Geiger-mode detectors at FBK: a sensing platform for Quantum Applications

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Abstract: FBK is one of the leaders in the development of single-photon and single-electron detectors, which are enabling technologies for several quantum applications, ranging from point sensing systems to readout of NV-centres.

Silicon Photomultipliers (SiPMs) and Single Photon Avalanche Diodes (SPADs) can detect single photons with excellent sensitivity and time resolution. In conjunction with a suitable redout electronics, and thanks to modern 3D-interconnection techniques, they are an ideal platform to build 1D and 2D arrays of single-photon detectors that can be used in applications such as time-correlated single-photon counting, spectroscopy, fluorescence lifetime imaging, single-photon imaging and timing. Furthermore, the Geiger-mode technology used in SPADs can be exploited to build single electron detectors for the readout of NV-centres in diamond.

In this context, Fondazione Bruno Kessler (FBK) is at the forefront of the developments. FBK's NUV-sensitive SiPM technology provide state of the art performance, such as a Photon Detection Efficiency (PDE) exceeding 60% in the NUV (Fig. top left), combined with low dark noise (DCR around 40 kHz/mm^2) and 20 ps SPTR for the single SPAD [1]. Thanks to a recent upgrade of FBK cleanroom dedicated to 3D processing and integration techniques [2] and using recently proposed concepts such as the single-cell TSV (Fig. top center), 1D and 2D arrays of single SPADs, fabricated in FBK custom technology, will be connected to a custom ASIC, also designed by FBK, with a dedicated connection for each SPAD (fig. top right), building hybrid analog/digital SiPMs. The hybrid SPAD/SiPM approach allows achieving ultimate sensitivity, noise and timing performance, provided by the custom SPAD/SIPM technologies, combined with advanced readout architectures, provided by advanced CMOS local readout.

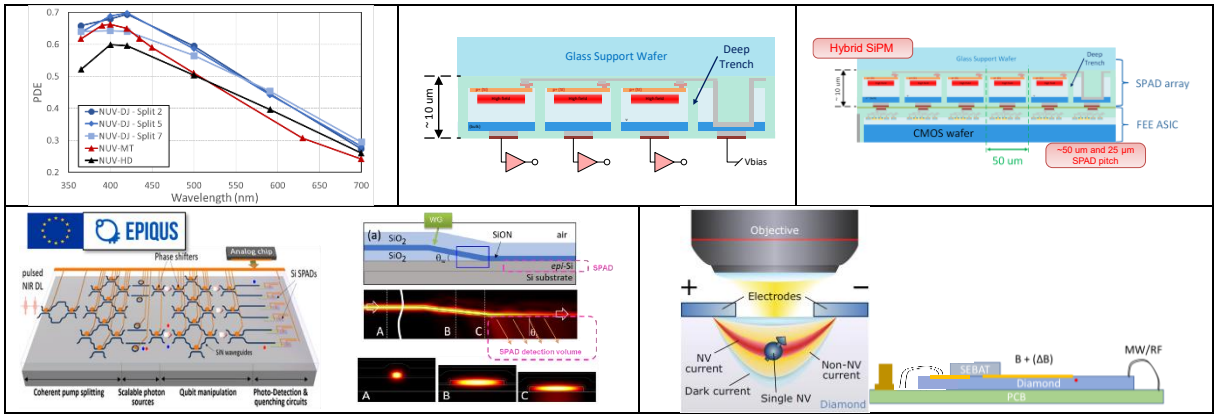

Fig. Top Left: PDE vs. wavelength for different NUV-sensitive, FBK SiPM technologies; **Top Center:** Single-cell TSV concept proposed by FBK. **Top Right:** Hybrid, 3D-integrated SPAD array. **Bottom left:** PICs and SPADs are fabricated together and optically coupled. **Bottom right:** photoelectric readout of an NV-centre in diamond using an heterogeneously integrated SEBAT device.

Another, advanced application that is possible thanks to the customization of the SPAD technology is the combination of Photonic Integrated Circuits and their single-photon readout by SPADs in the same wafer, to build an electronic-photonic integrated quantum simulator platform (EPIQUS project, Fig. bottom left) [3].

Finally, leveraging its expertise on Geiger-mode photon detectors, FBK is currently developing a Single-Electron Bipolar Avalanche Transistors (SEBAT), which is a promising technology for the measurement of the low-level currents in the photoelectric readout of NV centres in diamond (Fig. bottom right). In this case, the SEBATs will be fabricated on silicon wafers and coupled to the NV-centres, fabricated on diamond wafers, through heterogenous integration techniques, also being developed at FBK.

References

[1] Gola, Alberto, et al. "NUV-sensitive silicon photomultiplier technologies developed at Fondazione Bruno Kessler." Sensors 19.2 (2019): 308.

[2] Parellada-Monreal, L., et al. "3D integration technologies for custom SiPM: From BSI to TSV interconnections." NIMA 1049 (2023): 168042.

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