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Photodetection Frequency Response Peaking in Si Avalanche Photodetectors Fabricated in Standard CMOS Process

Hyo-Soon Kang, Myung-Jae Lee, and Woo-Young Choi
Department of Electrical and Electronic Engineering, Yonsei University

Abstract

We report the photodetection frequency response peaking in silicon avalanche photodetectors (APDs) fabricated with 0.18 ㎛ standard complementary metal-oxide-semiconductor (CMOS) process. The reflection coefficient measurement of CMOS-compatible APD (CMOS-APD) indicates that rf-peaking in the photodetection frequency response is due to resonance caused by appearance of inductive components in avalanche region. Utilizing this rf-peaking, 3-dB bandwidth of CMOS-APD can be extended.

Research of photodetectors based on CMOS technology has been received a great attention for application in short-distant optical access network and optical interconnect. Using well-developed CMOS-based integrated circuit technology, low-cost monolithic optical receiver having a photodetector as well as other necessary electronic circuits can be possible in cost-effective manner [1, 2].

In this work, we present CMOS-compatible avalanche photodetectors (CMOS-APD) using 0.18 ㎛ standard CMOS process and characterize rf-peaking effects in photodetection frequency response as reported in InGaAs/InAlAs APD [3]. Through the investigation of impedance characteristics of the CMOS-APD, the rf-peaking effect is examined its physical origin.

Fig. 1 shows the cross-sectional diagram of fabricated CMOS-APD. In order to enhance bandwidth of photodetector, we only use the vertical P+/n-well junction and form multi-finger electrode with narrow finger space of 0.5 ㎛ to block substrate and lateral diffusion components, respectively. The vertical PN-junction structure can also mitigate the edge breakdown in the avalanche regime. The active area of our CMOS-APD is about 30 × 30 ㎛^{2} and the salicide process is blocked for the optical window.

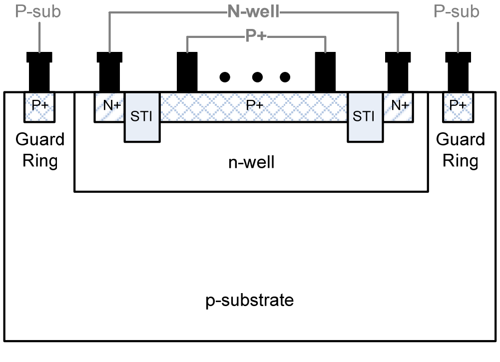

Fig. 1. Schematic cross-section of fabricated CMOS-APD

For characterization of the device, all experiments were done on wafer and 850 nm laser diode as well as electro-optic modulator are used. Fig.2 shows photocurrent and avalanche gain as well as current-voltage (I-V) characteristics with and without optical illumination. Avalanche gain is determined by the ratio of photocurrents between a given bias voltage and 1 V. It can be seen that CMOS-APD has avalanche breakdown voltage (V_{BK}) of 10.2 V and maximum avalanche gain of 1250 at this bias voltage under 0.1 mW optical illumination. Fig. 3 shows the photodetection frequency response of CMOS-APD when the incident optical power is 0.2 mW. Interestingly, at reverse bias voltage (V_R) larger than V_{BK}, rf-peaking is observed at the high frequency region. Such rf-peaking has been also reported in InGaAs/InAlAs APD [3]. The rf-peaking can be explained by changes in the impedance characteristics of CMOS-APD in avalanche region. As in transit-time diode such as IMPATT diode, the

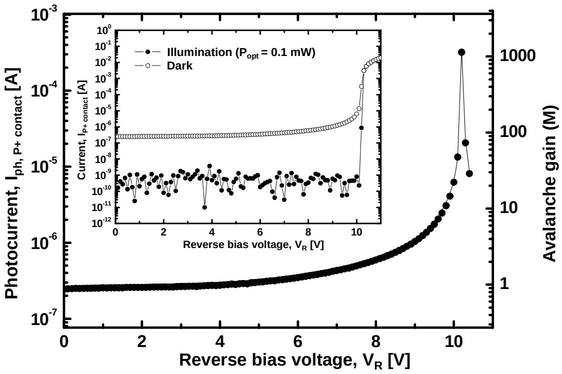

Fig. 2. Photocurrent and avalanche gain of the CMOS-APD. The inset is I-V characteristics under dark and illumination condition.

impedance of CMOS-APD can have an inductive component at V_R above V_{BK} in avalanche region and this inductive component can cause rf-peaking [4].

To investigate the impedance characteristics of CMOS-APD, we measured electrical reflection coefficients of the device from 50 MHz to 13.5 GHz using vector network analyzer with on-wafer calibration without any optical illumination as shown in Fig. 4. At V_R of 10.0 V, CMOS-APD does not have any inductive components. However, at V_R larger than V_{BK}, the device reactance changes from capacitive to inductive and then again to capacitive as the frequency increases. From this impedance characteristic on Smith chart, it is believed that CMOS-APD has inductive component as well as capacitive component in avalanche regime. We can expect that these inductive and capacitive components can cause resonance which results in rf-peaking in photodetection frequency response.

Under optical illumination condition, the impedance characteristics is not changed significantly due to the small amount of current change provided by optical illumination compared with the device dark current in avalanche regime.

In Fig. 3, it is noted that the rf-peak frequency increases with increasing V_R. This can be explained by the fact that the inductance in avalanche region is inversely proportional to the current and the CMOS-APD current increases as V_R increases as shown in Fig. 2 [4].

In summary, Si APD devices were fabricated in standard CMOS process and characterized. The CMOS-APD exhibits rf-peaking in photodetection frequency response at the bias voltage above the avalanche breakdown voltage due to resonance caused by appearance of inductive components in avalanche region. Through the results, it is expected that the optimization of the CMOS-APD utilizing rf-peaking can enhance photodetection 3-dB bandwidth while maintaining sufficient avalanche gain.

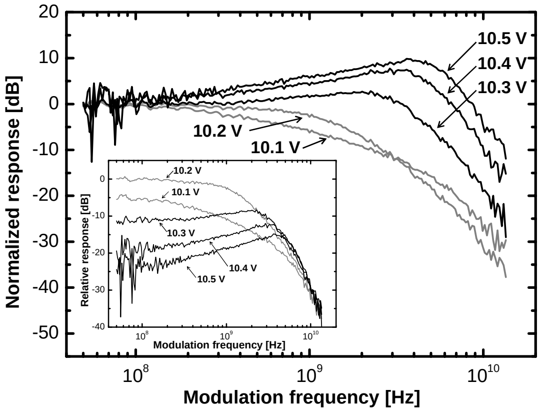

Fig. 3. Photodetection frequency response, which is normalized to response near dc. The inset shows relative photodetection frequency response. The incident optical power is 0.2 mW.

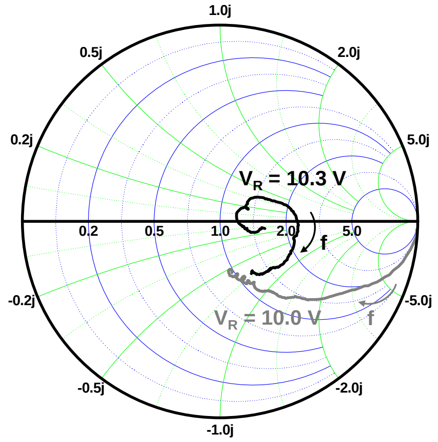

Fig. 4. Reflection coefficient at V_R of 10.0 and 10.3 V. S-parameter is measured from 50 MHz to 13.5 GHz.

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