Low Noise InGaAs/InP Single Photon Avalanche Diodes Integrated with 2PP-Printed Microlens

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High-performance SWIR detectors are essential for QKD and LiDAR, with InGaAs/InP SPADs representing the current gold standard. However, these devices face a critical trade-off between collection area and Dark Count Rate (DCR). To minimize noise and afterpulsing, active areas are often limited to small diameters (e.g., 10 µm), severely constraining the effective fill factor and complicating light coupling in free-space or fiber-based systems. In this work, we present the design, fabrication, and characterization of spherical microlenses directly integrated onto 10 µm InGaAs/InP SPADs. The lenses were fabricated via Two-Photon Polymerization (2PP) using a commercial Nanoscribe Quantum X Shape system available at POLIFAB, the cleanroom of Politecnico di Milano. This maskless additive manufacturing technique offers high-resolution 3D patterning and sub-micrometer alignment precision, which is critical for centering optical elements on small-area detectors (Fig. 1 (a),(b)). Experimental characterization proved that the DCR and timing jitter of the microlens-equipped devices remain comparable to those of bare SPADs, thus confirming that the 2PP process introduces no structural defects within the SPAD and that the polymer optical element does not degrade the timing response of the detector. PDE maps (at 1550 nm, NA = 0.25) reveal a ~53-fold increase in photon collection area (Fig. 1 (c),(d)). Concentration factor (CF) at 1550 nm was measured to be 4.63 and 7.1 with f-number 2.08 and 2.63, respectively. At 1310 nm, CF reached 3.8 and 5.5 for the same f-numbers (Fig. 1 (e)). Measurements are in line with simulated values. These values outperform existing literature for high-NA illumination [1][2], proving this approach ideal for compact LiDAR and quantum sensing in the SWIR range.

References

[1] J. M. Pavia et al, Opt. Express, vol. 22, fasc. 4, pp. 4202–4213, feb. 2014

[2] G. Intermite et al., SPIE Optics + Optoelectronics, Prague, Czech Republic, may. 2015

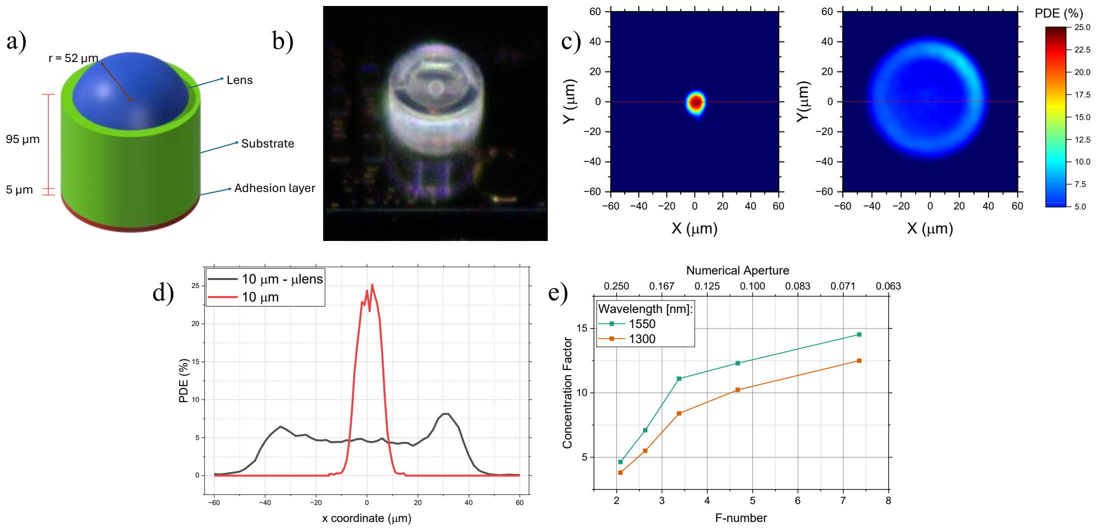

Fig. 1: *(a) Schematic illustration and (b) microscope image of fabricated microlens. (c) PDE maps at 1550 nm (NA=0.25) for bare (10 µm) and microlens-equipped device. (d) Cross section of the PDE maps at Y = 0 µm. (e) Measured concentration factor as a function of f-number at 1550 and 1310 nm.*