Back-Side Illuminated Ge-on-Si Single-Photon Avalanche Diode with a Light-Trapping Structure

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Germanium-on-silicon (Ge-on-Si) single-photon avalanche diodes (SPADs) combine efficient germanium absorption with low-noise silicon multiplication, offering strong CMOS compatibility and promising applications in short-wave infrared (SWIR) detection. Here, we propose a back-side illuminated (BSI) Ge-on-Si SPAD with a light-trapping architecture, integrating a silicon nano-cone array on the substrate back side and an aluminum reflector on the device front side. This design extends the optical path, suppresses broadband reflection via graded-index and multi-scale scattering effects, and enhances SWIR absorption. By synergizing optical and structural engineering, this architecture enables more efficient photon capture while minimizing surface reflection losses
Finite-difference time-domain (FDTD) and TCAD simulations demonstrate that the proposed device achieves single-photon detection efficiencies (SPDEs) of 37.7% at 1310 nm and 21.2% at 1550 nm, corresponding to enhancements of 102% and 86% over conventional frontside-illuminated structures. Meanwhile, a masked implantation scheme effectively suppresses sidewall electric fields, reducing tunneling and trap-assisted dark current and achieving a 61.2% reduction in dark count rate (21.9 MHz) [1]. This dual improvement in optical and electrical performance highlights the robustness of the proposed design across both key SPAD metrics.
Overall, this BSI light-trapping design simultaneously improves detection efficiency and dark count suppression while maintaining CMOS compatibility. It thus provides not only a performance boost but also practical manufacturability, bridging the gap between device-level innovation and system-level integration. It offers a scalable pathway toward large-format SPAD arrays, read-out integrated circuit (ROIC) integration, and future 3D-stacked SWIR single-photon de-tection systems.

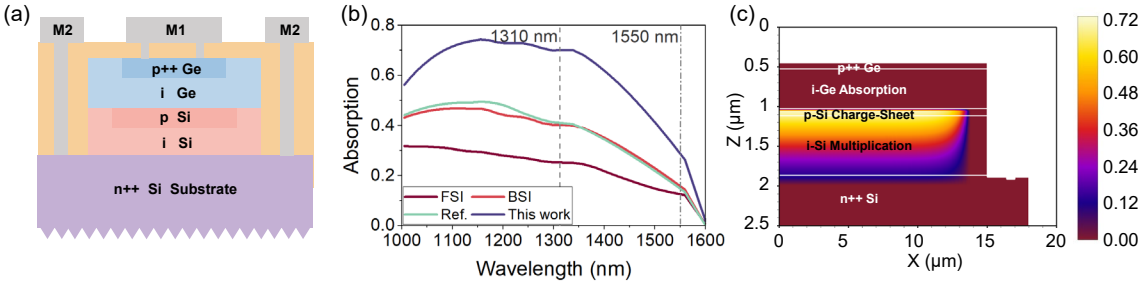

Fig. 1: *(a) Schematic of the BSI Ge-on-Si SPAD with a light-trapping structure. (b) Simulated absorption spectra of SPADs with different surface structures. (c) Simulated breakdown probability distributions of proposed SPAD.*

References

[1] L. Liu and Z. Xu, Optics Express, Vol. 33, No. 26, 53949–53964 (2025)