BCD SPAD arrays for quantum optics applications

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Quantum optics is a field that profits by the granular nature of light to process information. It branches into various applications, particularly quantum imaging and quantum communication.

In this work we present two different SPAD imagers, a 96 × 96 array for quantum enhanced microscopy (Fig. 1 left) and a 32 × 1 array to be primarily employed in the Quantum Random Generator block within a quantum key distribution system (Fig. 1 right).

The first imager has been designed to accomplish the requirements of the European Project Q-MIC (Quantum-enhanced on-chip interference MICroscopy), which aims at developing a miniaturized on-chip interferometric microscope without lenses and illuminated by short wavelength entangled photon pairs. This solution allows to reach unprecedented sensitivity in the imaging of ultrathin transparent materials, such as photosensitive cells, single protein layers and biomarkers. From the detection standpoint, Q-MIC needs a SPAD image sensor array able to detect short wavelength single photon coincidences, within a coincidence time window as short as possible. With such a large number of pixels, each consisting of 10 μm SPAD and 50 μm pitch, resolution is boosted. However, the major breakthrough is the ability to detect photon coincidences spread over the entire array directly on chip and to provide the addresses of the triggered pixels only when a coincidence is detected, thanks to a novel event-driven logic. The coincidence detection is performed in an analog way based on 12 × 12 sub-arrays bringing to coincidence windows of about 2 ns, while the way each triggered pixel communicates its address is similar to an I2C architecture. The readout lasts 330 ns, whereas state-of-art 96 × 96 arrays require tens of microseconds.

A second European project, UNIQORN (Affordable Quantum Communication for Everyone: Revolutionizing the Ecosystem from Fabrication to Application) proposes to conceive a full Quantum System on Chip (QSoC) for telecom application for QKD (Quantum Key Distribution). For this purpose, a source of random keys needs to be introduced, leading to the design of the aforementioned 32 × 1 SPAD array. The chip has three operation modes. First one is Single-Hit Mode, needed to reveal the position of the pixel triggered by a single photon in a time window synchronous with the laser emission. The 5-bit address of the pixel position is provided, representing a pseudo- random number. Multi-Hit Mode is used to identify a coincidence of a certain number of photons, detected within a specified time window, for applications such as background rejection in Light Detection and Ranging. This operation mode employs a logic able to detect the presence of more than a user-selectable number of photons impinging on the array, namely one, two, three or four. At last, Simple Detector Mode provides an output pulse for each of the 32 pixels, synchronous with the photon detection on the array.

The linear array architecture consists of 32 pixels, each made by 4 SPADs with different diameter (5 μm, 10 μm, 20 μm, 50 μm) and their own quenching circuit. A coincidence logic circuit based on a selectable multi-threshold current comparator implements both single-hit and multi-hit modes. At last, an output block deals with signals readout, operating either in serial or parallel mode. The design has been performed in 0.16 μm BCD technology.

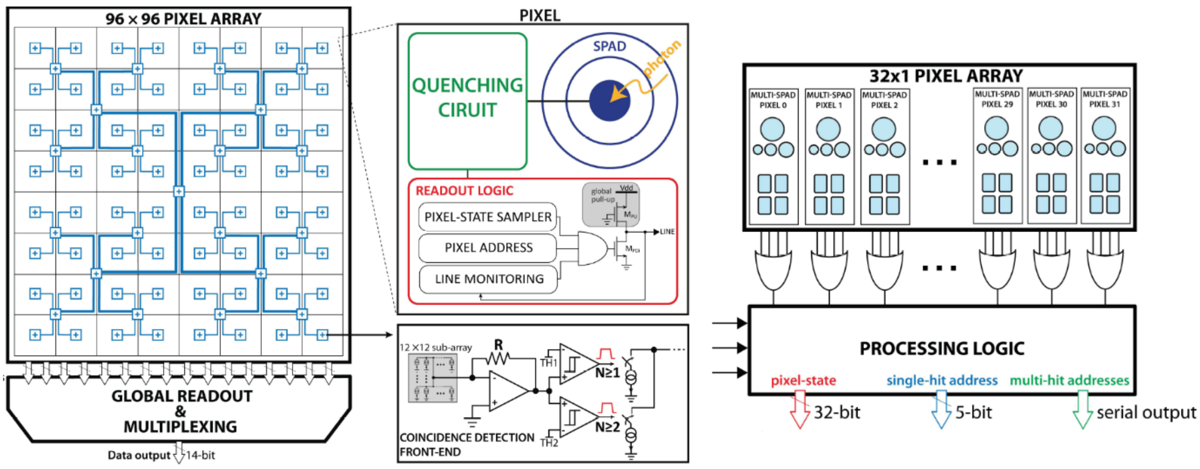

Fig. 1 Architectures of the Q-MIC 96 × 96 event-driven detector (left) and the UNIQORN linear array for coincidence detection (right).

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