Charge persistence dependence on double zinc diffusion geometry and guard ring bias in InGaAs/InP SPADs

Fabio Telesca, Fabio Signorelli, Alberto Tosi

Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, 20133 Milano, Italy

InGaAs/InP single-photon avalanche diodes (SPADs) are reliable and versatile detectors with high photon detection efficiency (PDE) in the short-wavelength infrared range, whose applications span from quantum cryptography and quantum optics to LiDAR. They are operated at low temperature (< 250 K) for reducing the thermal generation of carriers, although afterpulsing is worsened at low temperature, as well as charge persistence [1][2], which is often overlooked. Charge persistence is a source of noise originating from holes thermally- or photo-generated inside the InGaAs absorption layer at the periphery of the active area and that diffuse towards the active area: if they enter the multiplication region, they can ignite an avalanche. Charge persistence is highly undesirable, and it cannot be exploited as a charge-focusing effect for collecting photons absorbed outside the central active area, as it is based on the slow diffusion charge transport. Moreover, charge persistence of thermally-generated carriers adds up to DCR and, also, worsens the temporal response of the device. This effect can be mitigated by either increasing the electric field in the absorption layer (with the drawback of increased field-assisted noise) or by incrementing the number of grading layers (thus increasing fabrication complexity).

In this work, we show how charge persistence may be reduced by adjusting the double zinc diffusion geometry and exploiting the guard ring bias. By increasing the radius difference between deep and shallow diffusion (Δr, see Fig. 1), charge persistence is reduced since the persisting holes can tunnel through the hetero-barrier below the shallow diffusion and flow to the p-contact without entering the multiplication region. For devices with increasing Δr (see Fig. 2), charge persistence decreases, while PDE at 1550 nm (measured by scanning the chip with a focused CW laser) is roughly the same. We also fabricated a device with an additional contacted shallow guard ring, which can be biased so that the electric field is increased locally beneath it, in order to sink holes before they reach the active area (Fig. 3, a and b). However, if the GR junction reverse bias is increased too much, avalanches occur near the guard ring contact (Fig. 3, c), worsening the DCR. In conclusion, the reported measurements gave further insights on a SPAD design strategy to reduce charge persistence while decreasing DCR, without affecting PDE.

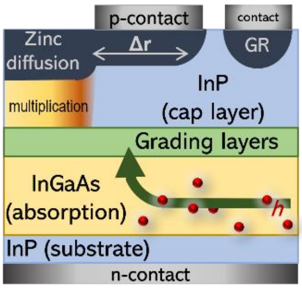

Fig. 1 Schematic cross section of an InGaAs/InP SPAD. Δr is the difference between the shallow diffusion radius and the deep diffusion one. The contacted guard ring (GR) is not present in the 25 µm SPAD shown in Fig. 2.

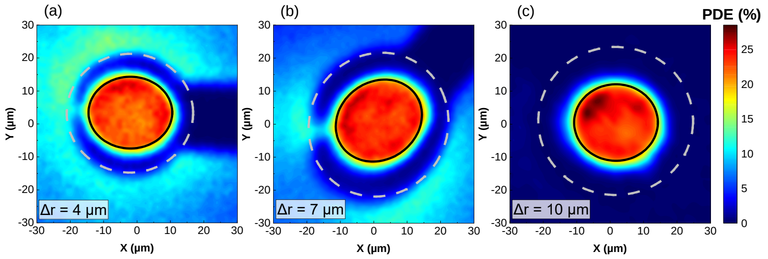

Fig. 2 PDE maps at 1550 nm of three different SPADs with 25 µm deep diffusion diameter (see black solid circle), with increasing shallow diffusion diameters (dashed white circle). Measurements were carried out scanning the chip area with a CW laser focused in a ~5 µm spot, at 225 K.

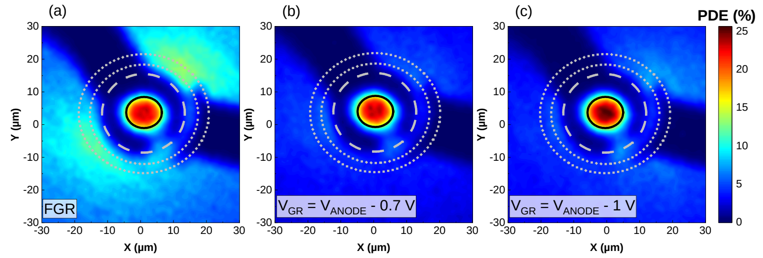

Fig. 3 PDE maps at 1550 nm of a SPAD with 10 µm deep diffusion diameter (black solid circle), Δr = 7 µm (white dashed circle) and a contacted guard ring (dotted white circle). The guard ring is: a) left floating; b) and c) reverse biased with increasing voltage.

References

[1] N. Calandri, M. Sanzaro, A. Tosi, and F. Zappa, “Charge Persistence in InGaAs/InP Single-Photon Avalanche Diodes,” *IEEE J. Quantum Electron.*, vol. 52, no. 3, Mar. 2016.

[2] Y. Lee, K. Chen, S. Chien and S. Chang, "Characteristics of Charge Persistence in InGaAs/InP Single-Photon Avalanche Diode," in IEEE Photonics Technology Letters, vol. 30, no. 22, pp. 1980-1982, 15 Nov.15, 2018.