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2022
Launch of SPAD direct ToF method depth sensor for automotive LiDAR (Sony)

~ Discrete Semiconductor/Others ~

LiDAR (Light Detection and Ranging) using by SPAD (Single Photon Avalanche Diode) direct ToF (Direct Time of Flight) method depth sensors, which enable highly accurate 3D measurements up to 200-300m away, has become important as the Advanced Driver Assistance Systems (ADAS) and Autonomous Driving (AD) become widely utilized.

The direct ToF method measures the distance to object by emitting a pulsed laser light and measuring the time of flight (ToF) until the light is reflected back from the object, as shown in Figure 1. The SPAD direct ToF method uses semiconductor device SPAD that detects single photon of reflected light.

Operation mechanism of the SPAD is as shown in figure 2 and figure 3. An excess bias voltage (VEX) over the breakdown voltage (VBD) is applied to the PN junction photodiode. When a photon penetrates into photo diode, the electrons generated by photoelectric conversion are drastically increased by avalanche multiplication, and large current flows (called Geiger Mode). When the voltage between the electrodes lowers than the breakdown voltage due to voltage drop by the quench resistor, the avalanche multiplication stops (quench operation). When the generated electrons are discharged and the voltage between the electrodes is set to the excess bias voltage, the diode returns to photon detectable state (recharge operation).

One voltage pulse can be generated with one photon, enabling highly sensitive photon detection by means of detecting changes in anode voltage. The time from light emission to pulse generation is measured by a time-to-digital converter (TDC), and the distance is calculated from the round-trip time of the light. While the SPAD is reacting to one photon, a period of time called Dead-Time occurs during which it cannot react to the next incoming photon. Optimal design of device structure including quench resistors and high-speed TDC circuits are required in order to shorten the Dead-Time.

In addition to the fact that the SPAD cannot detect incident photons during Dead-Time, it cannot distinguish between signal photons reflected back from the object and background noise due to the influence of background light such as sunlight. To solve the problem, it is required that a macro-pixel architecture (1) that analyses the spatial and temporal correlation of incident photons with macro-pixels consisting of multiple SPADs (3x3, 6x6) and signal processing circuits such as TCSPC (Time-Correlated Single Photon Counting) technology (2) that constructs a histogram of arrival times by repeated measurements to obtain distance information from the histogram peak positions.

Sony launched 1/2.9-inch (diagonal; 6.25mm) SPAD direct ToF depth sensor "IMX459" with approximately 100,000 effective pixels for automotive LiDAR in March 2022 [3,4,5] (Figure 4). The sensor consisted of a back-illuminated SPAD array chip and a logic chip with a quench circuit and signal processing circuit, stacked with Cu-Cu connections.

The pixel chip was back-illuminated 189 (H) × 600 (V) SPADs array with on-chip micro-lenses integrated at a pitch of 10 μm. In order to enhance the absorption of Near Infrared (NIR) light, 7 μm thick silicon layer was used in the photoelectric conversion layer of SPAD, with metal reflector inserted at the bottom. The optimum design of the high electric field in the avalanche region and the drift electric field in the photoelectric conversion region realized a photoelectron detection efficiency of over 24% at wavelength of 905nm. Crosstalk suppression was achieved by the deep trench filled with heavy metal from surface to bottom, which was named Full Trench Isolation (FTI). The pixel chip was manufactured using a 90nm CMOS process with an additional process for backside illumination. (Figure 5)

On the other hand, the logic chip, included a readout circuit that performed quench and recharge operations and signal processing circuits such as TCSPC-based DSP, was manufactured using a 40-nm CMOS process with 1Al 10Cu interconnections. Stacking the chips by Cu-Cu connection achieved high fill factor (FF).

By demonstrations with the Micro Electro Mechanical System (MEMS) based on SPAD LiDAR system, the depth sensor was able to measure distances of up to 300 meters. Under background light of 117 klux (equivalent to direct sunlight), the measurements were demonstrated to be possible up to 150 m for objects with reflectance of 10% and up to 200 m for objects with reflectance of 95%.

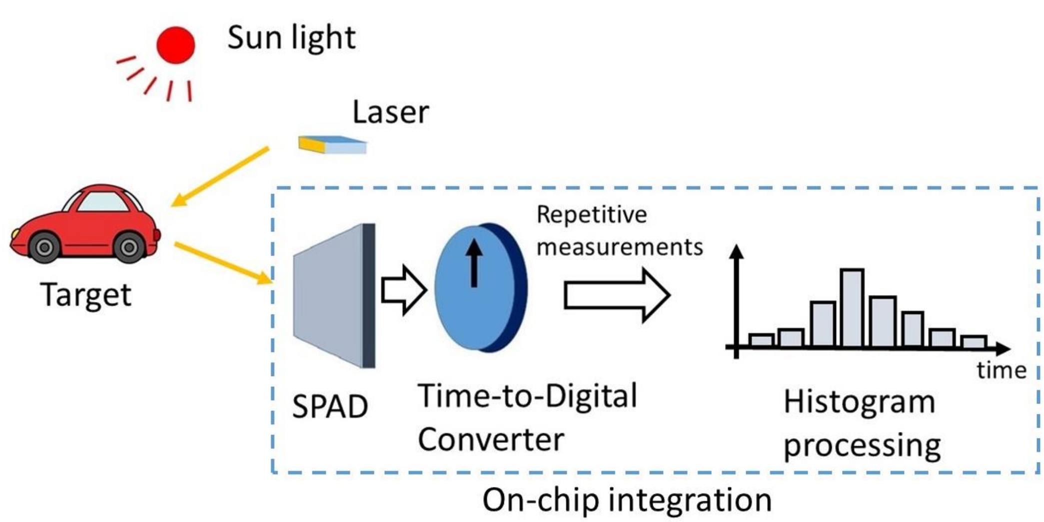

Figure 1　Schematic of LiDAR system

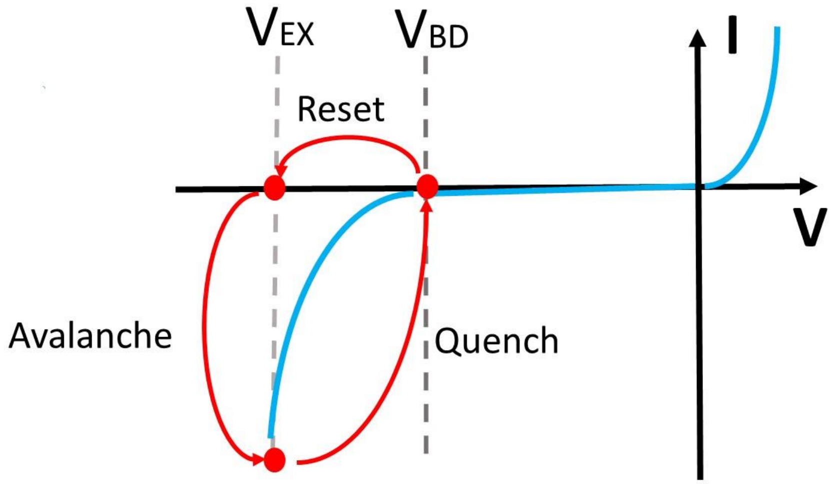

Figure 2　I-V characteristics of SPAD and photon counting operation

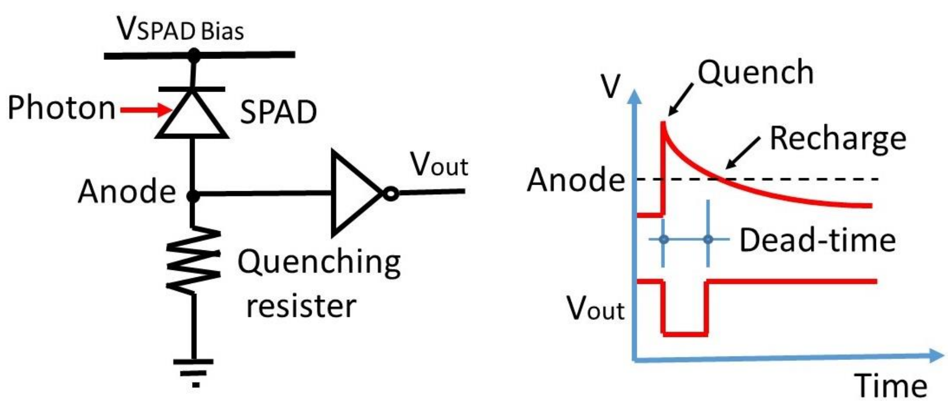

Figure 3　SPAD Photodetector circuit and operating waveforms

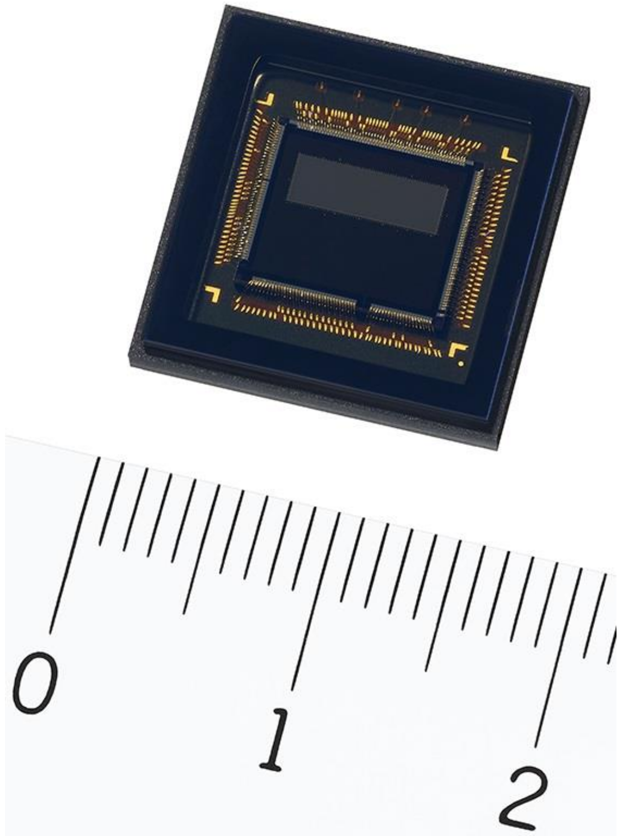

Figure 4　SPAD ToF depth sensor for automotive LiDAR "IMX459"
(Courtesy of Sony Semiconductor Solutions Corporation)

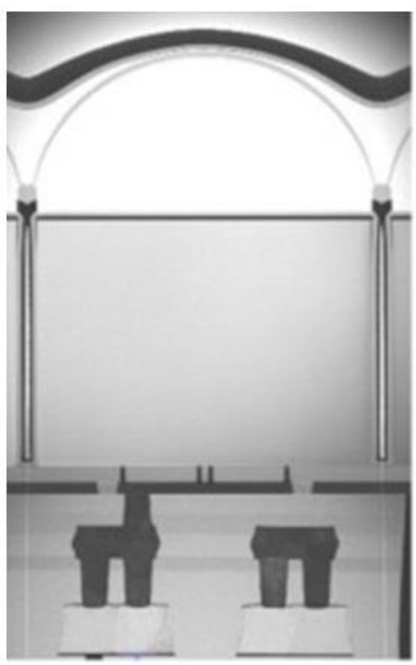

Figure 5　SPAD cross-sectional SEM photograph
(Courtesy of Sony Semiconductor Solutions Corporation)

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