

- DJ-LGAD: a device with deep gain layer
  - Avoid high field near the electrodes while maintaining gain
  - Fine pixelation of the top surface
  - First working DJ-LGAD prototype demonstrated but with some issues
- **Adaptive gain layer can increase greatly the radiation hardness** capabilities of LGADs
  - Adaptive gain layer can be combined with compensated gain layer and Carbon co-implantation
- **Current RD50 production with FBK using Epitaxial growth**
  - Started first short loop to study the effect of Epi growth to the implanted gain layer

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