Recent Advances in Silicon-Based Single-Photon Counting Modules for Visible to 1064 nm Applications

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Abstract

Recent developments in silicon-based Single-Photon Counting Modules (SPCMs) demonstrate significant enhancements in Photon Detection Efficiency (PDE), temporal resolution, and wavelength coverage spanning the visible to near-infrared (NIR) spectral range. The SPCM-1064 extends high-performance photon counting into longer NIR wavelengths, delivering a typical PDE of approximately 10% at 1064 nm while maintaining PDE values exceeding 50% across the 750–950 nm range and greater than 60% at 830 nm and 905 nm. Its large 500 µm active area improves photon collection from divergent beams and reduces alignment sensitivity, while supporting high linearity at elevated count rates. Reported advances now extend practical silicon photon counting into the 1064 nm regime while preserving high count linearity, closing a long-standing gap between Si and InGaAs detectors. In parallel, performance-optimized timing modules from the SPCM-TR family achieve single-photon timing resolution below 200 ps full width at half maximum (FWHM), while maintaining peak PDE above 70% near 650 nm on a 180 µm active area.

Summary

Silicon-based SPCM performance can be optimized along multiple parameters, including PDE, temporal resolution, and wavelength sensitivity. Figure 1 illustrates representative PDE spectra and timing characteristics for several detector architectures designed to emphasize different regions of this performance space. Standard SPCM designs (SPCM-AQRH) achieve peak PDE values up to approximately 70% near 650 nm and are available with a broad range of dark count rates. Timing-optimized variants (SPCM-TR) offer comparable peak efficiencies but exhibit a more pronounced roll-off at longer wavelengths. Conversely, NIR-optimized architectures (SPCM-NIR) achieve enhanced sensitivity in the 700–850 nm range through optical and structural optimization.

Optimizing PDE for specific wavelength ranges is inherently coupled with timing resolution performance. Devices optimized for fast timing can achieve single-photon timing resolution as low as 160 ps FWHM, while more broadband or NIR-optimized structures typically exhibit timing resolution in the 250–300 ps range. Architectures designed for extended NIR sensitivity, such as the SPCM-1064, employ alternative APD designs and exhibit timing resolution on the order of 400 ps FWHM.

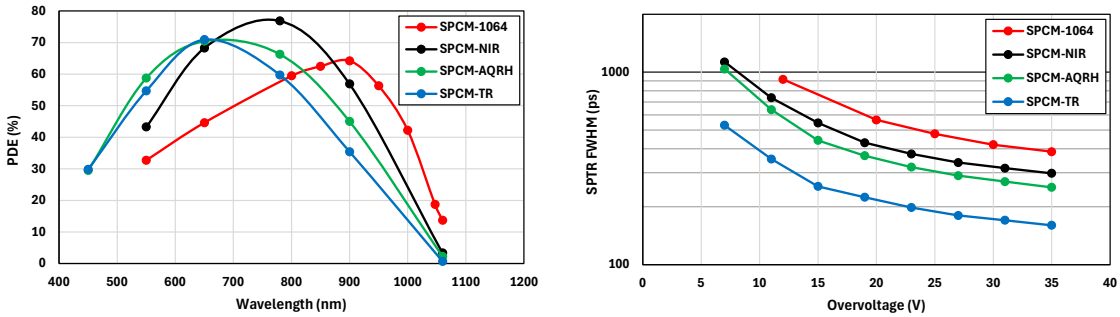

Fig. 1: *Photon Detection Efficiency Spectra (left) and Single-Photon Timing Resolution for Different SPCM Architectures (right).*