Panasonic

An Organic-Photoconductive-Film CMOS Image Sensor's Advanced Technologies

Kazuko Nishimura

Panasonic Corporation, Osaka, Japan

Who am I ?

Kazuko Nishimura

大阪大学 OSAKA UNIVERSITY

Mechanical Engineering

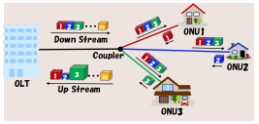
- Robot Manipulator using GA

Panasonic

R&D / Semiconductor Division

- High-Speed ADC for DVD, DVC

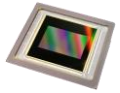
- Optical Transceiver for FTTH

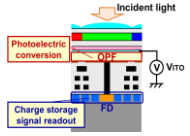


- Full Segment Tuner for Mobile Phone

- CMOS Image Sensor for several products

- **OPF CMOS Image Sensor**





Manager of Image Sensor Project, Technology Division

OPF: **O**rganic **P**hotoconductive Film

Society committee activities

1. A-SSCC DC subcommittee chair
2. ISSCC IMMD subcommittee
3. IEEE SSCS DL
4. IEEE SSCS Adcom
5. Image Sensor Europe advisory
6. CREST technical advisor
7. NISTEP expert technical researcher

*6,7 Japanese Government Ministry of Education Project

Outline

- Background
- What is OPF image sensor
- Advanced technologies of OPF image sensor
  1) Wide dynamic range
  2) Photoelectric conversion controlled global shutter
  3) NIR sensitivity modulation RGB-NIR sensor
- 8K4K sensor technologies
- Conclusion

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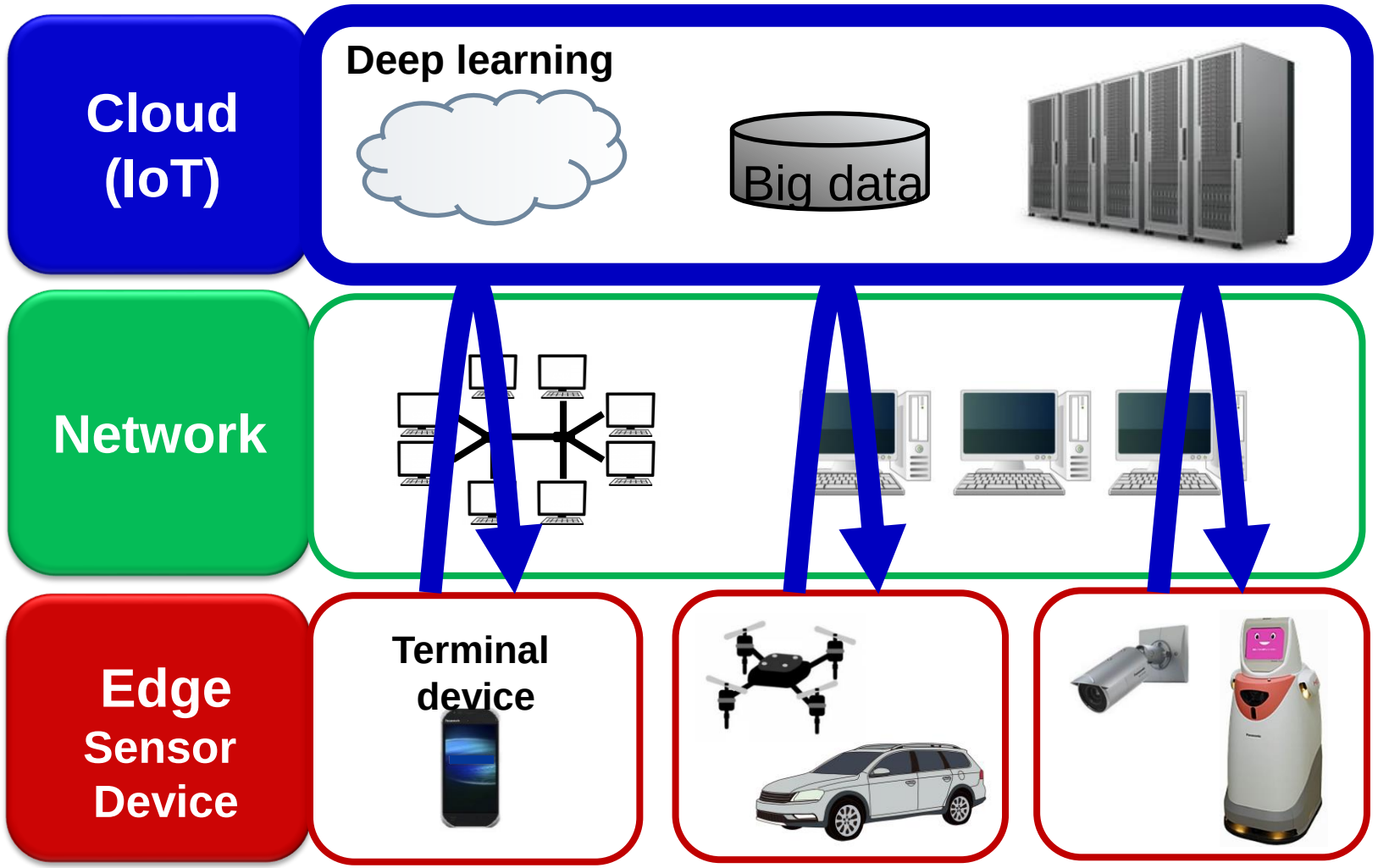
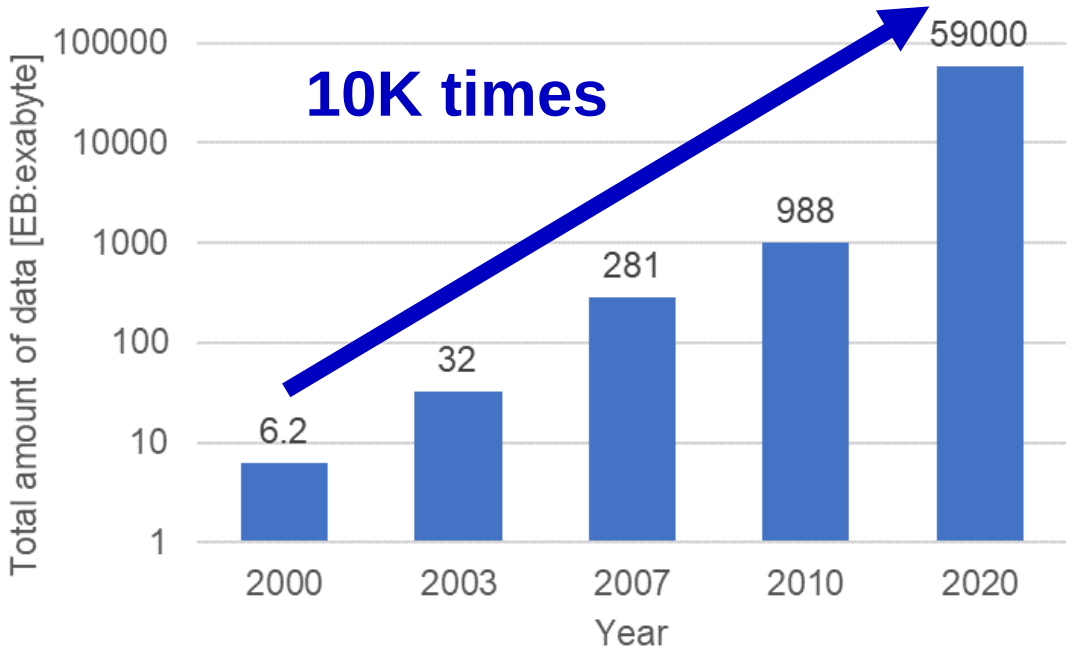
Now : Cloud ➡ Edge



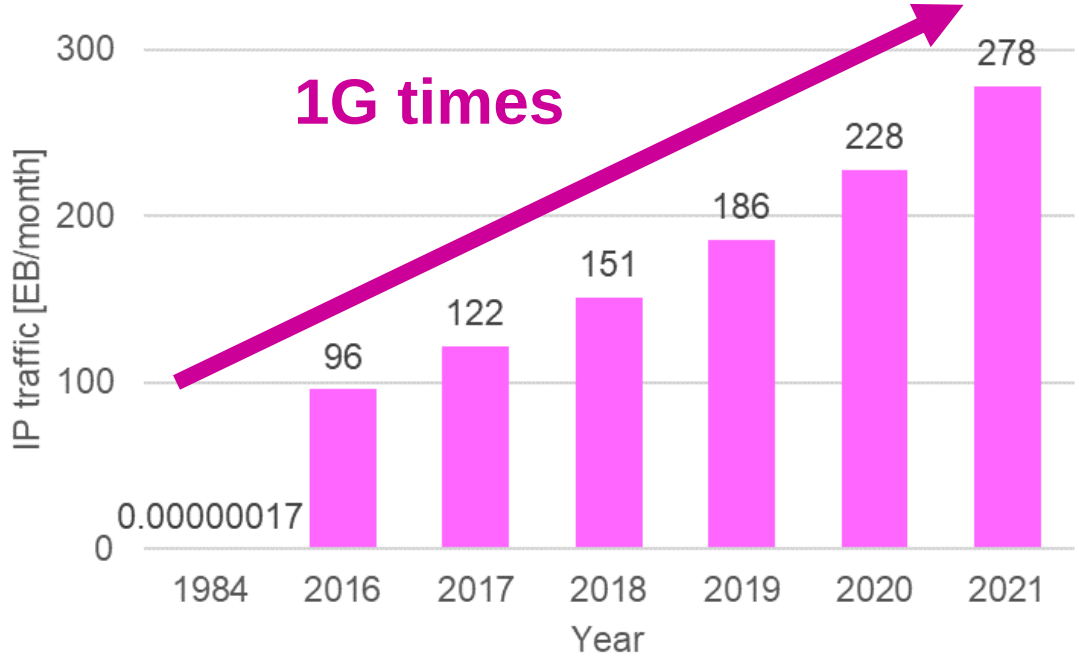
Amount of data:
large
Response:
slow
Security:
problem

Big Data Problem

Total Amount of DATA

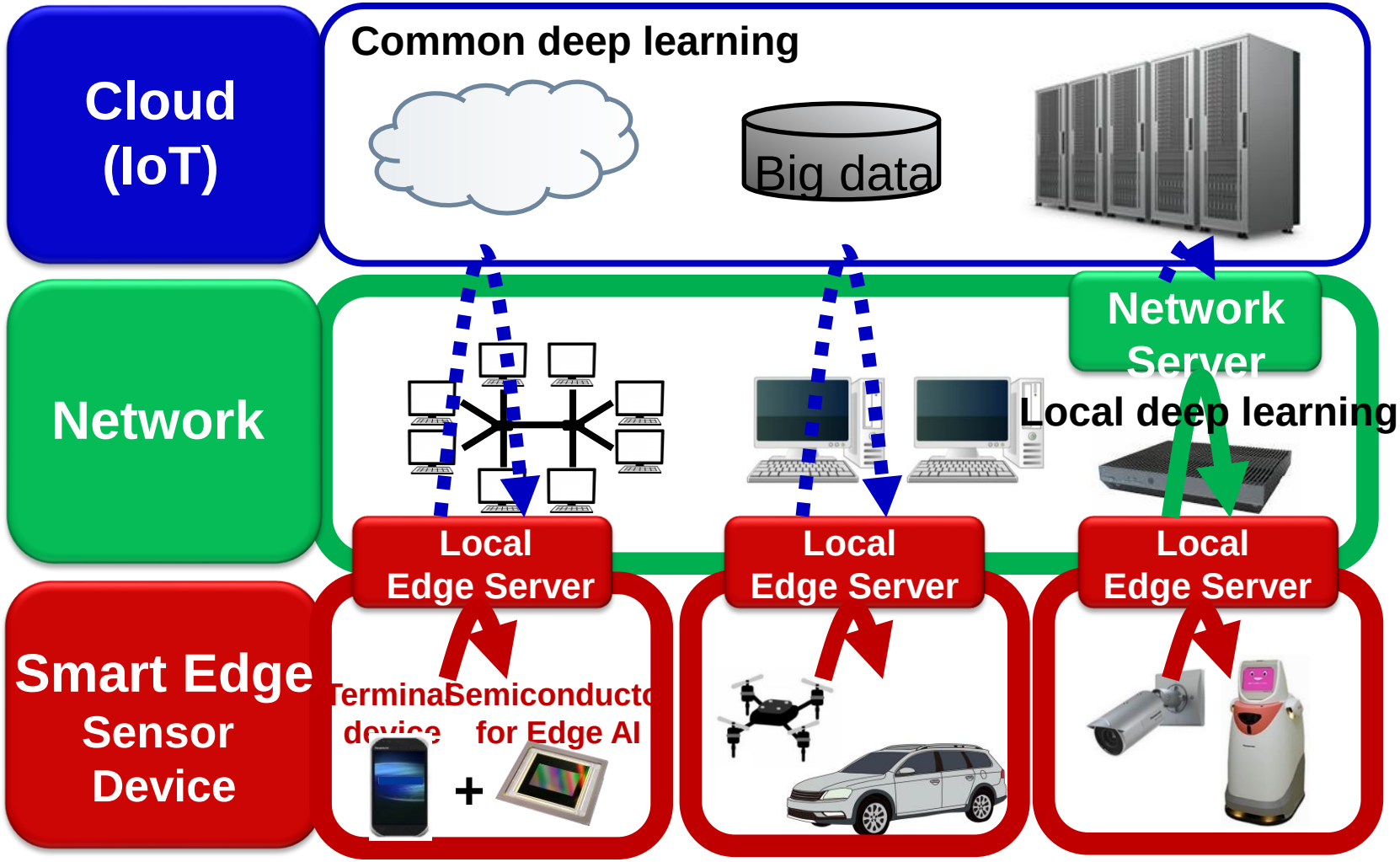


IP Traffic (/month)



By 2030, over 50% of the data will be **real-time data**.

Near Future : Smart Edge



Only sharing
- Common AI data
- Others' experience

Amount of data: **small**

Response: **fast**

Security: **safe**

Image Sensors become “Key Devices of Smart Edge”

- **Needs for “Imaging” and “Sensing”**
- Wide dynamic range (High saturation/Low noise)
- High speed imaging
- High sensitivity …

“Imaging” and “Sensing” Beyond Human Ability

Capture accurately ➡ Look at something invisible ➡ Predict the next action

We have to develop technologies for achieving these requests.

Under backlight

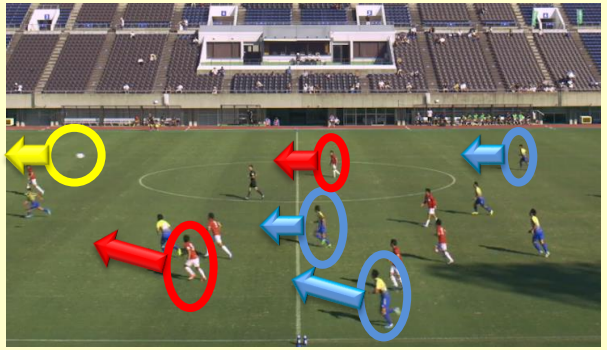
People detection
at disaster site

Required technology:

Wide dynamic range

At high speed

Motion detection
in the sport scene



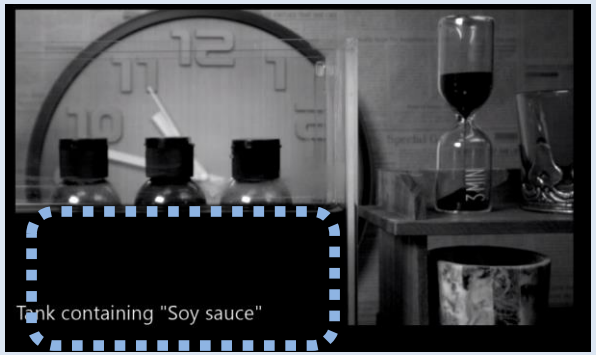
Required technology:

Global shutter

(Multiple-angles, Multiple-exposure)

In the dark

Non-destructive inspection



Required technology:

RGB + other wavelength

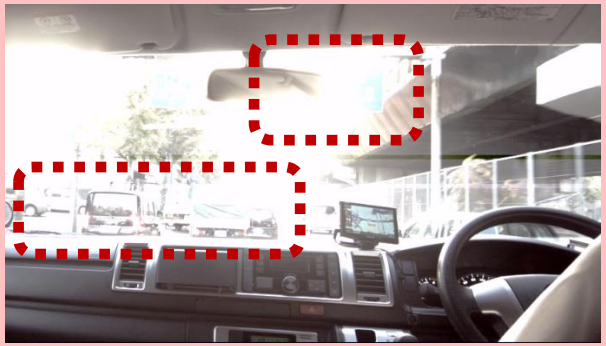
“Imaging” and “Sensing” Beyond Human Ability

Capture accurately ➡ Look at something invisible ➡ Predict the next action

We have to develop technologies for achieving these requests.

Under backlight

Accurate peripheral recognition in dark & bright conditions

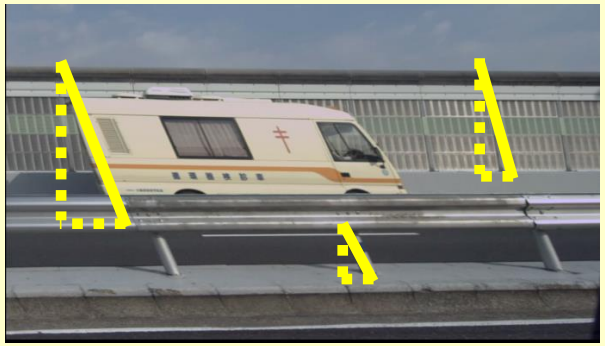


Required technology:

Wide dynamic range

At high speed

Accurate peripheral recognition in all condition

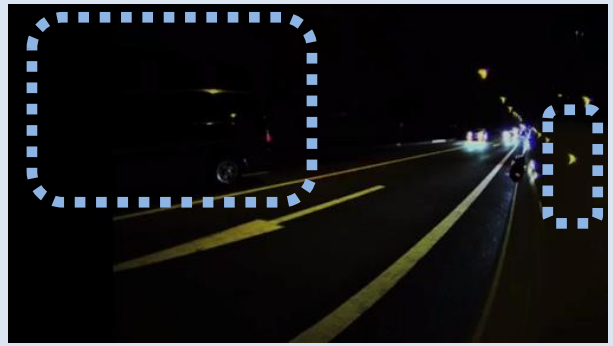


Required technology:

Global shutter

In the dark

Accurate peripheral recognition In day & night



Required technology:

RGB + other wavelength

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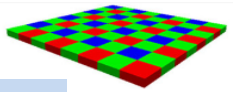
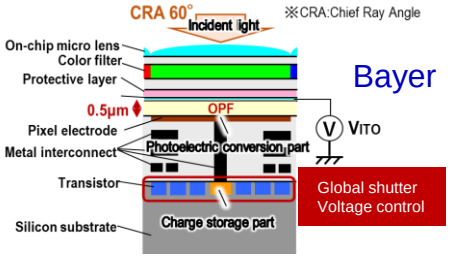
Comparison of OPF Image Sensor Configurations of Each Company

Panasonic

IEDM2015, ISSCC2016,2017,2018,
VLSI2013,2018, IS Europe2019

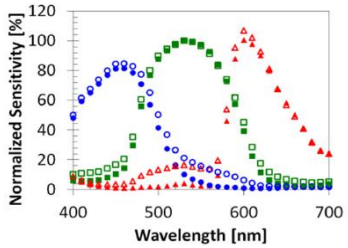


1 organic layer



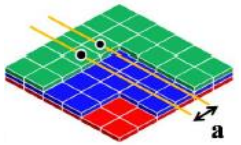
Bayer

Global shutter
Voltage control

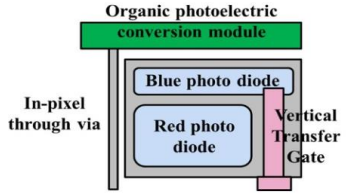


SONY

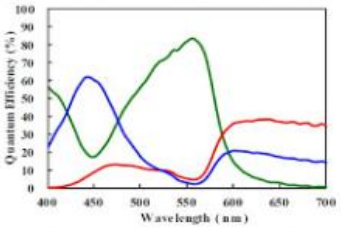
IEDM2019



1 organic layer + 2 PDs

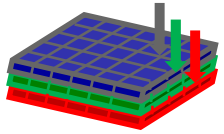


Green
+
Blue
+
Red

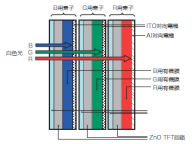


NHK

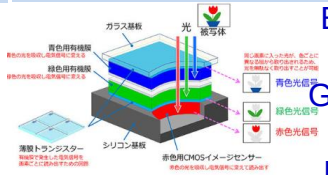
NHK STRL Report 2010～2020



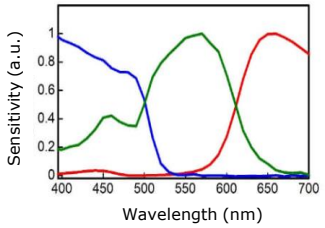
3 organic layers



2 organic layers +1 PD

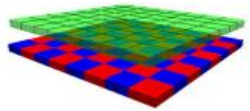


Blue
+
Green
+
Red

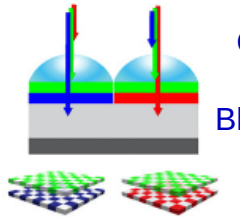


Samsung

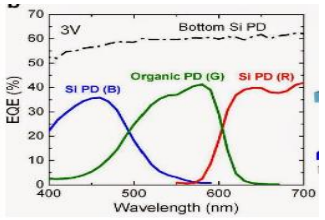
Nature2015,OSA Optics Express 2019



1 organic layer + 1 PD



Green
+
Blue/Red

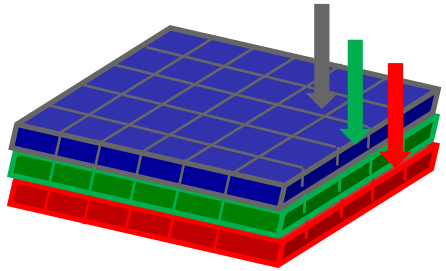


Comparison of OPF Image Sensor Configurations of Each Company

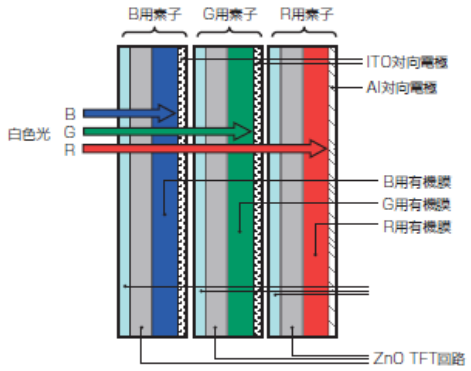
NHK 1

NHK STRL Report 2010～2019

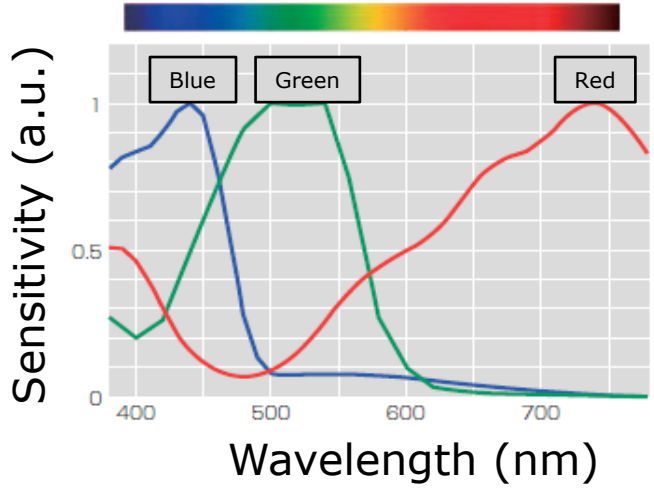
※NHK：Nippon Hoso Kyokai：Japan Broadcasting Corporation
STRL：Science & Technology Research Laboratories



3 organic layers



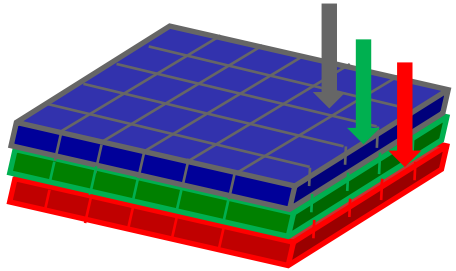
Blue
Green
Red



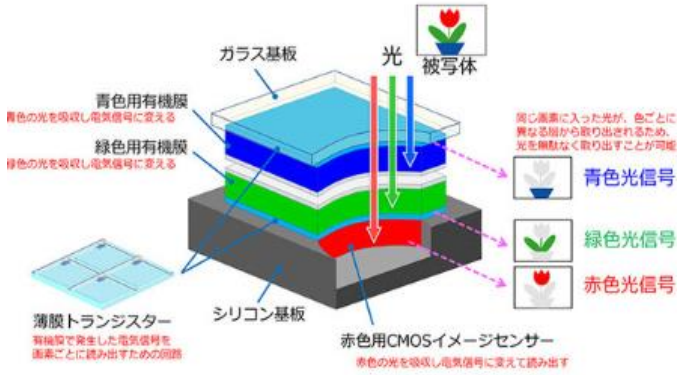
Comparison of OPF Image Sensor Configurations of Each Company

NHK 2

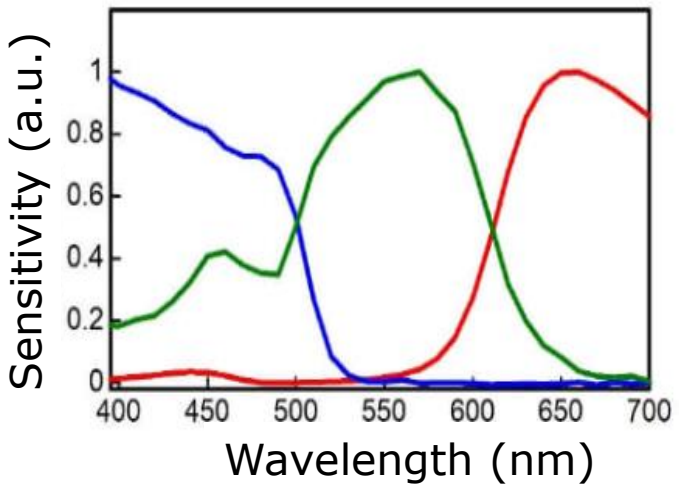
NHK STRL Report 2020



2 organic layers +1 PD



Blue
Green
+
Red



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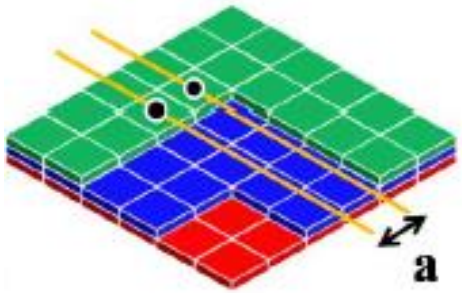
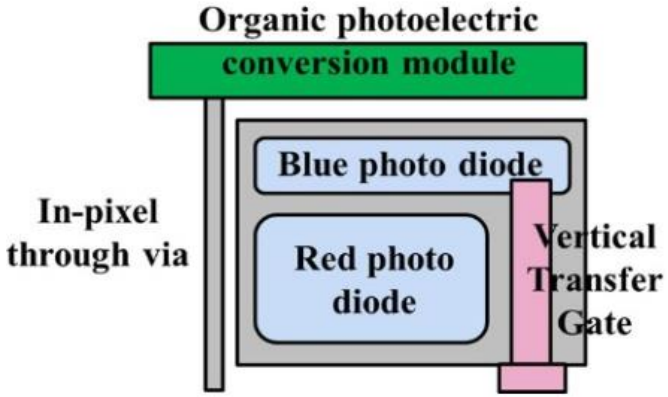
SONY

IEDM2019



1 organic layer + 2 PDs



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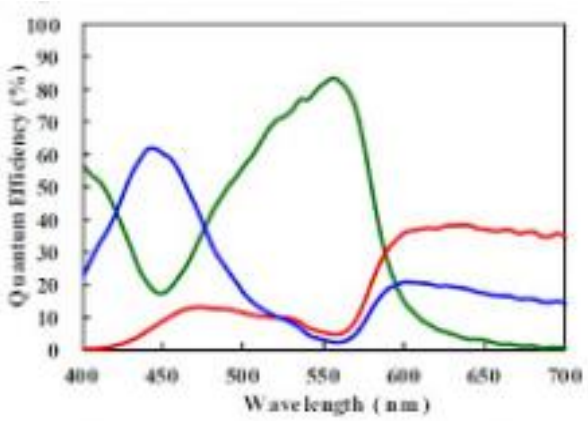
Red



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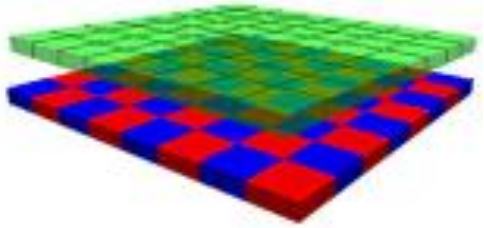
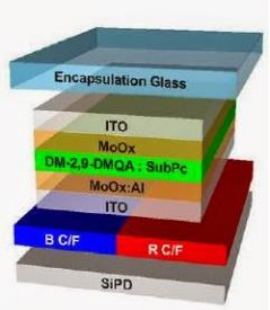
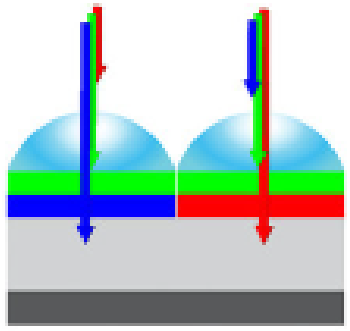
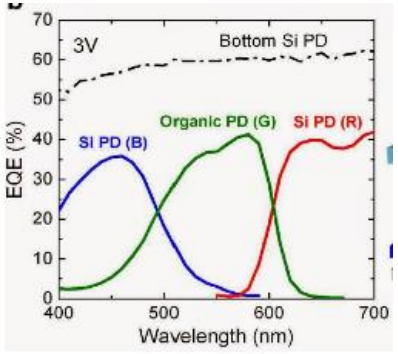


1 organic layer + 1 PD

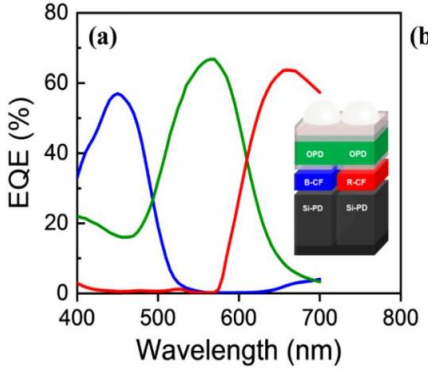




Green
+
Blue/Red



EQE improved in 2019



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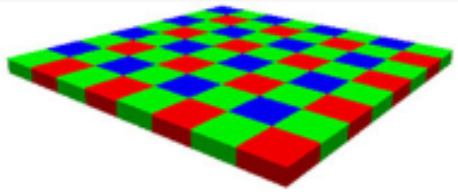
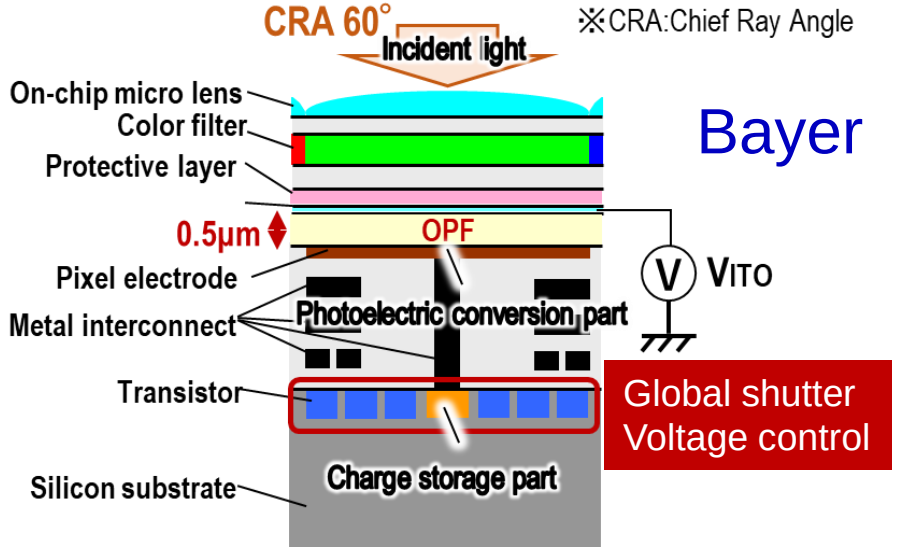
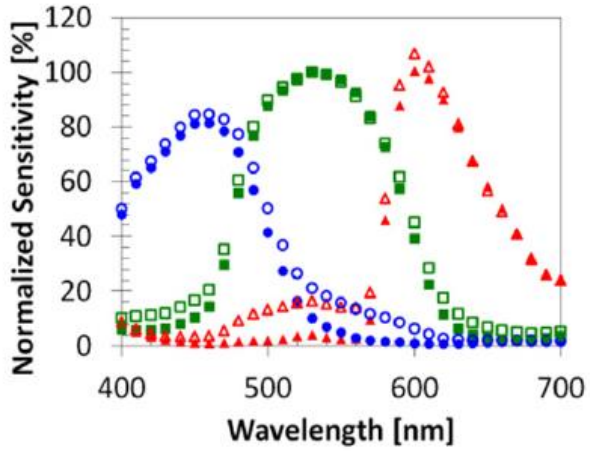


1 organic layer



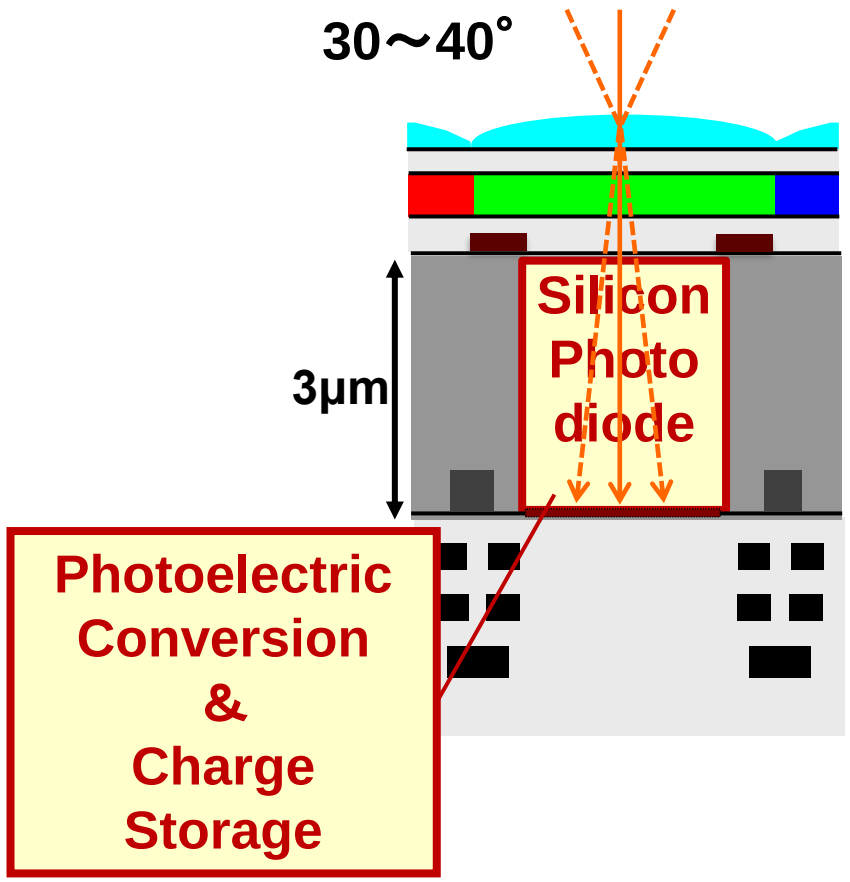
Bayer

Global shutter
Voltage control

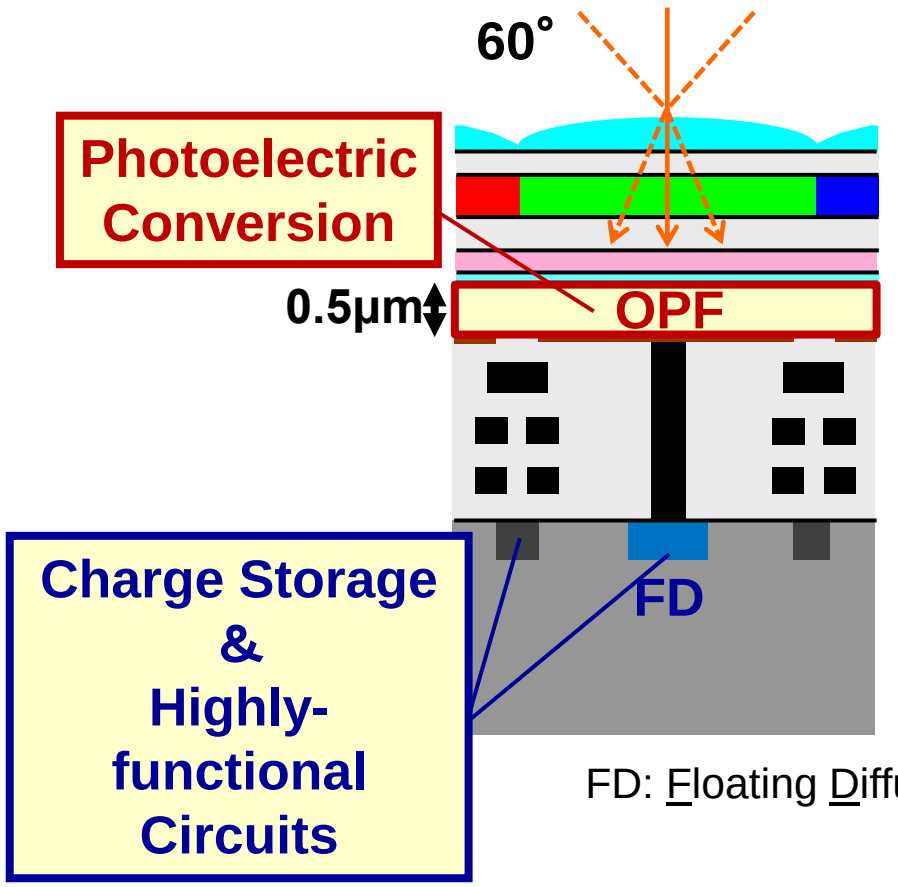


OPF Image Sensor of Panasonic

BSI Si image sensor



OPF image sensor of Panasonic



FD: Floating Diffusion

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  - **1) Wide dynamic range**
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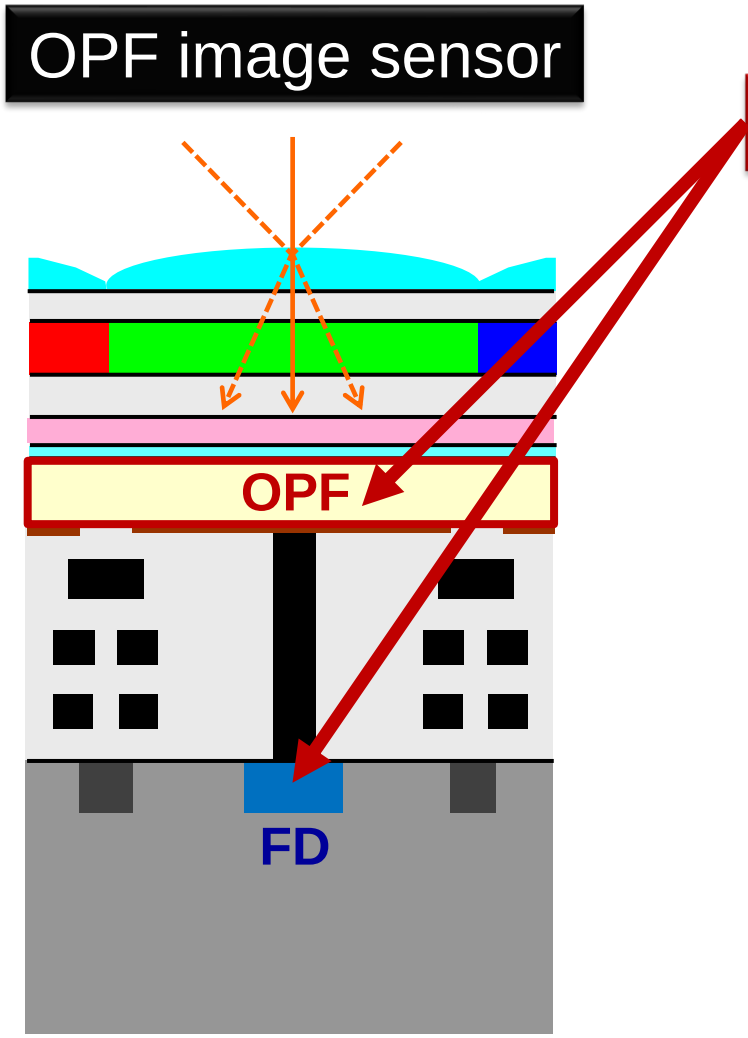
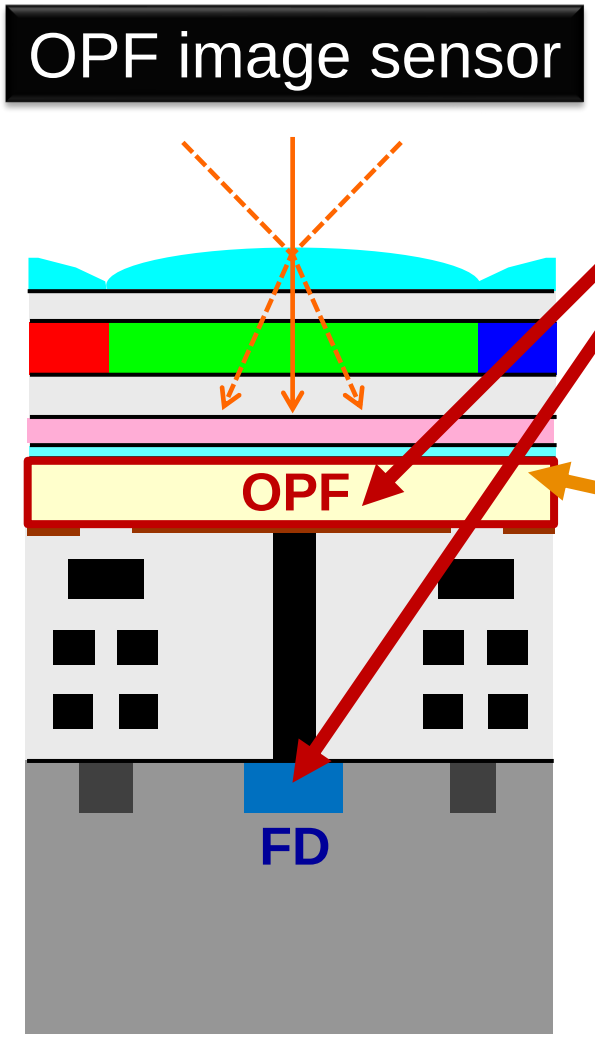
Advanced Technologies of OPF Image Sensor



Key Tech. 1: Wide dynamic range

Photoelectric conversion and charge storage parts are completely independent

Advanced Technologies of OPF Image Sensor



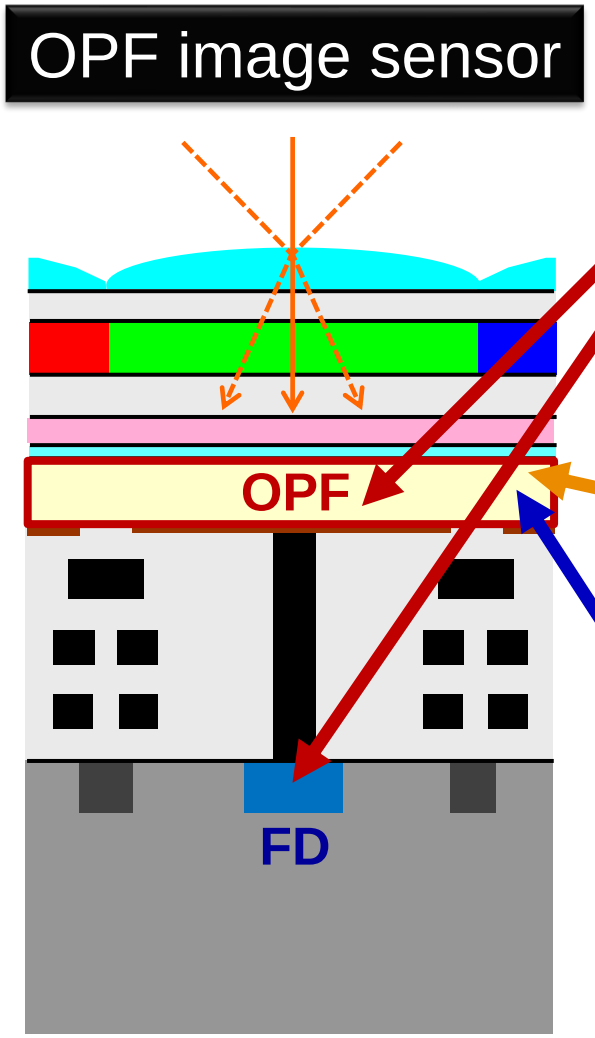
Key Tech. 1: Wide dynamic range

Photoelectric conversion and charge storage parts are completely independent

Key Tech. 2: Global shutter

Photoelectric conversion can be controlled

Advanced Technologies of OPF Image Sensor



Key Tech. 1: Wide dynamic range

Photoelectric conversion and charge storage parts are completely independent

Key Tech. 2: Global shutter

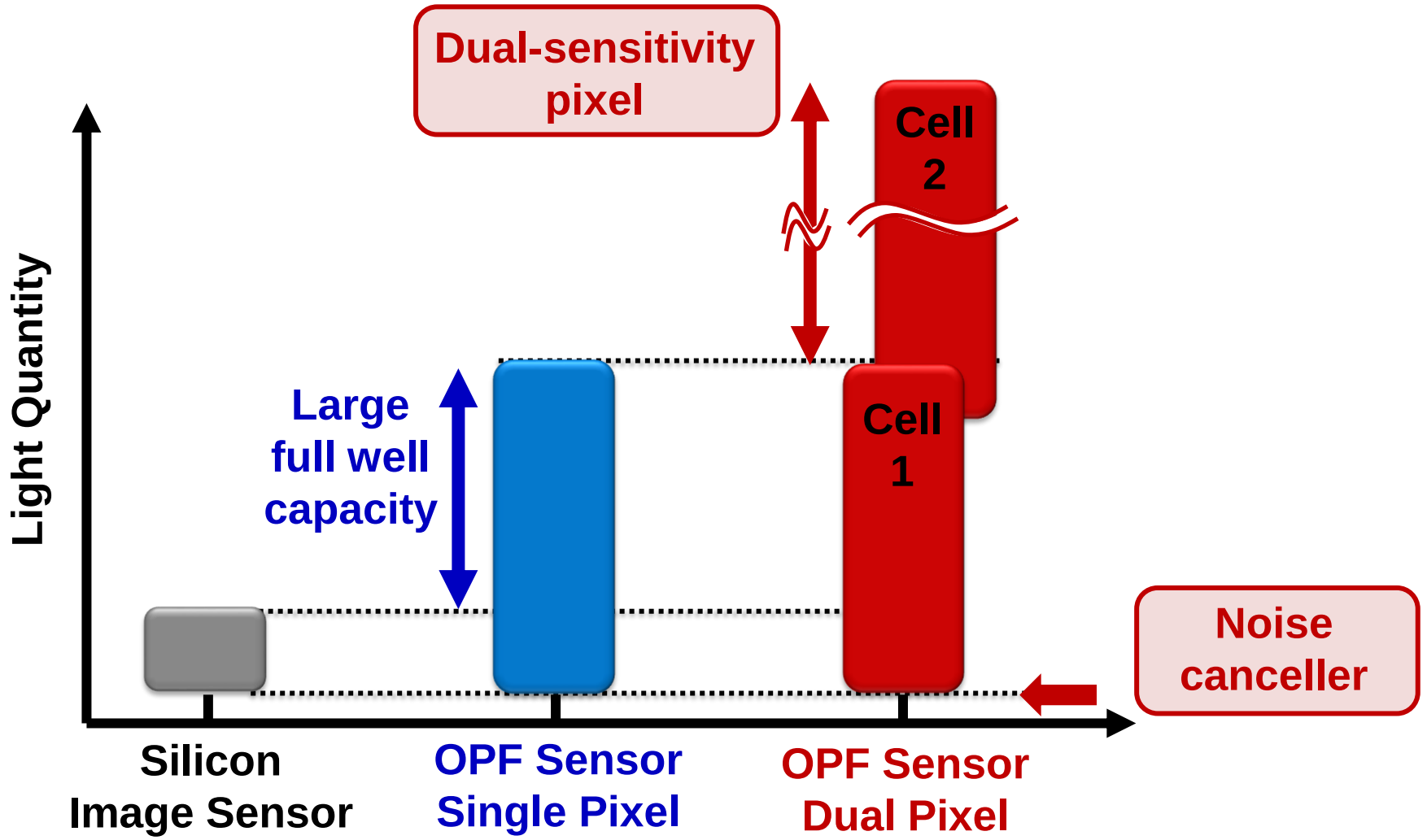
Photoelectric conversion can be controlled

Key Tech. 3: RGB-NIR sensing

NIR sensitivity is very high, and
NIR sensitivity can be modulated

Key Tech. 1

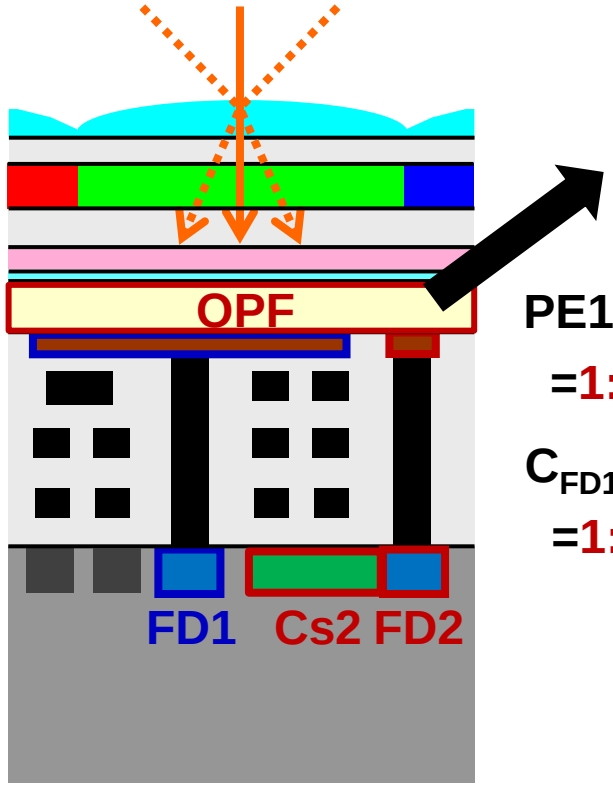
Wide Dynamic Range Technology



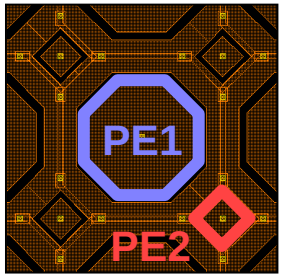
Key Tech. 1

Wide Dynamic Range Technology

Dual Sensitivity-Pixel



Pixel Electrode



PE1:PE2

$= 1 : \frac{1}{10}$

$C_{FD1} : C_{FD2} + C_{S2}$

$= 1 : 10$

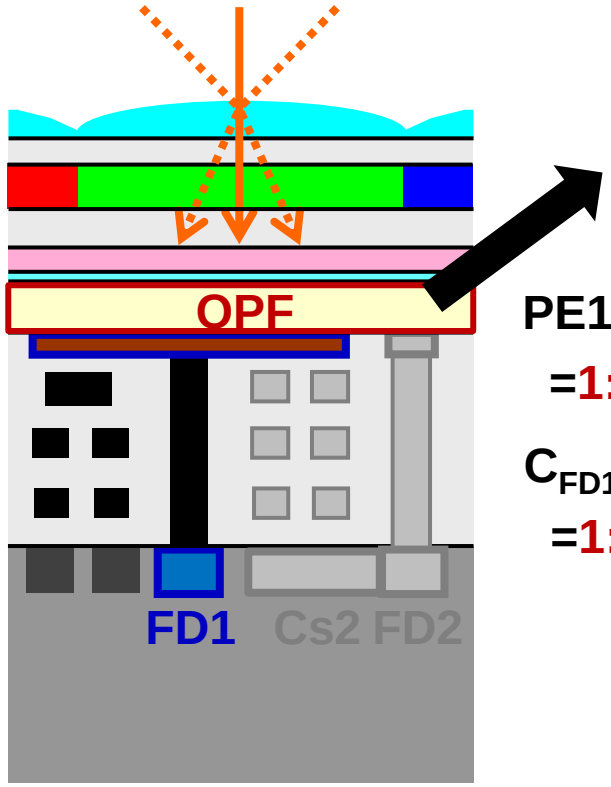
Cell1: High Sensitivity

Cell2: High Saturation

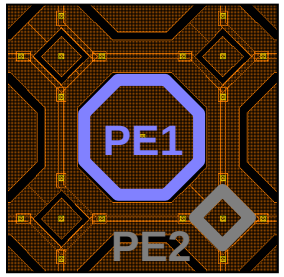
Key Tech. 1

Wide Dynamic Range Technology

Dual Sensitivity-Pixel

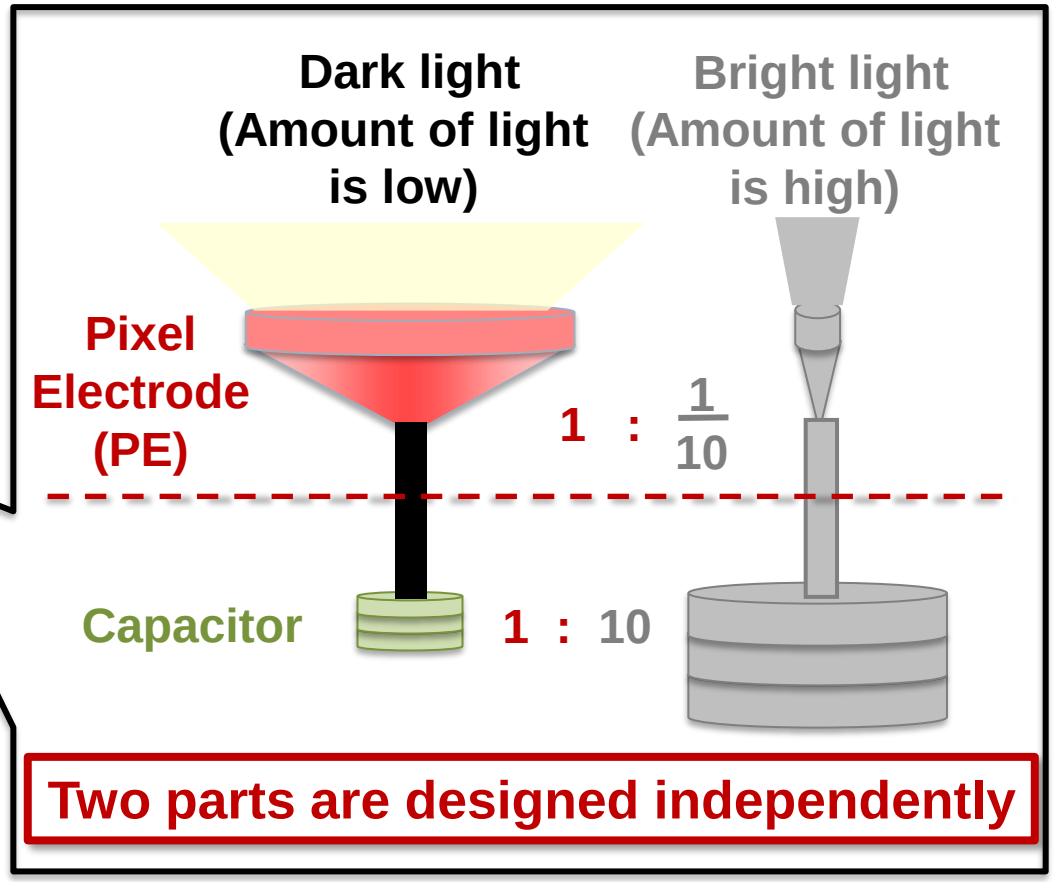


Pixel Electrode



PE1:PE2
=1:$\frac{1}{10}$

C_{FD1}:C_{FD2}+C_{S2}
=1:10



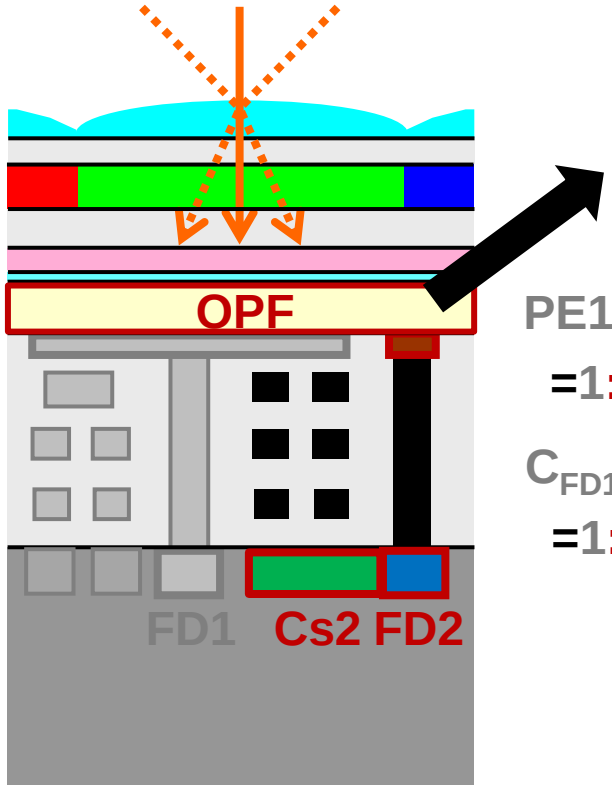
Cell1: High Sensitivity

Cell2: High Saturation

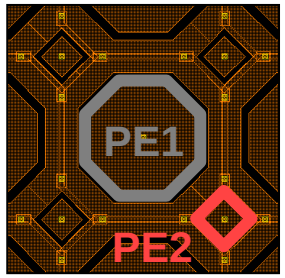
Key Tech. 1

Wide Dynamic Range Technology

Dual Sensitivity-Pixel

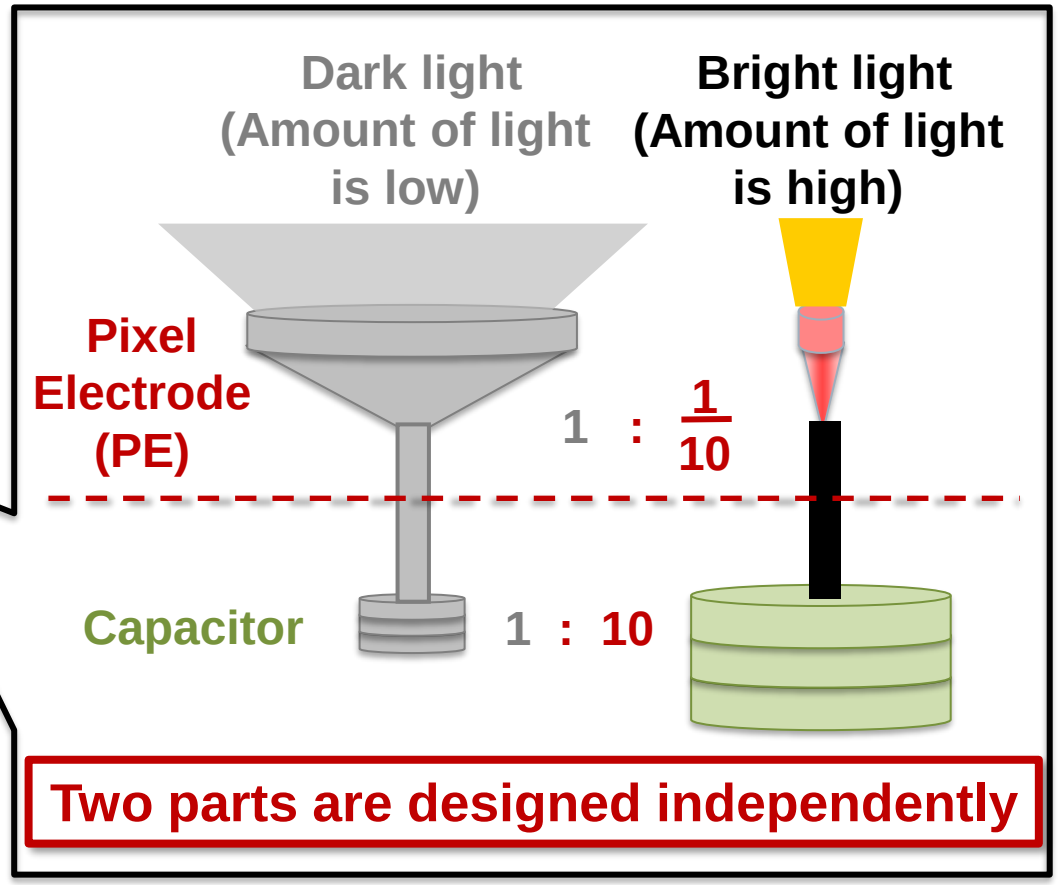


Pixel Electrode



PE1:PE2
=1:$\frac{1}{10}$

C_{FD1}:C_{FD2}+C_{S2}
=1:10



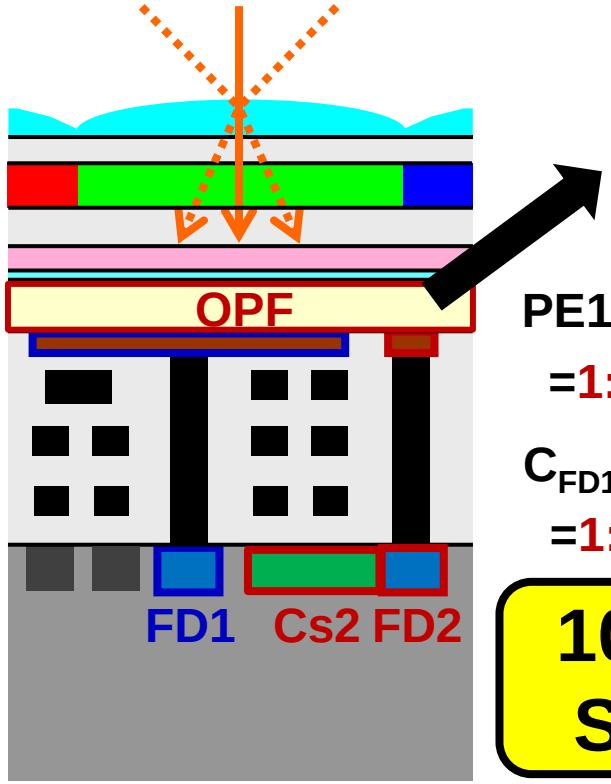
Cell1: High Sensitivity

Cell2: High Saturation

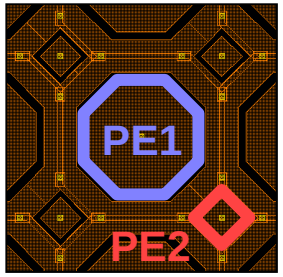
Key Tech. 1

Wide Dynamic Range Technology

Dual Sensitivity-Pixel



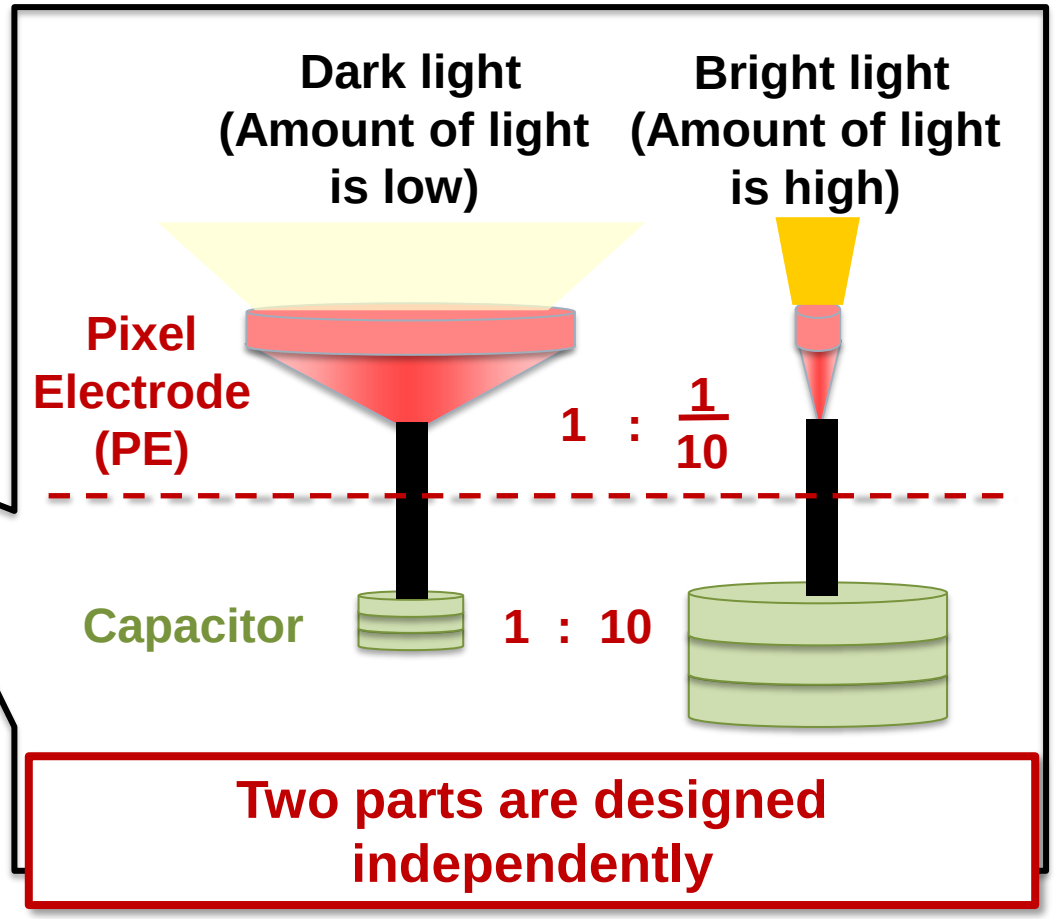
Pixel Electrode



PE1:PE2
=1:$\frac{1}{10}$

$C_{FD1}:C_{FD2}+C_{S2}$
=1:10

100 times SC-WDR



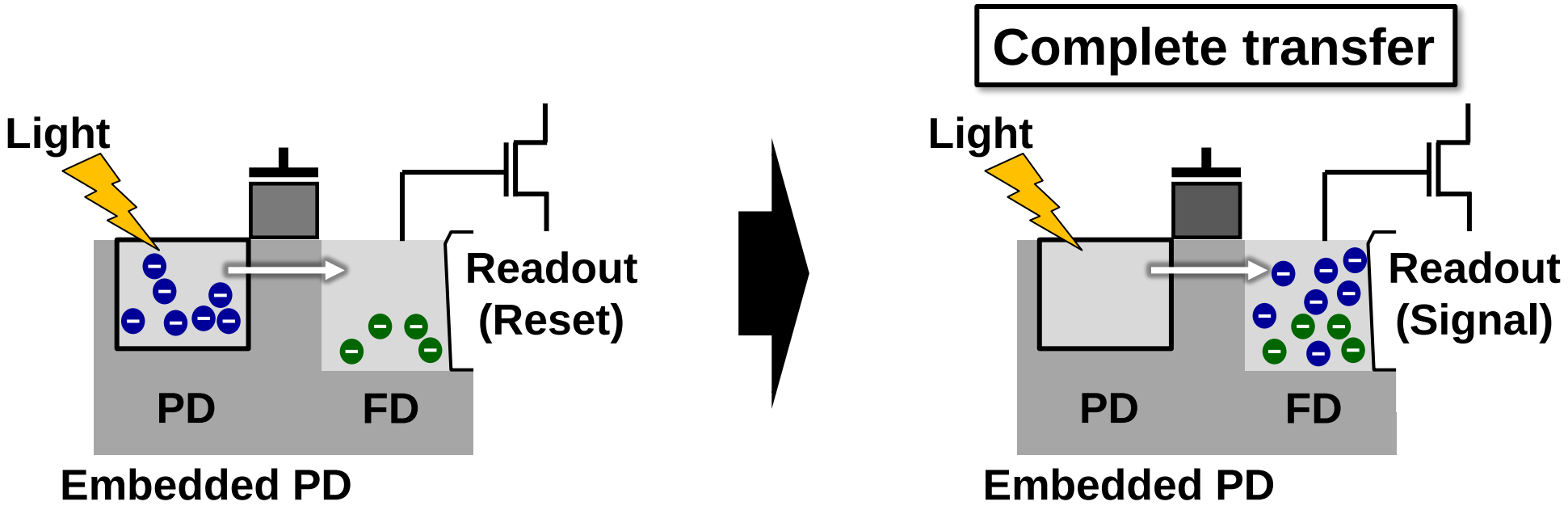
Two parts are designed independently

Cell1: High Sensitivity

Cell2: High Saturation

Reset Noise in Dark Region

Silicon Image Sensor

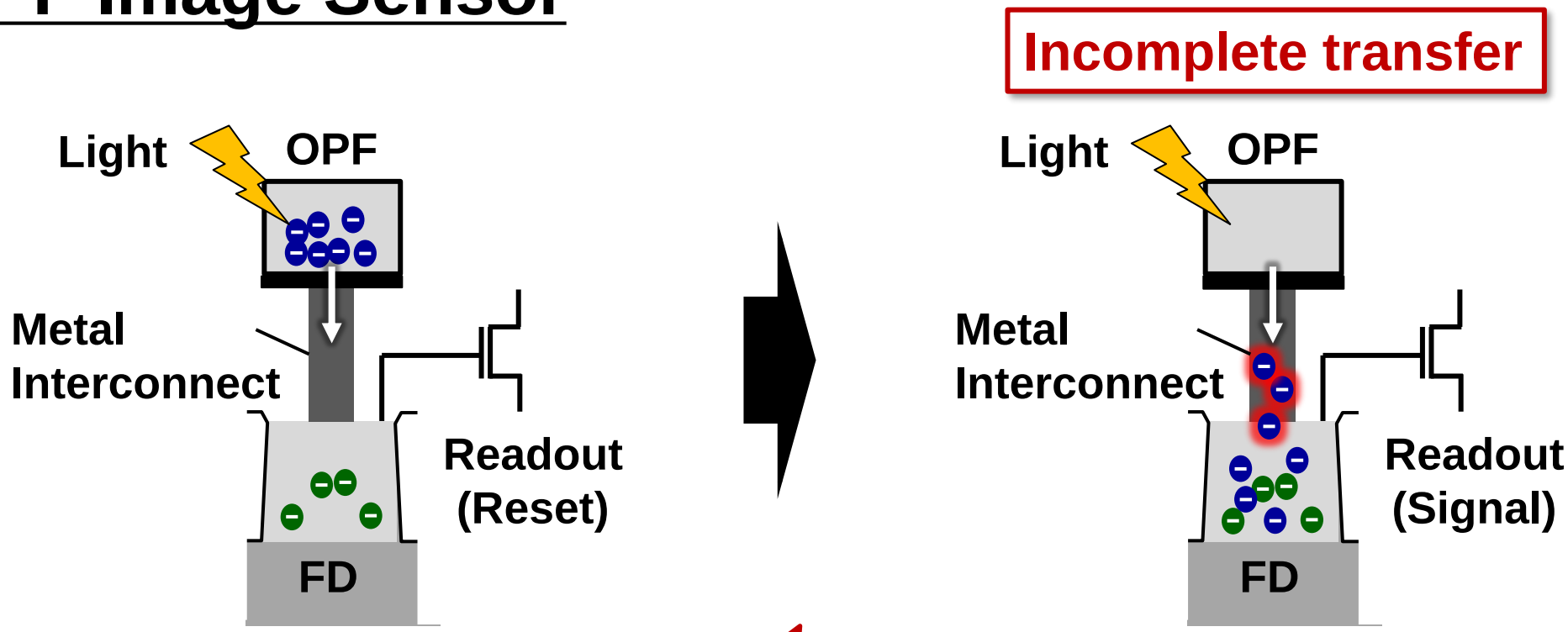


CDS method can be used
Reset noise is not a problem

CDS: Correlated Double Sampling

Reset Noise in Dark Region

OPF Image Sensor



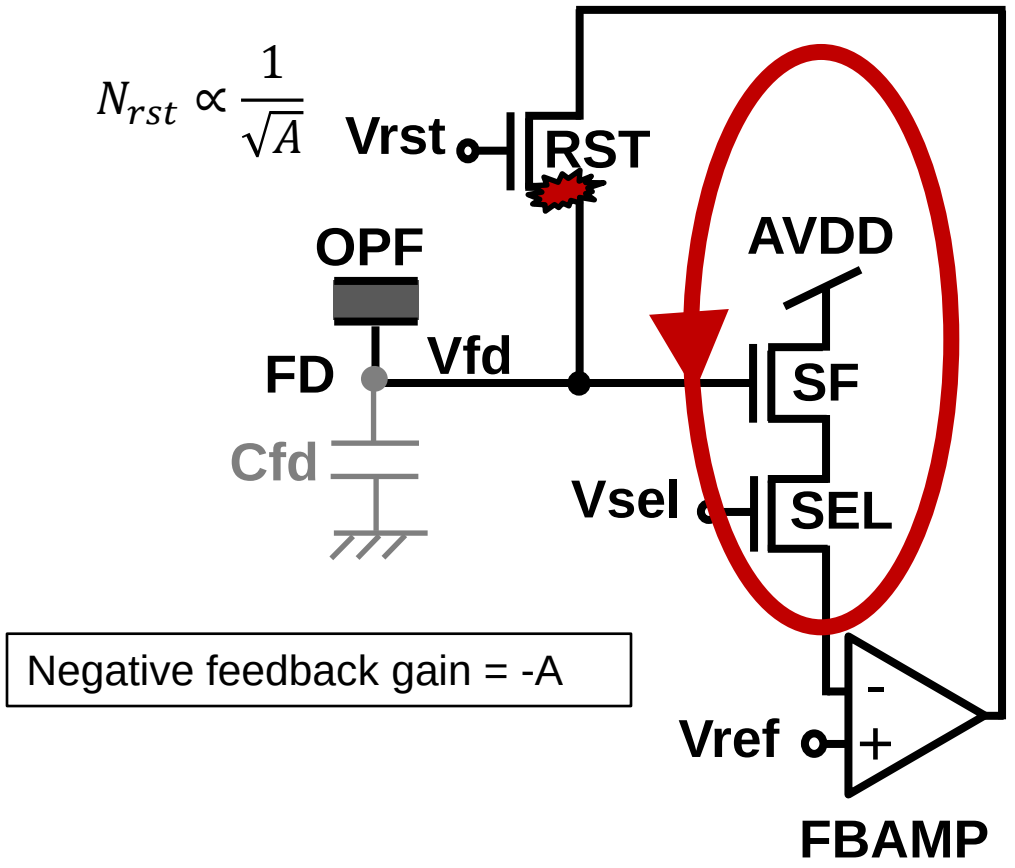
Problem

Reset noise is left on the FD (include the Metal Interconnect)

Key Tech. 1

Noise Cancellation Technology (1)

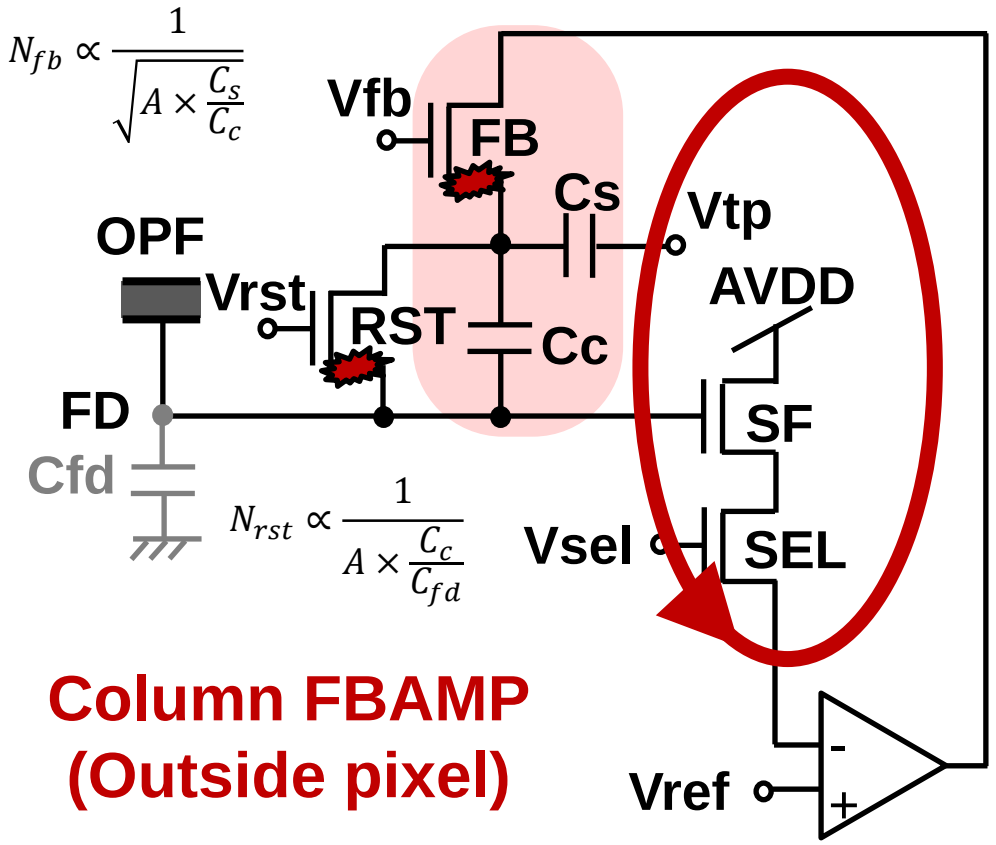
M.Ishii VLSI2013



Key Tech. 1

Noise Cancellation Technology (2)

K.Nishimura ISSCC2016



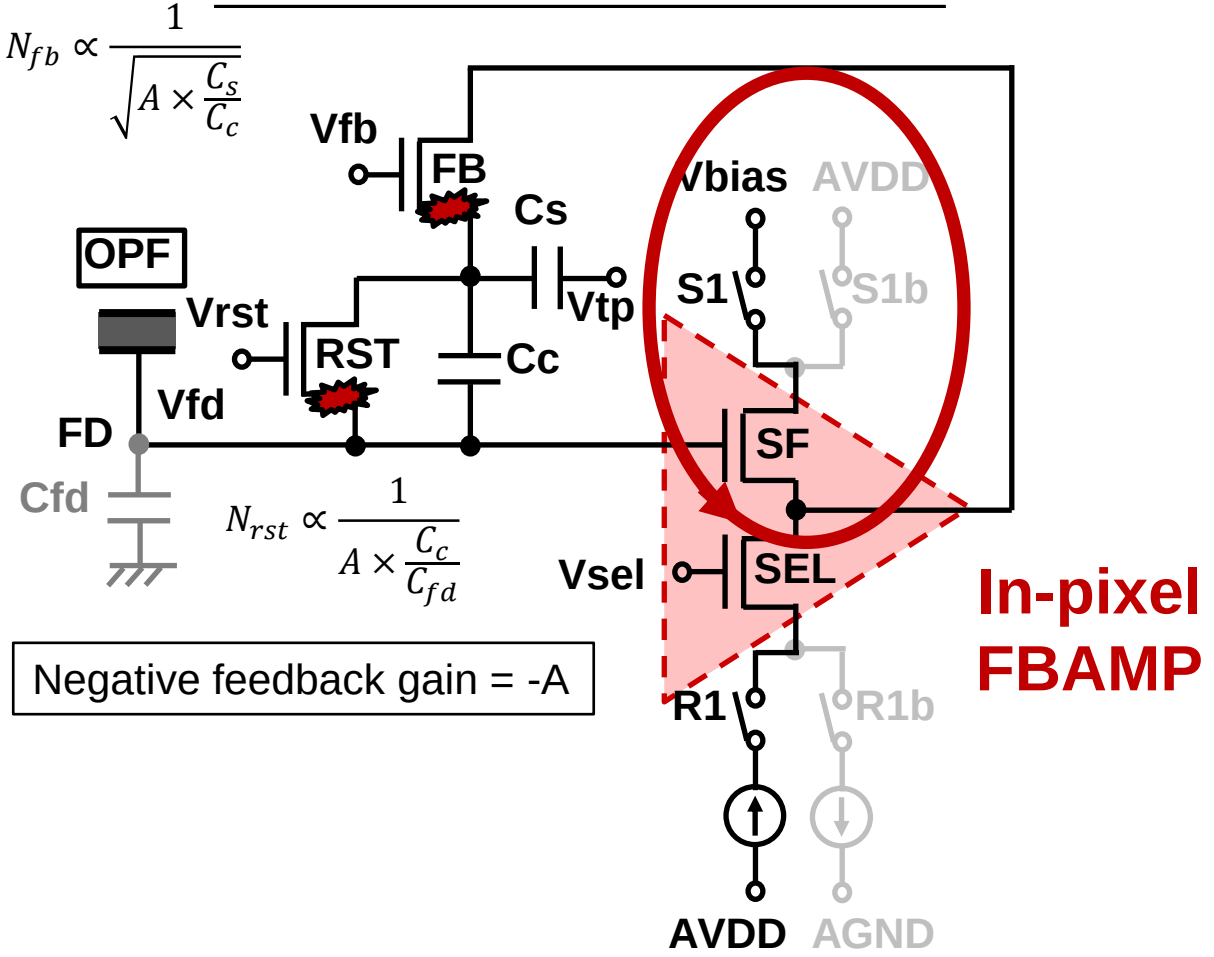
Negative feedback gain = -A

*FBAMP: Feedback Amplifier

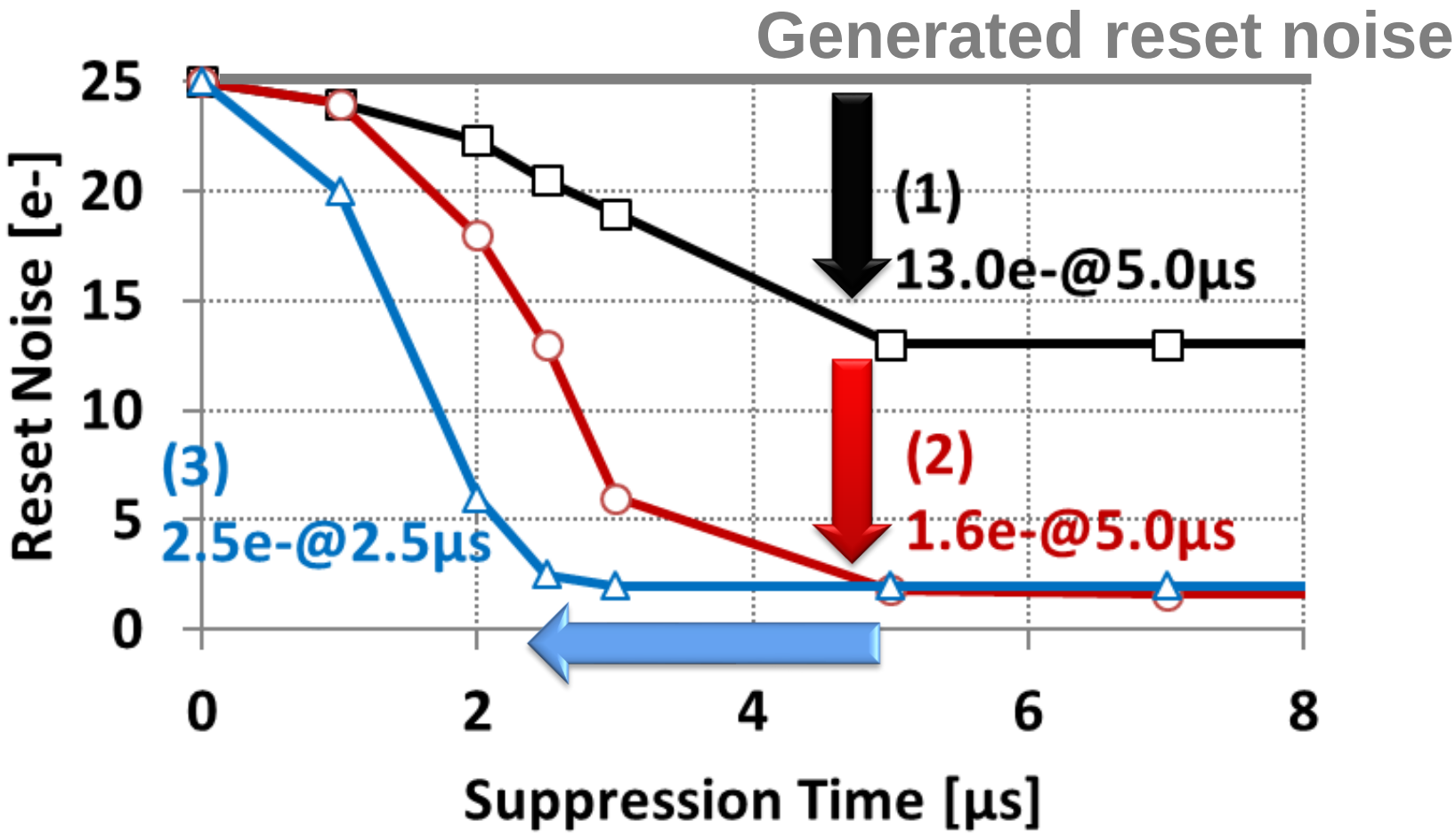
Key Tech. 1

Noise Cancellation Technology (3)

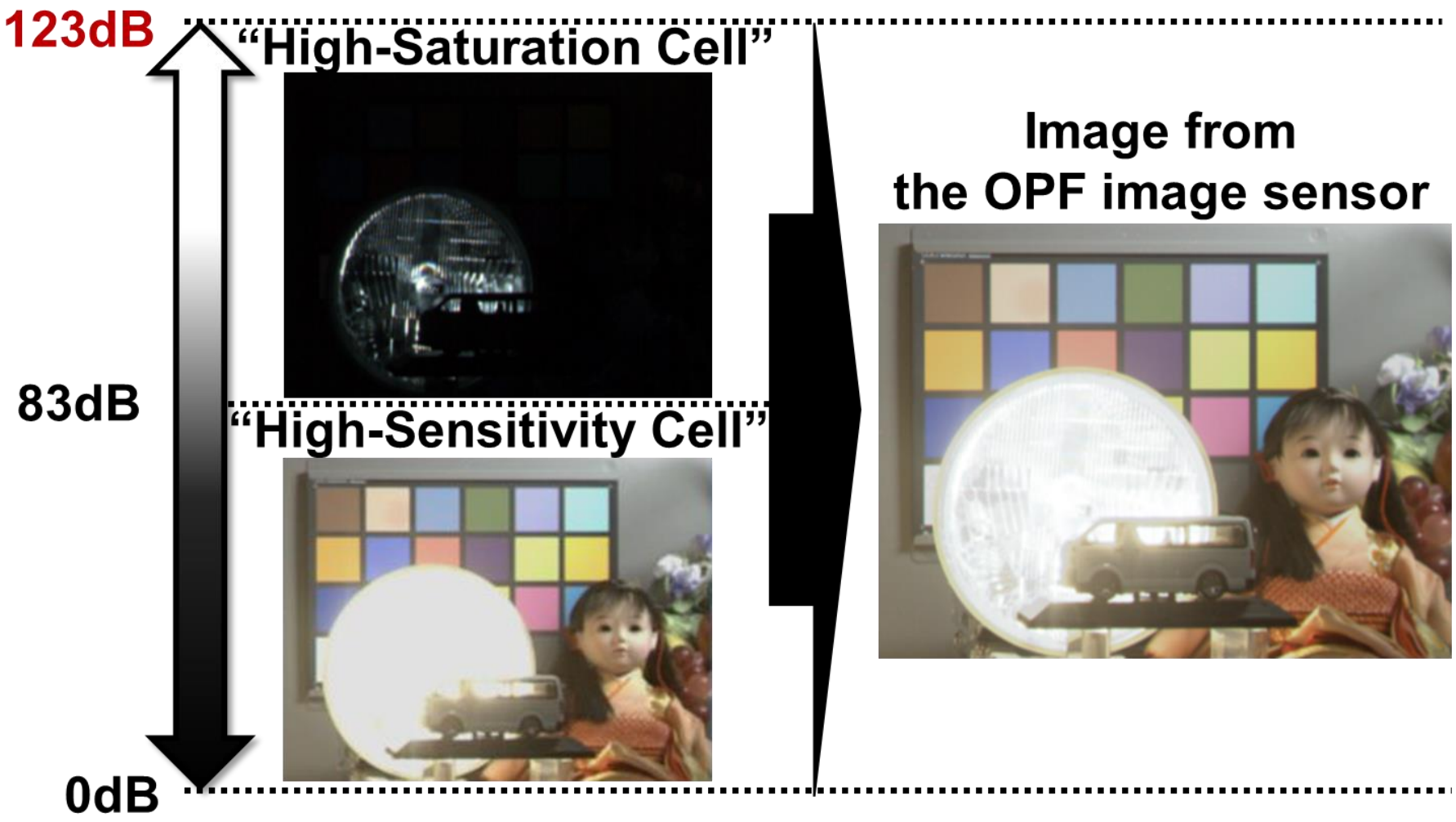
K.Nishimura ISSCC2018



Key Tech. 1 Comparison of Noise Cancellation Methods

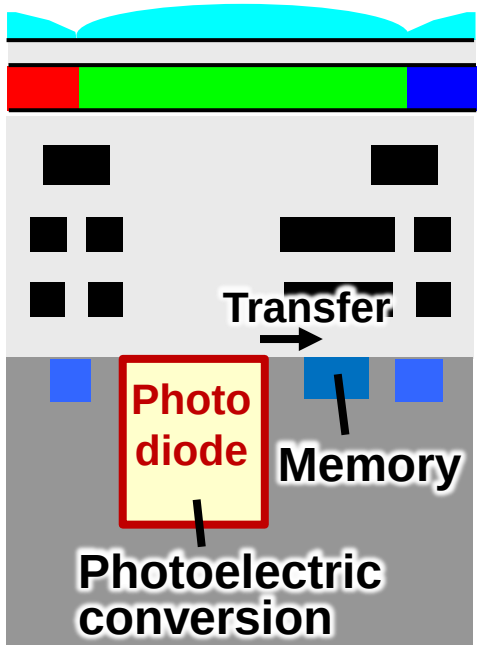


Key Tech. 1 Captured Image: Wide Dynamic Range



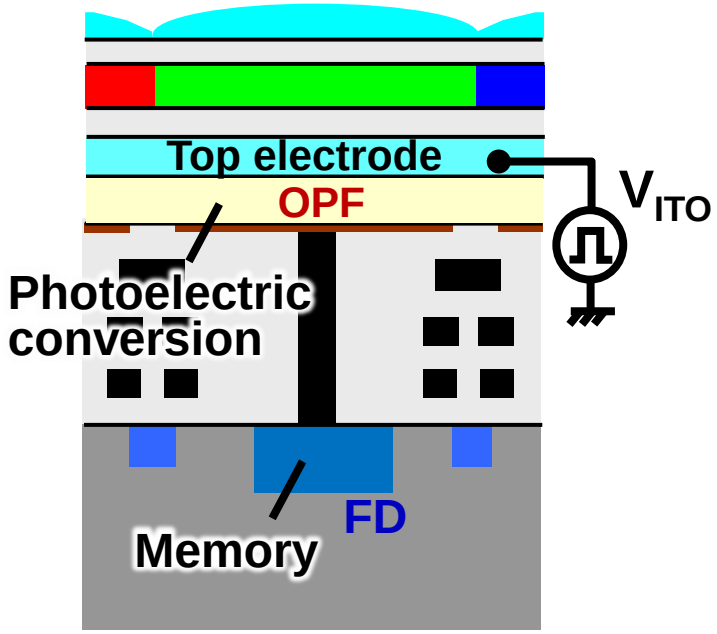
Key Tech. 2 Photoelectric Conversion Controlled Global Shutter

Conventional GS Sensor



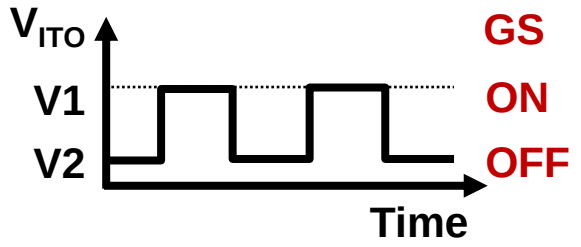
Add storage node and transistors

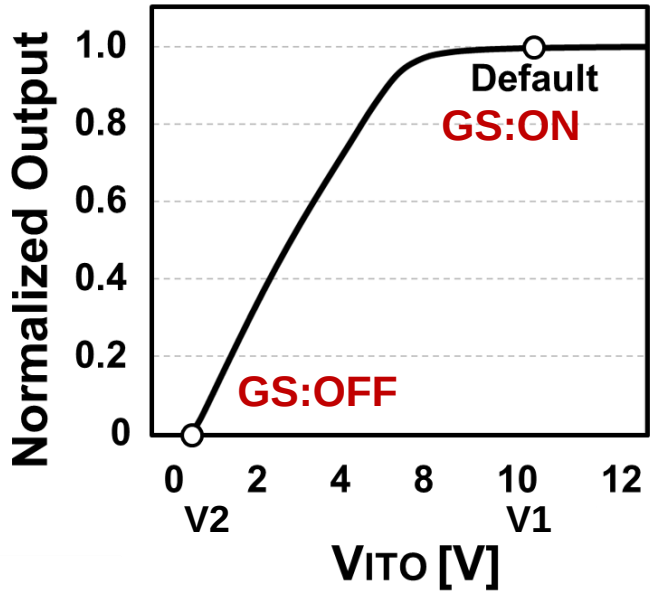
OPF GS Sensor



Apply pulsed voltage to top electrode

S. Shishido ISSCC2016



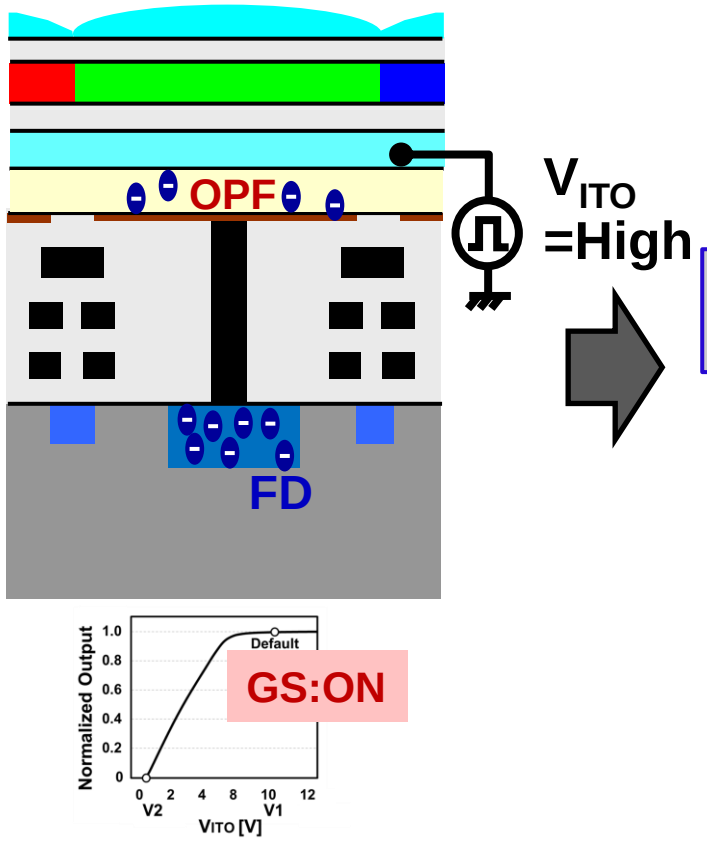


Key Tech. 2

Operation of OPF Global Shutter

OPF GS Sensor

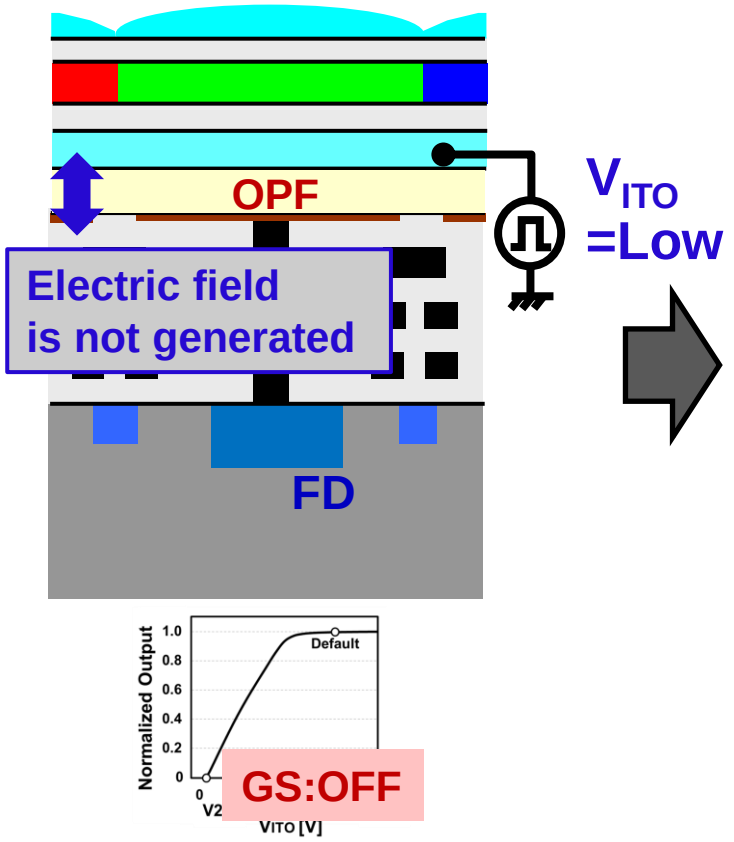
Exposure time



GS:ON

V_{ITO} =High

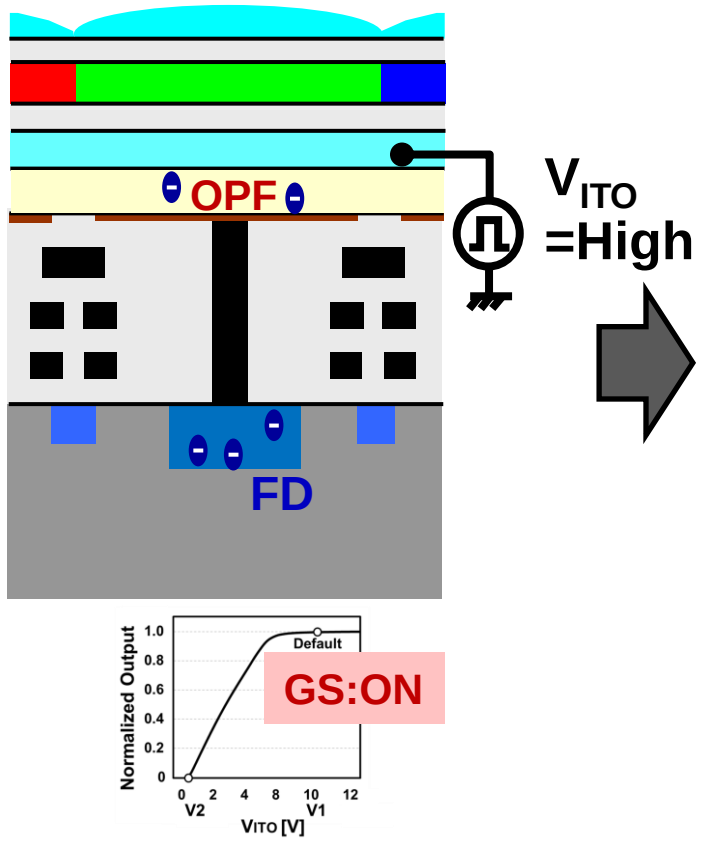
Light shield and readout time



GS:OFF

V_{ITO} =Low

Next exposure time



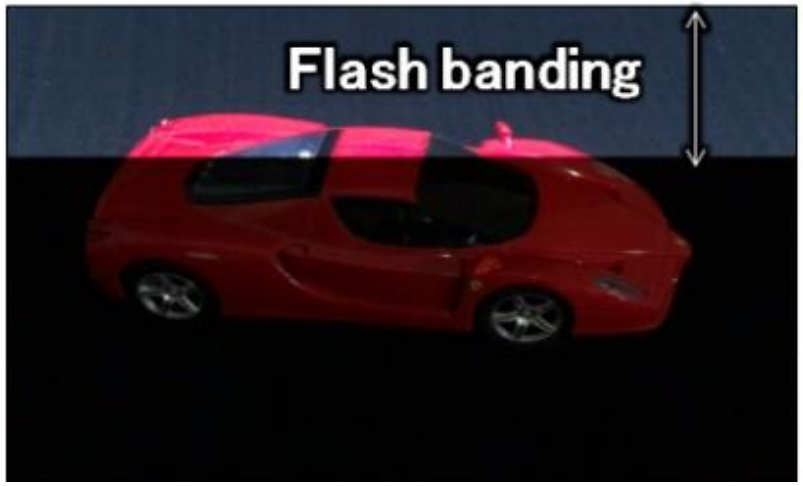
GS:ON

V_{ITO} =High

Key Tech. 2

Captured Image: Global Shutter

Rolling Shutter Mode

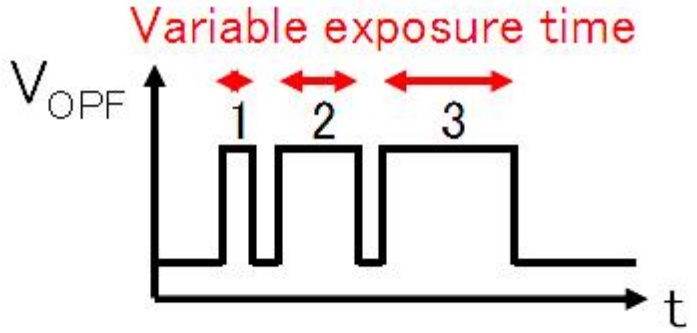


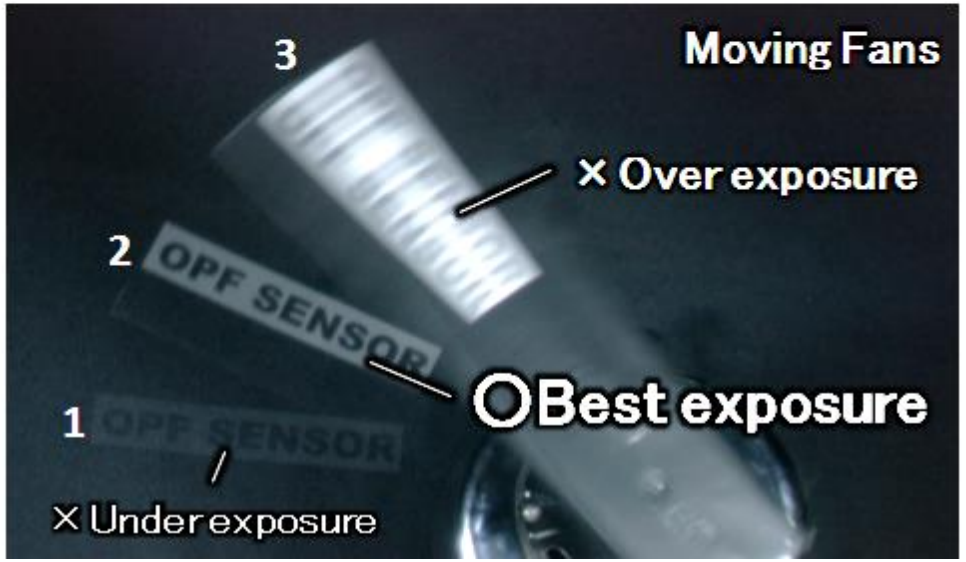
Global Shutter Mode

Key Tech. 2

Photoelectric Conversion Controlled Multiple Exposure

Multiple Exposure by Variable Pulse Duty

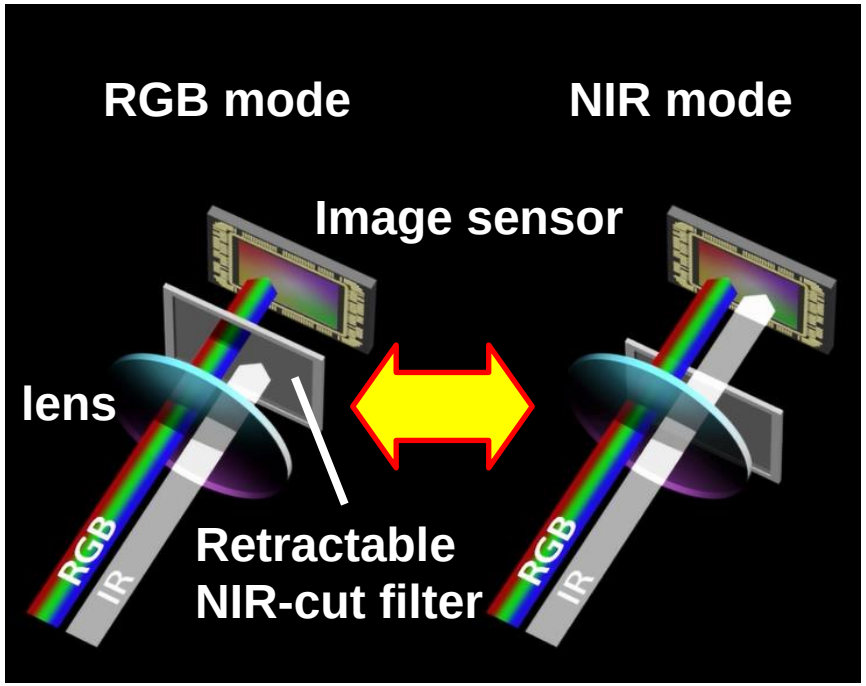




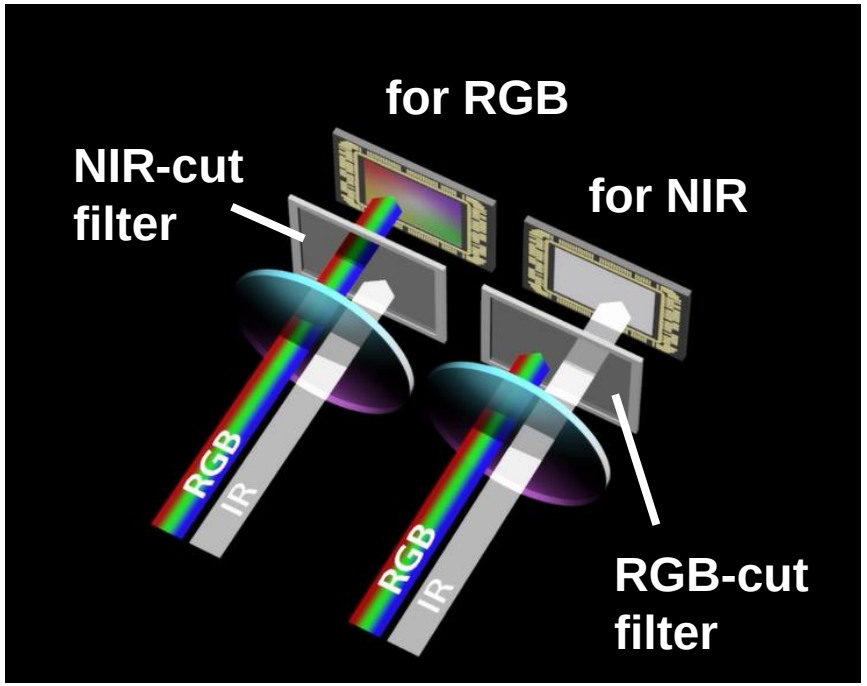
Key Tech. 3 RGB-NIR Sensor Conventional Issue

- **RGB capturing needs to prevent NIR from entering an image sensor**

Method1: Retractable NIR-cut filter
Issue: increased components

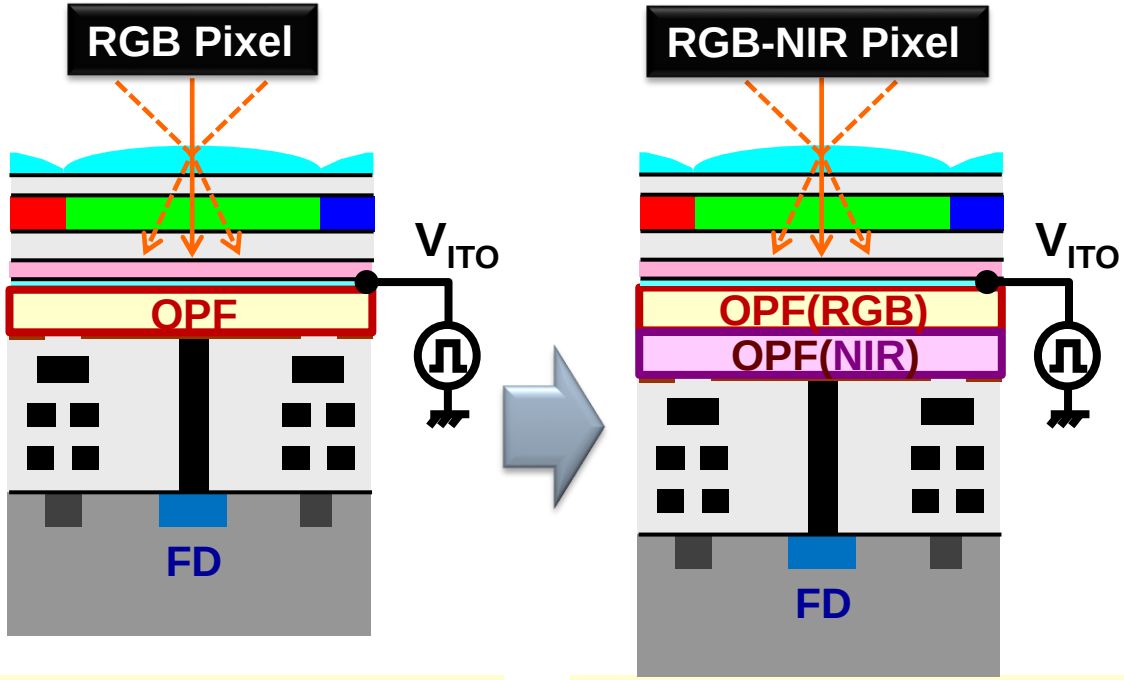


Method2: Two sensors
Issue: parallax error

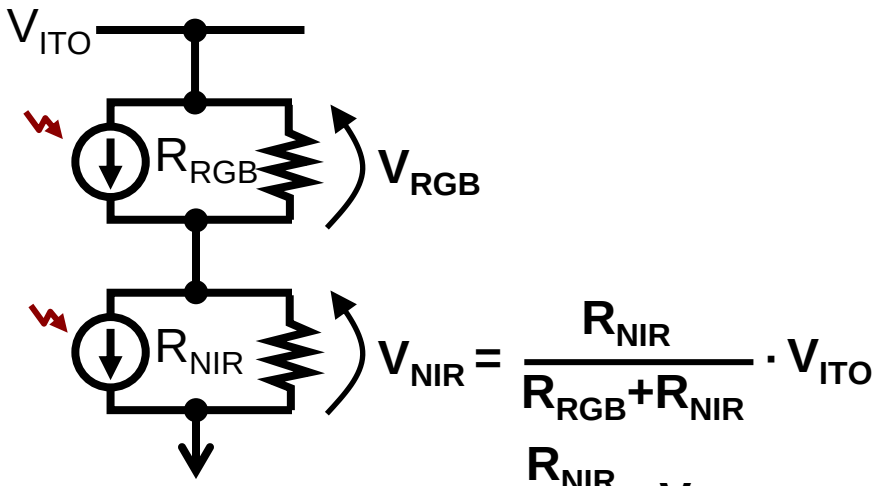


Key Tech. 3 Electrical control of NIR sensitivity

- Voltages applied to each OPF can be **controlled with the same voltage source depending on the resistance ratio**



S. Machida ISSCC2017



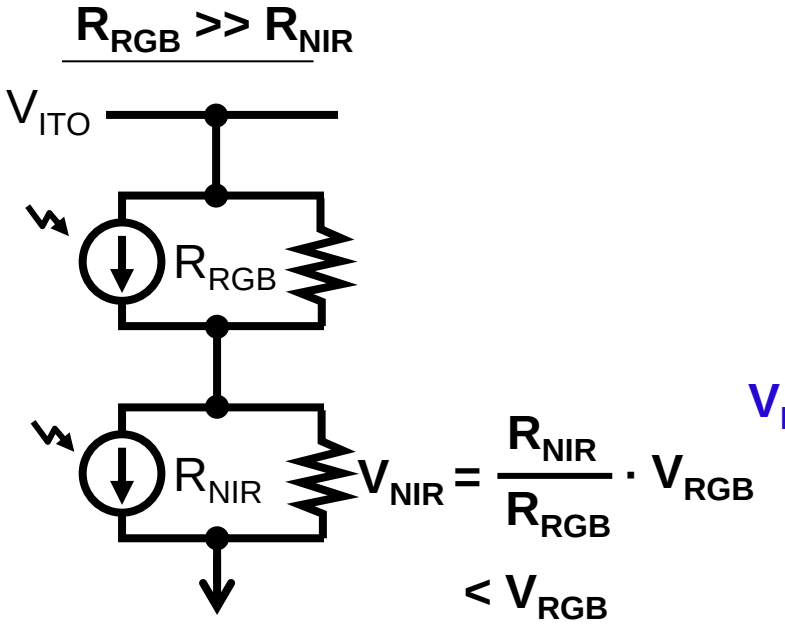
V_{ITO} = High : ON mode
V_{ITO} = Low : OFF mode

V_{ITO} = High : RGB-NIR mode
V_{ITO} = Mid : RGB mode
V_{ITO} = Low : OFF mode

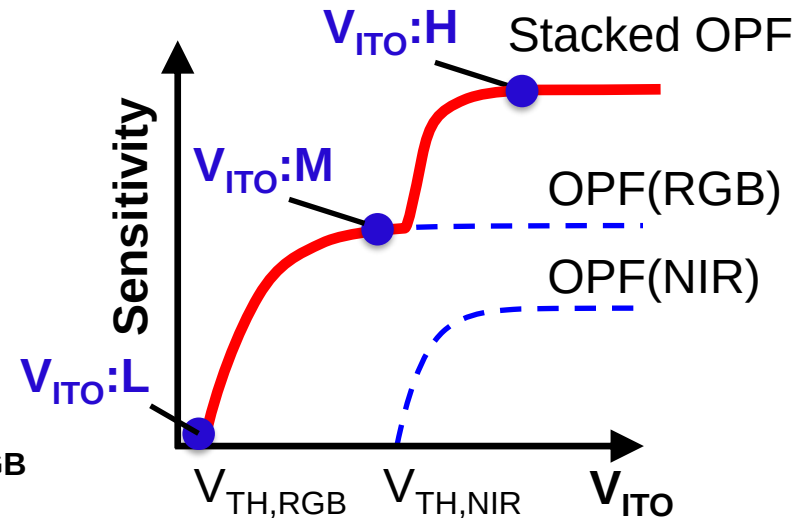
Key Tech. 3

Electrical control of NIR sensitivity

- **NIR sensitivity is controllable while maintaining the RGB-OPF in the ON-state**



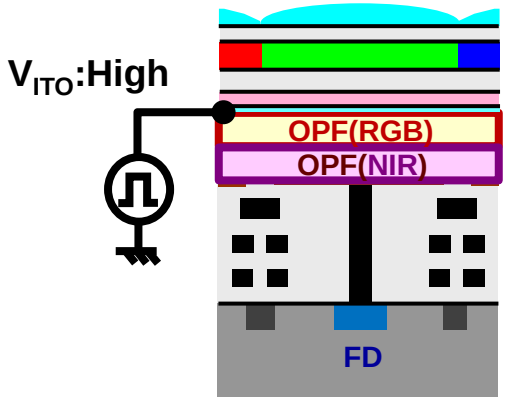
$$V_{NIR} = \frac{R_{NIR}}{R_{RGB}} \cdot V_{RGB} < V_{RGB}$$

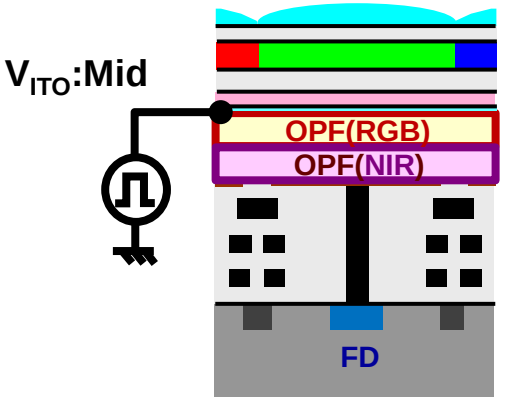


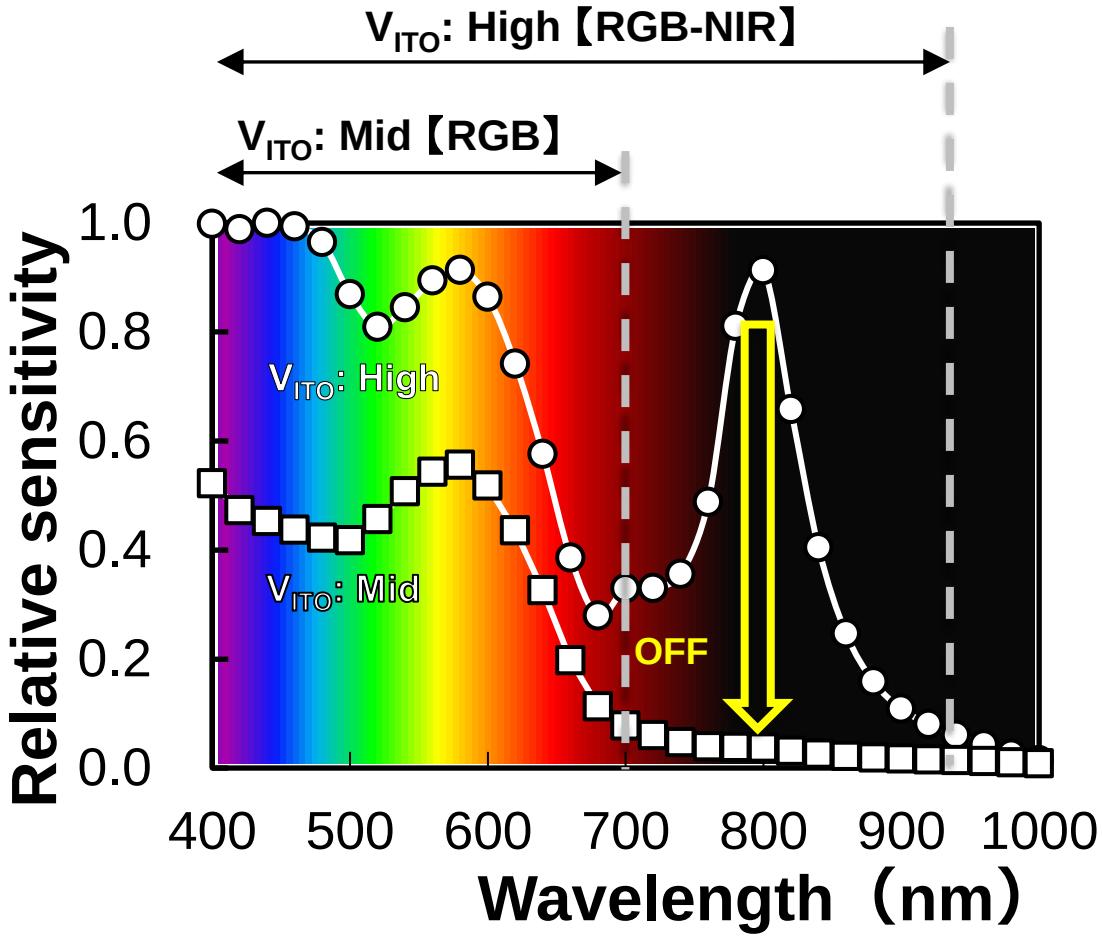
V_{ITO} = High :	RGB-NIR mode	($V_{ITO} > V_{TH,NIR} > V_{TH,RGB}$)
V_{ITO} = Mid :	RGB mode	($V_{TH,NIR} > V_{ITO} > V_{TH,RGB}$)
V_{ITO} = Low :	OFF mode	($V_{TH,NIR} > V_{TH,RGB} > V_{ITO}$)

Key Tech. 3 Electrical control of NIR sensitivity

➢ **Controlling NIR sensitivity without NIR-cut filter is realized**





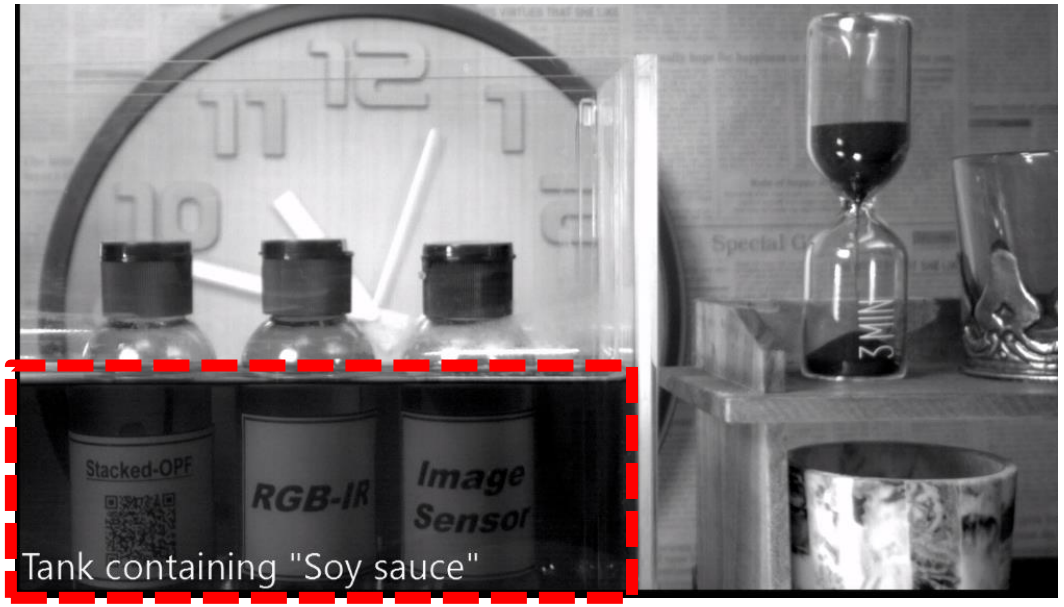


Key Tech. 3 Captured Image: RGB-NIR sensor

- **Non-destructive inspection can be realized**

RGB Mode

RGB-NIR Mode



The tank containing soy sauce
that is transparent only with NIR sensitivity.

Key Tech. 3 Captured Image: RGB-NIR sensor

- **Non-destructive inspection** can be realized
- RGB and RGB-NIR modes can be changed **frame by frame**

RGB Mode

RGB-NIR Mode

The barcode is painted with special ink
that is transparent only with NIR sensitivity.

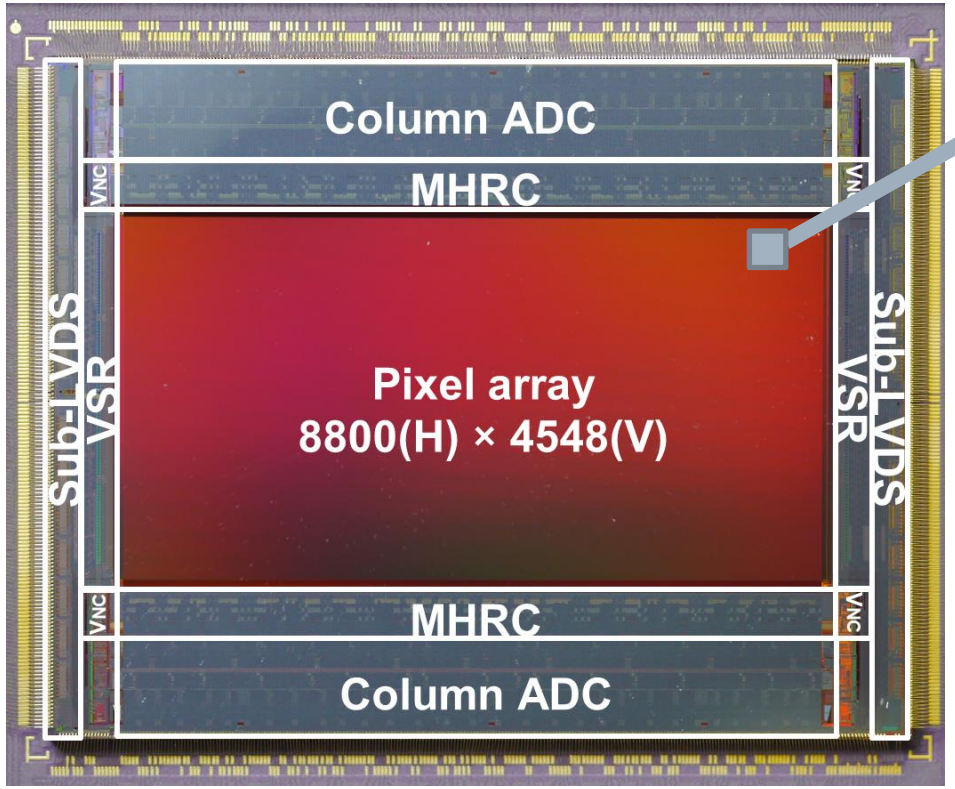
Outline

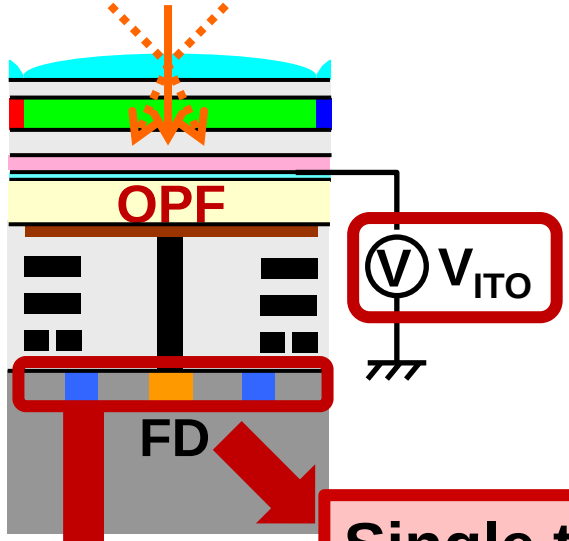
- Background
- What is OPF image sensor
- Advanced technologies of OPF image sensor
  1) Wide dynamic range
  2) Photoelectric conversion controlled global shutter
  3) NIR sensitivity modulation RGB-NIR sensor
- **8K4K sensor technologies**
- Conclusion

8K4K High-Resolution Image Sensor

8K4K OPF image sensor

65nm CMOS process, Pixel size: 3μm × 3μm





Sensitivity modulation
⇒ **Global shutter**

Single type OPF pixel
⇒ **High-saturation**

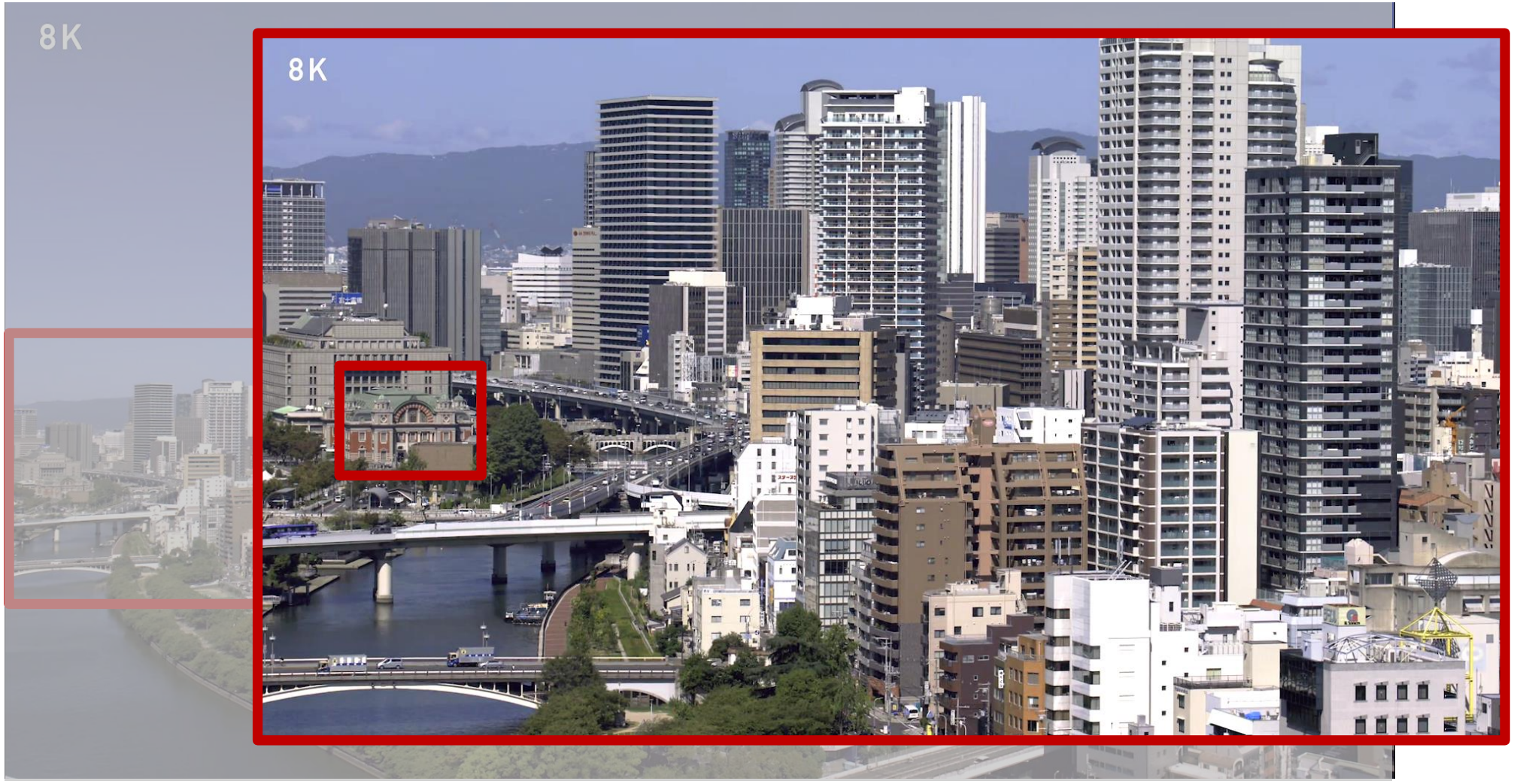
In-pixel reconfigurable structure
⇒ **High-speed noise cancel**
⇒ **High-speed readout**

Captured Image: 8K Resolution

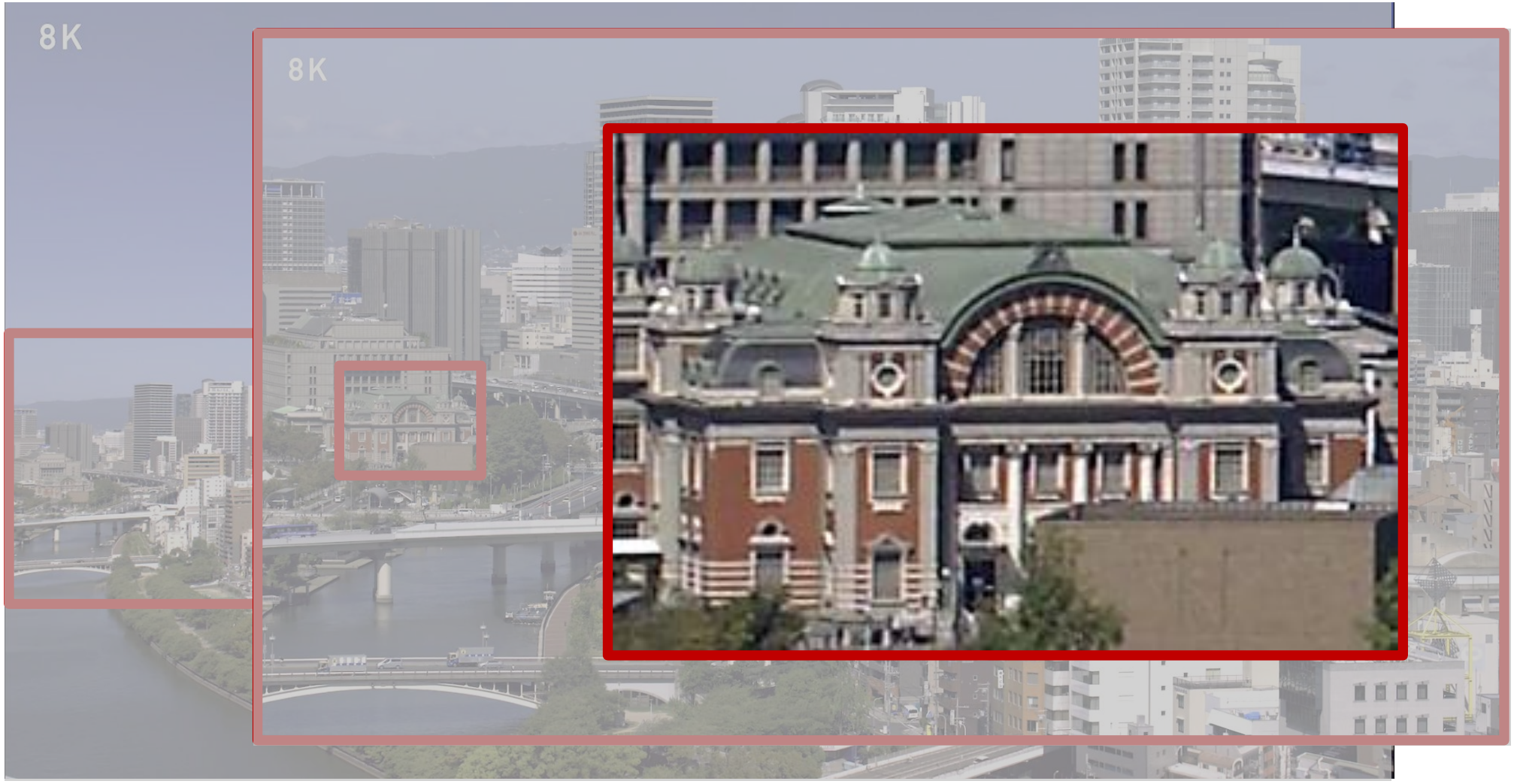
Captured Image: 8K Resolution

Captured Image: 8K Resolution

Captured Image: 8K Resolution



Captured Image: 8K Resolution

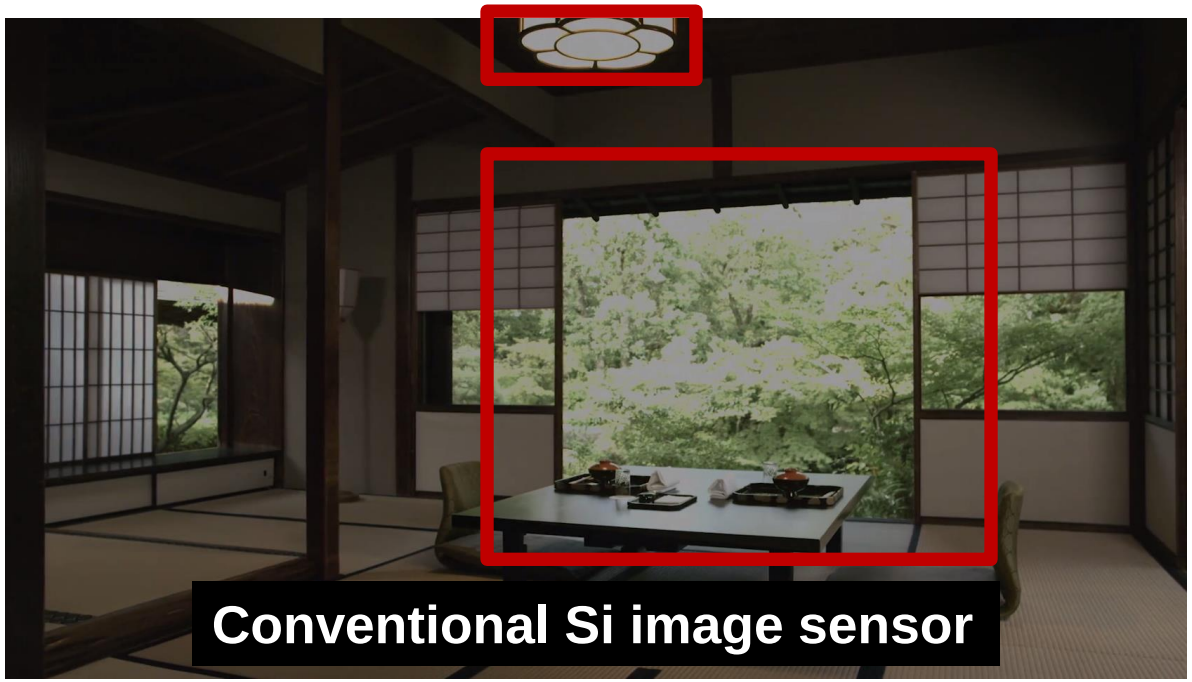


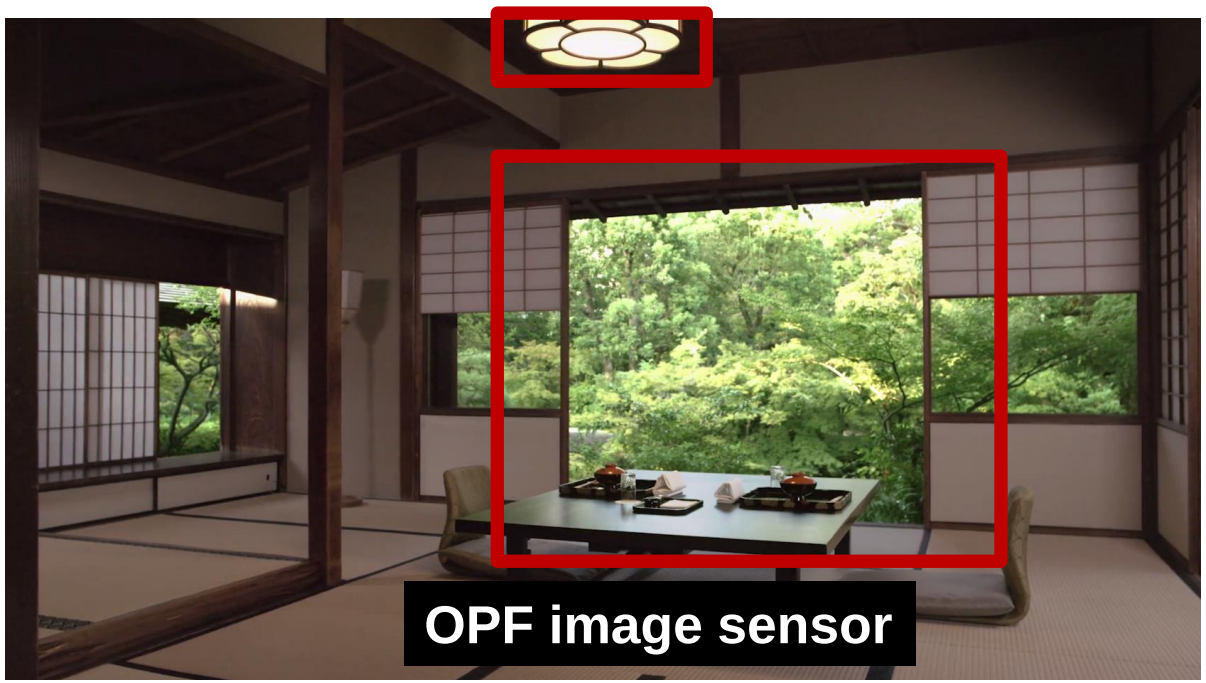
Captured Image: Wide Dynamic Range

➢**8K resolution** and **wide dynamic range** image can be captured.

Captured Image: Wide Dynamic Range

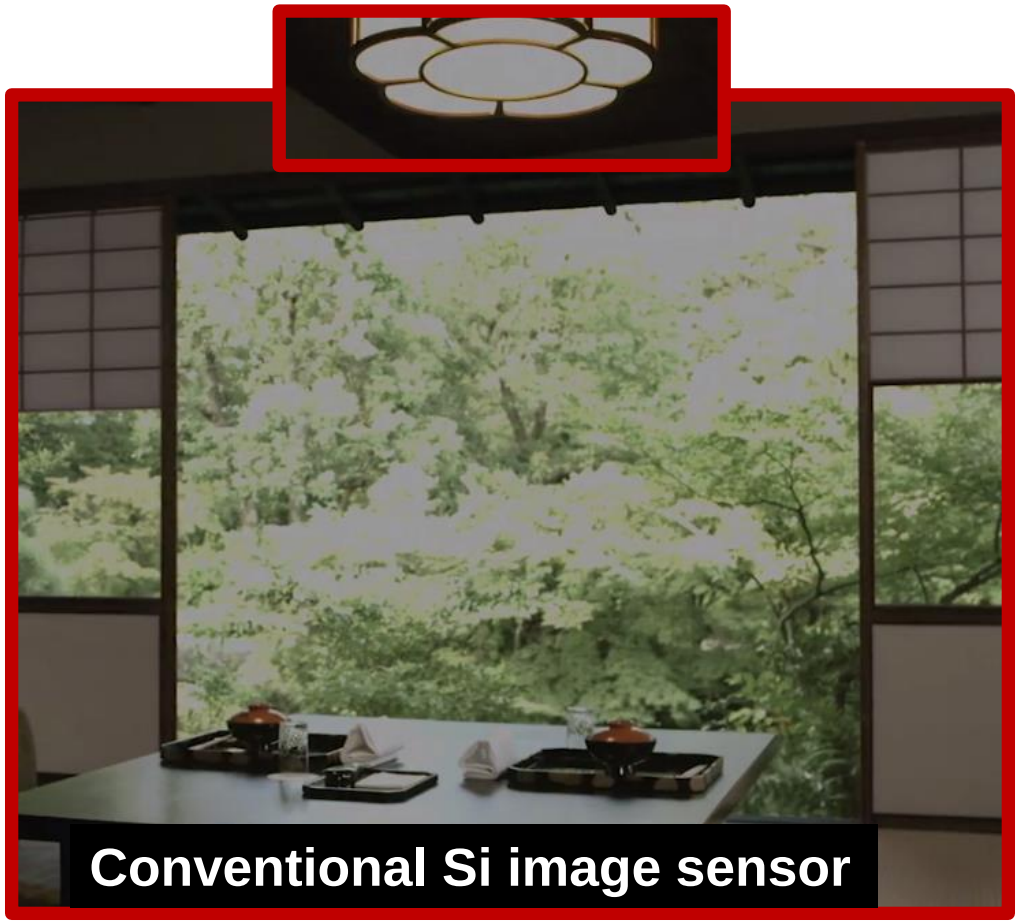
➢**8K resolution** and **wide dynamic range** image can be captured.

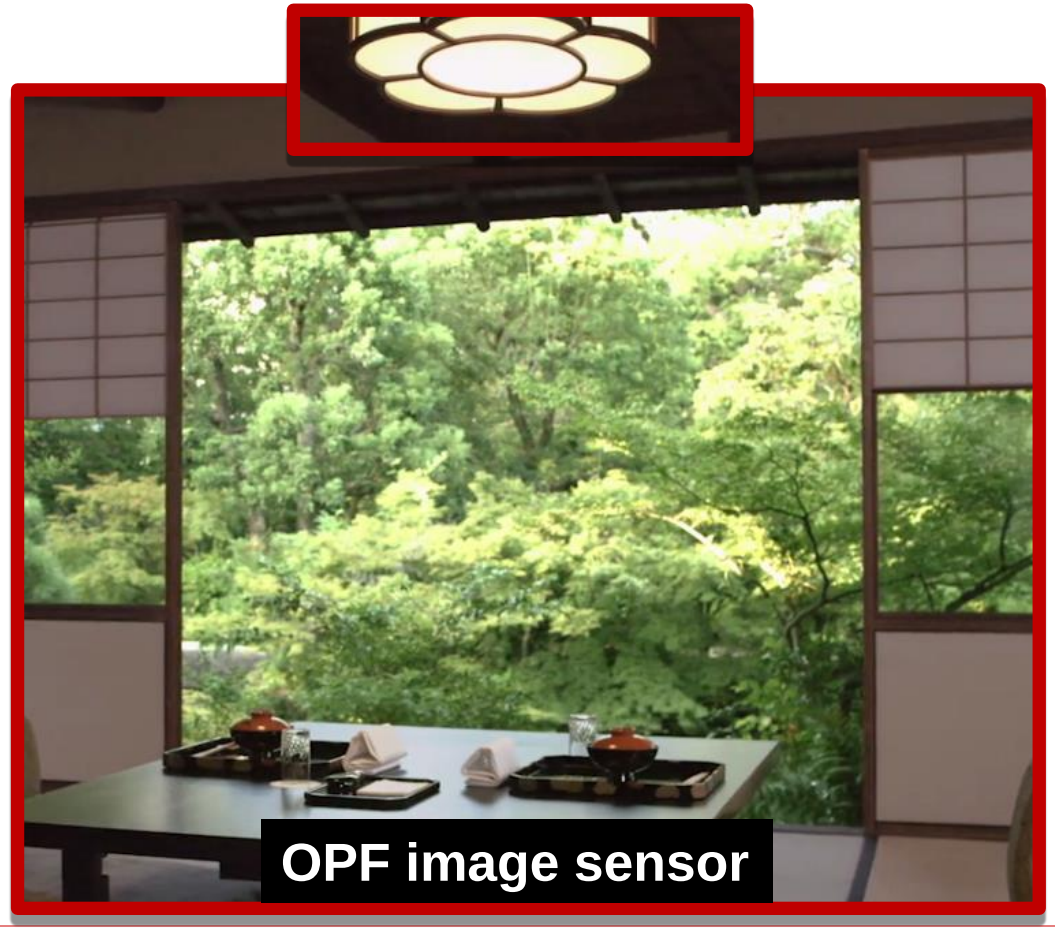




Captured Image: Wide Dynamic Range

➢**8K resolution** and **wide dynamic range** image can be captured.





Captured Image: Global Shutter

- By using **global shutter function**, **shutter distortion does not occur** even during high-speed panning image capturing.

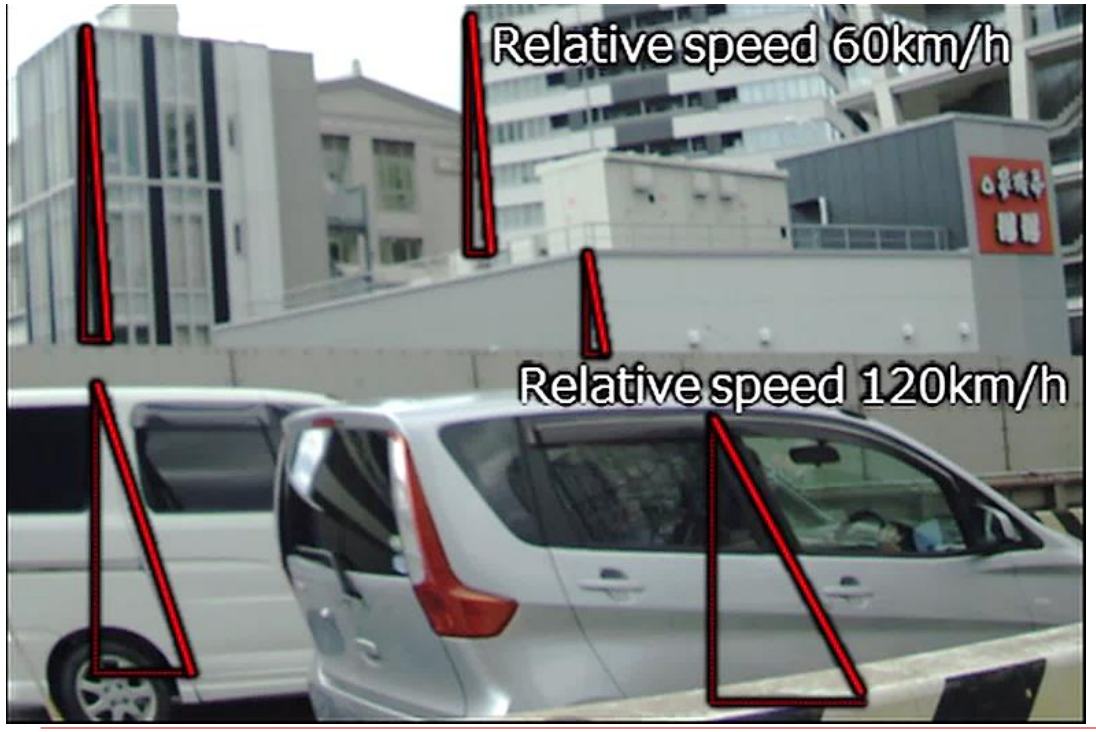
Rolling shutter mode

Global shutter mode

Captured Image: Global Shutter

- By using **global shutter function**, **shutter distortion does not occur** even during high-speed moving image capturing.

Rolling shutter mode



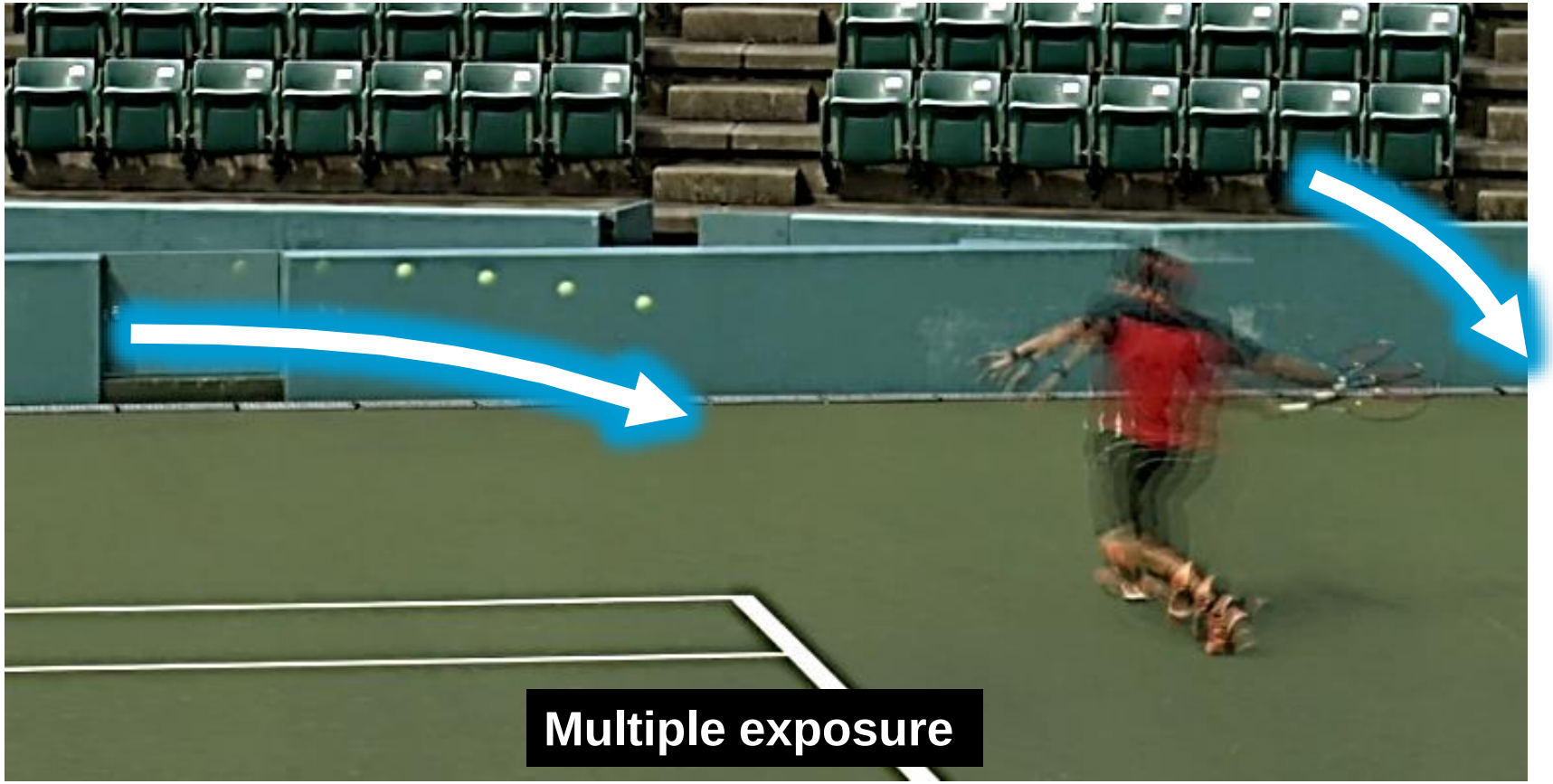
Global shutter mode

Captured Image: Global Shutter's Multiple Exposure

- By using **global shutter function**, **the desired moment can be captured without shutter distortion**.

Captured Image: Global Shutter's Multiple Exposure

- By using **multiple exposure of global shutter function**, **motion detection** can be realized.



Outline

- Background
- What is OPF image sensor
- Advanced technologies of OPF image sensor
  1) Wide dynamic range
  2) Photoelectric conversion controlled global shutter
  3) NIR sensitivity modulation RGB-NIR sensor
- 8K4K sensor technologies
- **Conclusion**

Conclusion

In the near future, the demands for image sensors will shift

- **Capturing precise images**

- **Recognizing captured data**
- **Seeing something invisible**
- **Predicting the next action**

We will contribute to these “smart edge” demands through advanced OPF image sensor technologies.

Thank you for your attention !

Panasonic