New Ultra-High cell-Density Silicon Photomultipliers (UHD-SiPM) with improved performance

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Summary

In the recent years, FBK developed “high-density” silicon photomultipliers (HD-SiPMs) → deep trenches, obtaining small cells, high fill factor (FF) → high photon detection efficiency (PDE).

New development → Ultra-High Density SiPM (RGB: UHD), with very small cell size → Cell pitches: 5 µm, 7.5 µm, 10 µm, 12.5 µm, 15 µm

Problem: in a very small cell, the “border effect” dramatically reduces the effective FF (much smaller than the nominal FF) → it is important to overcome this issue.

First solution: UHD-NGR 1: we modified the doping profiles inside the cell (i.e. the SPAD), developing the “new guard ring” (NGR) structure. → PDE is significantly improved but much higher DCR.

New solutions: based on new TCAD simulation we developed 2 new technological solution + cell layout optimization → newest version of UHD-SiPM, with high PDE but lower DCR.

New UHD SiPMs: optimized structures

• Tested and compared different structures, new low-field (LF) and the new “new guard ring 2” (NGR2) UHD-SiPMs → RESULTS: optimized structures with low dark count rate, good PDE and fast signals.

UHD-SiPM technology

• Aggressive layout and technological features:
  • Non-active region reduced to ~1 µm (including half of trench width)
  • SPAD with circular active area
  • Honeycomb configuration of cells

• Very high cell density + fast cell recovery
  • 5.0 µm cell → ~40000 cell/mm²
  • 12.5 µm cell → ~7400 cells/mm²
  • Very high dynamic range achievable

• High FF despite the very small cell pitch

• Applications: calorimetry (high linearity + radiation hardness); gamma imaging in proton therapy (high linearity), high-energy physics experiments (radiation hardness), etc.

Problem: important dead-border

• UHD SiPMs have very small cell pitch → very small SPAD size
  • Border region becomes very important.
  • Effective active area significantly smaller than design active area, eventually preventing correct working of the 5 µm cell.

• 1st optimization with TCAD simulation → “new guard ring” structure has been developed in Q4-2016:
  • PDE significantly improved but primary noise was also significantly higher.
  • This was probably due to high electric field very close to the silicon/trench interface.

• 2nd (new) optimization of the structure and fine tuning of high-field region distance from trenches.

Results:
  • New UHD NGR2 version
  • UHD low-field (LF) version

Conclusions

• Ultra high density (UHD) SiPM technology has been developed and optimized during last years.
• The goal was to increase the effective FF, thus the detection efficiency, while not increasing the noise (dark count rate).
• As a result of the optimization → new upgraded versions, featuring modified edge structure and lower overall electric fields at the junction.
• Small cells provide increased radiation hardness. R&D is ongoing to reduce electric field in the cell, for further improved resistance to radiation damage.

References

• V. Regazzoni et al. JINST, 2017, 12, P07001