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CMOS Single-Photon Avalanche Diodes for Light Detection and Ranging in Strong Background Illumination

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Abstract

Without any customization, SPAD array for high-speed high-precision light-detection-and-ranging (LiDAR) has been fabricated in 0.18-μm CMOS technology. Distance measurement up to 100 m has been achieved within 0.1 s under strong background illumination.

1. Introduction

Single-photon avalanche diodes (SPADs) in CMOS technology attracts increasing attentions due to the easy integration with CMOS circuits and the great potential for various applications, such as low-light/3-D imaging, fluorescence lifetime imaging microscopy, time-gated Raman spectroscopy, and light detection and ranging (LiDAR) for vehicles, etc.[1-3]. In particular, in advanced driver assistance system (ADAS), LiDAR using SPADs promises a highly reliable way for detecting distant pedestrians which may not be detectable by other means including camera and Radar [3]. By making LiDAR modules affordable to most cars without sacrificing its performance, the traffic accidents could be significantly reduced. In this report, we present the use of CMOS high-voltage 0.18-μm technology without any customization to fabricate a SPAD array and the module for SPAD LiDAR. The ranging results up to 100 m performed under various experimental conditions, such as integration time and background illumination, will be discussed.

2. Experimental Methods, Results, and Discussions

Single SPADs and SPAD array

Our SPADs and circuits were fabricated with CMOS high-voltage 0.18-μm technology. The SPAD device structure is illustrated schematically in Fig. 1(a). The p-n junction is formed by deep p-type well (DPW) and n-type buried layer (NBL). The high-voltage p-type well (HVPW) serves as a guard ring. The TCAD simulation result in Fig. 1(b) shows that the impact ionization region locates at the interface between DPW and NBL. Detailed device performance has been submitted elsewhere [4] and is summarized on Table I. The breakdown voltage is about 48 V and the PDP at 780 nm at excess voltage of 5 V is about 10 %. Low dark-count rate (DCR) and, low afterpulsing probability (APP) and low timing jitter were demonstrated with the SPADs in CMOS process without any customization. The chip having a 6x4 SPAD array was made for ranging. Each SPAD was equipped with a passive-quenching active-reset circuit and its output was shaped with a mono-stable circuit. The dead time was tunable and set at ~12 ns in the following measurement.

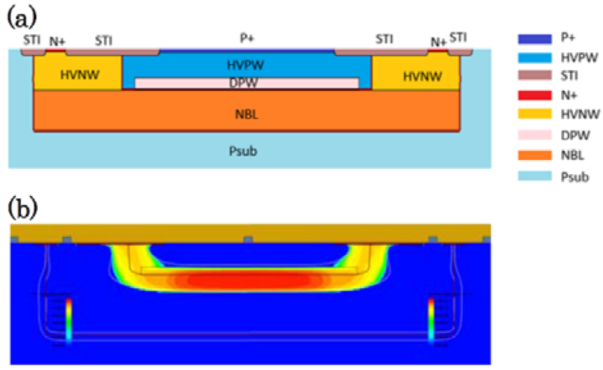

Fig. 1 (a) Schematic of our SPAD, and (b) its impact ionization distribution obtained from TCAD simulation.

Table I Measured Characteristics of Single SPADs

Parameters	Unit	Measured
Breakdown voltage, V_{BD}	V	48
Device active area	μm^2	314
DCR @ 5V	Hz	700
Peak PDP @ 5V	%	22
PDP @ 780 nm & 5V	%	10
APP@ 5V & 20 ns dead time	%	1.6
Timing jitter @ 780 nm	ps	128

Experimental setup

Figure 2 shows the schematic and photo of our ranging setup. The light source is a pulsed laser (Pico-Quant, λ = 780 nm, pulse width ~ 50 ps) operated at the repetition rate of 1 MHz and at the average power of 0.16 mW. Note that this laser power is extremely low comparing with those used in long range LiDAR. A white paper on a board was used as a scattering target. The scattered light was collected by the optics ahead of our SPADs, including a focus lens, a band-pass filter (778-781 nm), and a long-pass filter (>720 nm). A time-correlated single-photon count (TCSPC) counting card with bin time of 250 ps and dead time of 5 ns was used to record arrival times of photons. Both laser and TCSPC were triggered by a function generator. In addition, a commercial Bosch range finder was mounted on the board and in parallel to our laser path to calibrate the target distance.

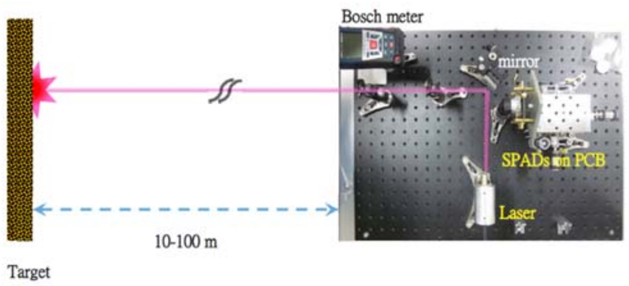

Fig. 2 Schematic and photo of our SPAD-LiDAR module.

Result and Discussion

Figure 3 shows the measured distance as a function of the actual distance under various background illumination and at the integration time of 0.1 s. The background illumination is recorded as the background counts, C_{BG}, obtained from the counts of 24 SPADs without laser emission. The lowest C_{BG} of 0.05 MHz indicates the total DCR without background counts and the highest one of 25 MHz represents the approximate background counts from 50 klux sunshine. The measured distance was determined with the center-of mass method [5] and the data were calculated by averaging 20 measurements. It is clear from Fig. 3 that the distance measurement up to 100 m are achieved for all background counts with our setup. The standard derivations of distance are about 2-3 cm for all measurements. For vehicle LiDAR application, high-speed ranging are necessary so we tested the shorter integration times under strong background illumination. Figure 4 shows the measurable maximum distance (D_{max}) as a function of the background count C_{BG} under the integration times (T_{int}) of 0.1, 0.01, and 0.001 s. At shorter T_{int}, the D_{max} decreases due to the lower signal-to-noise ratio in the arrival time histograms (not shown here). Because the laser signal count is proportional to the laser power, we expect that 100-m ranging in 1 ms under strong background illumination can be easily accomplished by using a 20-mW laser instead [3].

3. Conclusions

A setup for LiDAR using SPADs has been realized. By using CMOS HV18 process without any customization, we successfully fabricated a SPAD array chip with integrated active-reset quenching circuit, which is capable to measure 100 m in 0.1 s under strong background illumination. The measureable maximum distance as a function of background illumination and integration times has been obtained, Our work is valuable for developing low-cost and high-performance LiDAR module for ADAS.

Acknowledgements

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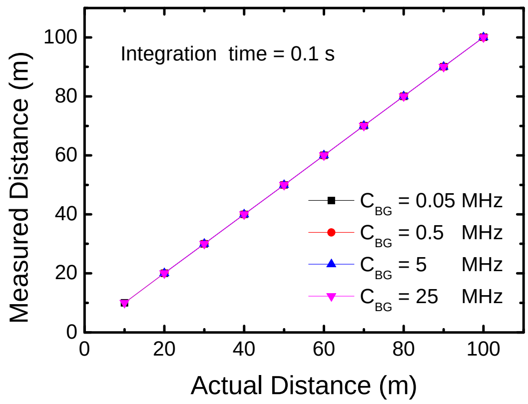

Fig. 3 Distance measurement results with 0.1 s integration time under various background illumination.

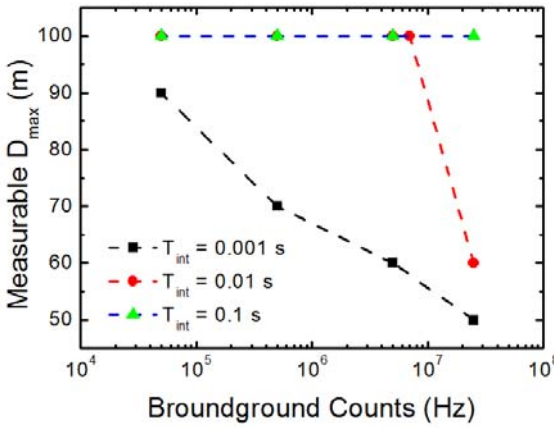

Fig. 4 Measurable maximum distance Dmax as a function of background counts at integration times of 0.1, 0.01, and 0.001 s.

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