Afterpulsing reduction for InGaAs/InP SPAD with integrated diffused resistor

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InGaAs/InP Single-Photon Avalanche Diodes (SPADs) today are employed in high-performance, compact and reliable instruments for single-photon counting applications in the near-infrared range (up to 1.7 μm). In the last years, many efforts were made to improve material quality, thus reducing their noise. However, afterpulsing still limits high frequency operation of such devices. An attractive solution to reduce the avalanche charge flow, and thus the afterpulsing, without the complexity of short gating techniques is to employ integrated quenching resistors in order to passively quench the avalanche with the smallest stray capacitance.

This approach has been explored by others for InGaAs/InP SPADs, by depositing thin film resistors with high (few MΩ) resistance, at the expense of a long exponential recovery time (hundreds of ns) that limits the maximum count rate [1]. We employed a smaller value integrated quenching resistor (few tens of kΩ), which has to partially quench the avalanche, in combination with an external active circuit that completes the quenching. Such approach still provides a strong avalanche charge reduction, while keeping the SPAD recovery time in the nanosecond range. The much faster recovery brings the further advantage that the detector can be gated with relatively fast rising edge. Moreover, the active quenching circuit guarantees a selectable hold-off time.

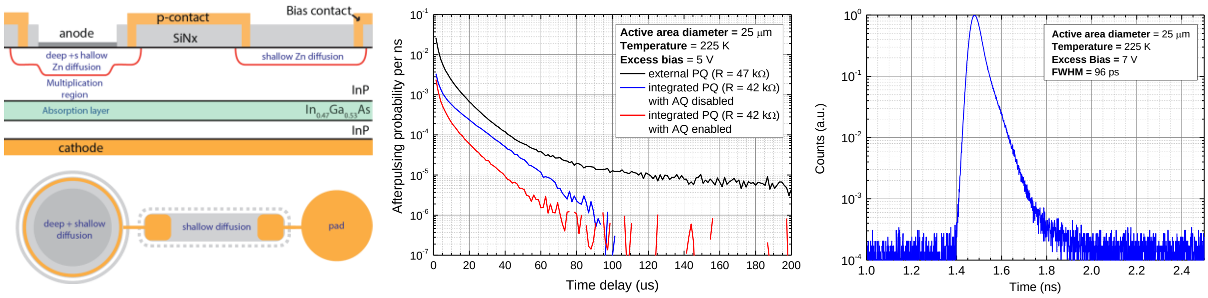

Fig. 1. Left: Schematic representation of a SPAD connected to a diffused quenching resistor: cross-section and top view. Centre: Dependence of afterpulsing probability in 1 ns on the time delay after previous avalanche for three quenching methods: i) external passive quenching (47 kΩ); ii) integrated passive quenching (42 kΩ); iii) integrated passive quenching with external active quenching circuit. Right: Temporal response of the detector with an integrated resistor R_{qi} = 42 kΩ, when illuminated by a sharp (~ 20 ps) pulsed laser at 1550 nm. For comparison, the FWHM of a standard SPAD from the same wafer and an external quenching circuit is about 80 ps.

A new implementation of the integrated quenching resistor was pursued, which does not require neither additional process steps (like material depositions) nor masks, and guarantees very good yield. In detail, we exploited the shallow Zinc diffusion, already present in the SPAD heterostructure [2], to fabricate a diffused resistor in close proximity to the annular anode contact, as illustrated in Fig. 1 (left).

For the experimental characterization, we employed a front-end electronics with a couple of broadband and matched trans-impedance amplifiers, all housed inside a cryostat with the detector, a low time jitter comparator, an active quenching circuit and a baseline restoring bias-tee.

Avalanche charge is strongly reduced, thanks to the prompt quenching that results from the low parasitic capacitance at the SPAD anode, as demonstrated from electroluminescence measurements. Consequently, a significant reduction of afterpulsing and crosstalk is observed (Fig. 1 center). Additionally, this detector can be gated with fast rising/falling edges and hold-off times shorter than 1 μs, thus achieving high count rates. We also demonstrated that integrated resistors can reduce the mutual crosstalk probability of two pixels at 120 μm distance from about 90 % to about 10 %. Finally, a good timing resolution (< 100 ps), suitable for most application, can still be obtained, despite the readout is impaired by the internal resistor.

References

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