Development and Application of CMOS based SPAD Arrays

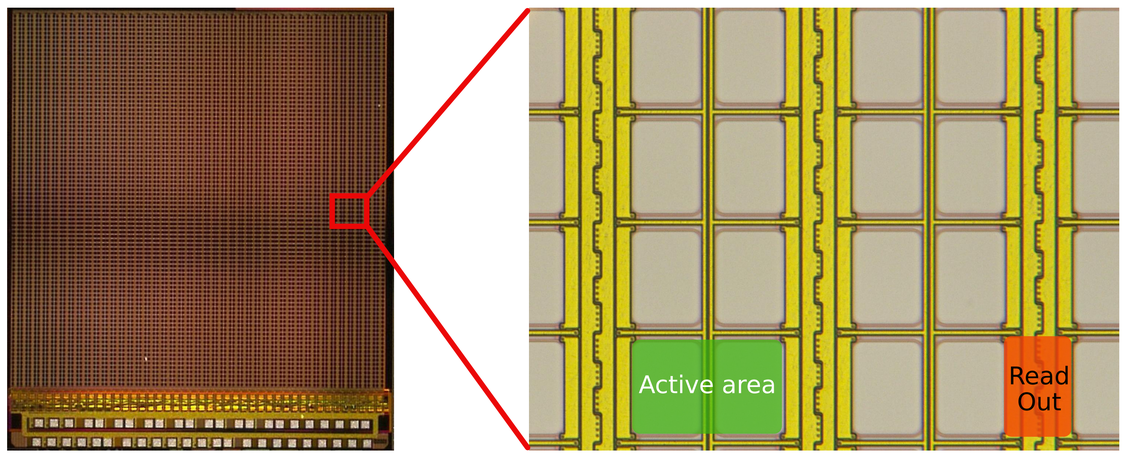
Michael Keller, Institute of Computer Engineering, Heidelberg Uni.

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

CMOS based SPAD arrays

- Combination of Single Photon Avalanche Diodes (SPADs) and CMOS readout electronics on a single chip
- Signal of each SPAD is directly digitized: purely digital output
- Capable of detecting single photons
- Excellent timing resolution due to fast SPAD signal
- Spatial resolution is directly available
- Totally flexible readout architecture: research driven technology

Present Sensor



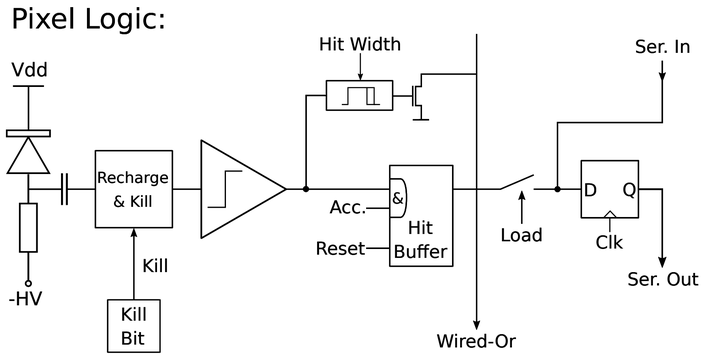
Sensor overall:

- Single Photon Avalanche Diode (SPAD) array fabricated in a CMOS technology
- 2D Array with $88 \times 88 = 7744$ pixels
- Pixel size is $56.4 \times 56.4\ \mu m^2$
- Fill Factor $\approx 50\,\%$
- Total active area $\approx 12\,mm^2$
- Pixels can be turned off: reduces overall noise

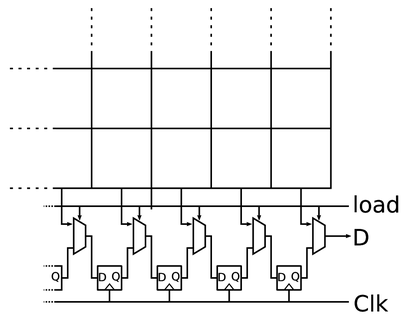
On chip readout:

- Full frame readout
- Pixels are sensitive in a defined time window and can save one hit in their buffer
- Data read out with horizontal and vertical shift registers
- Records 2D binary images: Spacial information is directly available
- Frame rates up to $400\,kHz$

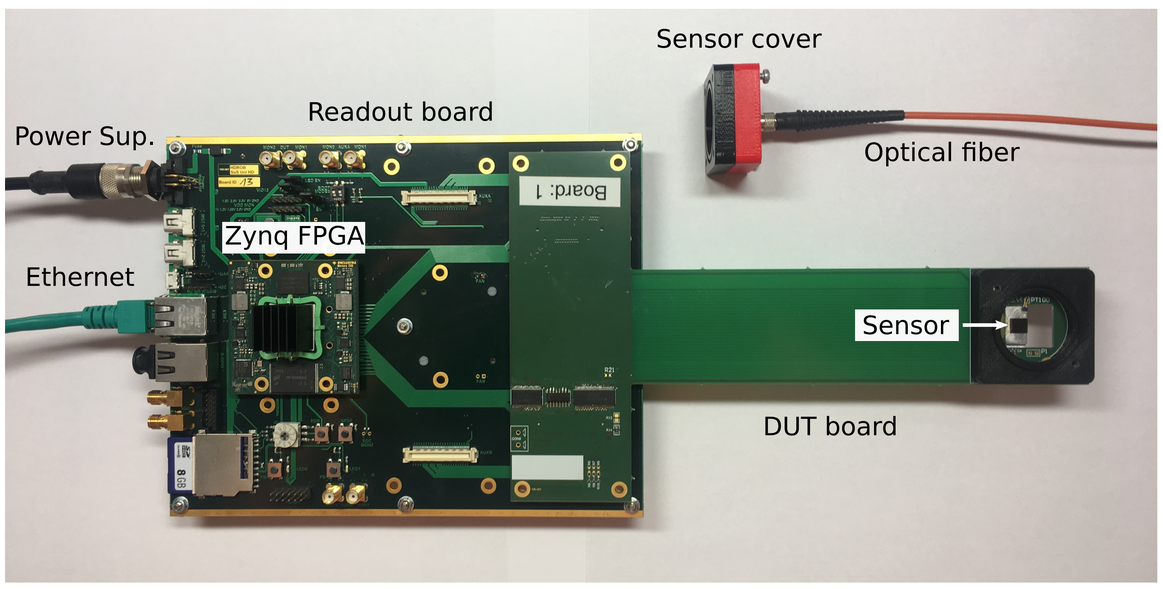
Pixel Logic:



EOC Logic:



Measurement Setup



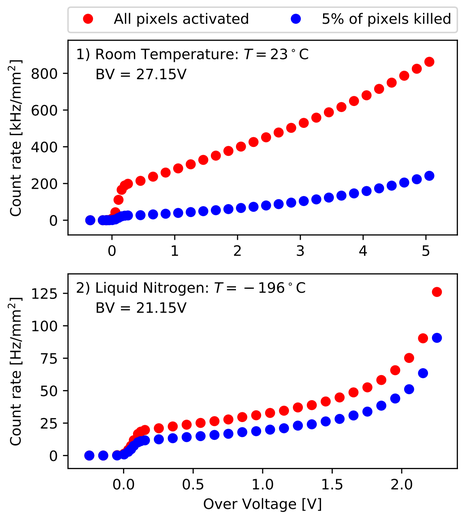
Readout board:

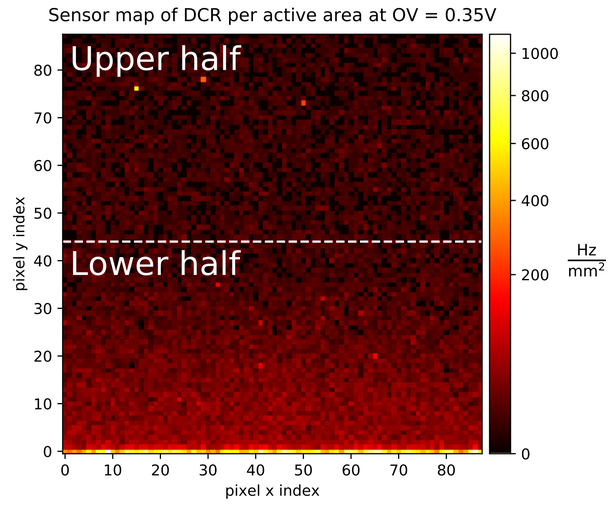
- Zynq FPGA for sensor control and local data processing
- TPC connection to the PC
- Timing of readout sequence is controllable at run time

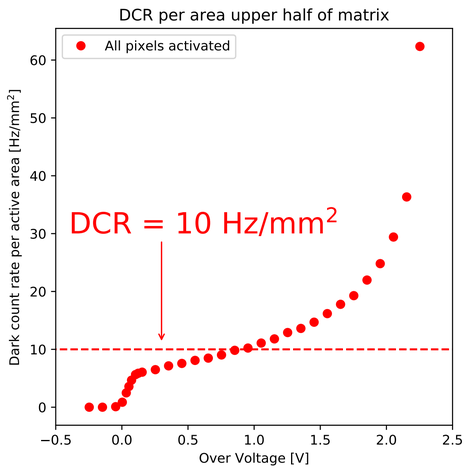
DUT Board:

- Special "T" shape to keep readout board at room temperatures while sensor is cold
- PT100 as temperature sensor
- Optical fibre for illumination

DCR at low temperature



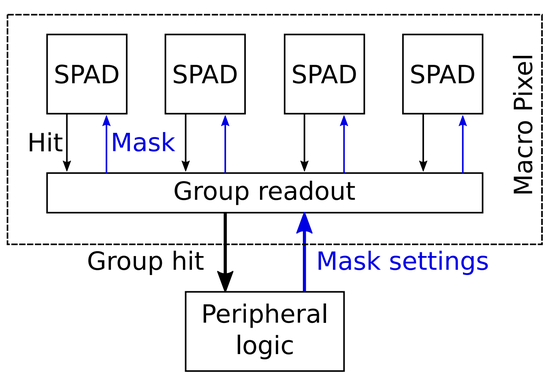


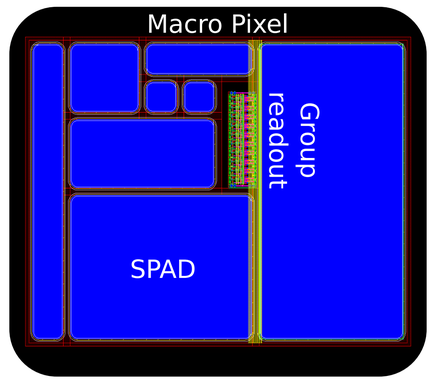


- DCR is about a factor of 10^4 reduced
- Breakdown voltage is $6\,V$ lower
- Killing of pixels is less effective
- Sensor map shows a higher noise in the lower part: Peripheral circuitry emit photons
- Upper half: DCR factor of 2 lower than overall DCR

Upcoming 2D arrays

Low flux detector:

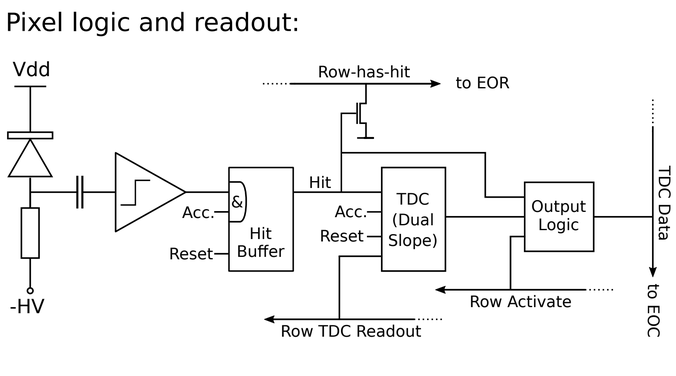


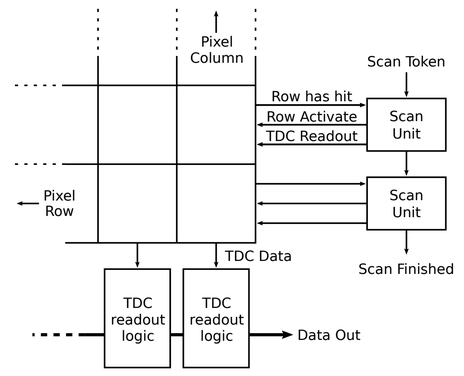


- Low power and high fill factor detector operated at cold temperature to detect low photon fluxes
- Application: Rare event search experiments like DARWIN

Time-of-Flight camera:

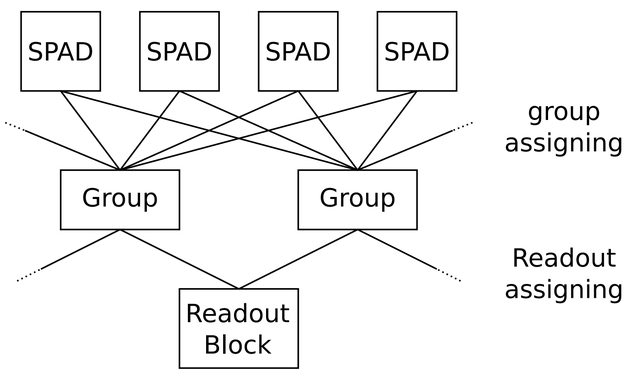
Pixel logic and readout:

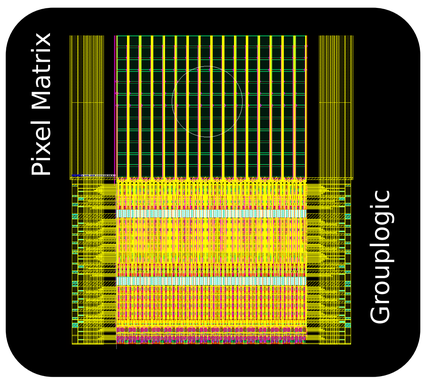




- Measures the timing of an instantaneous burst of many photons
- Application: ToF camera, LIDAR, fluorescence lifetime imagine

Optical fibre readout:





- Timing and amplitude of a photon cluster can be measured by forming pixel readout groups
- Application: Readout of optical fibres, cell tracing in biology