Single-Photon Avalanche Diode Implemented in 90 nm Standard Bipolar-CMOS-DMOS Technology Achieving Broad Spectral Sensitivity

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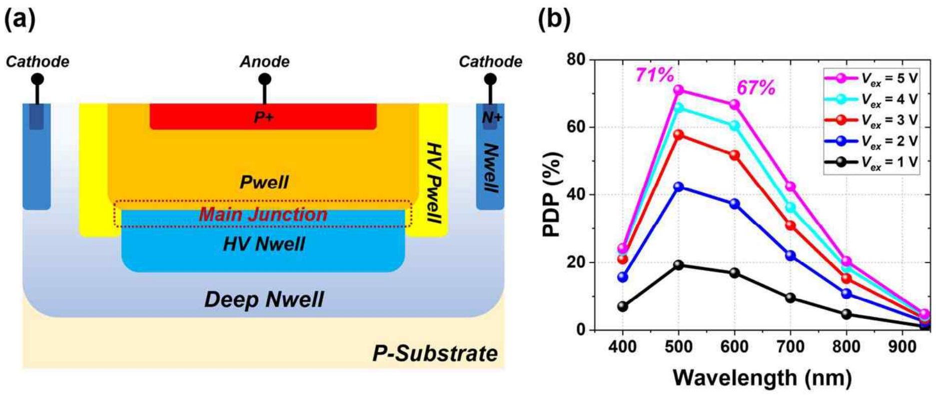

Fig. 1. (a) Cross-section of the front-illuminated SPAD and (b) its PDP performance.

Front-illuminated (FI) single-photon avalanche diodes (SPADs) are widely adopted in biomedical imaging systems owing to their compact pixel architecture, broad foundry accessibility, and suitability for monolithic integration with readout circuitry. However, as standard CMOS technologies continue to scale aggressively, increased doping concentrations and consequential reduction in depletion widths inherently degrade photon detection probability (PDP) while increasing dark count rate (DCR), thereby inducing fundamental limitations on high-performance SPAD development.

To address these limitations, bipolar-CMOS-DMOS (BCD) technology serves as a practical alternative, as it provides lightly doped and deep well layers that enable wider and more controllable depletion regions while maintaining compatibility with advanced CMOS fabrication processes.

Although a recent SPAD implementation has demonstrated exceptionally high peak PDP [1], such performance is optimized over a narrow spectral range. This narrowband optimization can limit its applicability in various biomedical imaging applications that require effective photon detection across a broader wavelength range.

In this work, we present a FI SPAD fabricated in a 90 nm standard BCD process. The main junction is formed between a Pwell and a high-voltage (HV) Nwell embedded in a deep Nwell, enabling efficient carrier collection and stable avalanche operation. Figure 1(a) illustrates the cross-sectional structure of the proposed SPAD using HV options for the guard ring as well as junction.

The measured PDP characteristics, shown in Fig. 1(b), span a wavelength range from 400 nm to 940 nm under various excess bias voltages (V_{ex}). The proposed device exhibits a relatively broad PDP response covering the visible and near-infrared spectrum. This broadband sensitivity aligns well with the wavelength requirements of diverse biomedical imaging applications.

Overall, these results demonstrate that combining a FI SPAD architecture with the BCD technology enables balanced SPAD performance, making the proposed device a promising candidate for biomedical imaging systems where broadband detection is essential.

Reference [1] W. -Y. Ha *et al.*, "SPAD Developed in 55 nm Bipolar-CMOS-DMOS Technology Achieving Near 90% Peak PDP," *IEEE J. Sel. Topics Quantum Electron.*, vol. 30, no. 1, pp. 1-10, Jan./Feb. 2024, Art. no. 3800410.

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