Technology Offer

Modular Large-Area Low-Light Detectors with Hybrid SiPM Architecture for Scalable and Adaptive Photon Detection

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Abstract

This invention presents a modular and scalable system for low light level detection using hybrid silicon photomultiplier (SiPM) base cells. Each base cell comprises three vertically stacked layers: a detector (e.g., single-photon avalanche diodes (SPAD)), a first-level read-out (e.g., complementary metal-oxide semiconductor (CMOS)), and a second-level back-end interface (BE). These base cells are interconnected laterally to form large-area detector arrays, which can reach sizes up to square meters. The resulting detection surface may be planar or curved, depending on application needs. The system allows for the integration of up-to-date detectors and electronics, modular reconfiguration, and flexible spatial resolution via virtual pixel merging. It also supports fast signal read-out with low power consumption. This innovative concept opens up new possibilities for large-scale, high-performance light detection in various fields, including tomography, particle physics, and biomedical imaging.

Background

SiPMs have become essential in detecting low-intensity optical signals across various fields such as life sciences, tomography, and high-energy physics. However, current SiPM solutions face significant limitations: detector sizes are typically below 10 mm, fabrication lacks standardization, and assembling larger detection surfaces is complex and inconsistent. Furthermore, the read-out electronics are often custom-made and not easily scalable. These constraints limit performance, scalability, and flexibility in many applications. To address these issues, a more modular, reconfigurable, and scalable detector system is required—one that combines high sensitivity, fast signal processing, and large-area coverage while remaining easy to integrate with existing technologies.

Technology

The invention introduces a modular, hybrid architecture for low-light-level detection using vertically integrated “base cells.” Each base cell is composed of three functional tiers (compare Figure 1): (i) a photodetector array, typically single-photon avalanche diodes or other silicon photomultipliers, (ii) a first-level read-out circuit, typically realized with complementary metal-oxide semiconductor technology for initial signal processing and amplification, and (iii) a second-level read-out and interface layer for data aggregation, communication, and synchronization. Each tier connected via vertical electrical interconnects. The vertical stacking allows for compact integration of detection and signal handling functionalities within each cell.

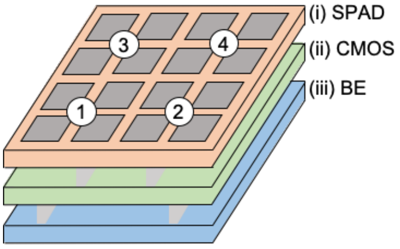

Figure 1: A base cell made up of three tiers: (i) a low light level detector, here a single-photon avalanche photodiode (SPAD) detector, (ii) a first level electronic read-out, here a complementary metal-oxide-semiconductor (CMOS), and (iii) a second level read-out: back end (BE), interfaces, whereas the tiers are connected. The SPAD array is divided into 4 SPAD groups.

These base cells can be laterally interconnected via optical or electrical links to form seamless, large-area arrays. The scalability enables detector surfaces ranging from a few square centimeters to several square meters, which can be either planar or conform to a curved geometry to suit specific applications. Each base cell remains independently accessible, facilitating maintenance or upgrades with minimal disruption.

Advanced electronic configurations allow for dynamic reconfiguration of spatial resolution through virtual grouping of adjacent detectors. For instance, a 16-element array can be operated as a 4×4-pixel detector or aggregated into fewer, larger virtual pixels to enhance sensitivity while reducing resolution. Fast data read-out in the nanosecond range is supported across the entire array, with power consumption kept below 100 mW/cm². This enables high-performance, adaptable detection platforms.

Advantages

- **Scalable detector surface**: Enables seamless expansion from small modules to square-meter arrays.
- **Flexible geometry**: Supports both flat and curved surfaces to fit diverse system architectures.
- **Modular design**: Easy replacement or upgrade of detector or electronics layers without system overhaul.
- **Adaptive resolution**: Virtual pixel grouping allows tuning between higher sensitivity and finer spatial detail.
- **Efficient performance**: Low power consumption (<100 mW/cm²) with fast, nanosecond-level read-out.

Potential applications

- **Medical imaging**: PET/SPECT systems requiring large-area, high-sensitivity detectors.
- **High-energy physics**: Particle detectors in accelerator and neutrino experiments.
- **Astroparticle research**: Light detection arrays for cosmic ray or gamma-ray observations.
- **Biological imaging**: Sensitive detection in fluorescence microscopy and single-photon studies.
- **Optical sensing systems**: Time-resolved detection in LIDAR or quantum photonics setups.

Patent Information

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