Reaching GHz single photon detection rates with HgCdTe avalanche photodiodes detectors

S. Pes, J. Rothman, P. Bleuet, J. Abergel, S. Gout, P. Ballet, J.-L. Santailler, J.-A. Nicolas, J.-P. Rostaing, S. Renet, A. Vandeneynde, L. Mathieu, J. Le Perchec
Univ. Grenoble Alpes, CEA, Leti, F-38000 Grenoble, France

Context and objectives

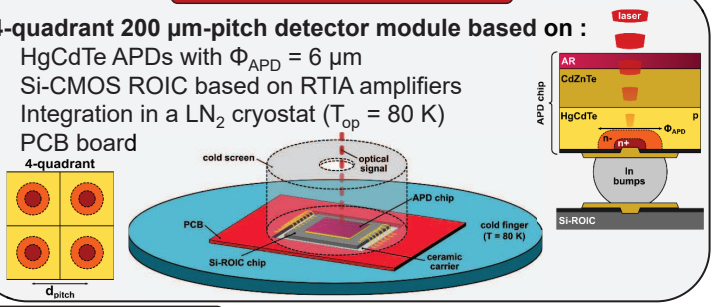
Development of a ground-segment detection module for 1.55 µm high data rate long-distance free-space optical (FSO) communications in collaboration with the European Space Agency

Linear-mode HgCdTe APDs: high gain × bandwidth product

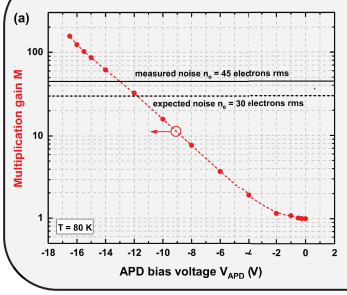
IDEAL CANDIDATES
- high dynamic range
- low excess noise
- high quantum efficiency
- no dead time

Detector architecture

4-quadrant 200 µm-pitch detector module based on :
- HgCdTe APDs with Φ_{APD} = 6 µm
- Si-CMOS ROIC based on RTIA amplifiers
- Integration in a LN_2 cryostat (T_{op} = 80 K)
- PCB board

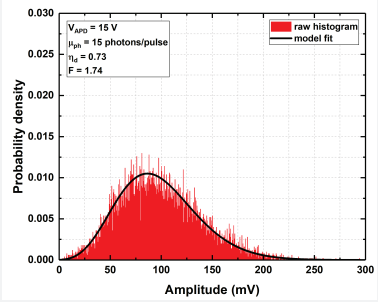


Meso-photonic state detection



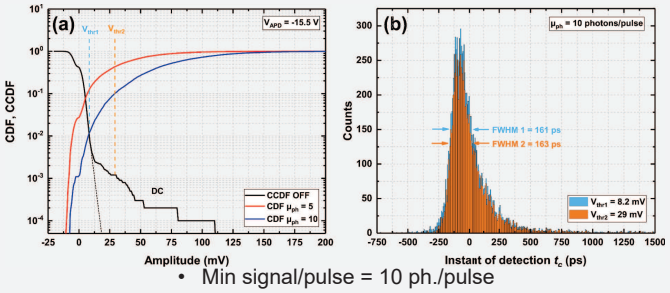
- Multiplication gain M > 150
- ROIC input referred noise N_e = 45 el. rms
- Bandwidth BW_d = 450 MHz
- Detection efficiency η_d = 0.73 } QEFR = 0.45
- Excess noise factor F = 1.74
- Meso-photonic states detection (1 to tens of ph./pulse)

Linear-mode meso-photonic detection exceeding 500 MHz
(cumulative: **2 GHz if signal is dispatched over 4-quadrants**)



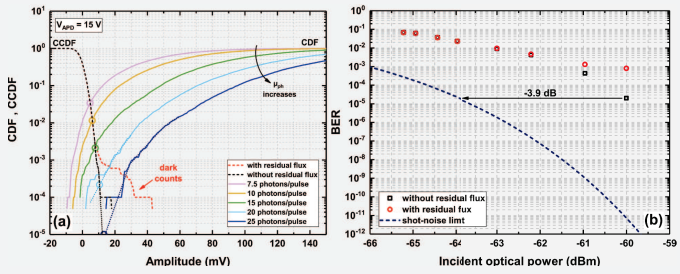
Performance evaluation for deep-space datacom

PPM



- Min signal/pulse = 10 ph./pulse
- Detection rate = 0.99 (0.90)
- False alarm rate = 10^{-2} (1.2×10^{-3})
- Minimum time slot = 500 ps
- Temporal jitter FWHM = 160 ps

625 Mbps OOK



-3.9 dB penalty wrt a quantum-limited situation

Detector BER limited by the detector QEFR (= 0.42)

Conclusions

- Development and characterization of a 4-quadrant HgCdTe APDs-based detector module for ESA deep-space FSO communications with high gain and high bandwidth
- Meso-photonic state detection ranging from 1 to 10s of ph./pulse demonstrated
- Performances evaluation for PPM and OOK modulation formats

Perspectives

- Current development of a **new APD technology** with larger area, more homogeneous multiplication layer with high gain, lower excess noise and faster response (reduced jitter).
- **µ-lens array** current development to improve optical coupling,: reduce temporal jitter and improve quantum efficiency
- **Optimized detector module in development for deep-space optical communications and quantum applications.**

CONTACTS : salvatore.pes@cea.fr, johan.rothman@cea.fr

FUNDINGS : ESA contract no. 4000121291/17/D/MB
LabEx FOCUS - grant ANR-11-LABX-0013

ICSO 30 March to 2 April 2021 2020 100 % VIRTUAL
ICSO 2020 INTERNATIONAL CONFERENCE ON SPACE OPTICS VIRTUAL
esa FOCUS Focal Plane Array for Universe Sensing
INSTITUT CARNOT CEA LETI