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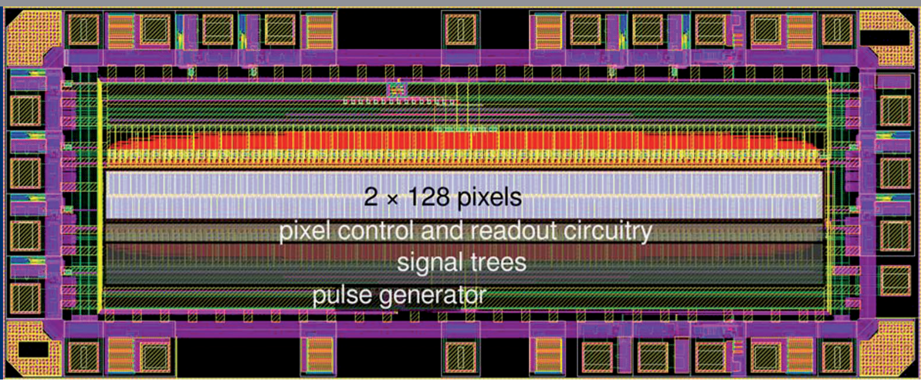

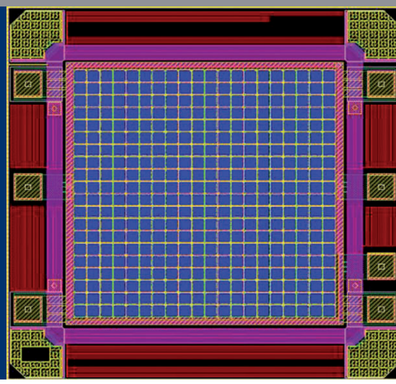

1 *Linear Sensor*

2 *Silicon Photomultiplier*

CMOS SPADS FOR LIDAR APPLICATIONS

LIDAR systems measure the distance from the camera to an object by illuminating it with a laser beam and detecting the reflected light.

There are different LIDAR (Light Detection and Ranging) techniques, such as Flash, Spot or scanning LIDAR, each of which requires a different detector in order to maximize both accuracy and speed. Spot LIDAR systems are used when the application only needs depth information in a single point. To increase sensitivity, large sensors with a single output can be used. Scanning LIDAR uses one or multiple detectors or linear sensors to mechanically scan the desired field of view. In Flash LIDAR applications, the full field of view is illuminated and captured on every frame when using a 2D-array image sensor.

In order to achieve high depth resolution and high speed even in challenging environmental conditions these systems require the use of fast and highly sensitive photodetectors. Since Single-Photon Avalanche Diodes (SPADs) excel in those essential requirements, a SPAD-based sensor represents the ideal receiver for LIDAR systems.

SPADs for LIDAR

SPADs feature a high sensitivity down to the single-photon level, which can significantly extend the range of the system, compared to other photodetectors. If the required range is limited (for example in indoor applications) a lower level of illumination can be employed, thus reducing system power requirements.

SPADs from Fraunhofer IMS manufactured in its 0.35 µm CMOS processes feature low dark count rate and high dynamic range.

CMOS integration allows for active quenching and recharge circuitry, which reduces device dead time on the pixel level and further increases the dynamic range allowing the detection of more photons. This technique also allows time gating measurements by synchronizing the sensors with external illumination.

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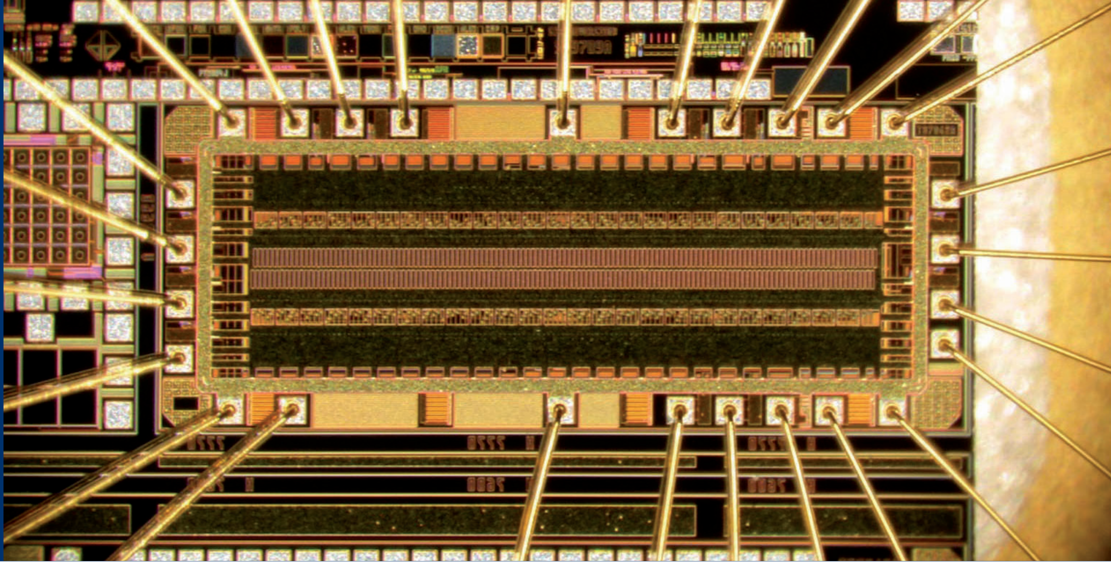
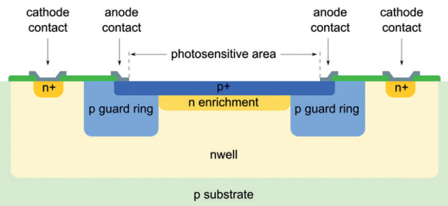


Integration of tailored CMOS readout electronics on the same chip allows adaptation of the sensor performance according to the requirements of the intended applications.
The SPADs can be used as 1D or 2D arrays and, by integration of quenching resistors on the pixel level, even as silicon photomultipliers (SiPM).

Due to the sensor design and placement of frontend circuitry next to the pixel lines, linear sensors achieve a high fill factor (thus higher photon detection efficiency) without affecting the performance of the device.
By measuring the intensity of the total reflected light in addition to the time-of-flight, it is possible to acquire greyscale image data and depth information simultaneously.



Applications for SPAD-LIDAR

Because of their unique characteristics, SPAD-based LIDAR sensors can be used for a multitude of different applications in various fields.

Applications in the automotive field include Advanced Driver Assistance Systems (ADAS) and fully autonomous vehicles. Additional applications of LIDAR systems include traffic monitoring, people counting, and gesture recognition. Logistics can benefit from employing LIDAR techniques for fast shape and volume measurement of bulk goods, while production facilities can use this technology to monitor manufacturing processes.

Since LIDAR systems employing IR illumination also operate in the dark, they are also particularly suitable for property surveillance.

If the intended application does not require any spatial resolution, as for example distance and speed measurement with a single laser spot, a large detector area with SPAD elements connected in parallel can increase the range and decrease the needed laser power.

Other applications of SPADs

Because of their high sensitivity, good timing resolution, high dynamic range, and comparatively low voltage requirement, many applications can benefit from the utilization of SPAD-based sensors.

Such applications include, among others:

- low-light vision
- time-correlated spectroscopy
- fluorescence lifetime microscopy
- positron emission tomography

Working Principle of SPADs

Compared to conventional photodiodes, SPADs operate above breakdown in the so-called Geiger mode. This allows the diodes to produce a considerably larger output signal even when the detected light is of low intensity.

Since the avalanche effect responsible for the signal amplification is very fast, the timing resolution of SPADs is in the picosecond range, which is why SPADs are widely used in photon time-of-arrival measurements and direct time-of-flight systems.

SPAD characteristics (30 µm active area)

Dark count rate (DCR)	< 50 cps at room temperature
Timing response	< 140 ps FWHM
Uniformity	95 % of pixels have close to avg. DCR
Breakdown voltage (V_{BD})	26 V
Temperature drift of V_{BD}	37.8 V/K
Afterpulsing probability	< 1 % at dead time > 50 ns
Pixel pitch	As low as 10 µm
Spectral range	300 nm - 1000 nm
Dynamic Range	106 dB
Noise-equivalent Irradiance at 905 nm	11 pW/cm²

3 *Chip Photo of SPAD Chip*

4 *SPAD structure cross-section*