QuaSI – A 256×256 Quantum SPAD Imager

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Abstract: We report one the design of a 256×256-pixel single-photon sensor for quantum imaging applications. The chip has advanced photon timestamping capabilities thanks to a clustered architecture and the smart re-use of the available in-pixel logic.

Quantum science represents one of the most challenging applications for scientific imagers, due to a combination of conflicting needs: the photon detection efficiency must be as high as possible to compensate for the poor efficiency of entangled photon sources; both the uncorrelated and the correlated noise events should be rare; the timing resolution should be as small as possible, ideally in the sub-picosecond regime, to take advantage of the temporal correlations existing among entangled photons. Single-Photon Avalanche Diodes (SPAD) in CMOS technology are one of the leading sensing technologies in the field, finding their strength in the unique combination of imaging configuration with on-chip time-domain processing capabilities [1]-[3]. Recently, they have been integrated in quantum systems to demonstrate super-resolution imaging [4], sub-minute quantum ghost imaging [5], and non-line-of-sight imaging.

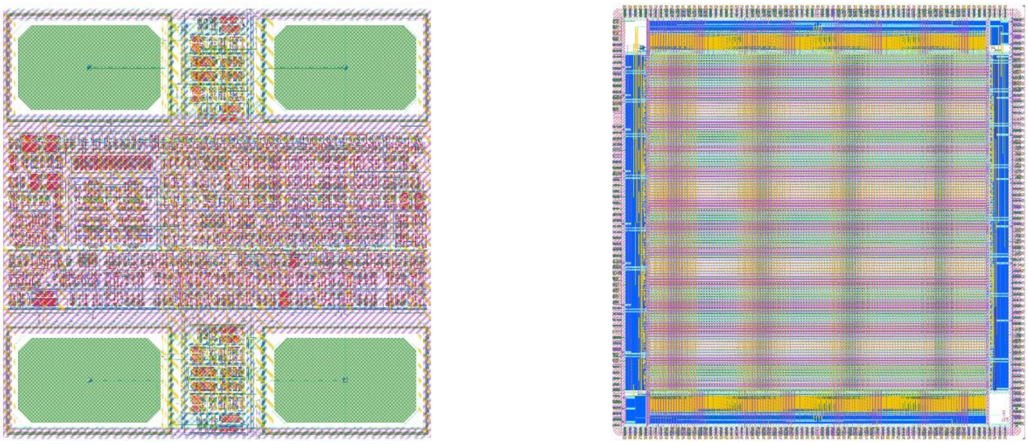

Fig. 1 Layout of the pixel (left) and of the complete 256×256-pixel array (right).

Within the NQSTI project we developed a general-purpose quantum SPAD imager (QUASI) targeting a broad range of possible quantum imaging applications. The chip covers a total area of 9.5×9.95mm2 and includes a 256×256 SPAD array which is organized in 128×128 macropixels (2×2 SPADs). The 4 SPADs belonging to the same macropixel share the TDC, the logic arbiter circuit and other in-pixel resources. Thanks to this choice it has been possible to increase the SPAD active area, reaching a Fill Factor (FF) around 20% with a SPAD size of 30 µm.

To improve the chip duty cycle, it has been also foreseen to share the aforementioned electronics blocks among the neighboring macropixels located on the same row. This means that, in case of multiple events detected by the SPADs within the same macropixel, if the TDCs of the adjacent macropixels (left and right) are available, they can be used to timestamp two of the detected events from the fired SPADs.

Example References

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[3] Gasparini, M. M. García, M. Zarghami, A. Stefanov, B. Eckmann and M. Perenzoni, "A reconfigurable 224×272-pixel single-photon image sensor for photon timestamping, counting and binary imaging at 30.0−µm pitch in 11 0nm CIS technology," ESSCIRC 2022- IEEE 48th European Solid State Circuits Conference (ESSCIRC), Milan, Italy, pp. 189-192 (2022), doi: 10.1109/ESSCIRC55480.2022.9911497.

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[5] Valerio Flavio Gili, Dupish Dupish, Andres Vega, Massimo Gandola, Enrico Manuzzato, Matteo Perenzoni, Leonardo Gasparini, Thomas Pertsch, and Frank Setzpfandt, "Quantum ghost imaging based on a "looking back" 2D SPAD array," Appl. Opt. 62, 3093-3099 (2023)