imec

NIR SENSORS BASED ON PHOTOLITHOGRAPHICALLY PATTERNED PBS QD PHOTODIODES FOR CMOS INTEGRATION

EPIMITHEAS GEORGITZIKIS,

PAWEL E. MALINOWSKI, LUIS MORENO HAGELSIEB, VLADIMIR PEJOVIC, GRIET UYTTERHOEVEN, STEFANO GUERRIERI, ANDREAS SÜSS, CELSO CAVACO, KONSTANTINOS CHATZINIS, JORICK MAES, ZEGER HENS, PAUL HEREMANS,

DAVID CHEYNS

KU LEUVEN

UNIVERSITEIT GENT

PUBLIC

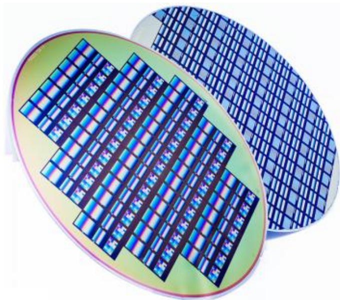
Leuven – R&D HQ
3500 people

IMEC vzw

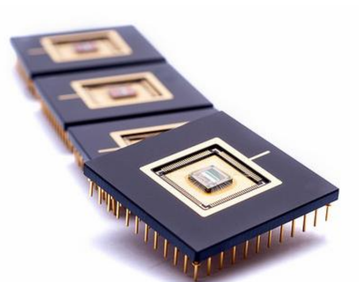
IMEC R&D

EXPERTISE IN IMAGE SENSORS AND THIN-FILM ELECTRONICS

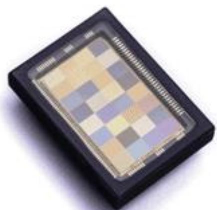
Image Sensors



design and tech platforms



integration and testing



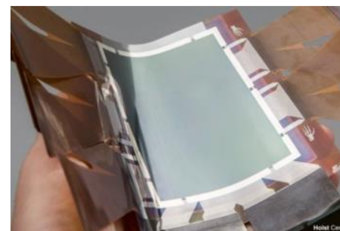
custom image sensors and cameras

UV, VIS, NIR, hyperspectral, lensfree, integrated photonics

Thin-Film Electronics

new materials

large area electronics



flexible image sensors

thin-film PV

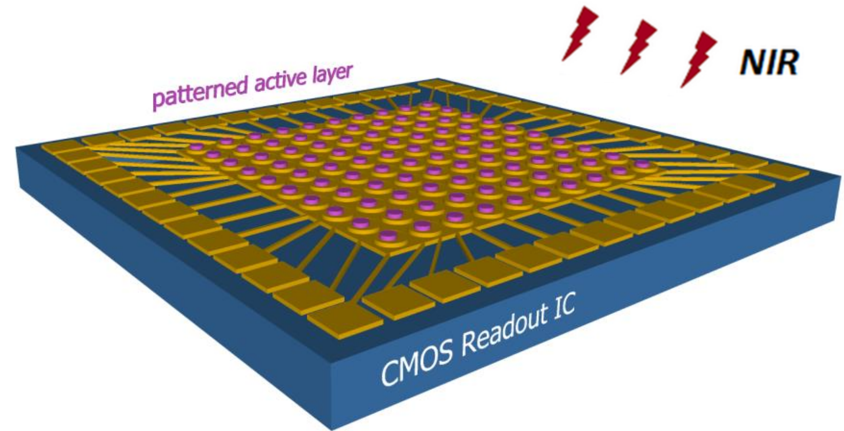
NIR SENSORS BASED ON PHOTOLITHOGRAPHICALLY PATTERNED PBS QD PHOTODIODES FOR CMOS INTEGRATION

i. **Our approach: monolithic infrared imager**

i. **Colloidal quantum dots as an IR absorber**

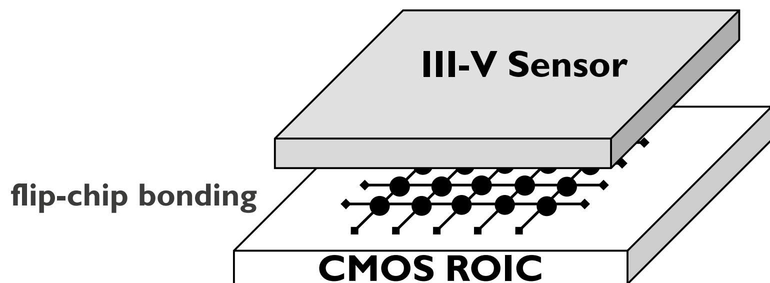
ii. **Quantum dot photodiode**

iii. **CMOS Integration**



HYBRID VS MONOLITHIC IMAGER

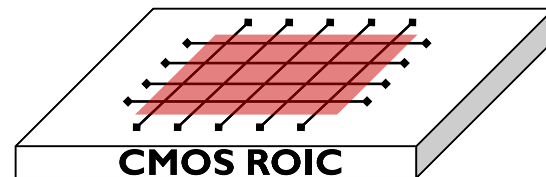
Hybrid Imager



- + mature technology
- + high QE in III-V materials

- – high cost due to hybridization
- – low resolution due to flip-chip
- – low throughput due to epi substrates

Monolithic + TFPD



- + small pixel size (<5 µm)
- + large resolution (>1 MPx)
- + full wafer processing
- + VIS, NIR, VIS+NIR

- ? noise
- ? integration
- ? contamination

MATERIAL SELECTION

IR ABSORBERS AND APPLICATIONS

application

See-through vision

Low-light imaging/surveillance

Eye/head tracking (VR/AR)

automotive (LiDAR)

night-glow vision

IR absorbers

PbS quantum dots

polymers / small molecules (OPD)

HgCdTe

InGaAs

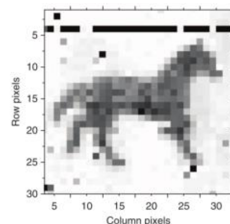
Si

.2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0 λ (nm)

PREVIOUS DEMONSTRATIONS

Panasonic
VIS with OPC
0.9 µm CMOS pixel
2007 → now

Siemens
1310 nm with QDPD
a-Si TFT backplane
2009



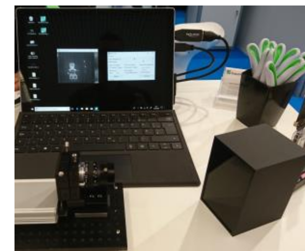
TU Munchen
850 nm with OPD
15 µm CMOS pixel
2012

InVisage / Apple
940 nm with Quantum Film
1.1 µm pixel
2017

common challenges:

- processing on full wafers
- integration in fab environment
- noise level with TFPD
- material supply for TFPD
- next-gen: multispectral arrays

SWIR Vision System
400 – 1700nm with TFPD
15 µm CMOS pixel
2018

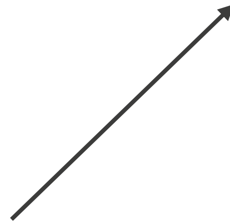


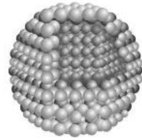
Fraunhofer FEP
940 nm with OPD
2018

COLLOIDAL QUANTUM DOTS AND THE QUANTUM DOT PHOTODIODE

COLLOIDAL QUANTUM DOTS AS INFRARED ABSORBER

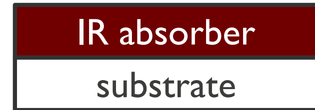
TUNABLE WAVELENGTH SPECTRUM



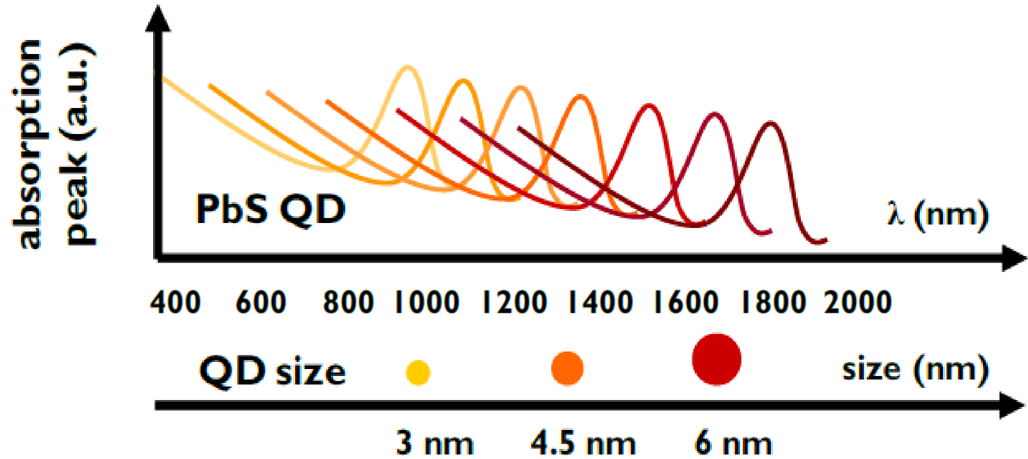


colloidal quantum dot

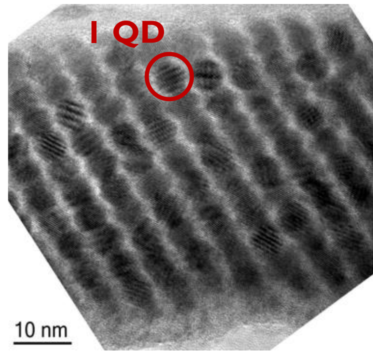
Semiconductors known from displays
Tunable absorption peak
Infrared sensitive

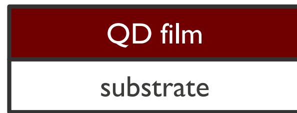


material screening

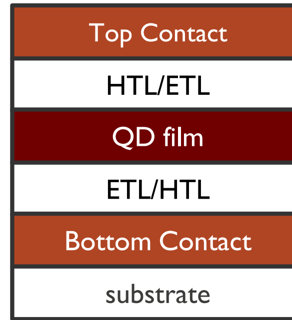


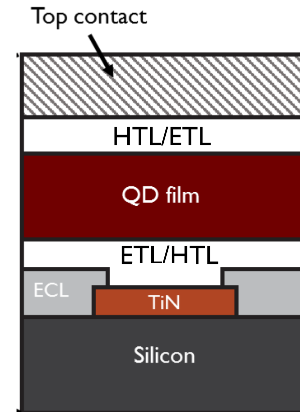
QUANTUM DOT PHOTODIODE





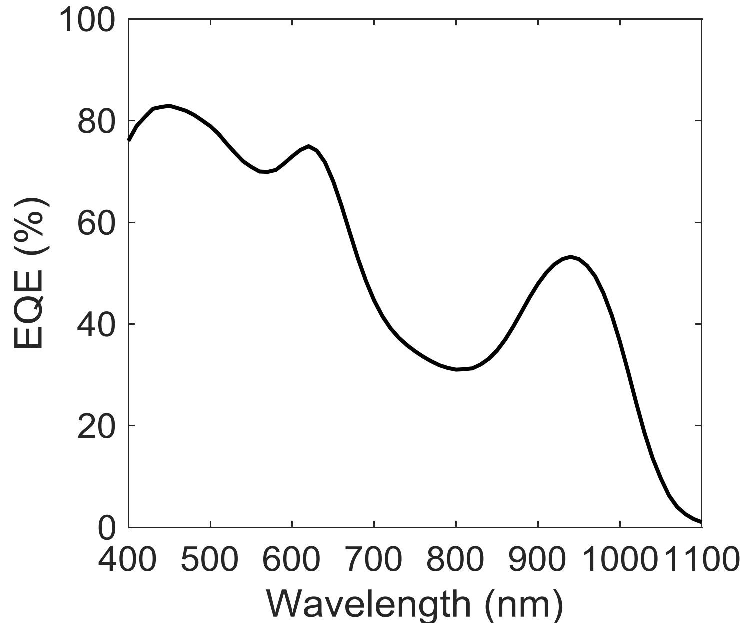
P-N or N-P photodiode configuration



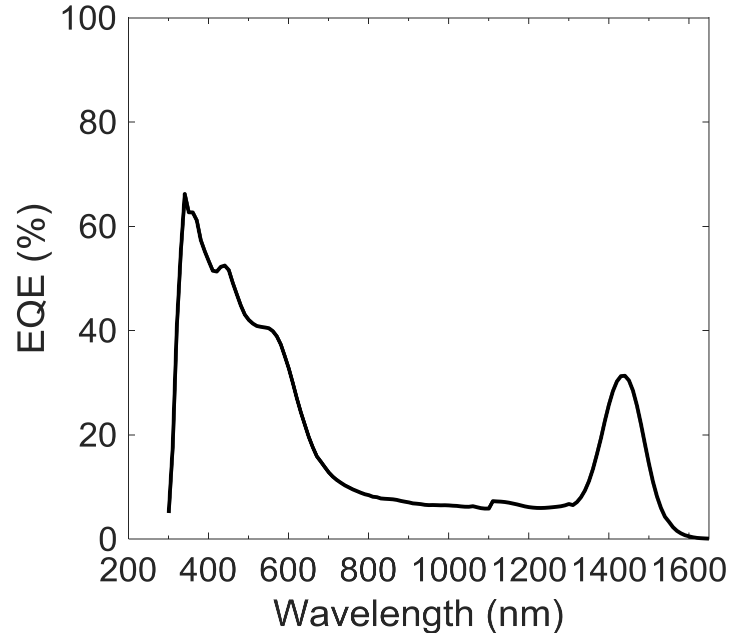


PHOTODETECTOR STACK DEVELOPMENT

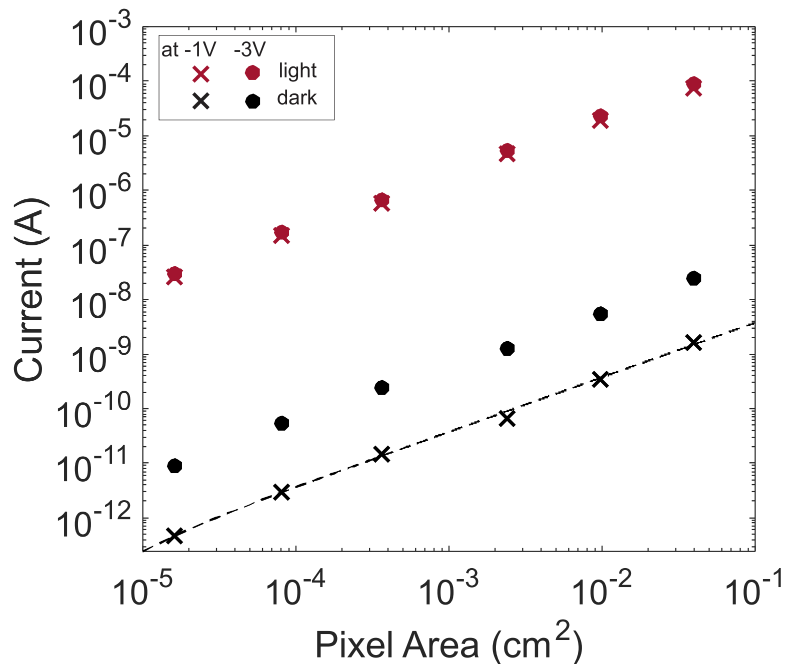
EQE: > 55% in NIR
Dark current at -1V: < 100 nA/cm^2 @300K
Detectivity (D*) at 940 nm: 10^{12} Jones

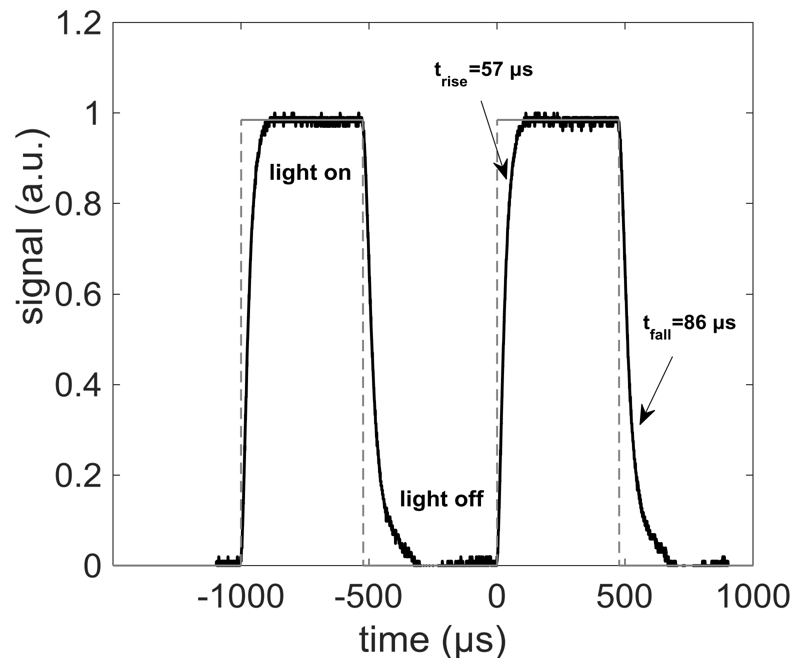


EQE: ~ 30% in SWIR
Dark current at -2V: 1 $\mu A/cm^2$ @300K
Detectivity (D*) at 1450 nm: 5×10^{11} Jones



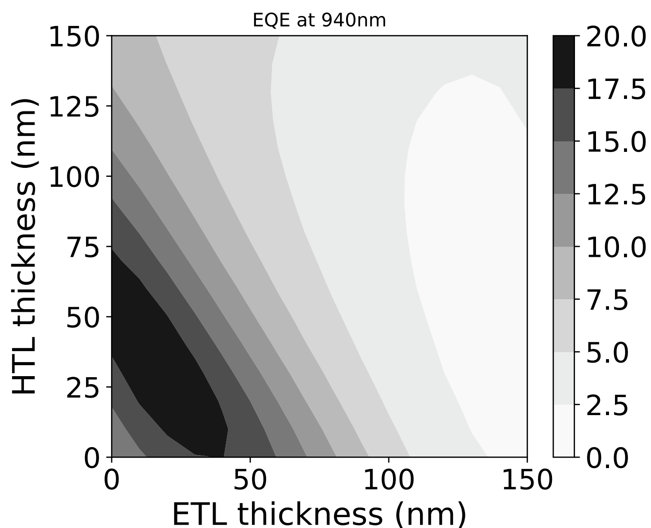
PHOTODETECTOR STACK DEVELOPMENT

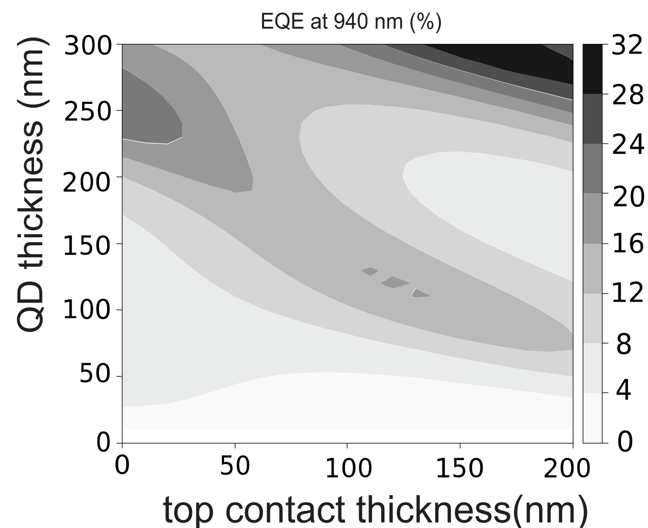


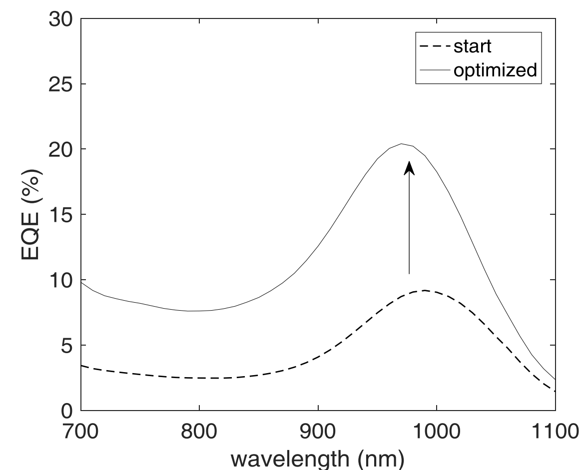


OPTICAL CAVITIES IMPROVE EQE PERFORMANCE

TUNING LAYER THICKNESSES WITH OPTICAL MODELING



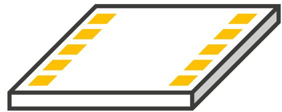




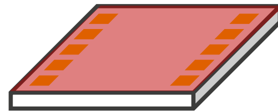
E. Georgitzikis, P. E. Malinowski, J. Maes, A. Hadipour, Z. Hens, P. Heremans, D. Cheyns, *Adv. Funct. Mater.* 2018, 28, 1804502.

ROIC INTEGRATION AND UPSCALING

INTEGRATION ROUTE

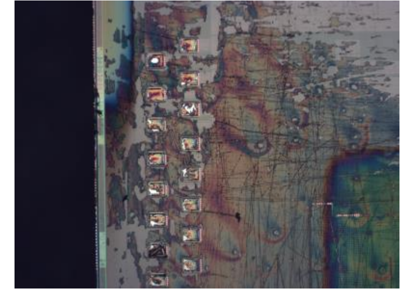


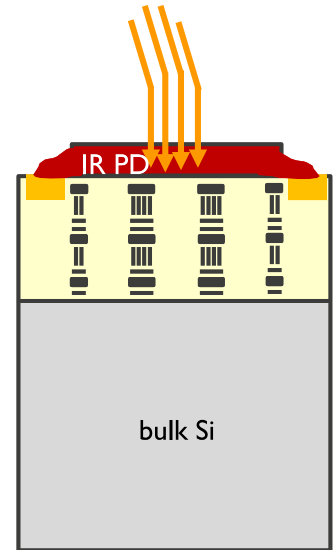
ROIC with
contact pads

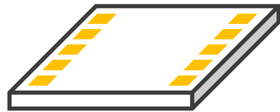


stack deposition
(spin-coating)

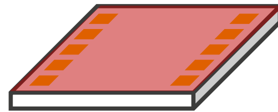
INTEGRATION ROUTE



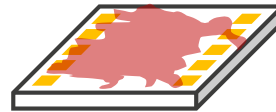




ROIC with
contact pads

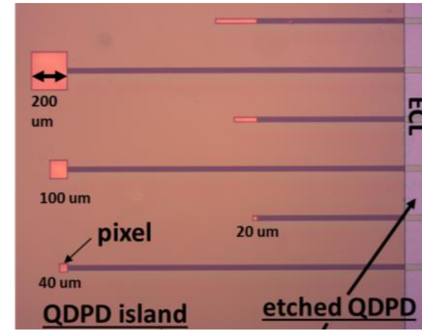


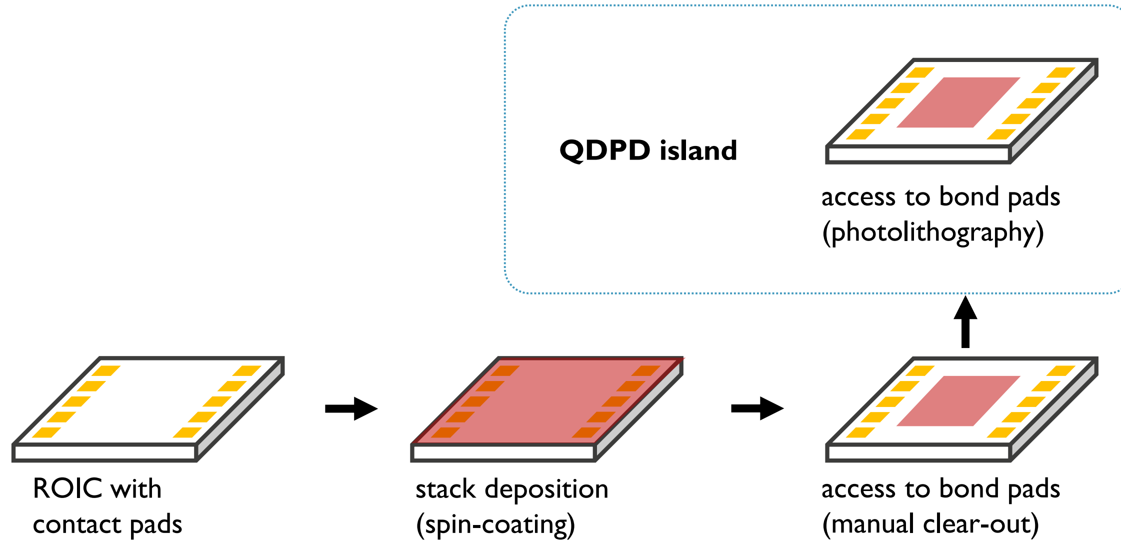
stack deposition
(spin-coating)

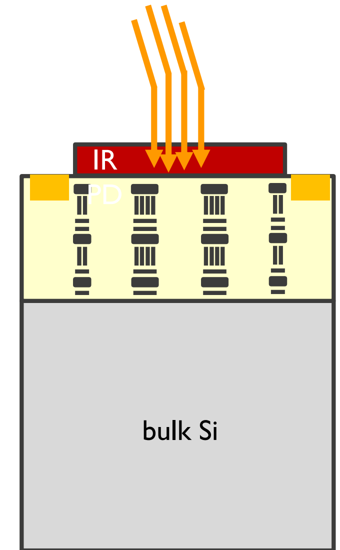


access to bond pads
(manual clear-out)

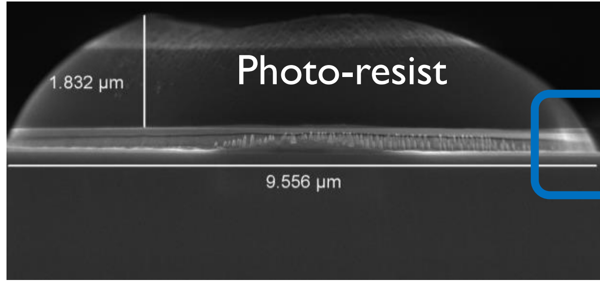
INTEGRATION ROUTE

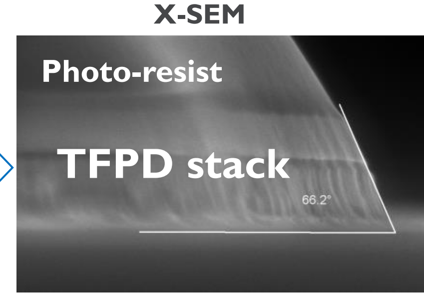


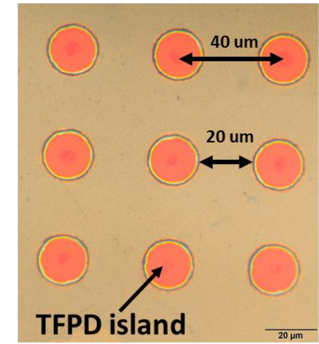


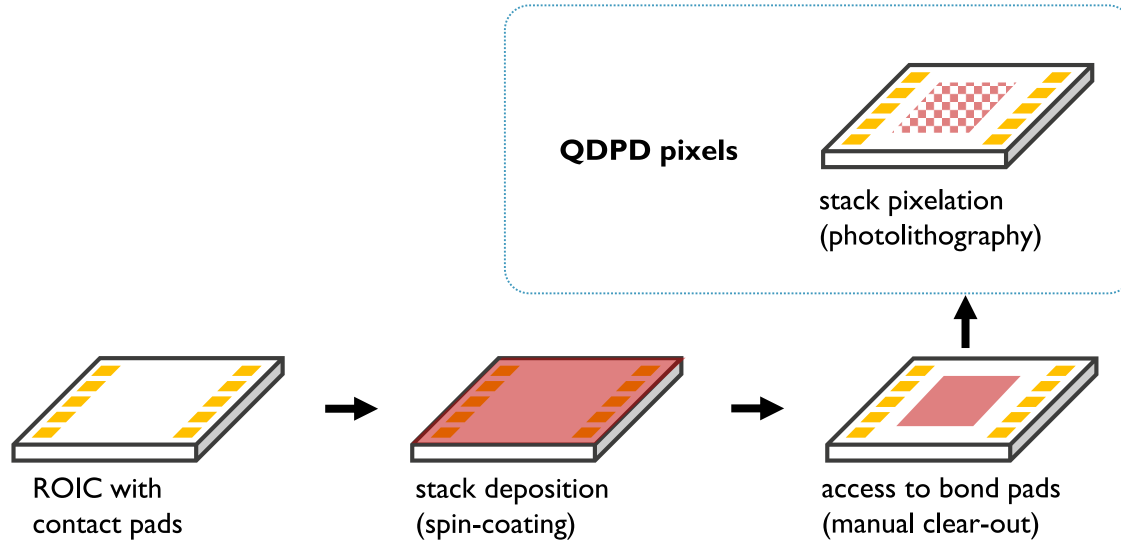


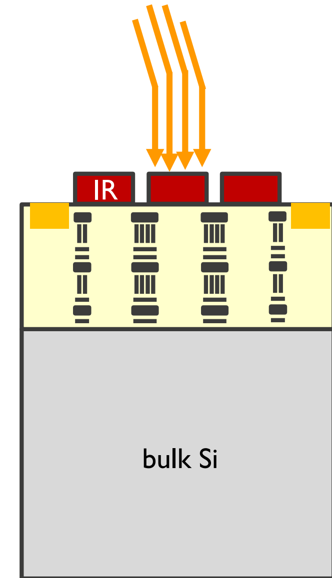
INTEGRATION ROUTE



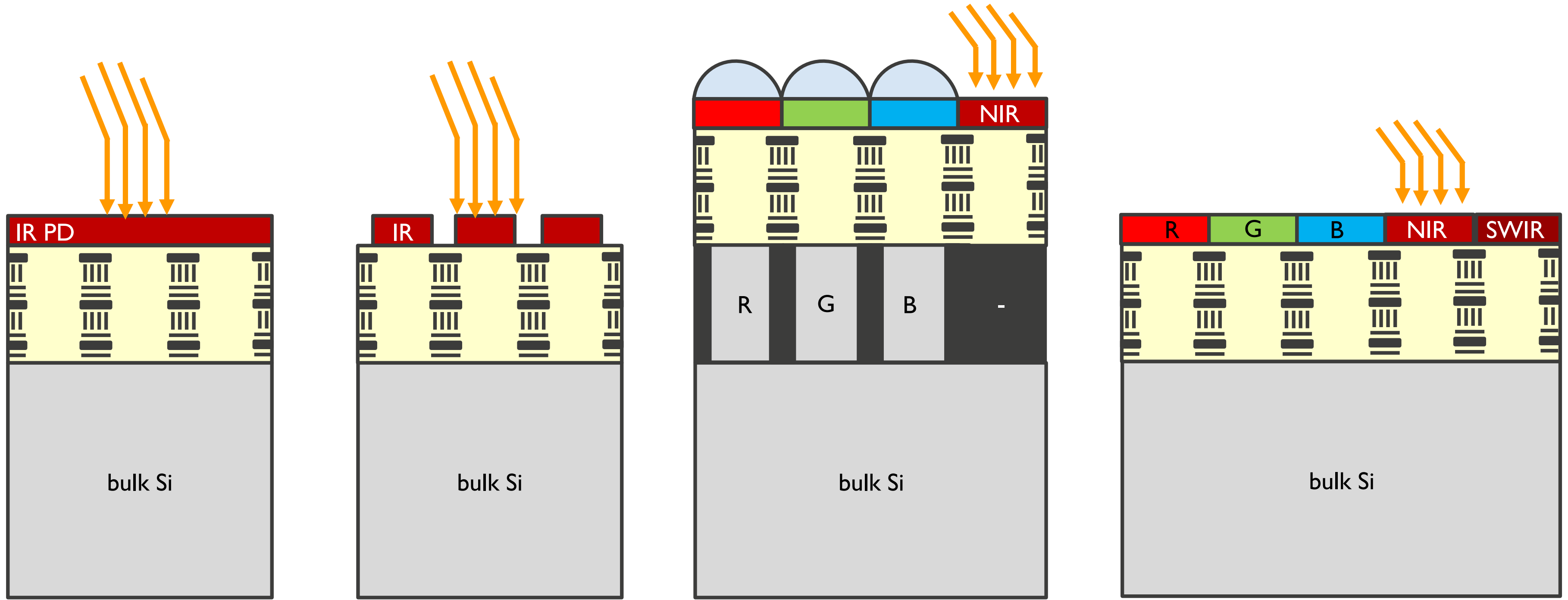








THIN-FILM INTEGRATION OPTIONS



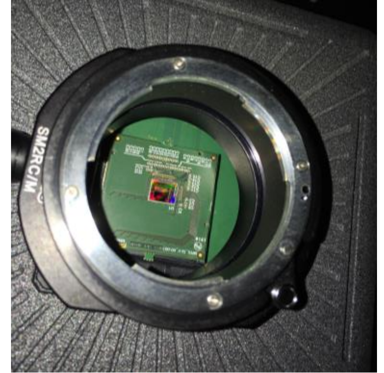
new technology

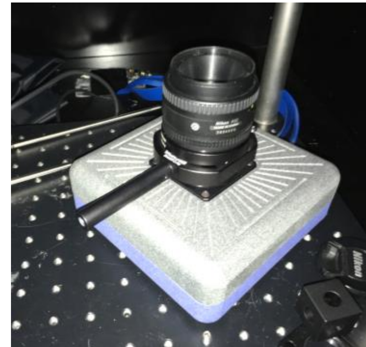
imec

NEXT STEPS

FROM PIXEL STACK TO MONOLITHIC INFRARED IMAGER

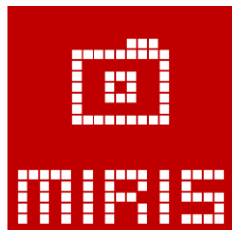
- Testing the first QD imagers
- Continuous optimization of the photodiode stack
- Further optimizing the top contact transparency
- Improving photolithographic patterning
  - High resolution pixel arrays: pitch of 1.5 µm
  - VIS + NIR in one plane
- Scaling up to wafer level





THANK YOU!

EPIMITHEAS.GEORGITZIKIS@IMEC.BE



AGENTSCHAP
INNOVEREN &
ONDERNEMEN

Vlaanderen
is ondernemen

KU LEUVEN

embracing a better life