Technology development on CMOS Image sensors

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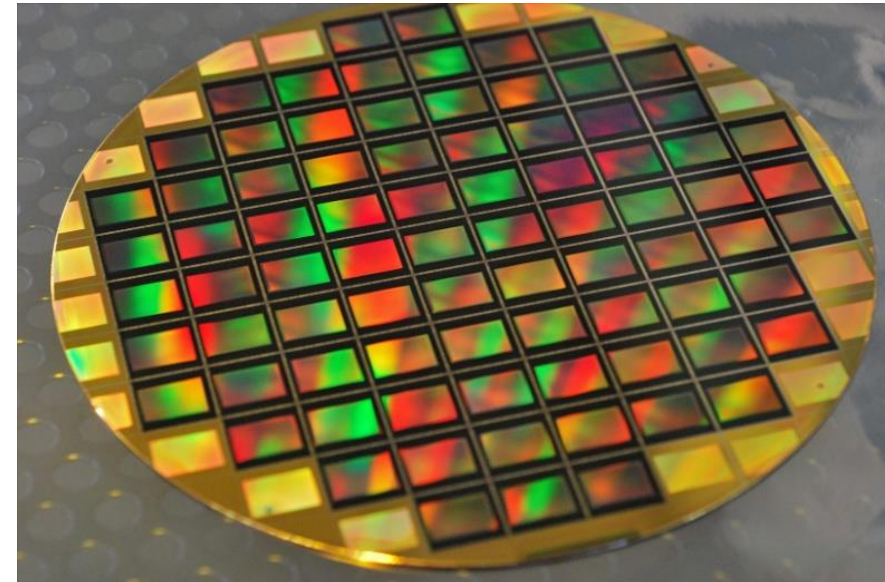
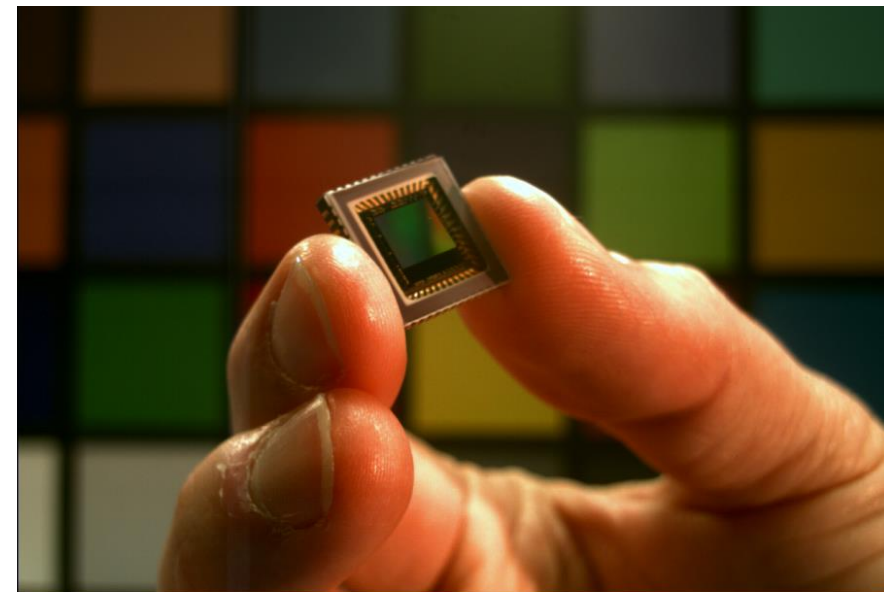
Manufacturing CMOS image sensors

The wafer fab in Avezzano

200 mm wafer



Packaged sensor



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LFOUNDRY

About the company

- LFoundry Fab is located in Avezzano, in Abruzzo region, currently employing about 1500 people. The fab is equipped with a 11.000 m^2 wide clean room area;

- The fabrication of the plant was completed on 1989, by Texas Instruments. In 1998 it was acquired by Micron Technology Inc and fully dedicated to DRAM mass production until the introduction of CMOS Image Sensor production in 2006;

- In May 2013 LFoundry acquired the site from Micron;

- In June 2016 SMIC acquired 70% of the company;

- In July 2019 the company has been acquired by Wuxi Xichanweixin Semiconductor;

- We have been developing and manufacturing CMOS image sensors since 2006. Our technology portfolio, based on 200 mm wafers, includes different process nodes down to 90 nm (minimum feature for transistor gate length).

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Imaging system 1/2

Auto Focus

Auto Exposure

Control and Interface

Scene

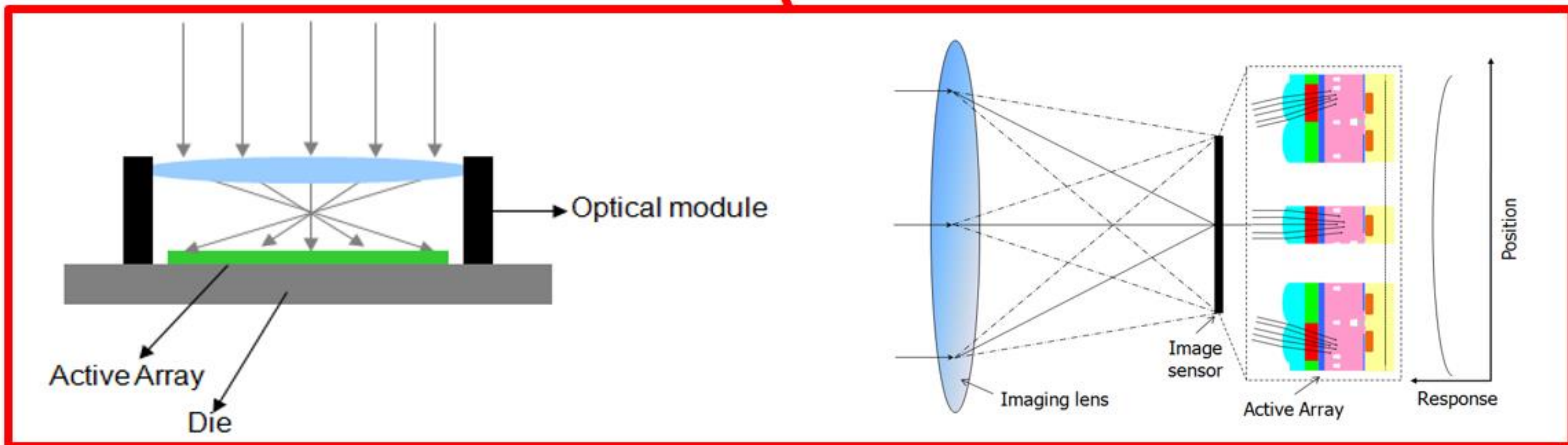
Imaging Optic

Microlens Array
Color Filter Array
Image Sensor

ADC

Color Processing

Image Enhancement and Compression



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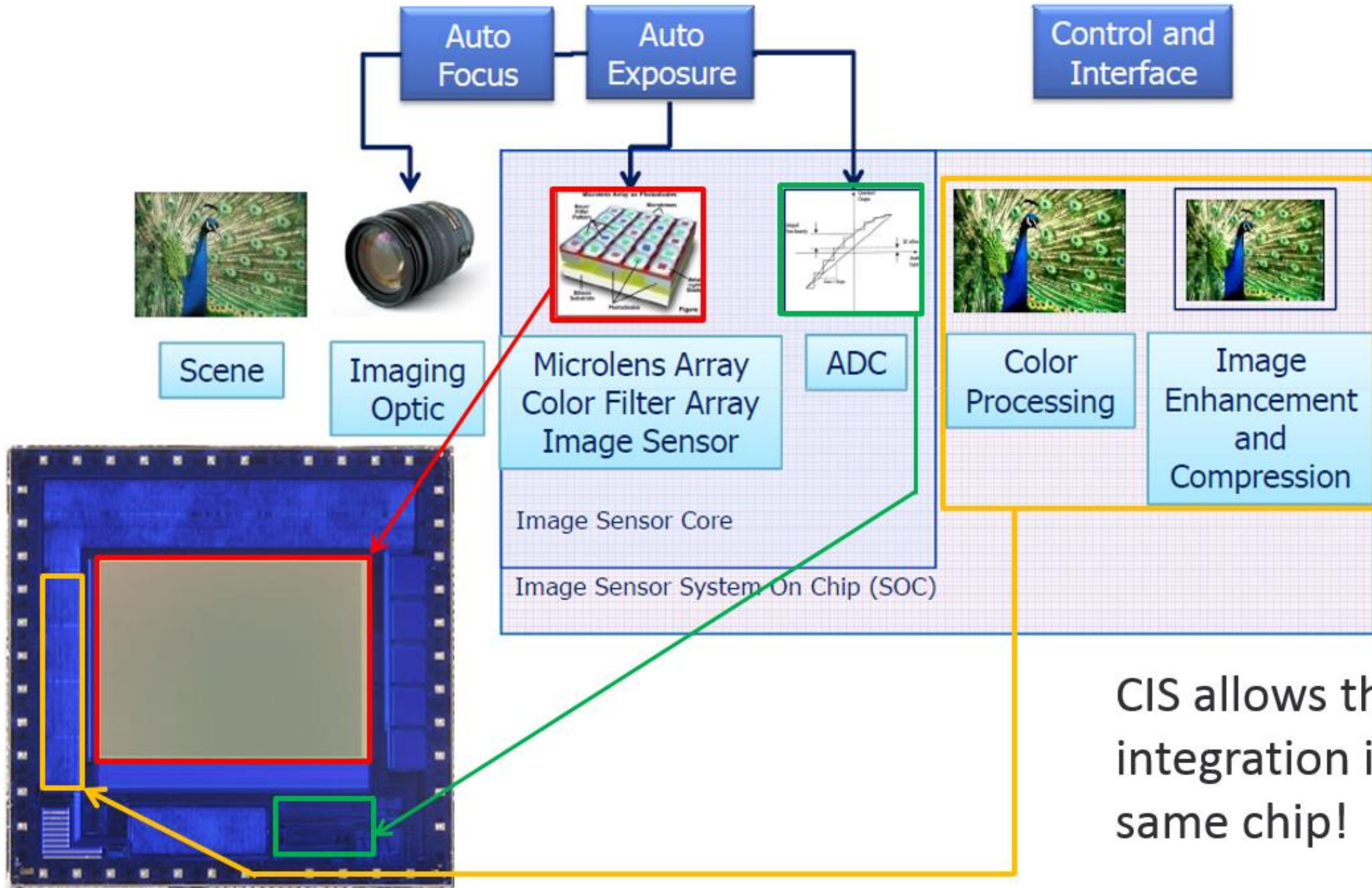
Imaging system 2/2



CIS allows the integration in the same chip!

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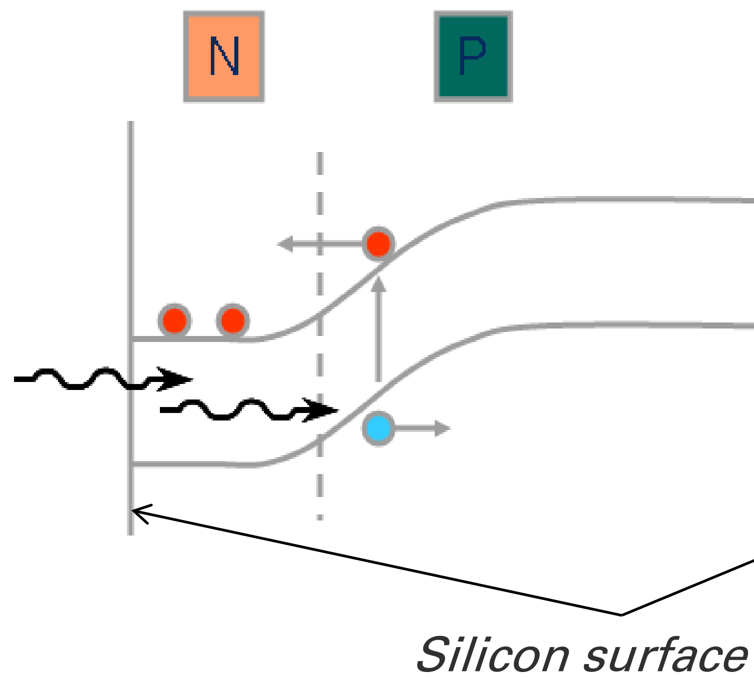
Pinned photodiode and 4-T cell

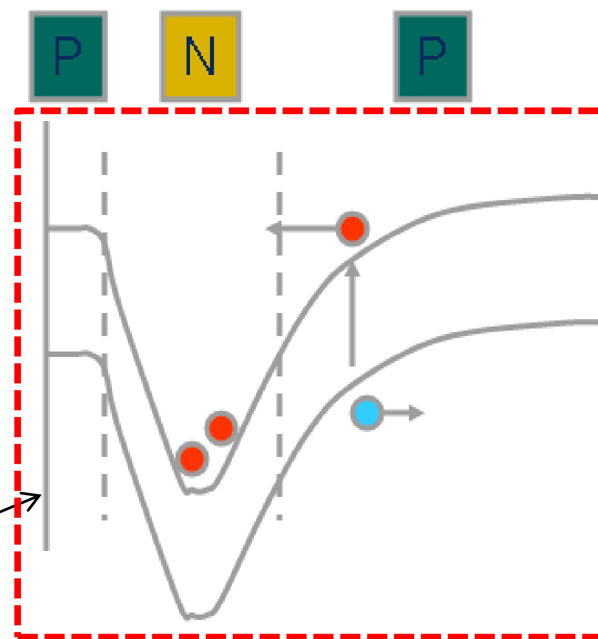
Conventional photodiode
(p-n junction)

Pinned photodiode
(p-n-p structure)

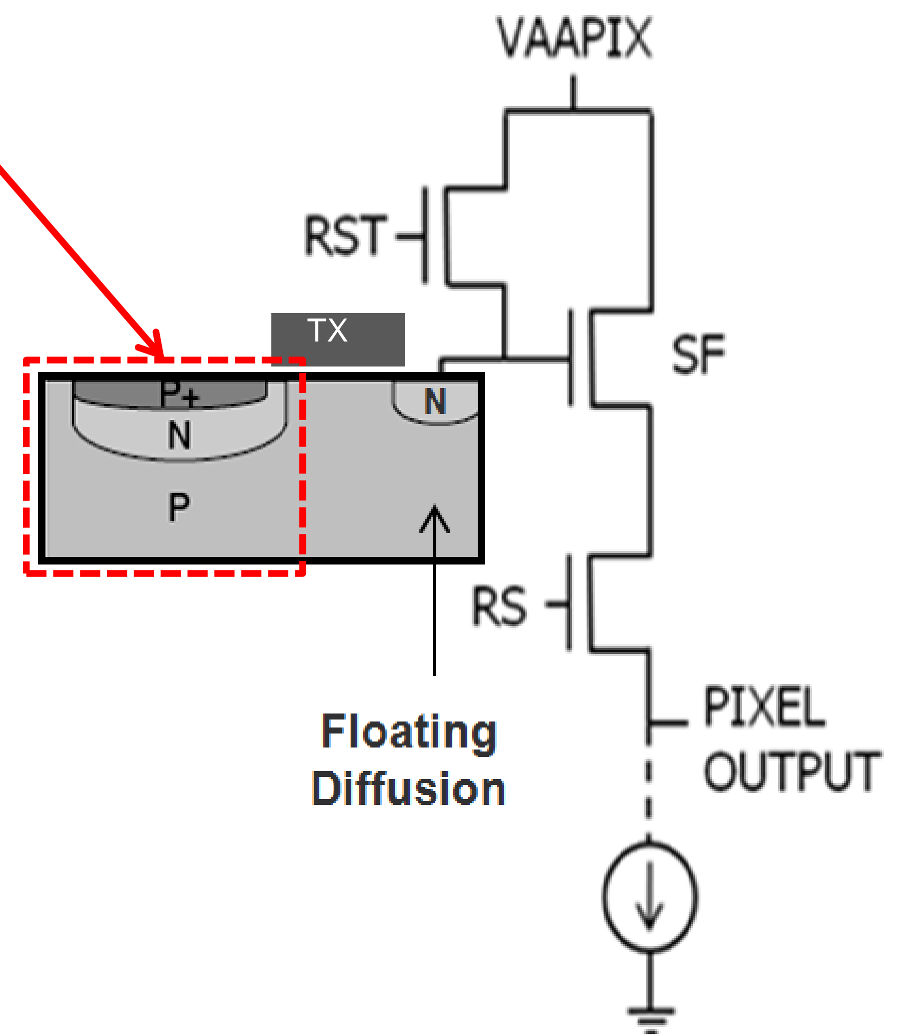
Conventional
Photodiode



Buried
Photodiode



4-T cell



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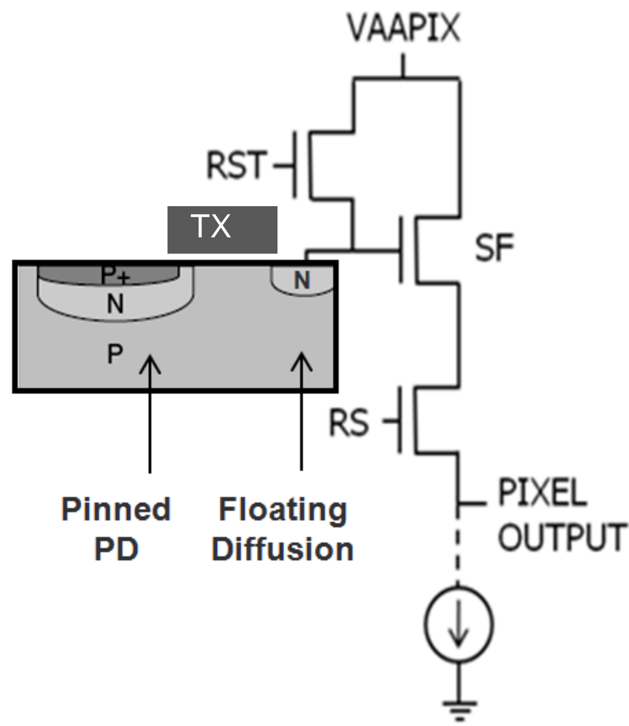
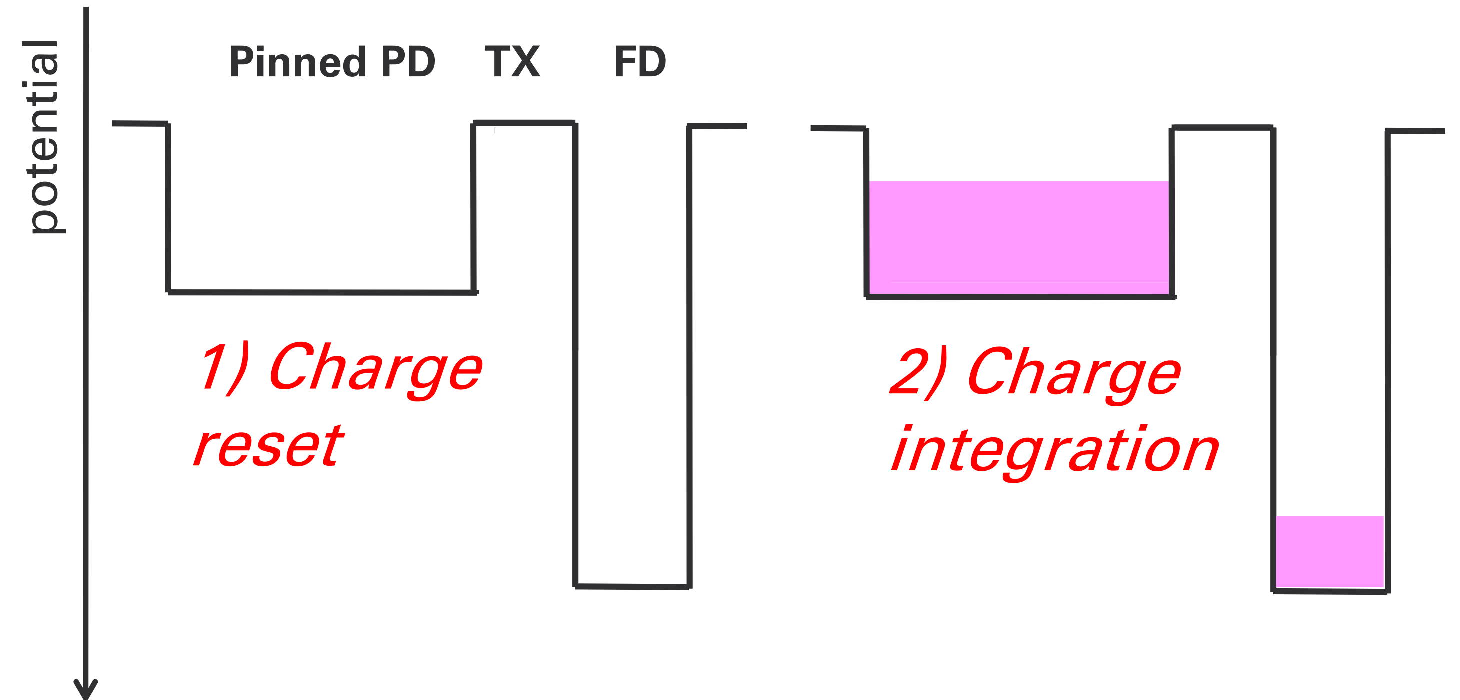
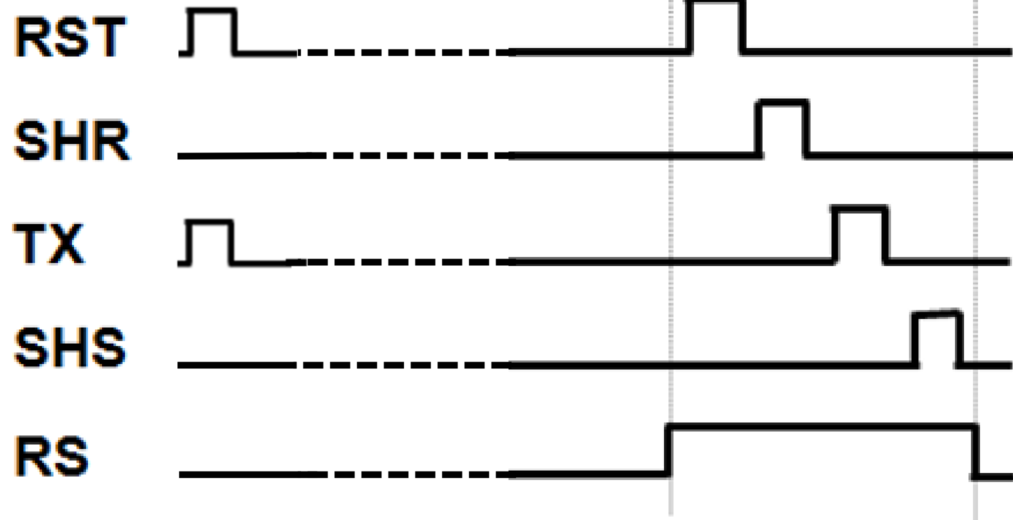
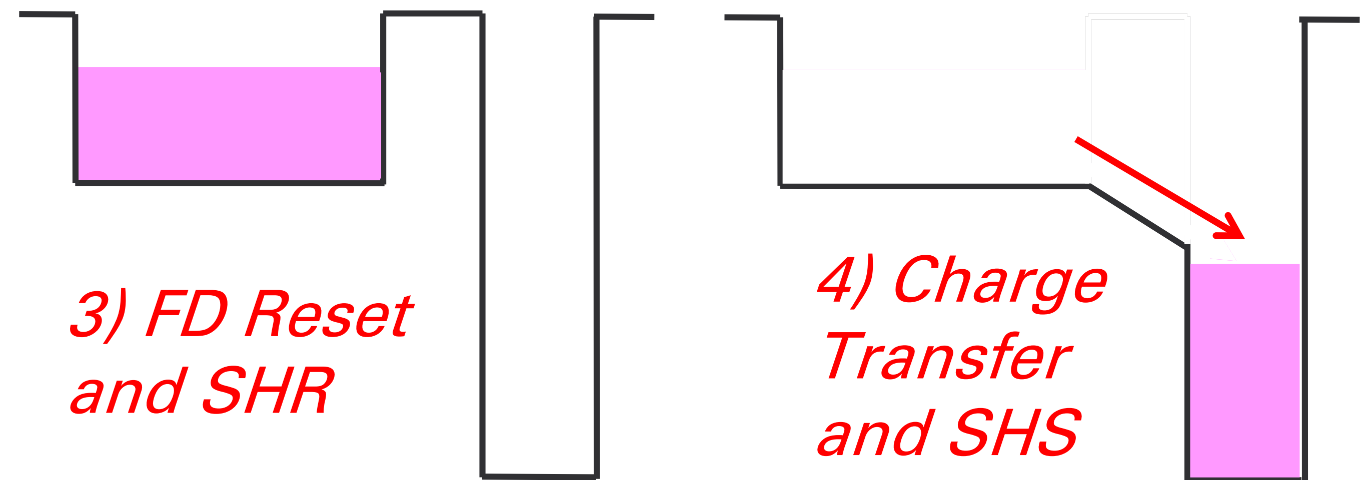
4-T cell readout









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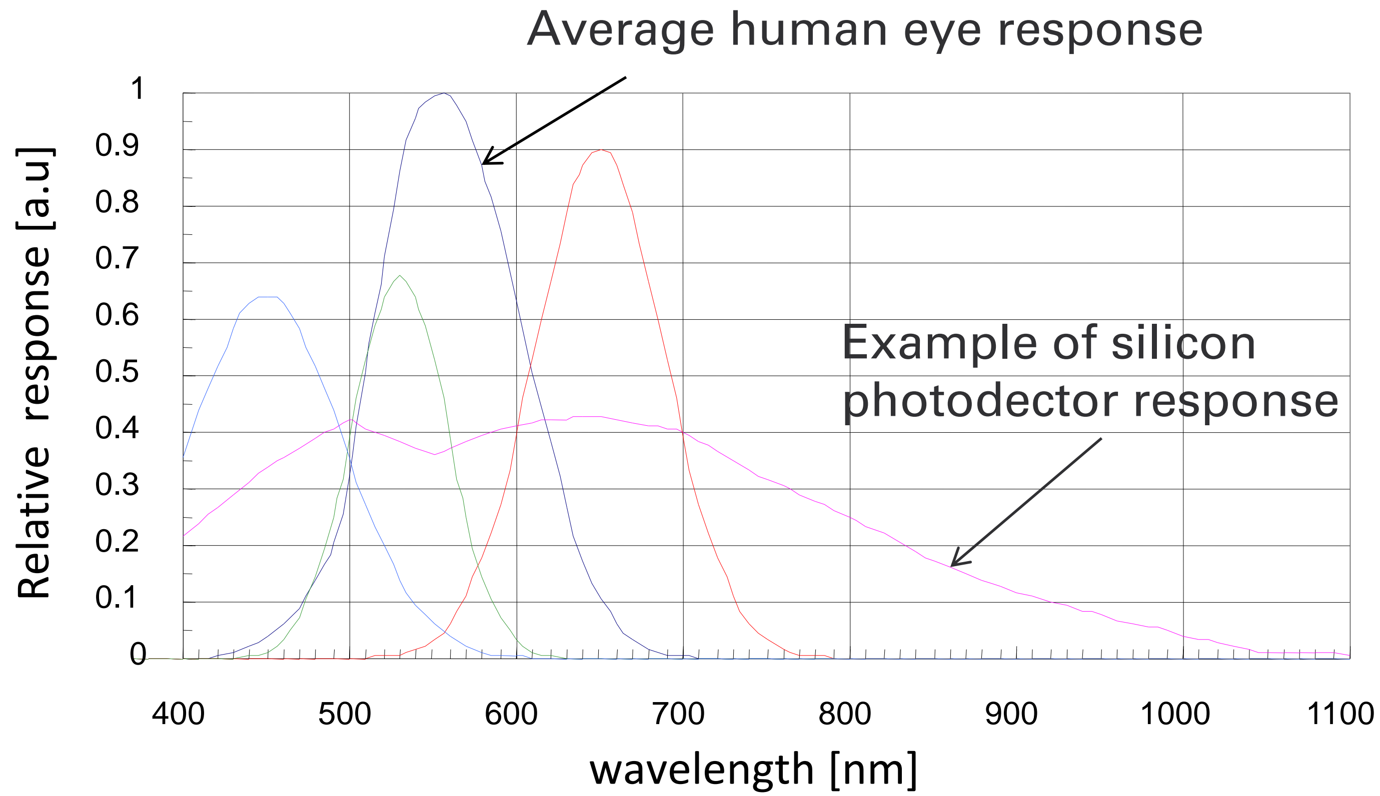
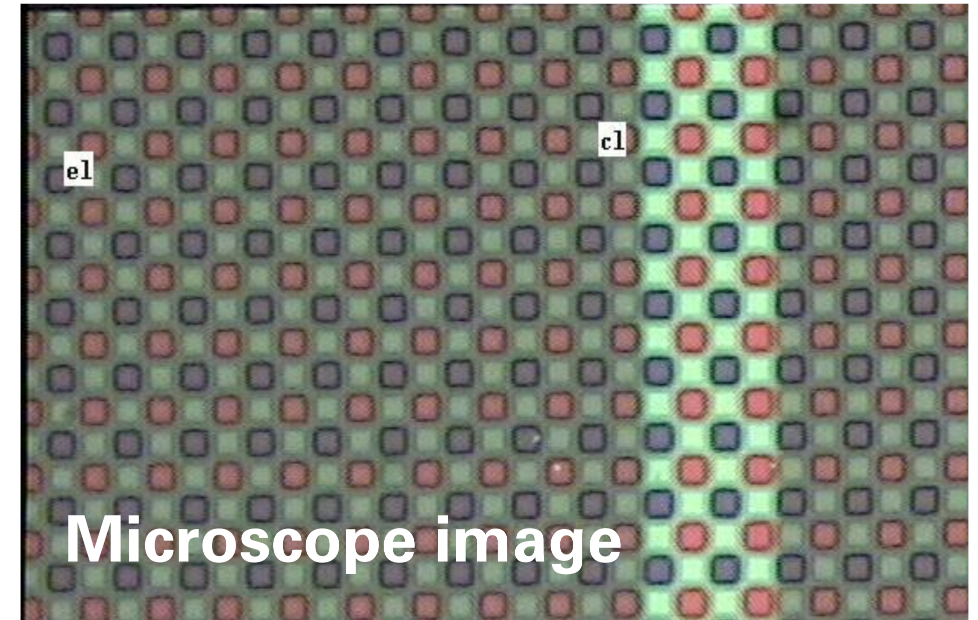
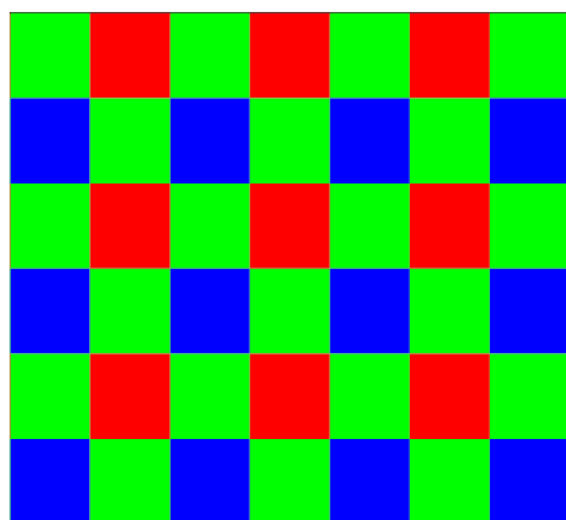
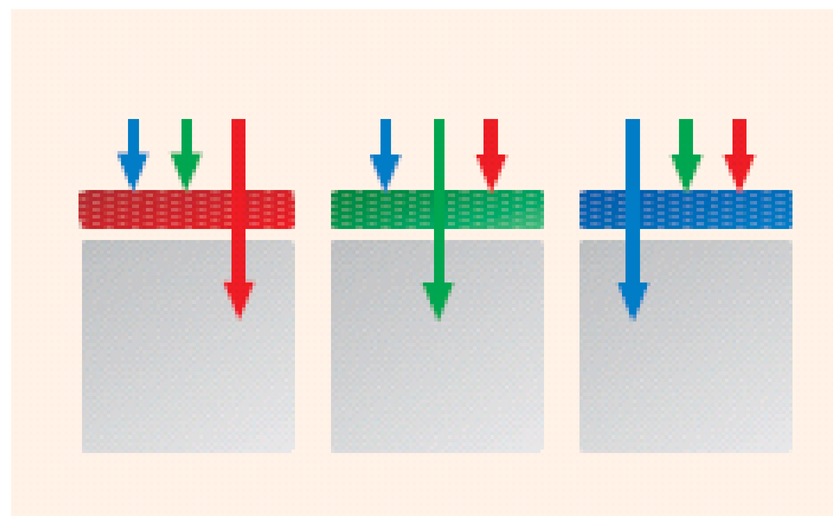
Color Filter Array (CFA)

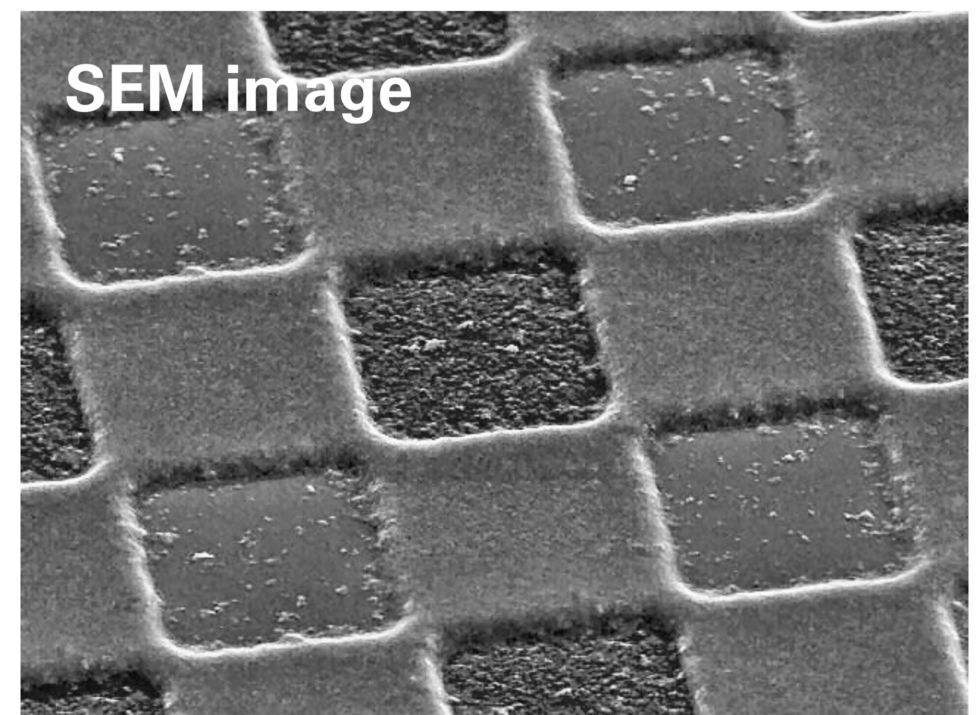




Bayer pattern







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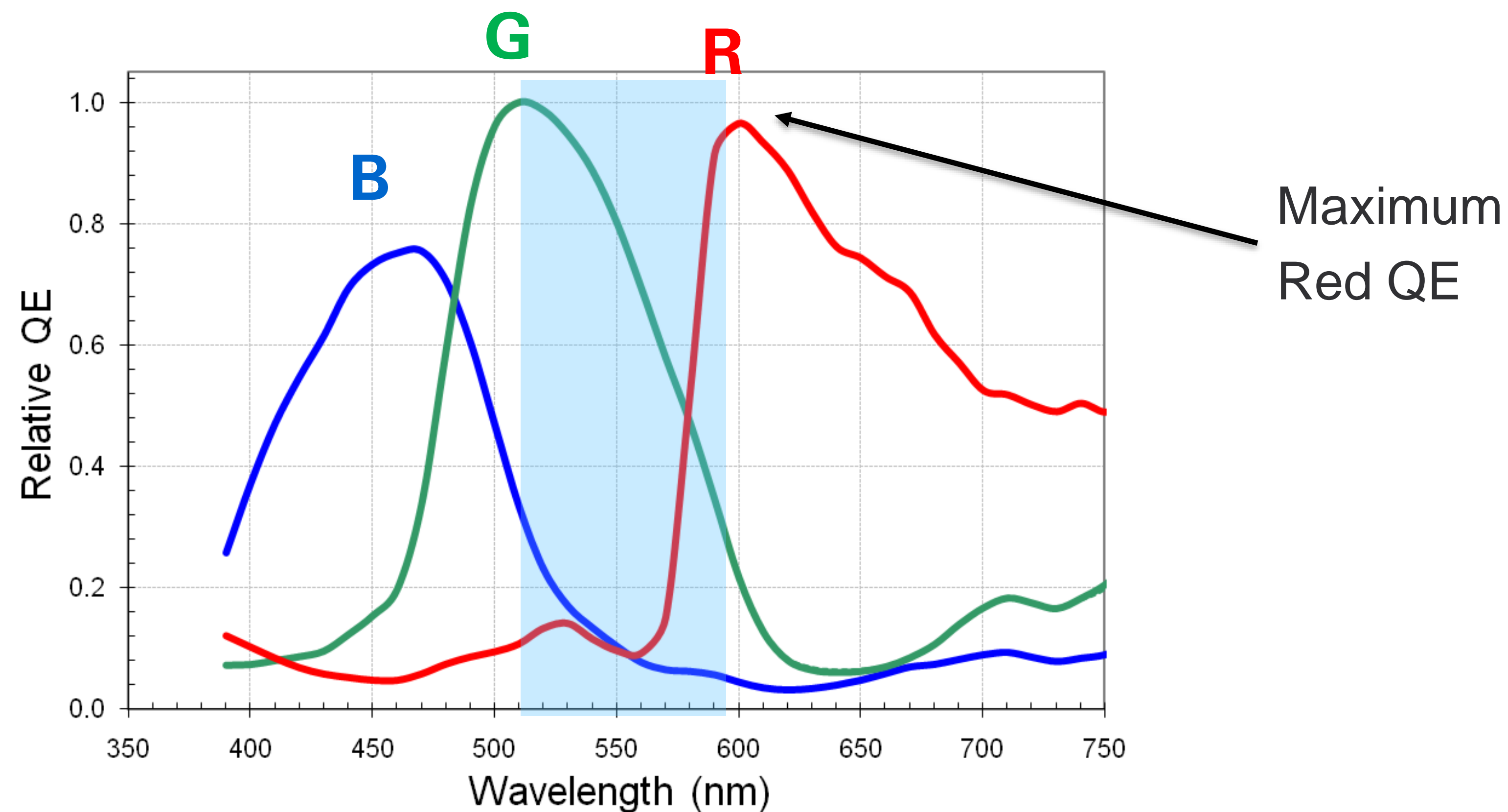
Sensor performance: Spectral quantum efficiency

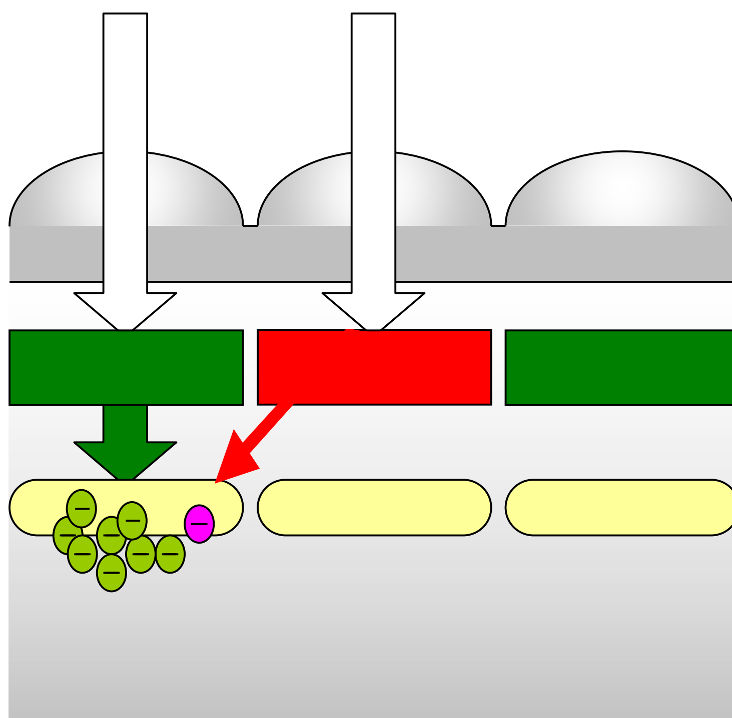
Crosstalk from blue and from red to green

$$C_{b\to g} = \int_{515}^{575} R_{blue} \cdot d\lambda \bigg/ \int_{515}^{575} R_{green} \cdot d\lambda$$

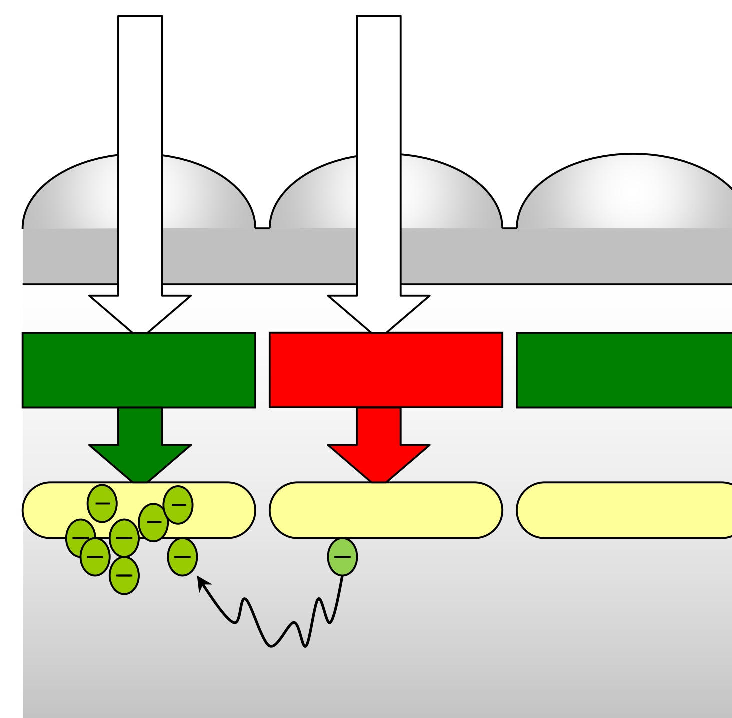
$$C_{r\to g} = \int_{515}^{575} R_{red} \cdot d\lambda \bigg/ \int_{515}^{575} R_{green} \cdot d\lambda$$



Optical crosstalk



Electrical crosstalk



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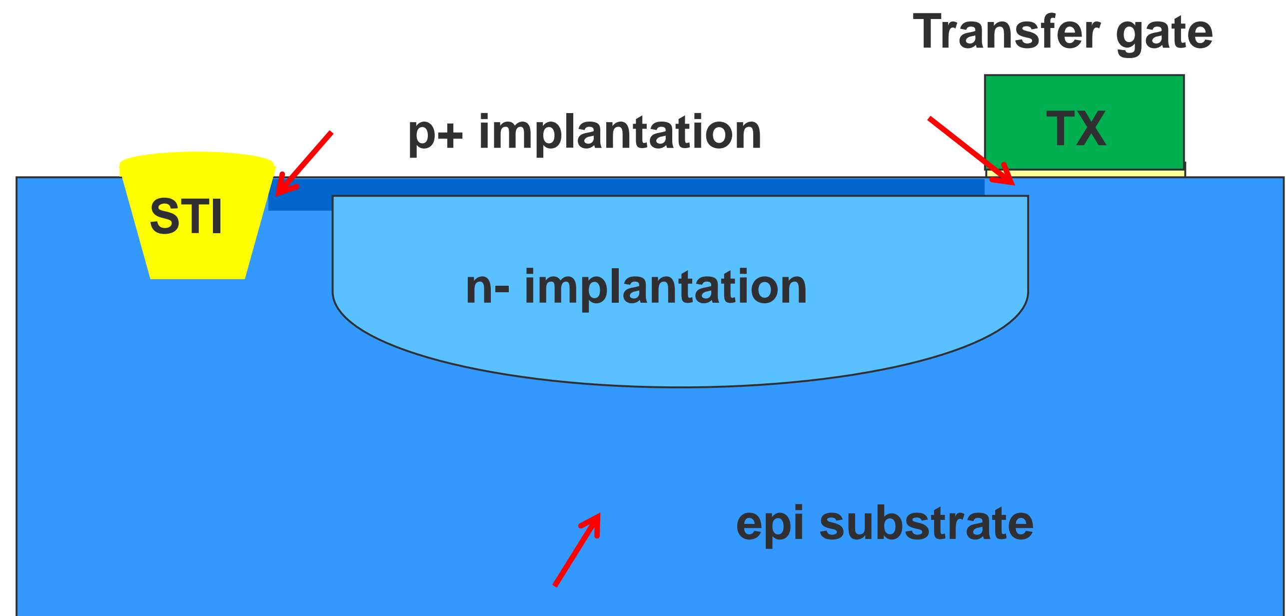
Dark Current and its impact on image quality

$$N_{dark} = \frac{I_{dark} \cdot t_{int}}{q}$$

Undesired signal integrated in dark conditions

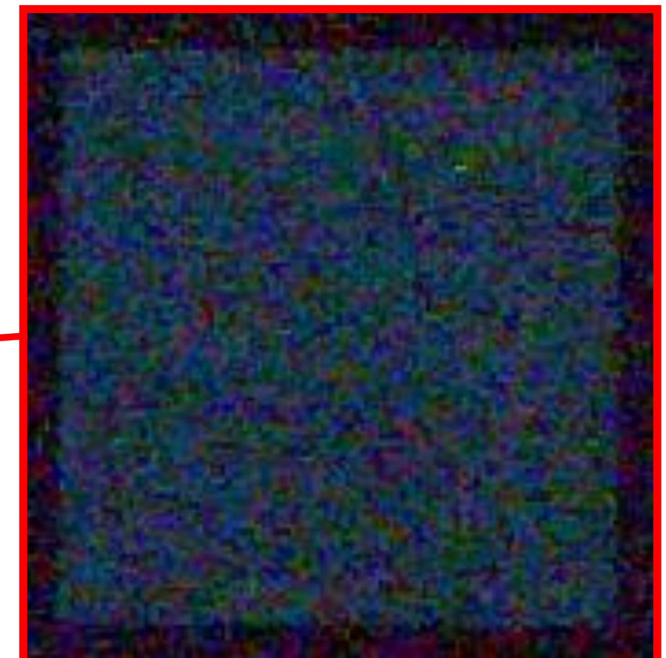
Sources of dark current and hot pixels

1. STI around the photodiode
2. Photodiode surface
3. Substrate
4. Overlap of PD with transfer gate
5. Contamination & defects



Medium light

Low light



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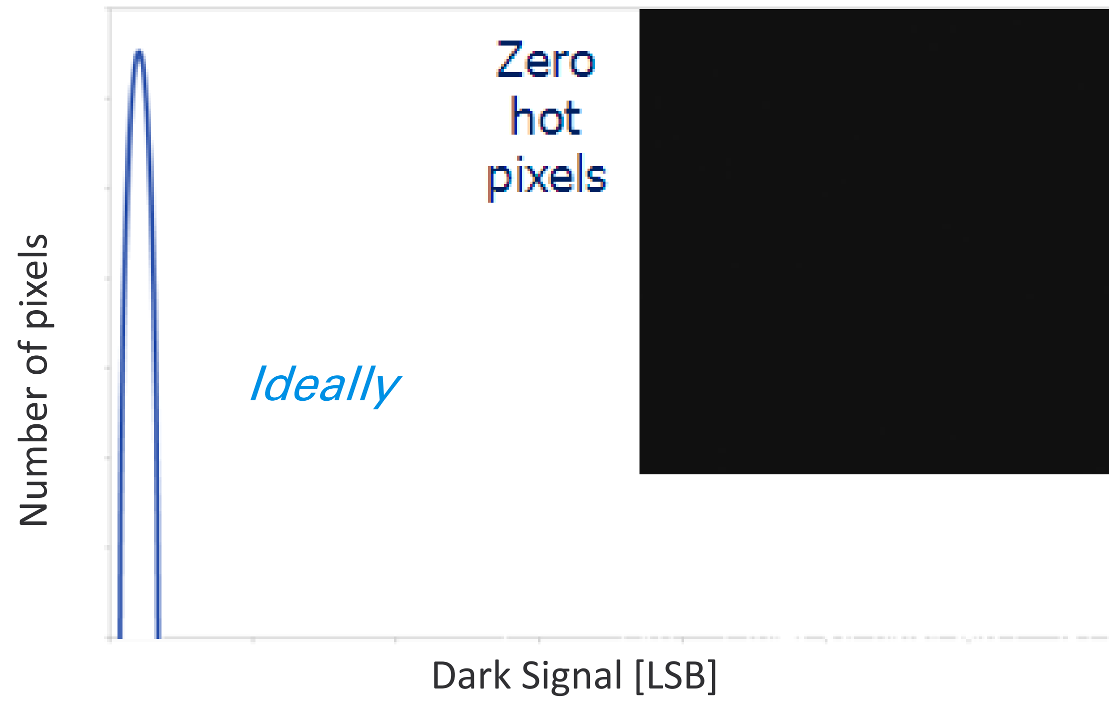
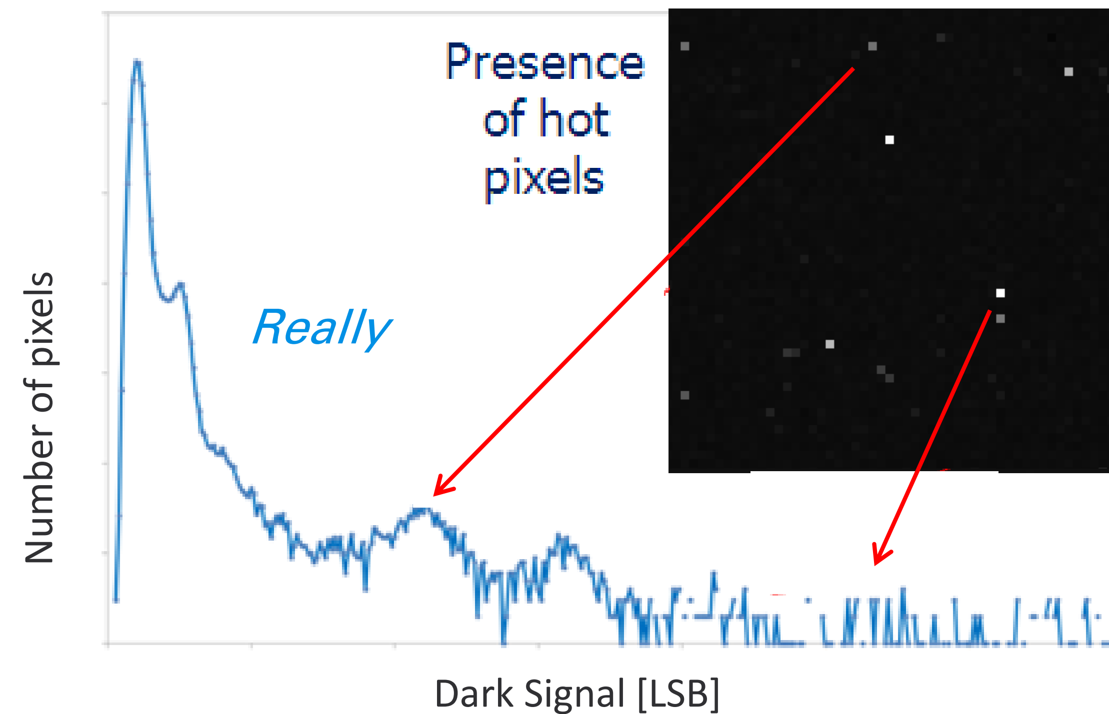
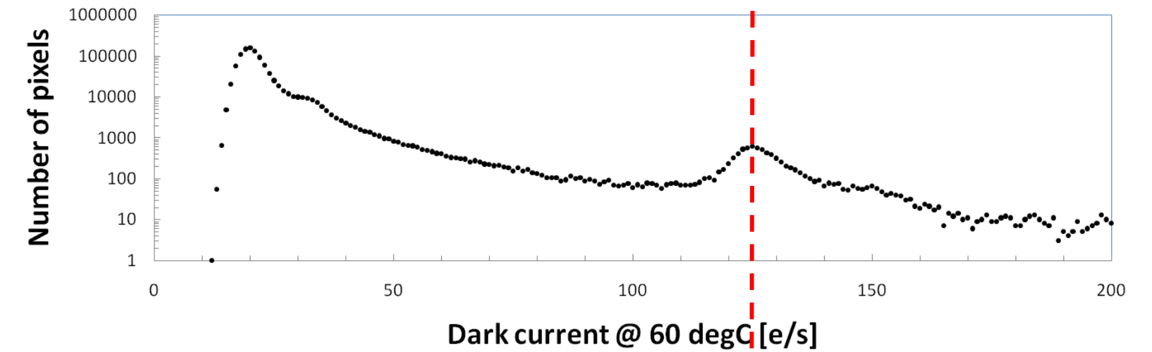
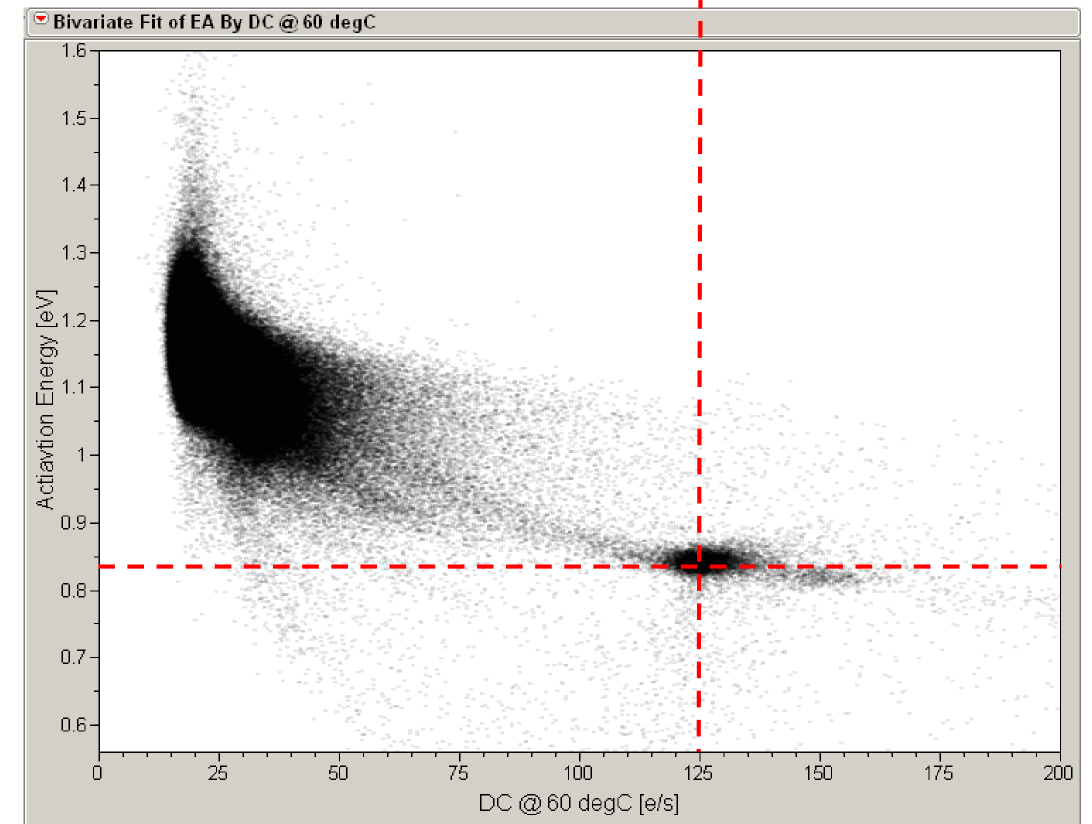
Hot pixels - One of the main requirements for digital cameras









A specific dark current and activation energy value corresponds to the defect in silicon crystal causing the peak

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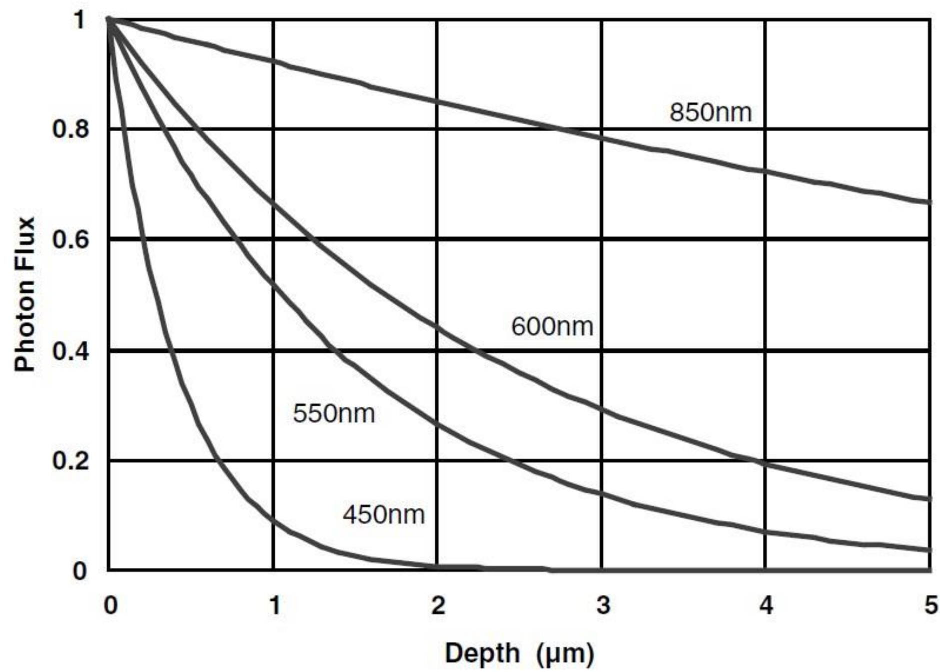
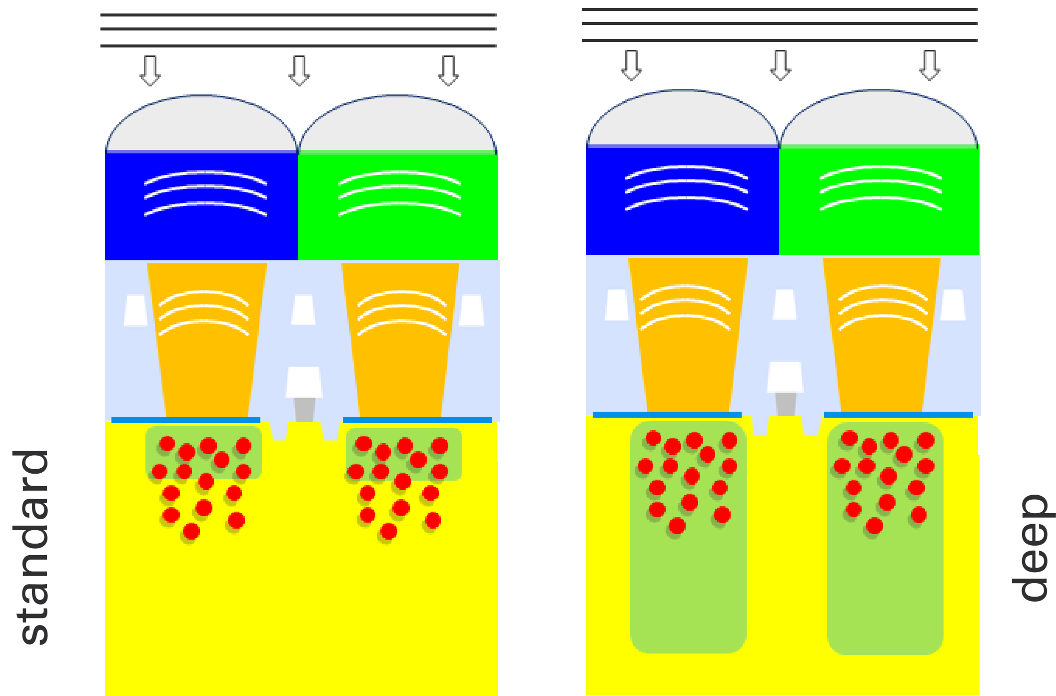
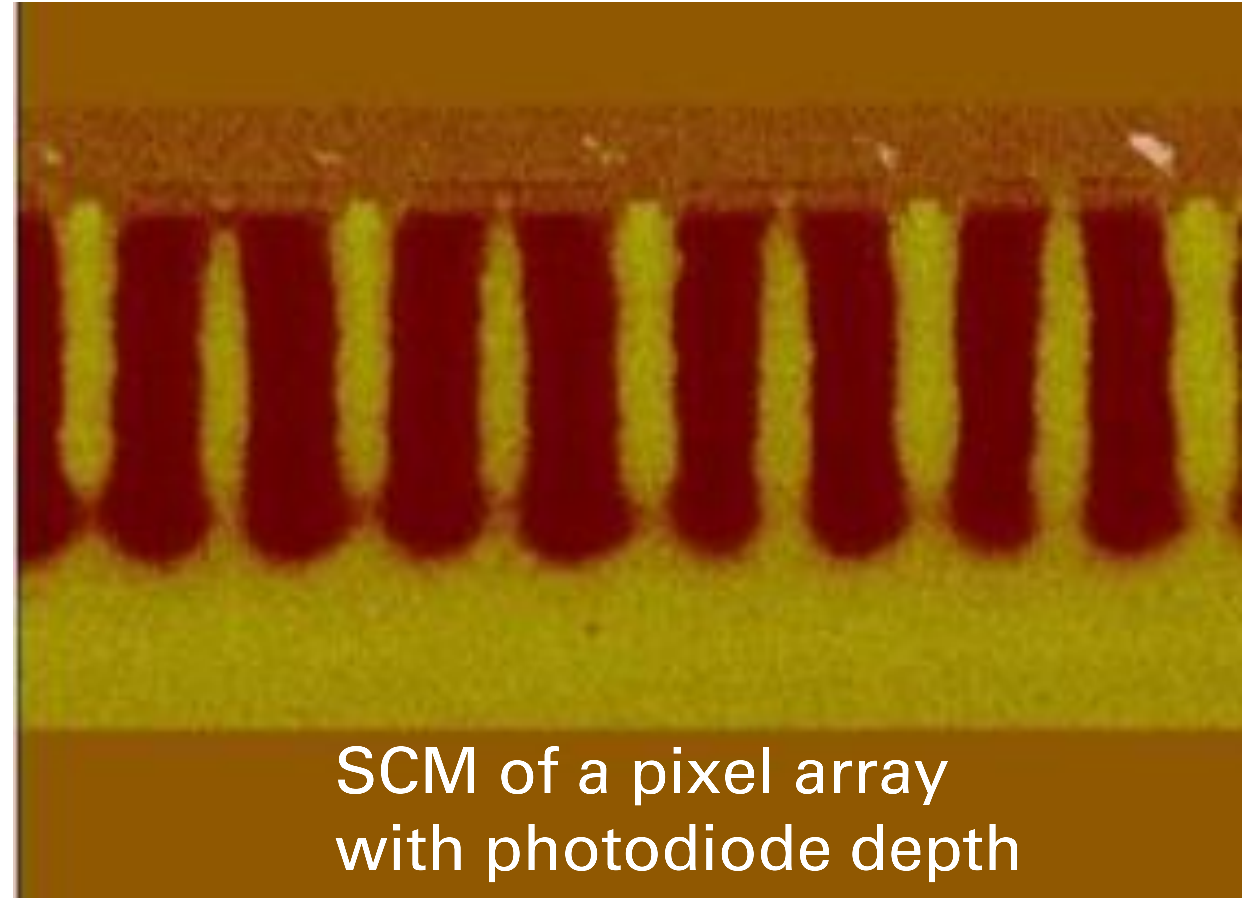
Deep Photodiode







Max implant energy capability:

- Boron 2800 KeV
- Phosphorous 4800 KeV

Implant masking approach:

- Resist up to 15:1 Aspect Ratio
- Hard mask

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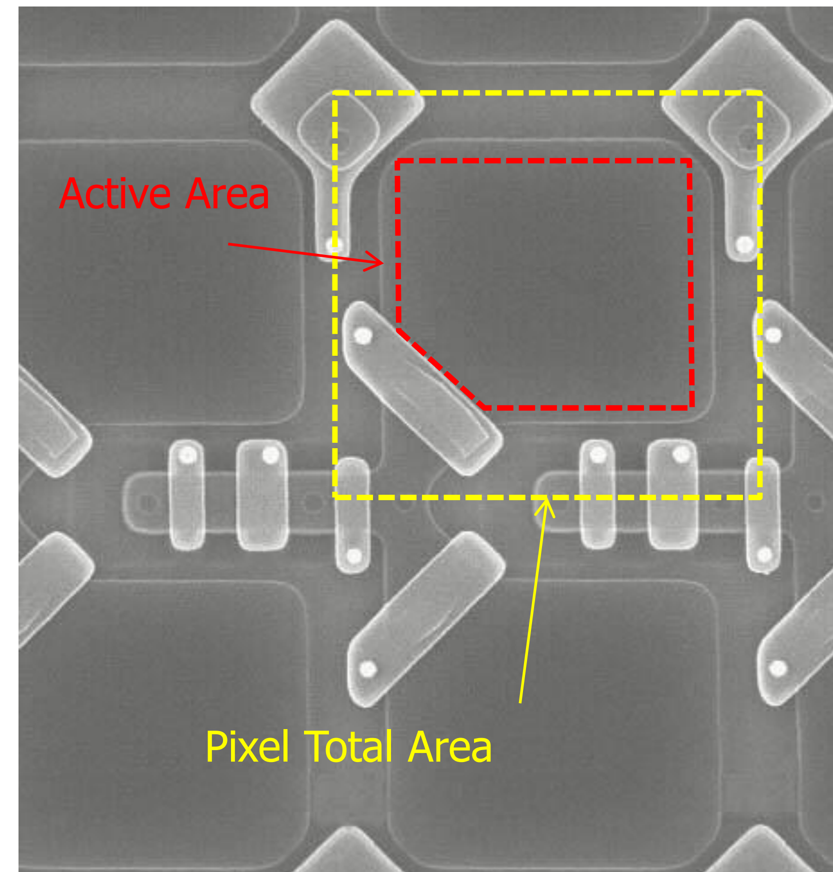
Fill Factor



$$FF = \frac{Active\ Area}{Pixel\ Area}$$

The fill factor is the ratio between the photodiode active area and the pixel area

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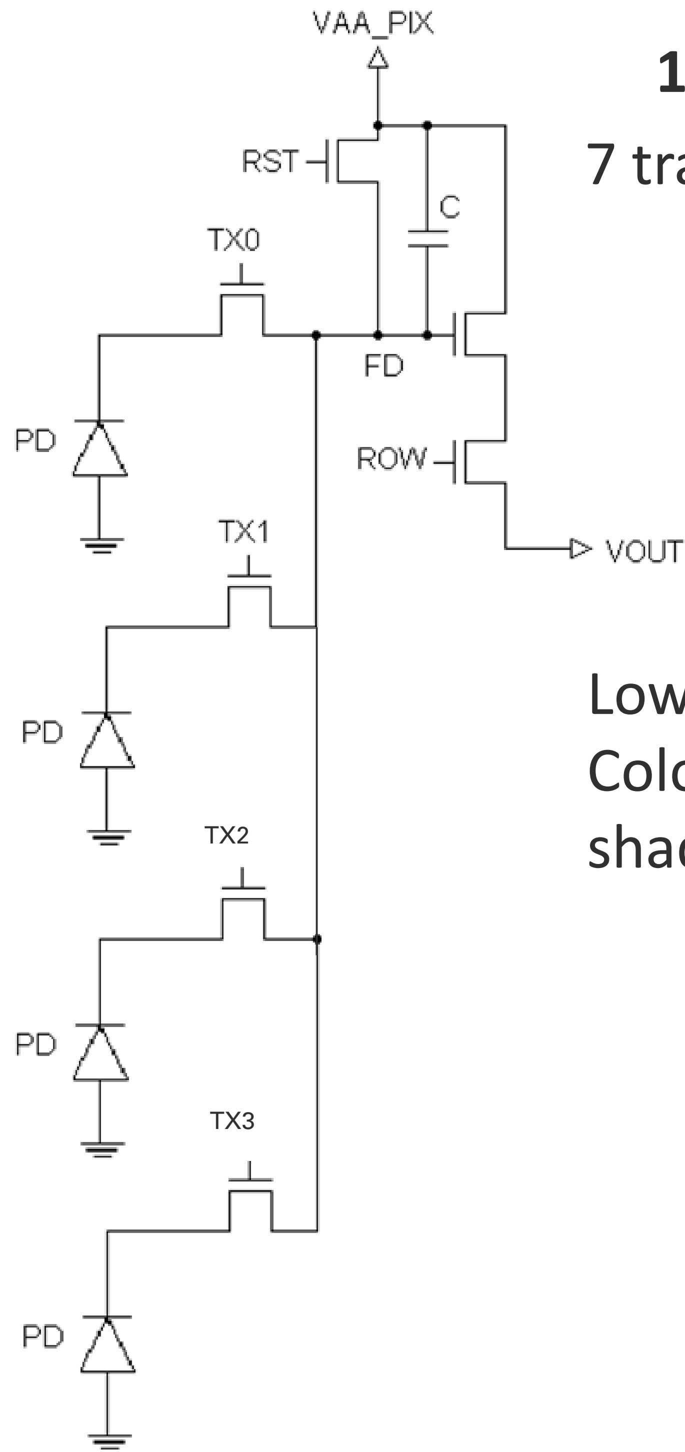
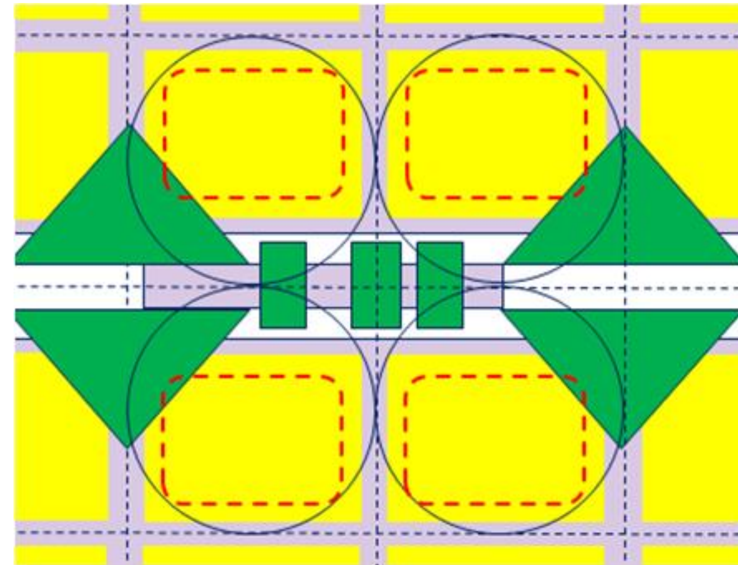
Common Element Pixel Architecture (CEPA)



1.75 T cell

7 transistors for 4 pixels

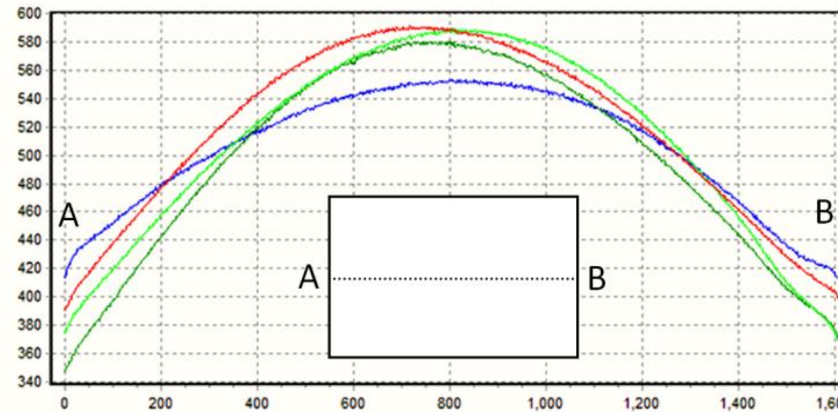


Asymmetry of layout!

Each color plane has its own angular response

Low Color shading

High Color shading



Response of the 4 color planes

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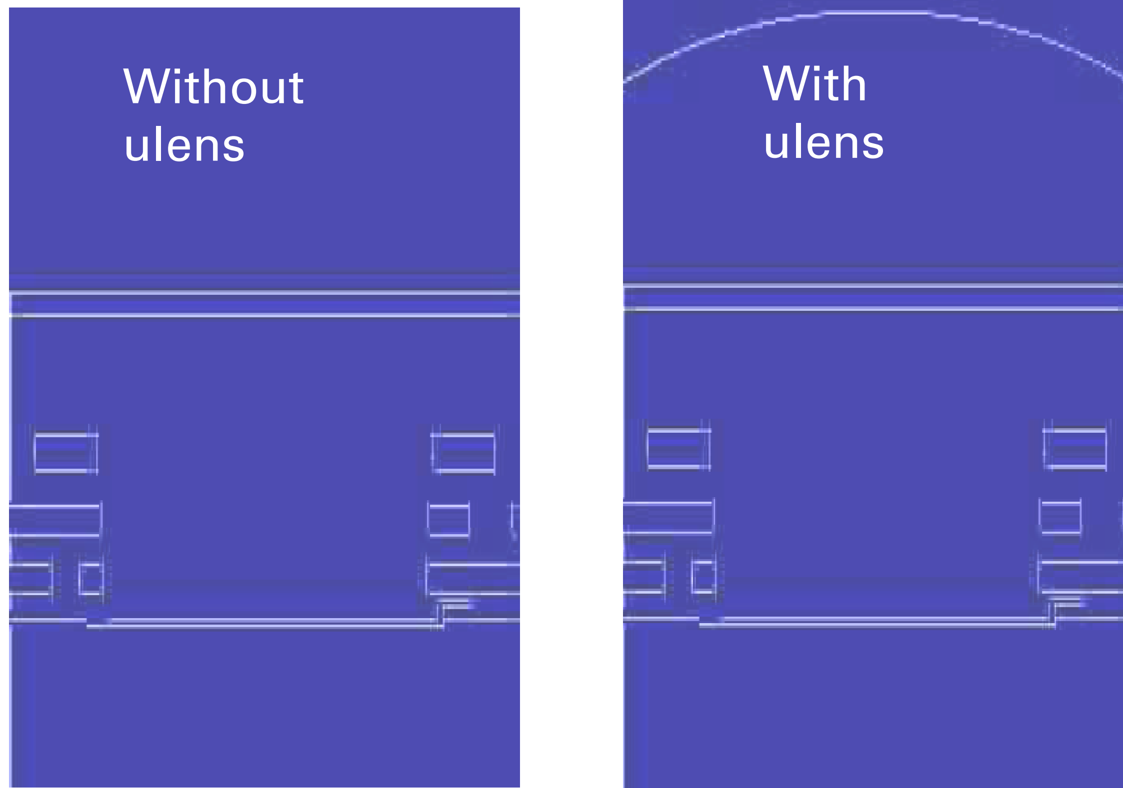
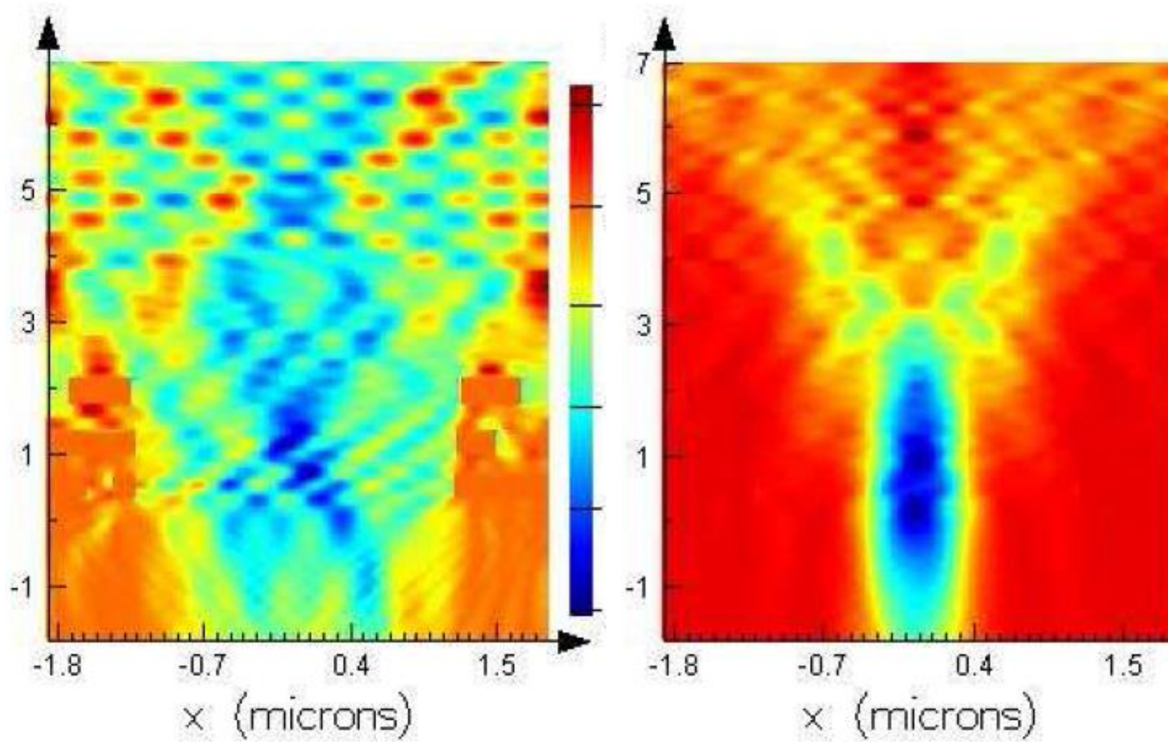
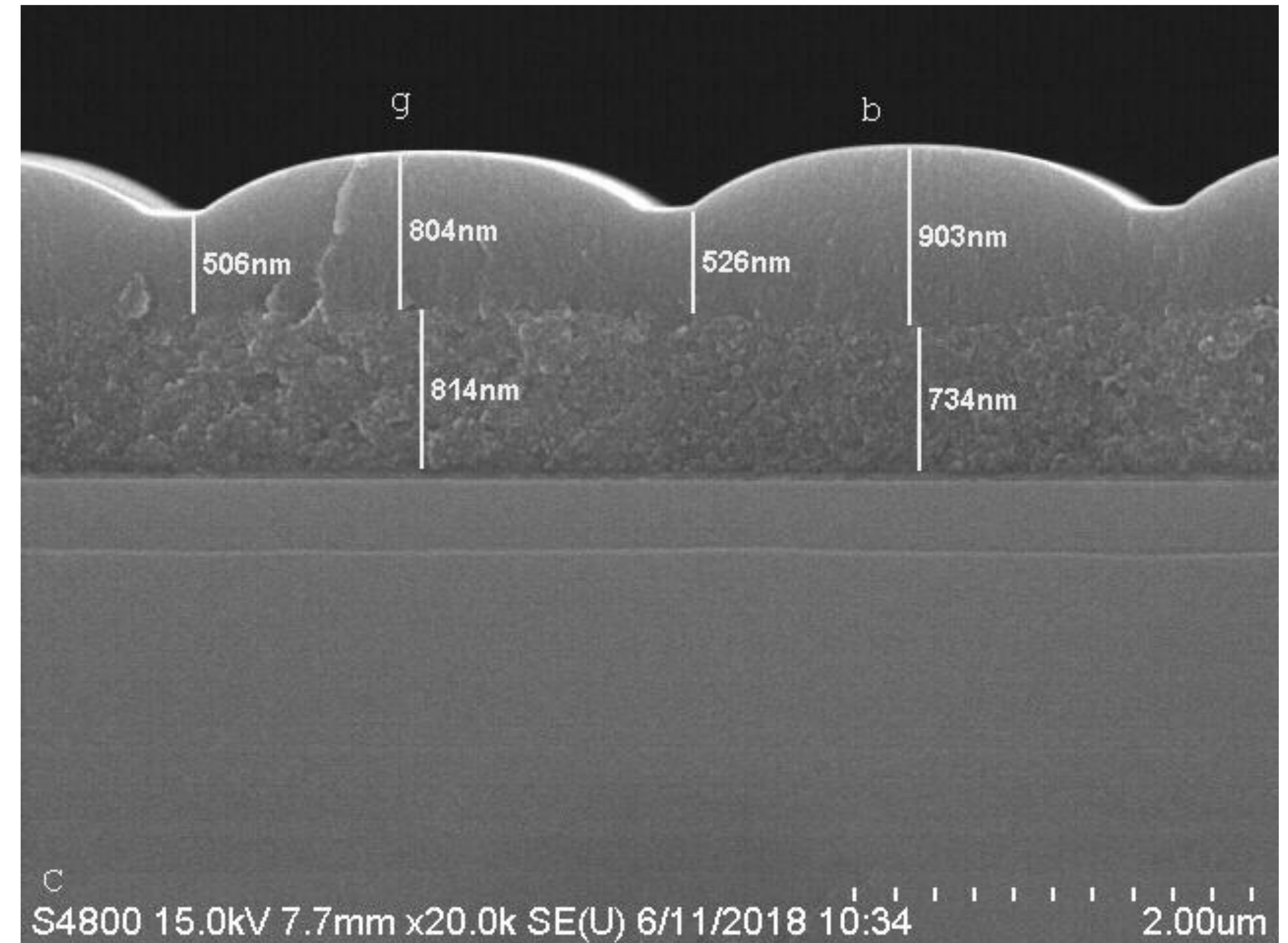
Microlenses to enhance fill factor







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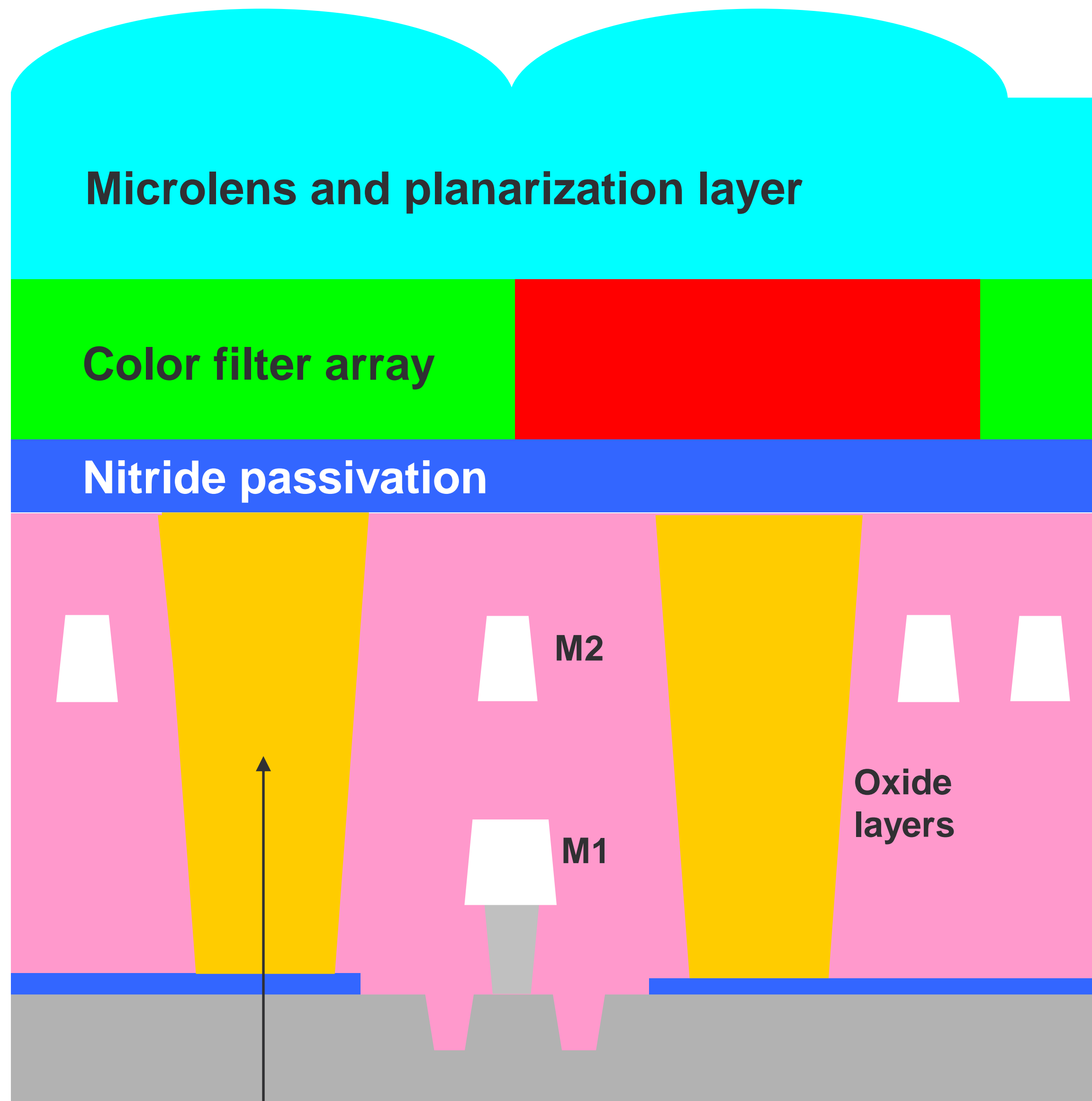
Step index polymeric lightguides



High refractive index
Polymer (n = 1.6-1.7)

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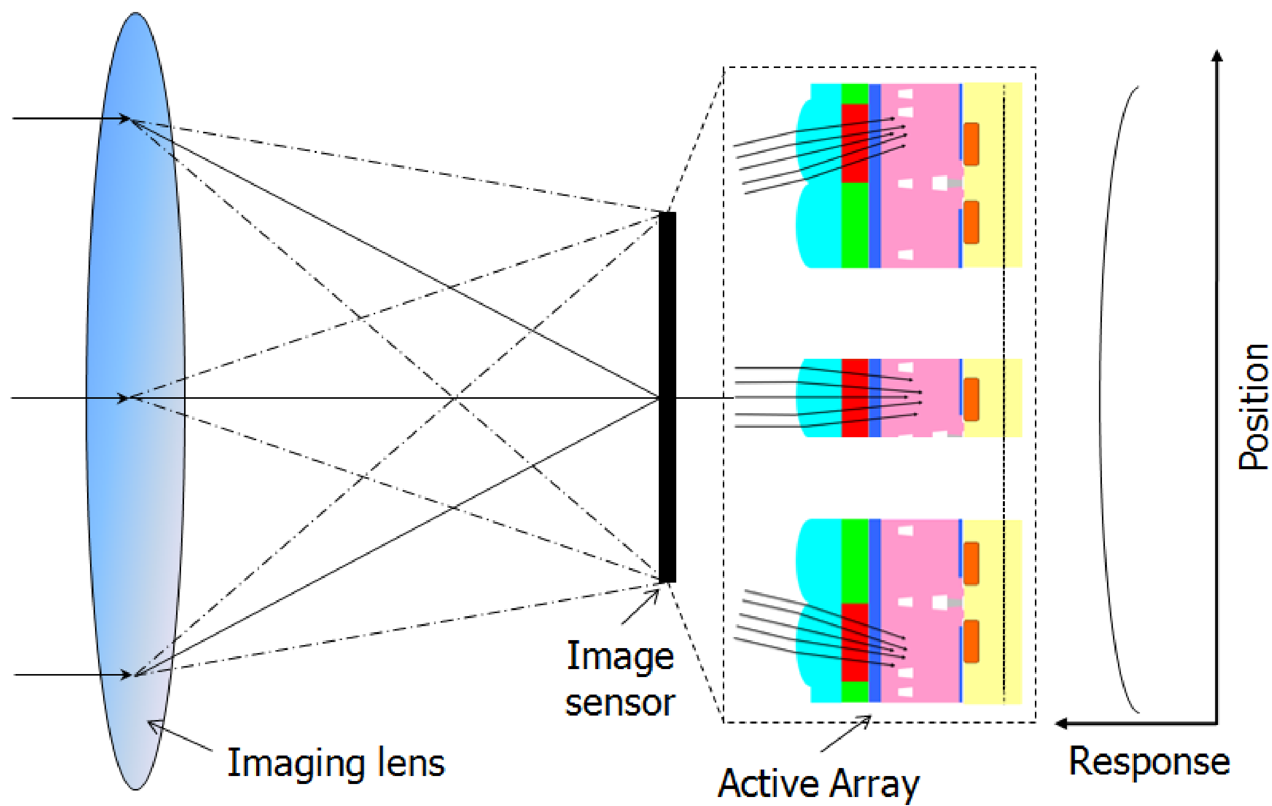
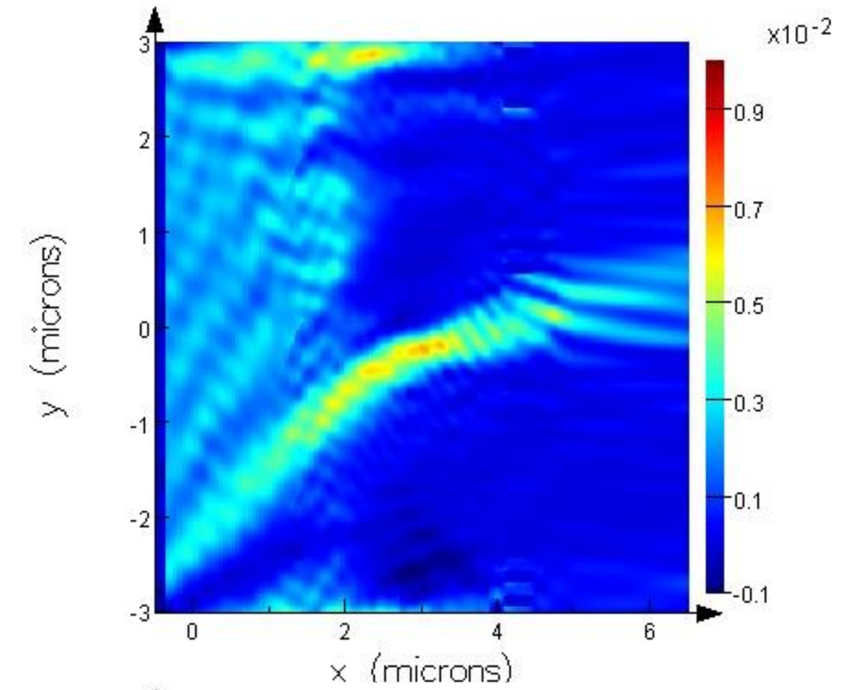
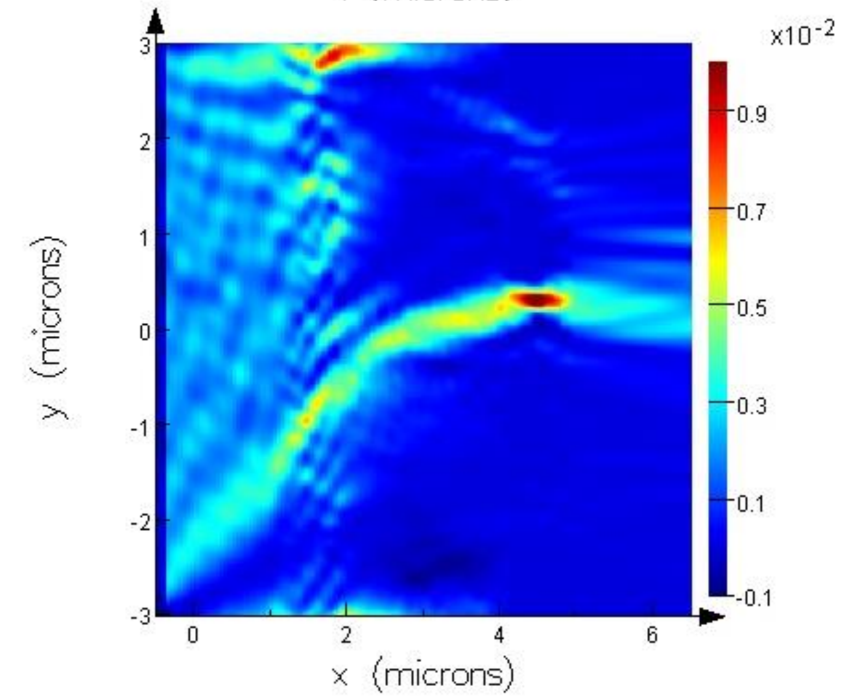
Effect of lightguides on angular response

Simulation run with 25° angle of incidence



Without lightguide





With lightguide

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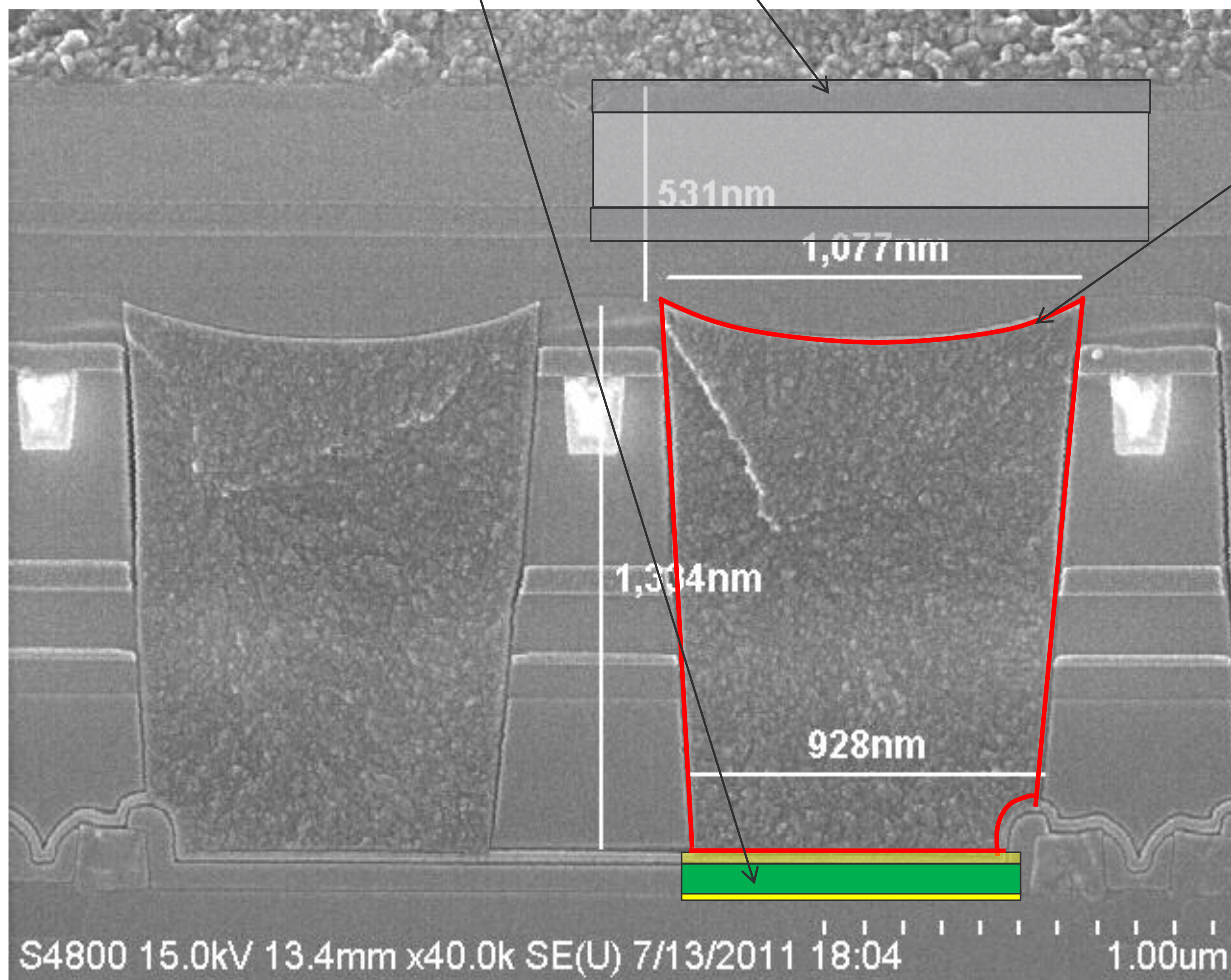
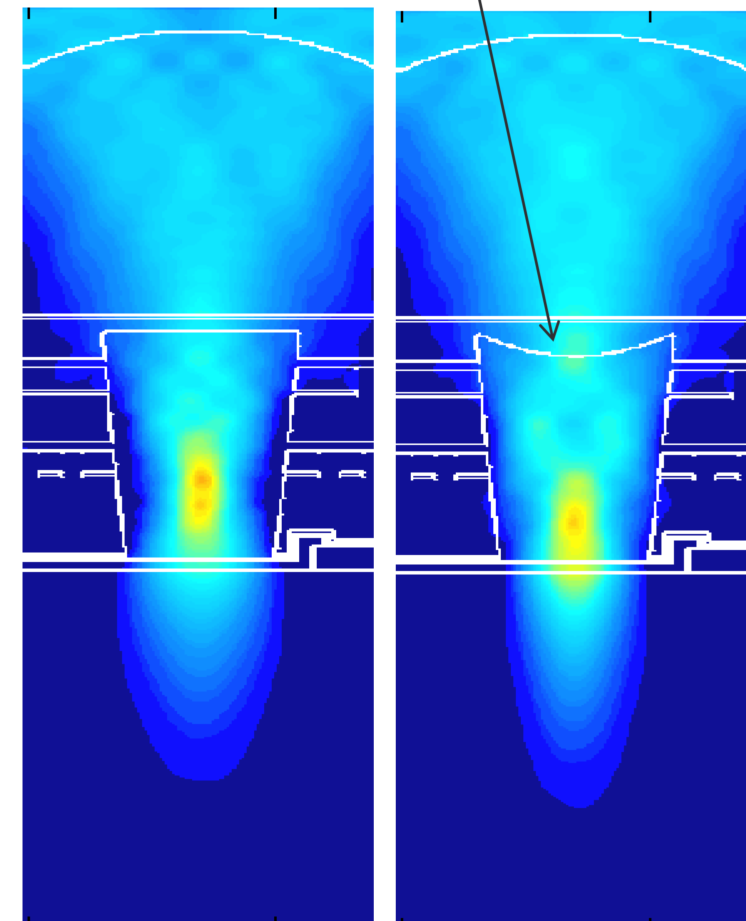
Optical stack optimization

Introduction of anti-reflective coatings with proper thicknesses and refractive indexes

Optimization of the optical performance of structures present in the optical stack





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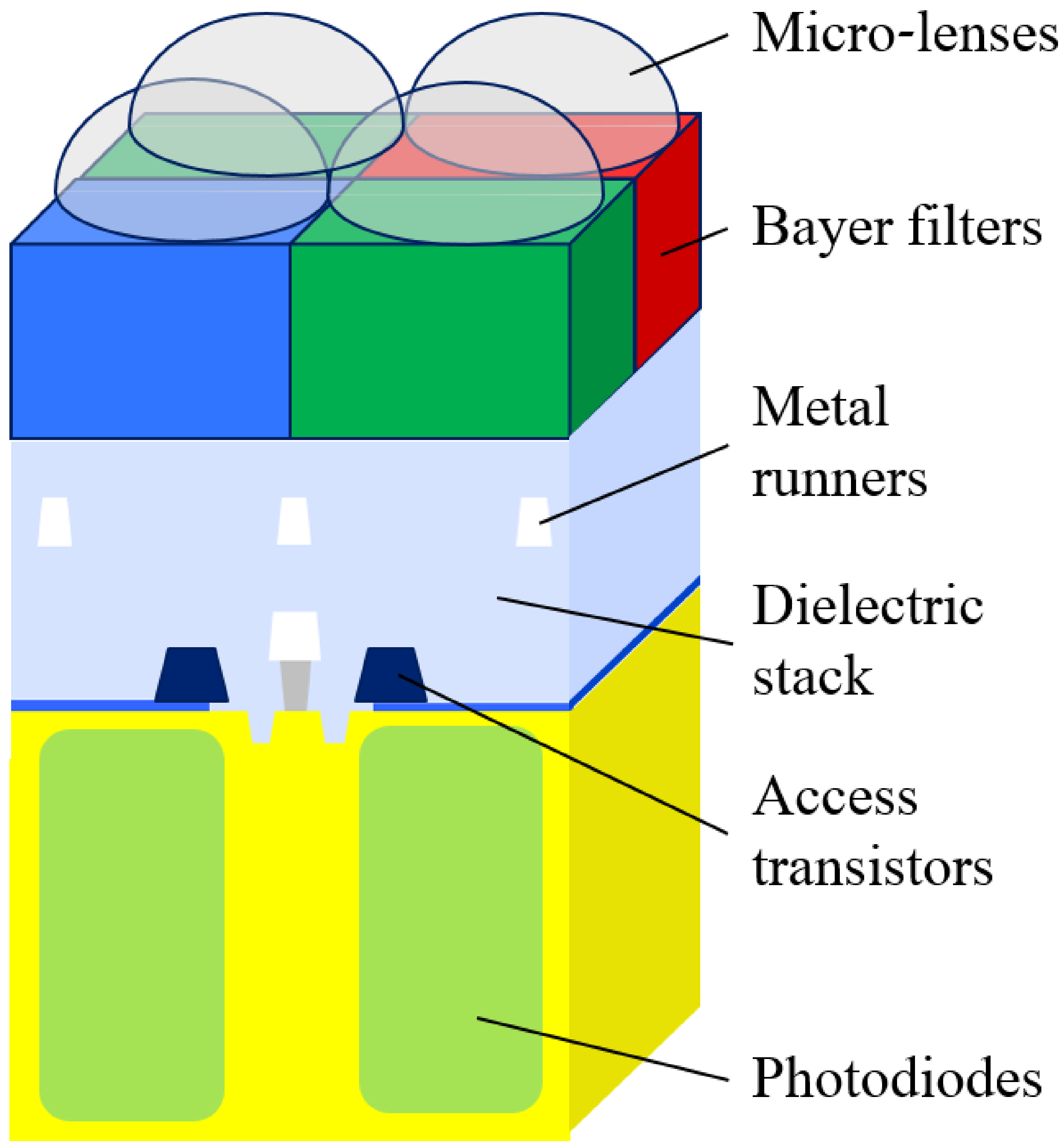
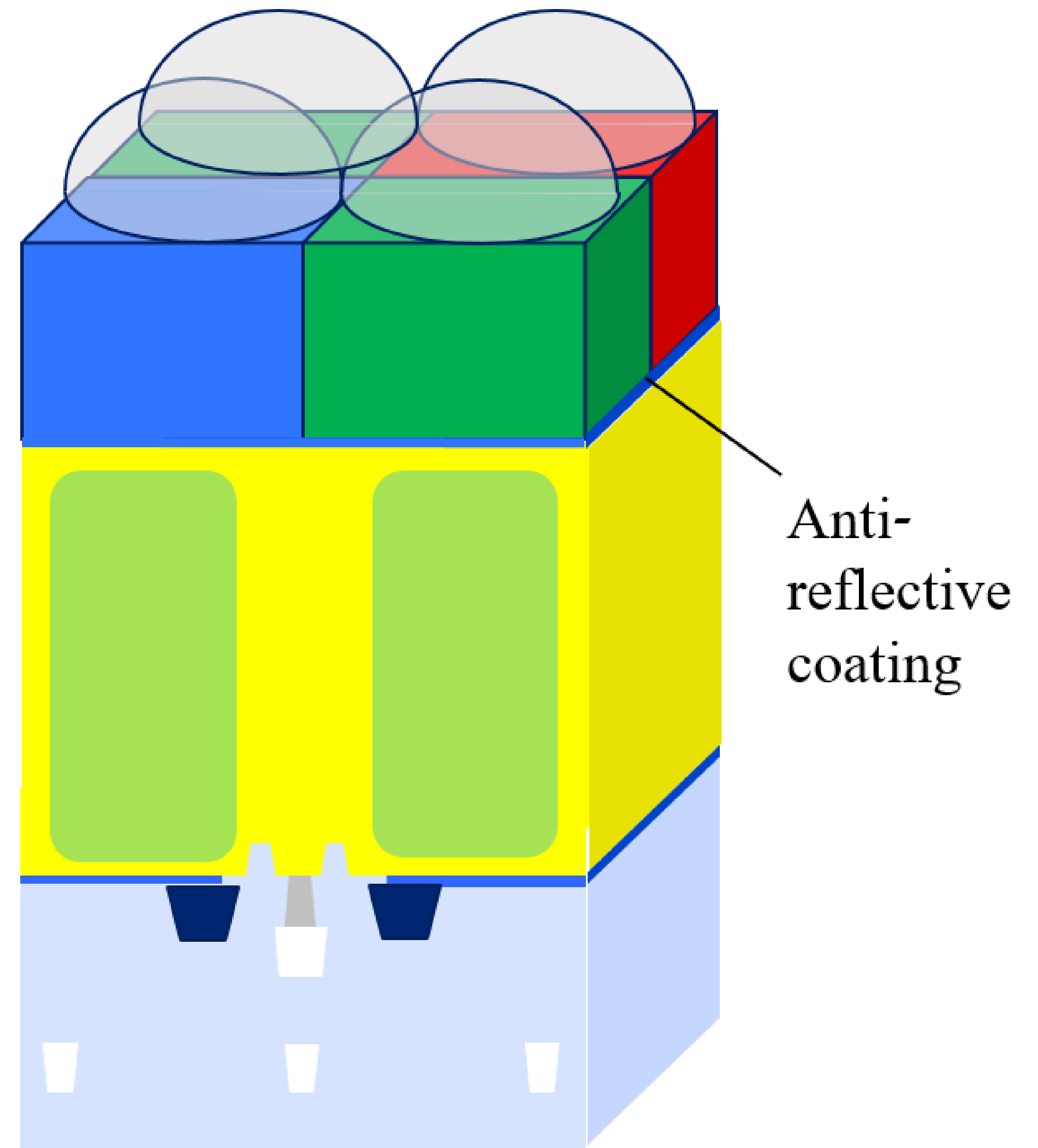
FSI vs BSI pixel



FSI



BSI

(100% fill factor)

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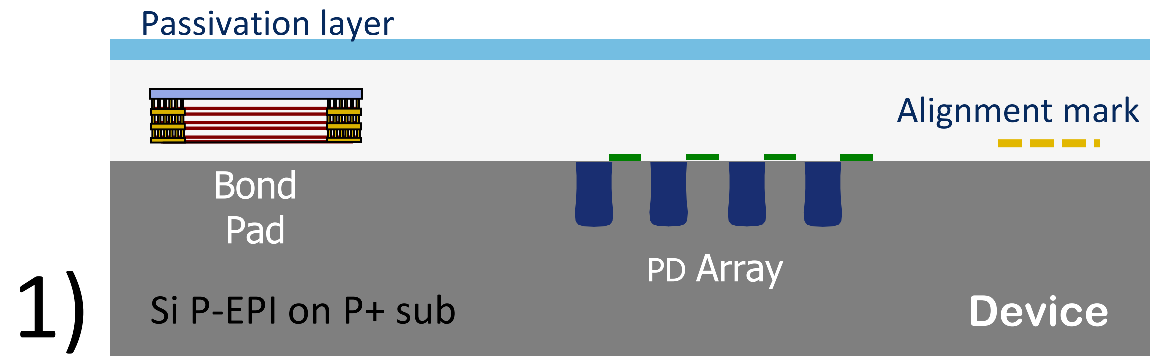
BSI process flow

1)



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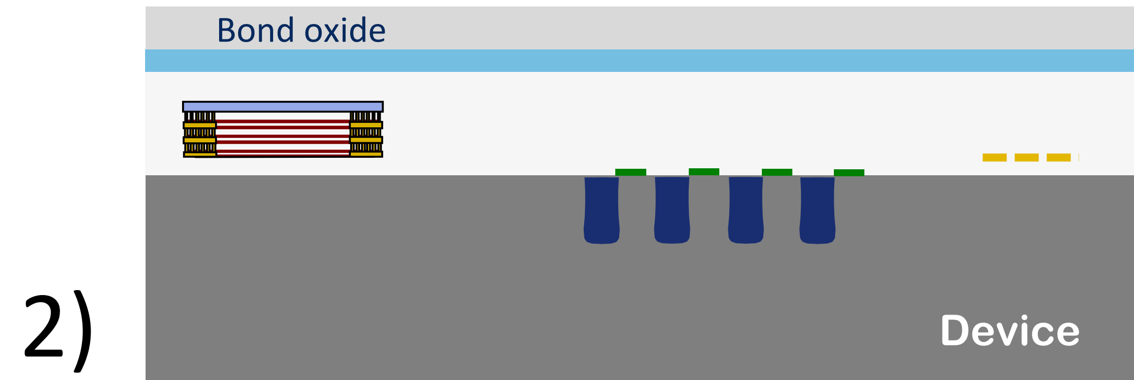

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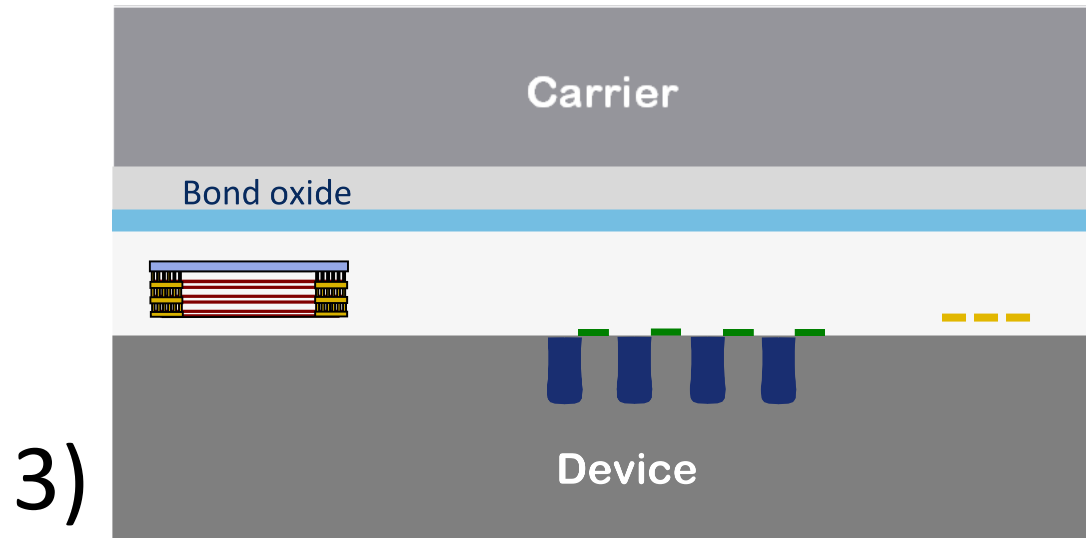

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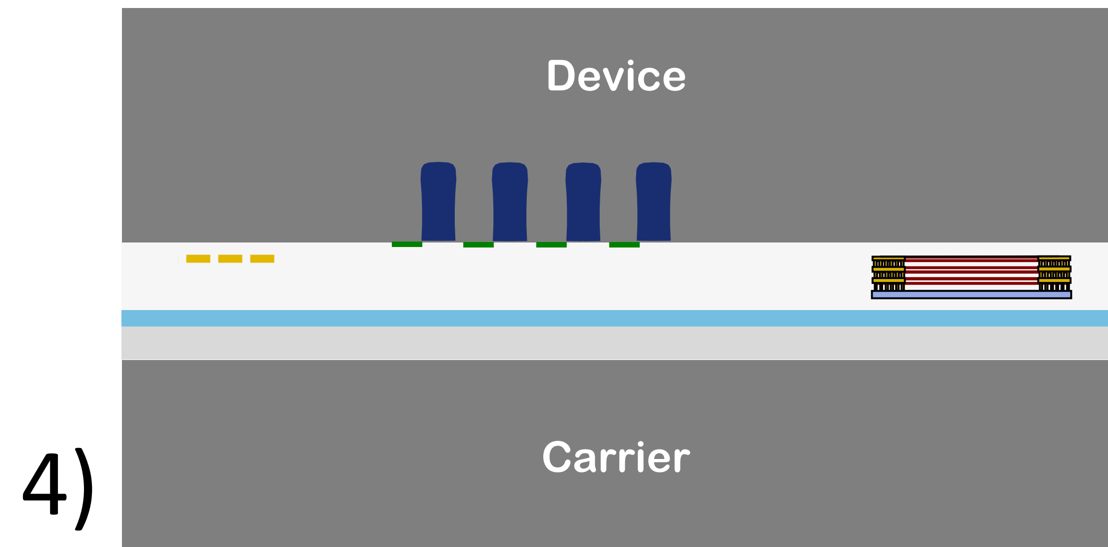
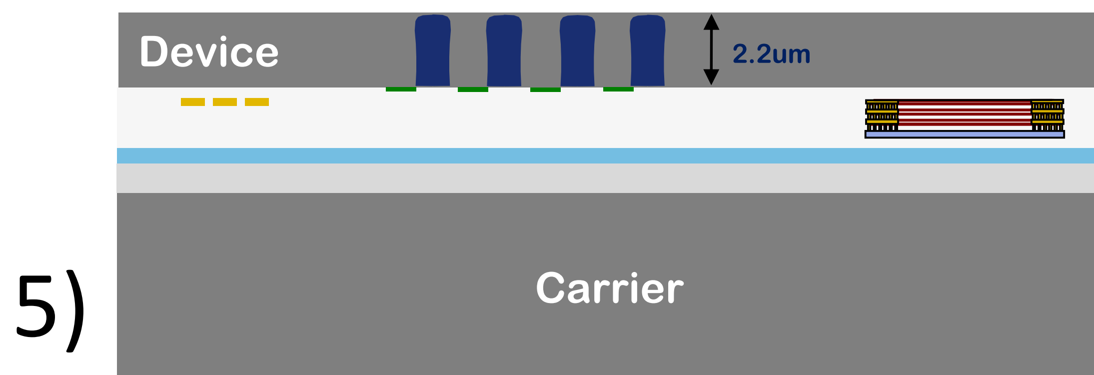
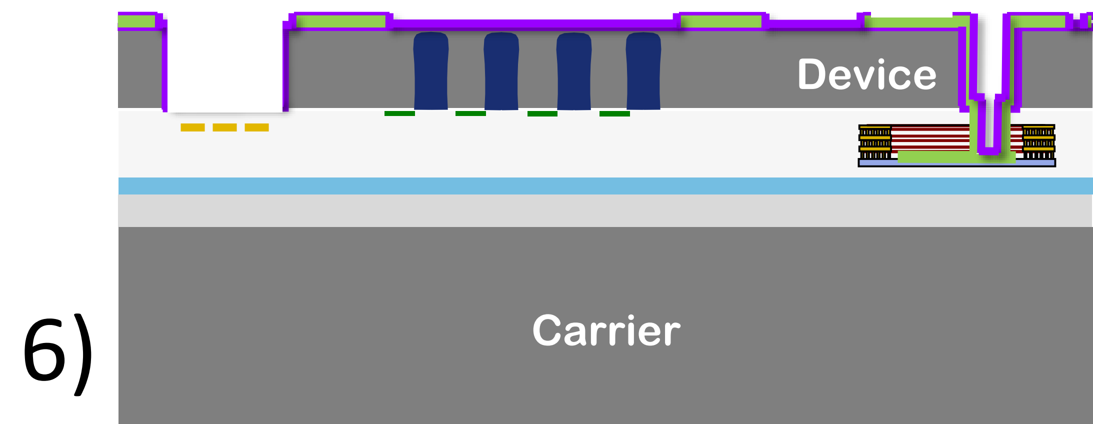


5)



6)



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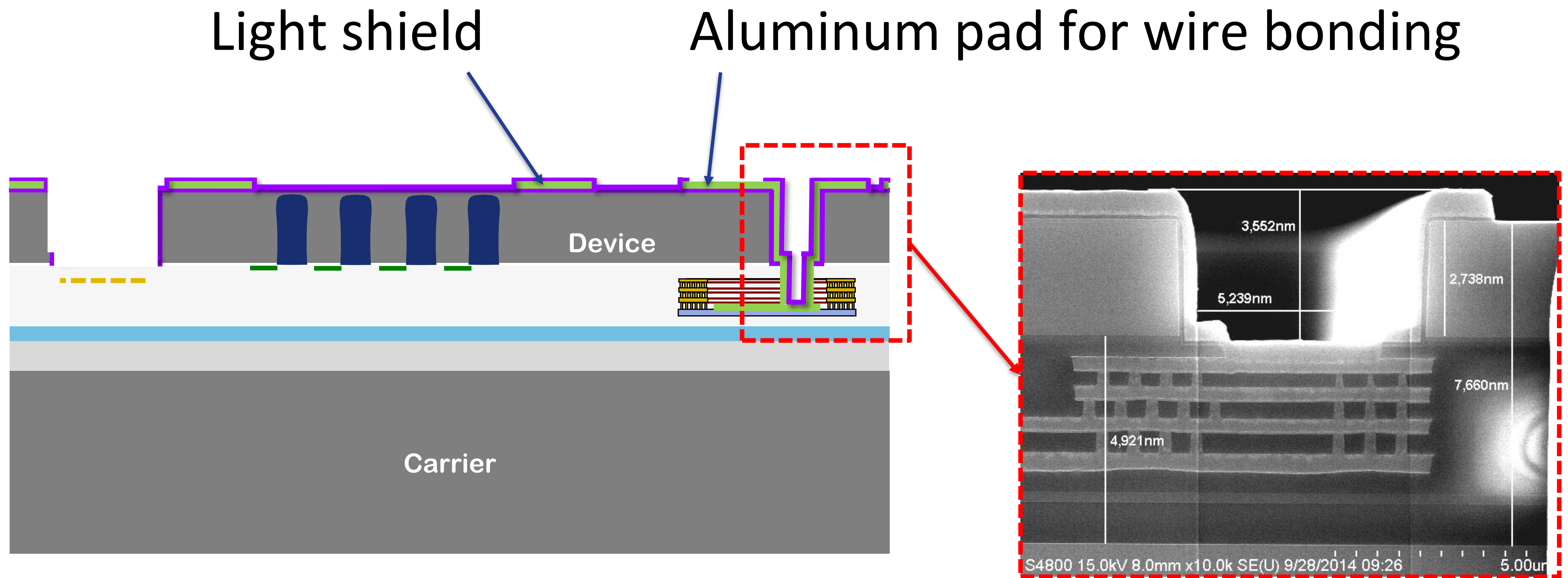
BSI Final structure with SEM x-section on pad structure



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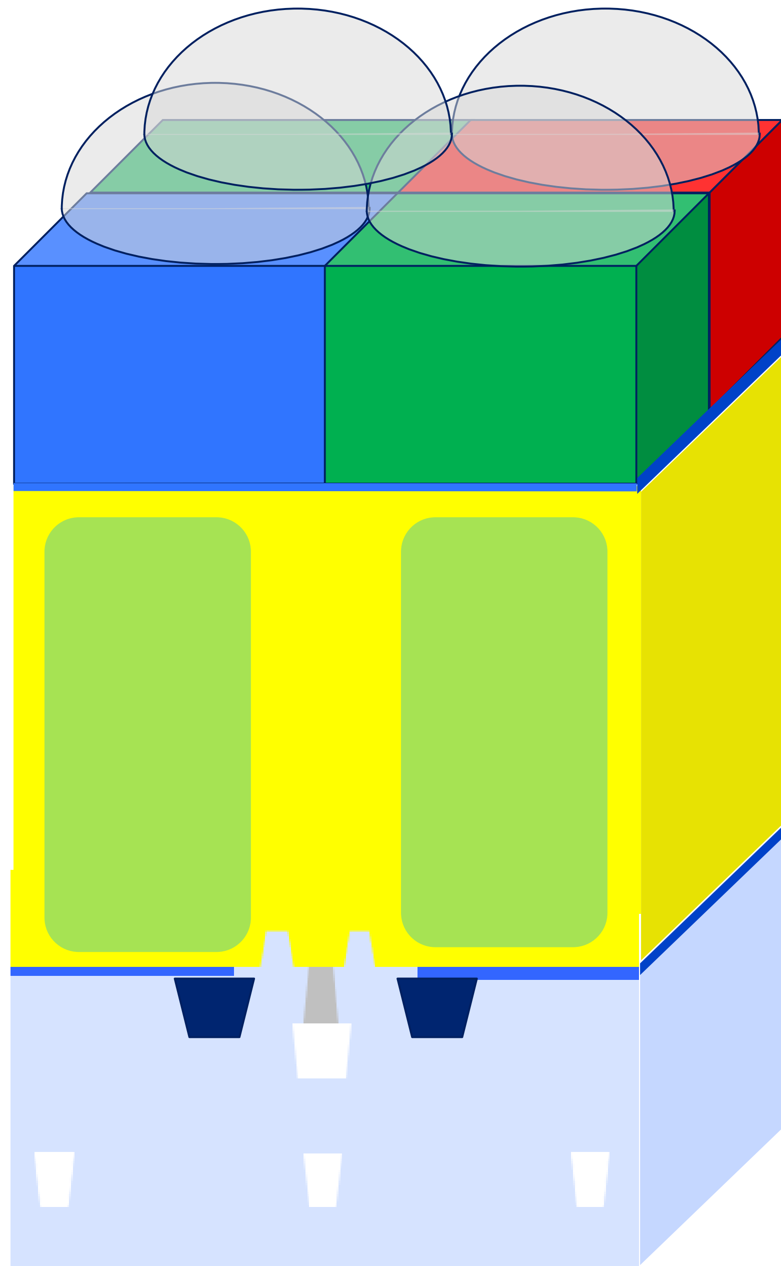
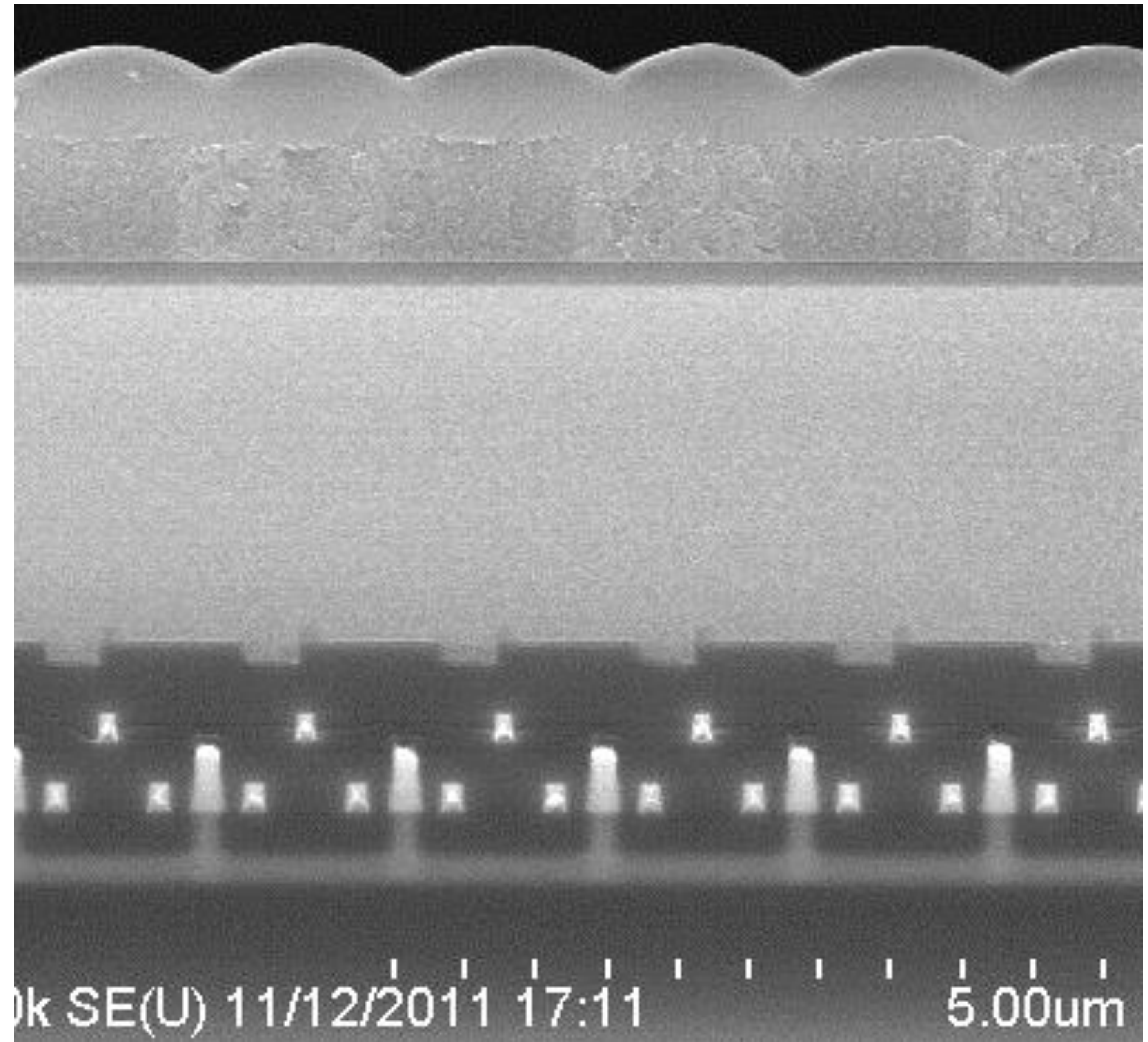
BSI cross-section





100% fill factor, stack height reduced decreasing crosstalk and improving sensor angular response

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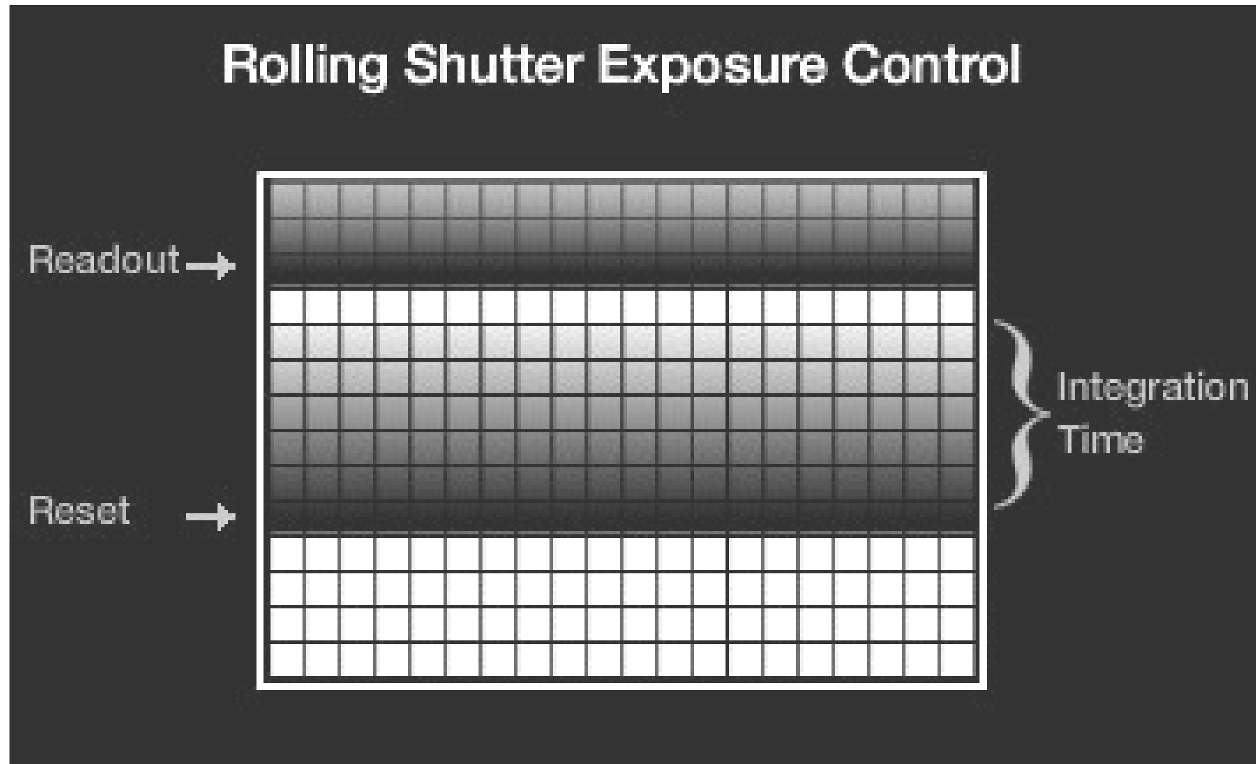
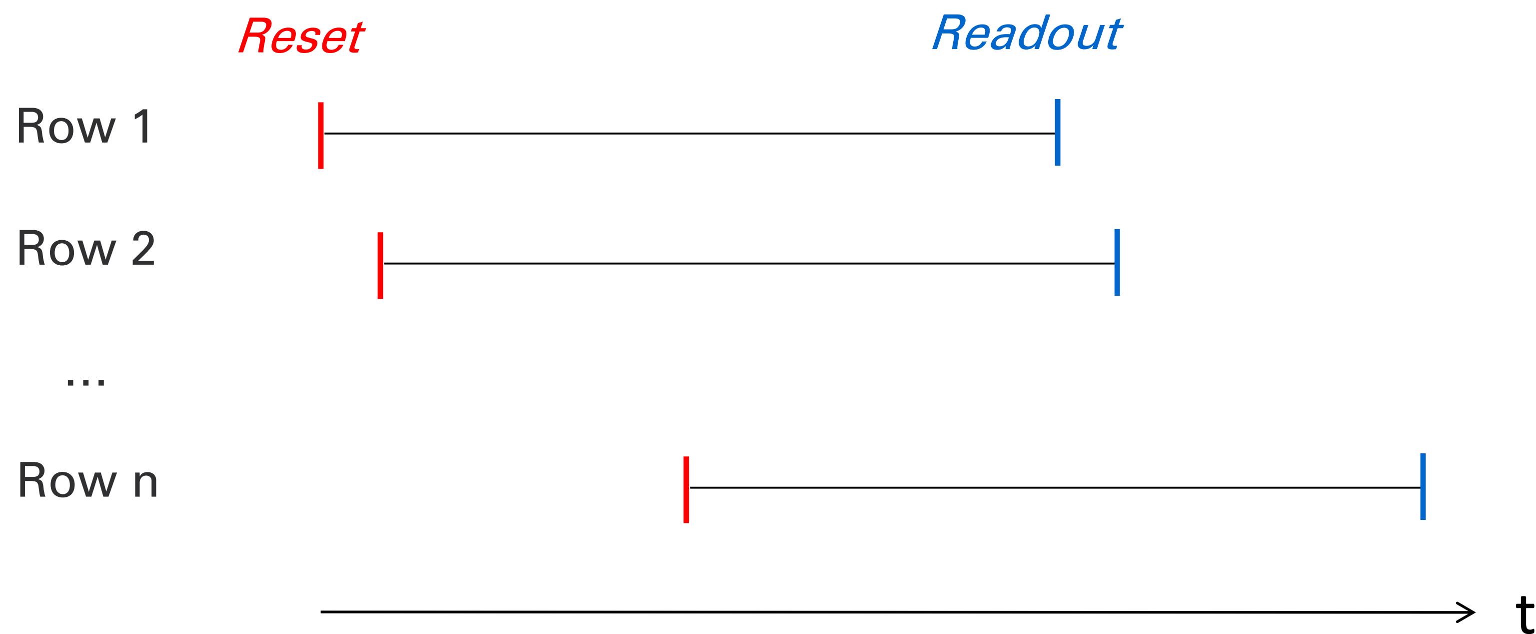
Electronic rolling shutter





The integration time of different rows starts and ends in a different time, causing the artifacts

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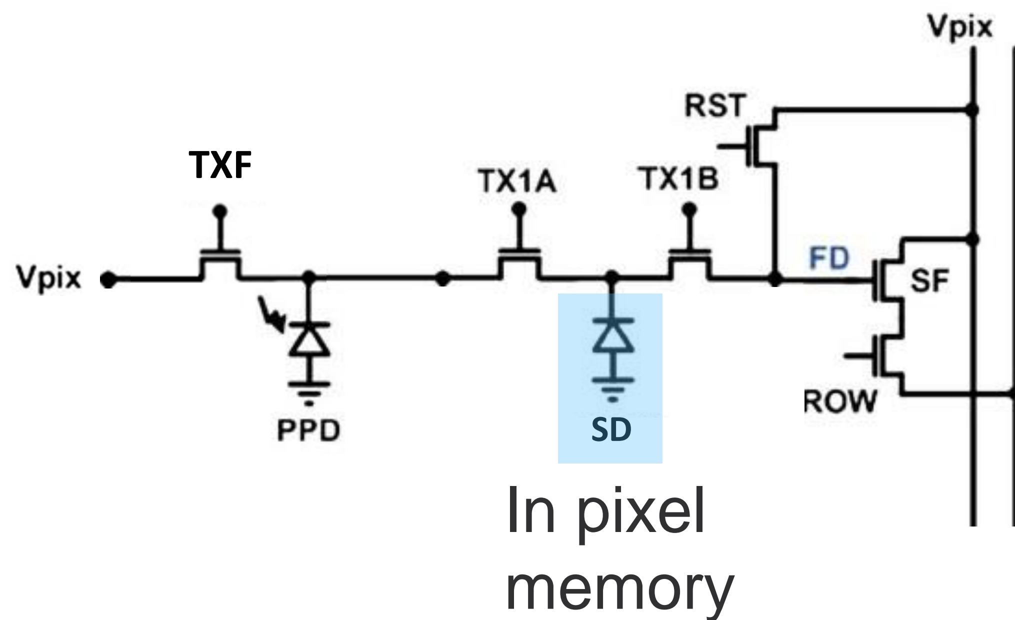
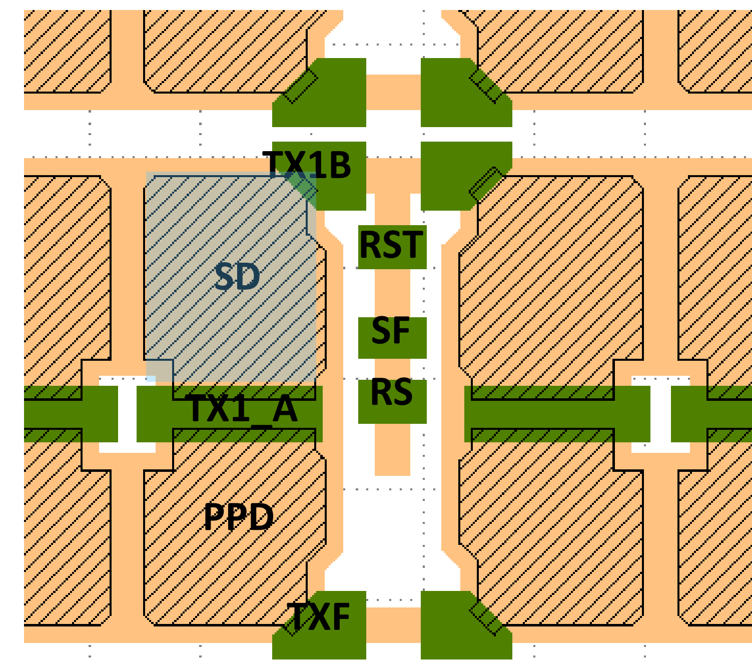
Global shutter

Introducing the "in pixel memory" all the rows start and end the integration time at the same time, while the in-pixel memories can be read row by row.





But the "In pixel memory" needs an effective shield from light!

No distortion!

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SEM tilted view of a state-of-art global shutter CMOS Image sensor (without filters and microlenses)

Metal grid

Light shield

Lightguide

Buried light shield

E-Beam 10.0 kV | Det TLD-S | Mag 20.0 kX | FWD 5.003 | Tilt 52.0° | 11/06/15 19:56:57 | Spot 3 | 2 µm

Storage diode

Photodiode

Active pixels
(for image capture)

Reference pixels
(for dark current correction)

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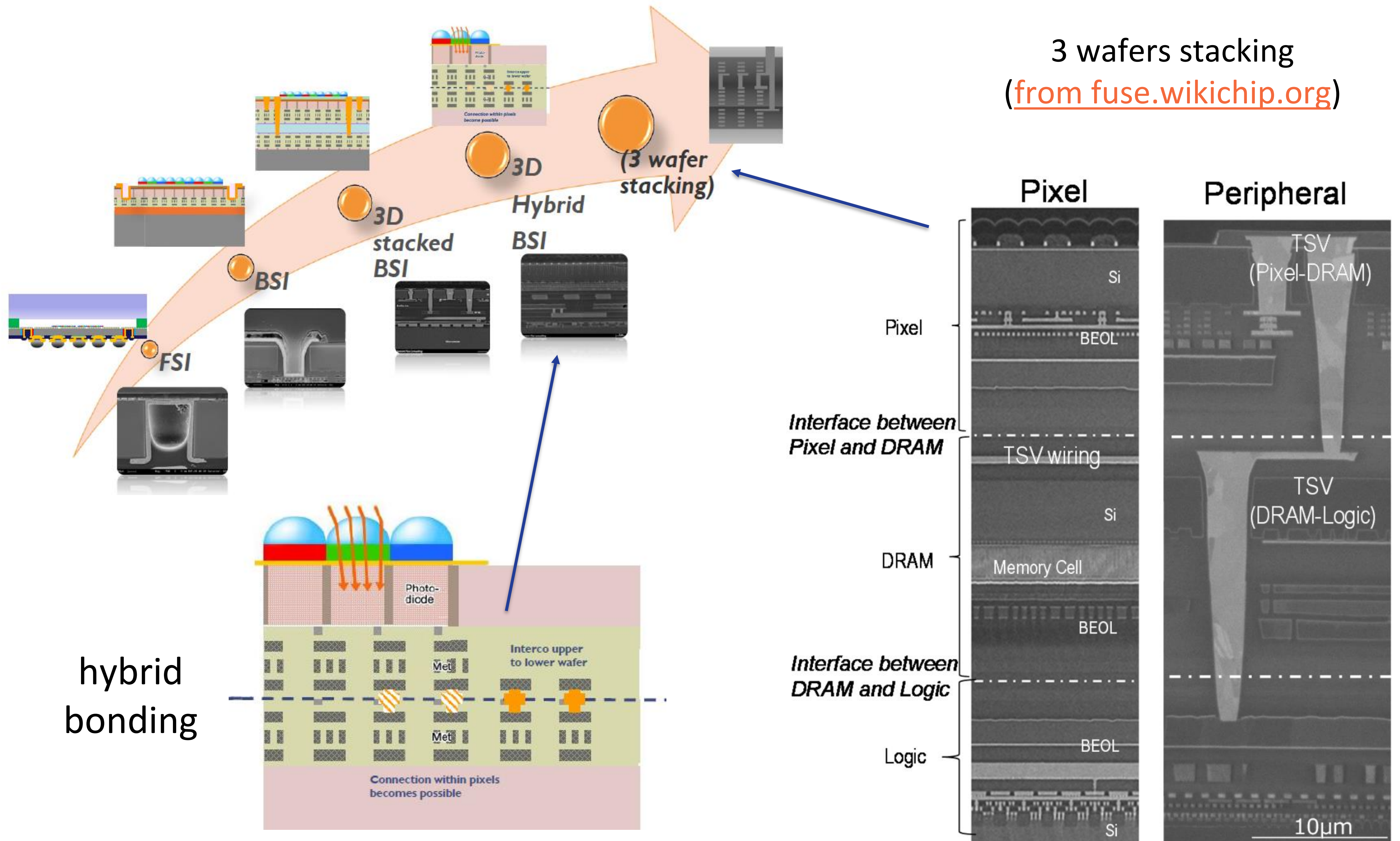
Technology trends



Reduced chip size, higher speed, low power consumption

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Thanks!

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