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[Chemnitzer Seminar 23th June, 2015] A 3D stacked CMOS image sensor with 16Mpixel global-shutter mode using 4 million interconnections

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- Summary
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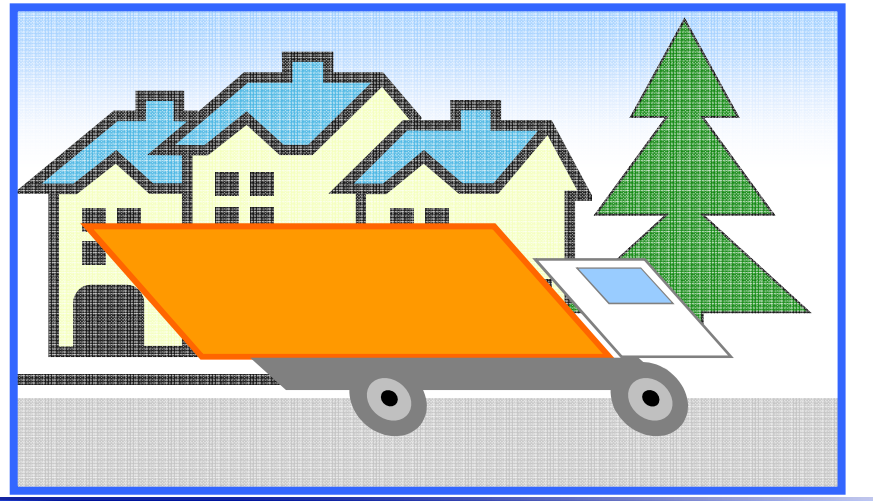
  - Future work

Contents

Rolling shutter (RS) operation

- **To prevent “rolling shutter distortion”, mechanical shutter is necessity.**

Rolling shutter image sensor : line by line exposure
=> It has the distortion when captured moving target



Background (Motivation)

Global shutter (GS) CMOS image sensor (CIS) ideal for digital cameras

- **No rolling shutter distortion/no mechanical shutter**
  - -High speed continuous shooting
  - -Seamless shooting between still mode and movie mode
  - -No black-out period for electronic view finder

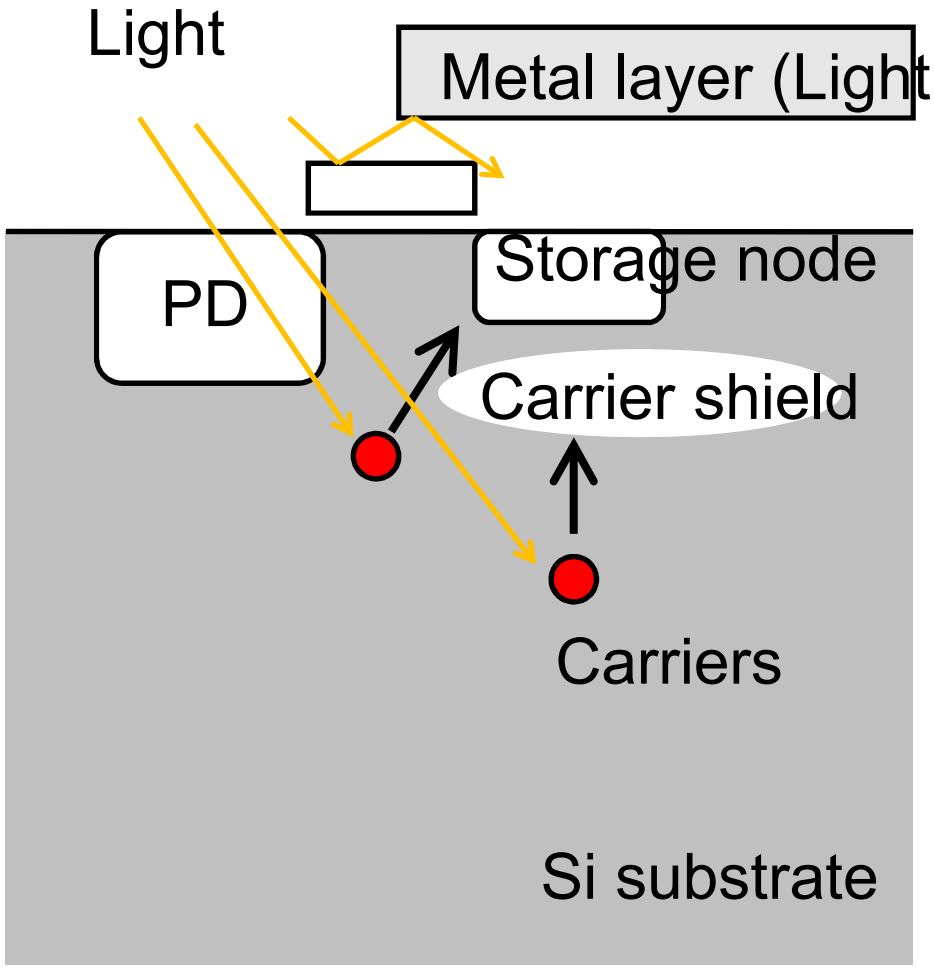
Our Targets

To develop a GS image sensor for digital cameras with:

- **High resolution: 16M pixels**
- **High image quality: 3.8-um BSI pixel**
- **No artifacts: small parasitic light sensitivity**

General Problems of Global Shutter CIS

Storage node in same substrate as Photo Diode (PD)
Storage node beside PD



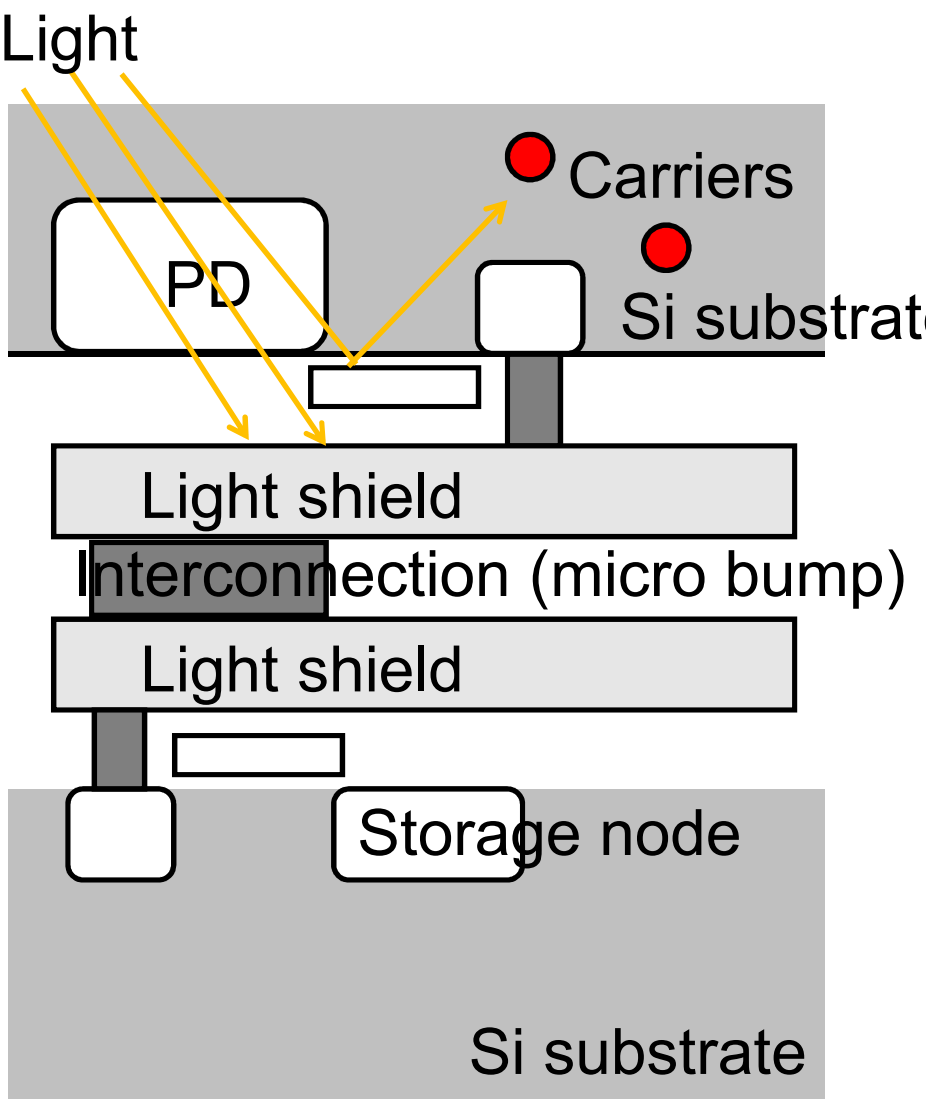
Problems

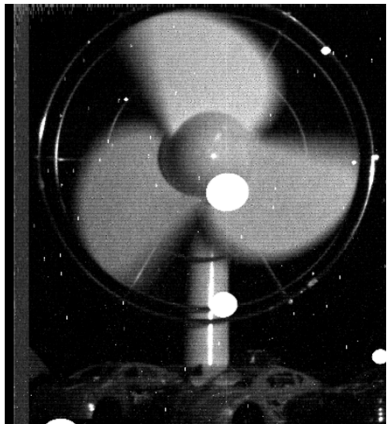
・PD area decreased because of storage node
=>Low full well capacity

・Shielding light to storage node difficult
=>High parasitic light sensitivity

Our Previous Work (ISSCC2013)

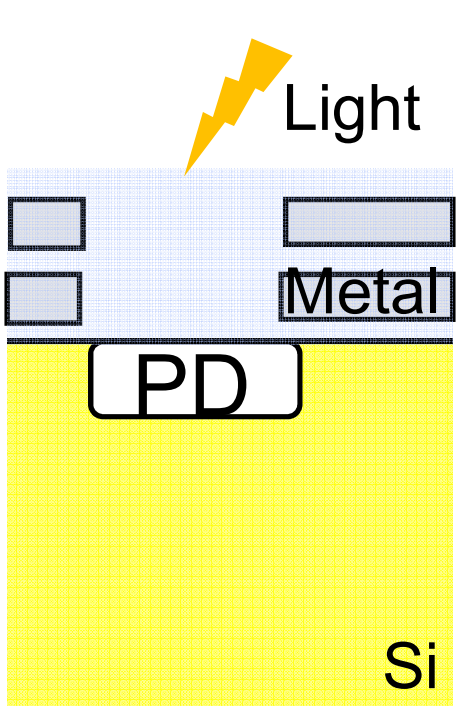
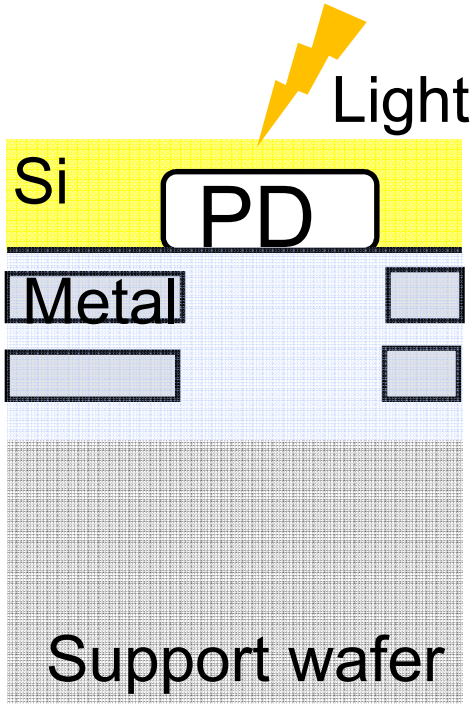
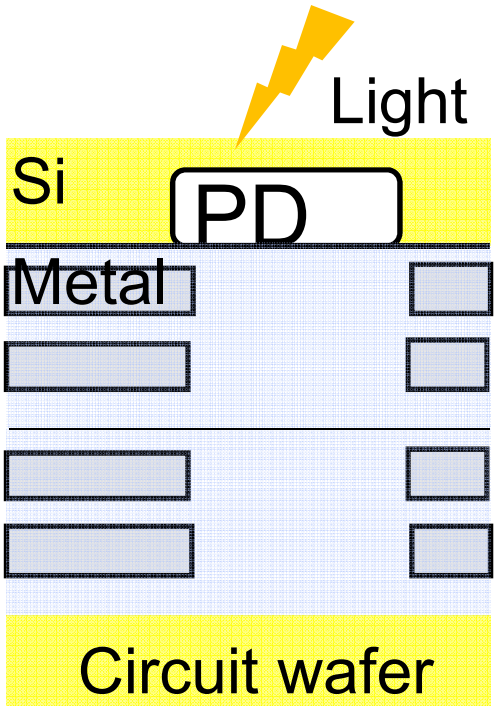
3D stacking technology with micro bumps





Chip size	6.5 × 6.5 mm
Effective pixels	704 (H) × 512 (V)
Pixel size	4.3 × 4.3 μm
Number of interconnections	90,112
Minimum pitch of interconnection	8.6 μm
Parasitic light sensitivity (PLS)	-160 dB

FSI, BSI, 3D stacked image sensor

	FSI	BSI	3D stacked
Structure			
Feature	・Easy to fabricate	・PD can receive much more light ・Pixel metal layout is easier	・Higher functionality ・Higher performance
Process	・Normal CIS process	・Wafer bonding ・Wafer thinning	・Wafer bonding ・Inter connection ・Wafer thinning

Our New Work

ISSCC2013	
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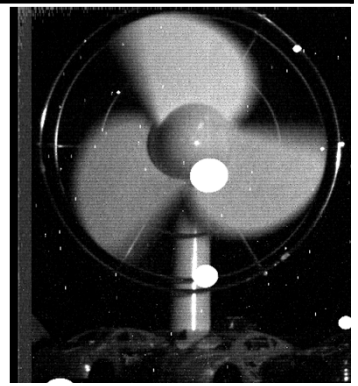

New Target

- Bigger chip size
- Higher resolution
- Smaller pixel size
- Higher number
- Smaller pitch
- Keep high performance
- Better image quality

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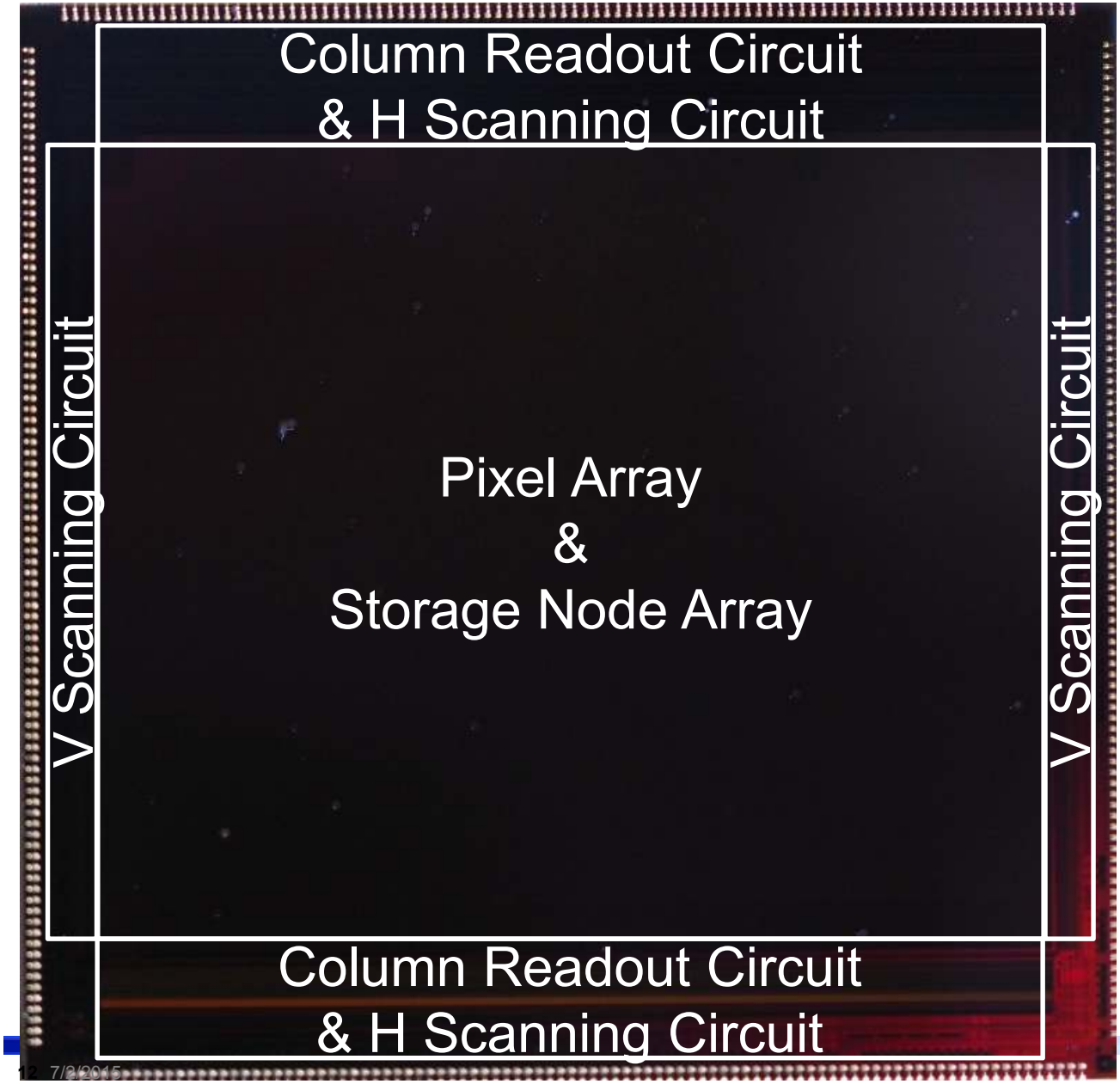
Appearance of Die



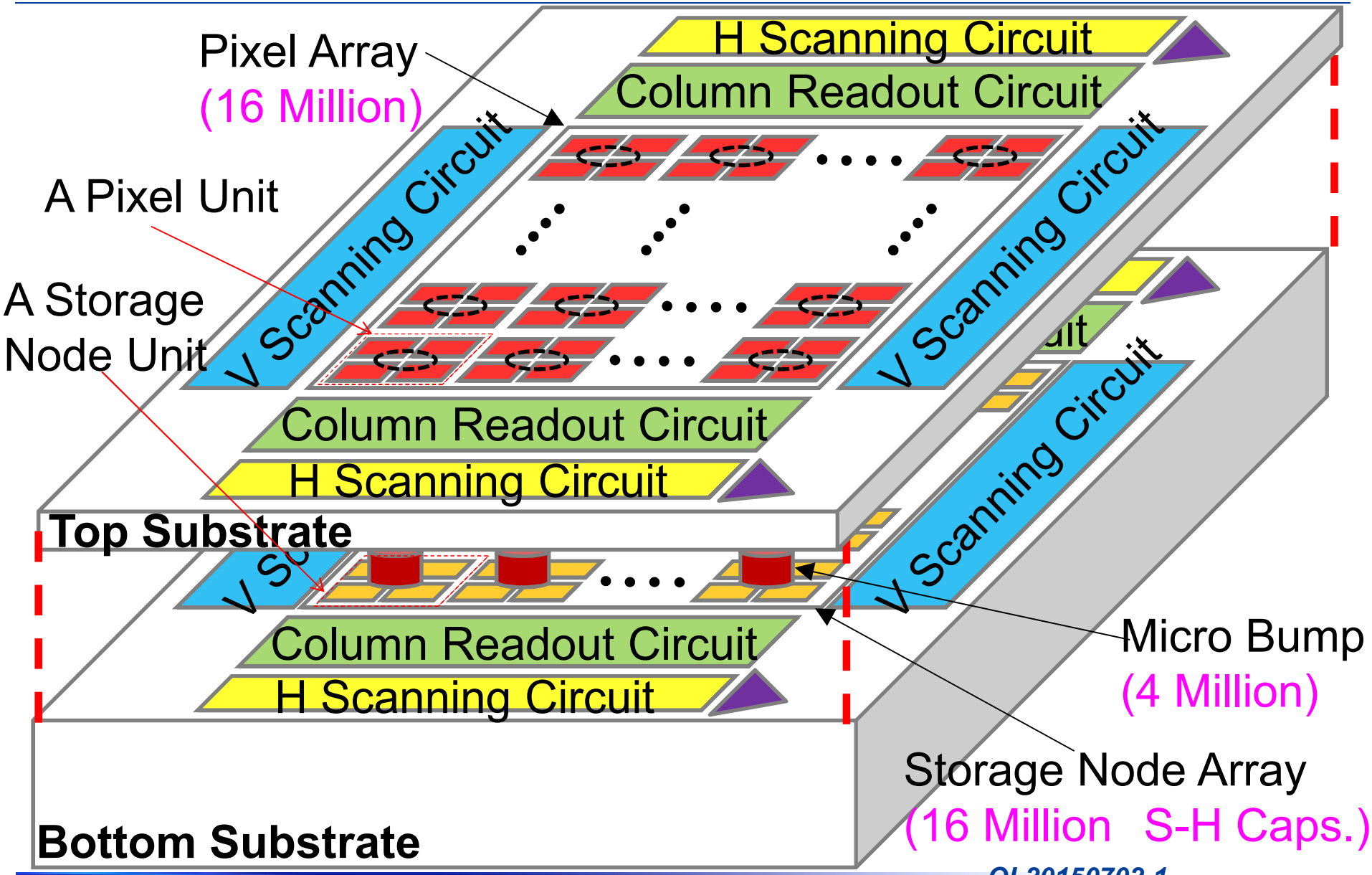
Chip Size
20.1 × 19.7 (mm)

Pixel Area
17.5 × 13.2 (mm)

Effective Pixels
4608 × 3480

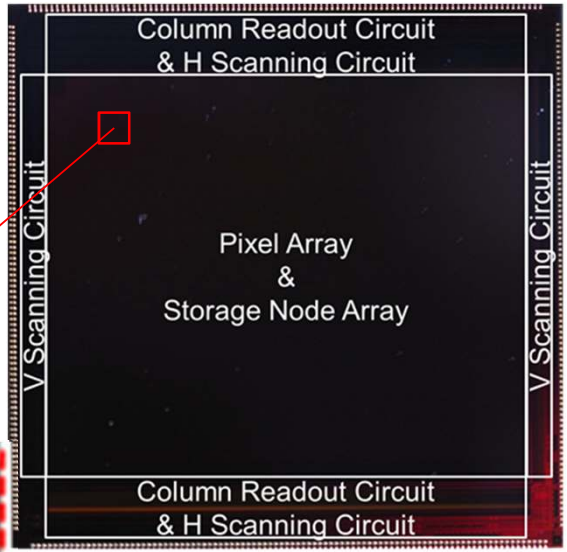
Pixel Size
3.8 × 3.8 (μm)

Block Diagram (Whole Chip)

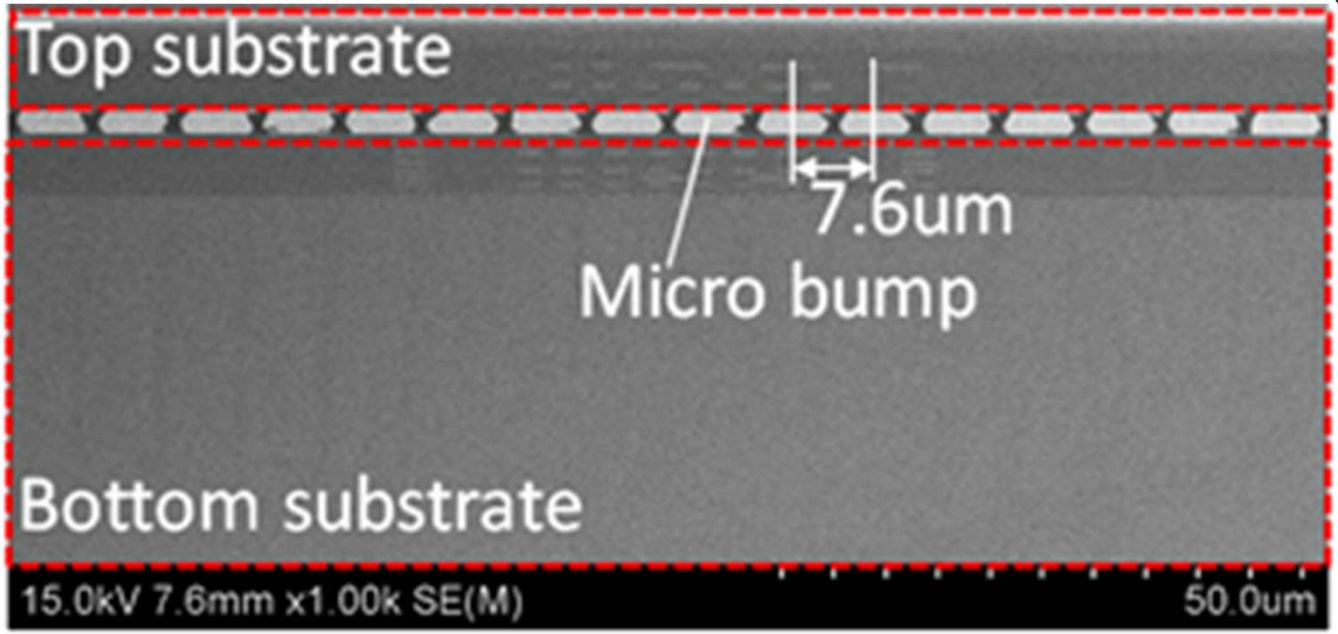


Device Structure

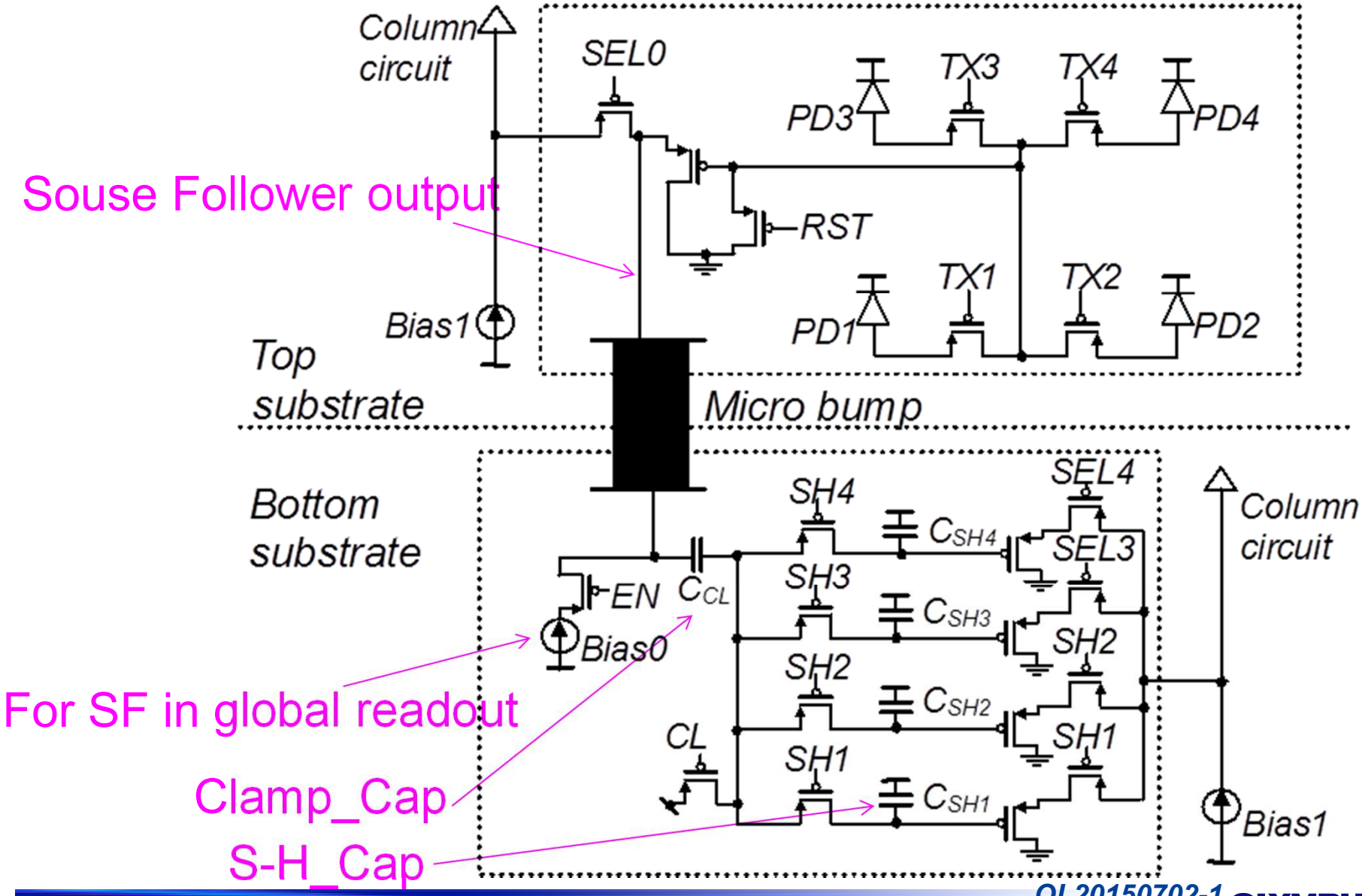
7.6-μm micro bump pitch



Cross Section



Schematic of a pixel unit circuit

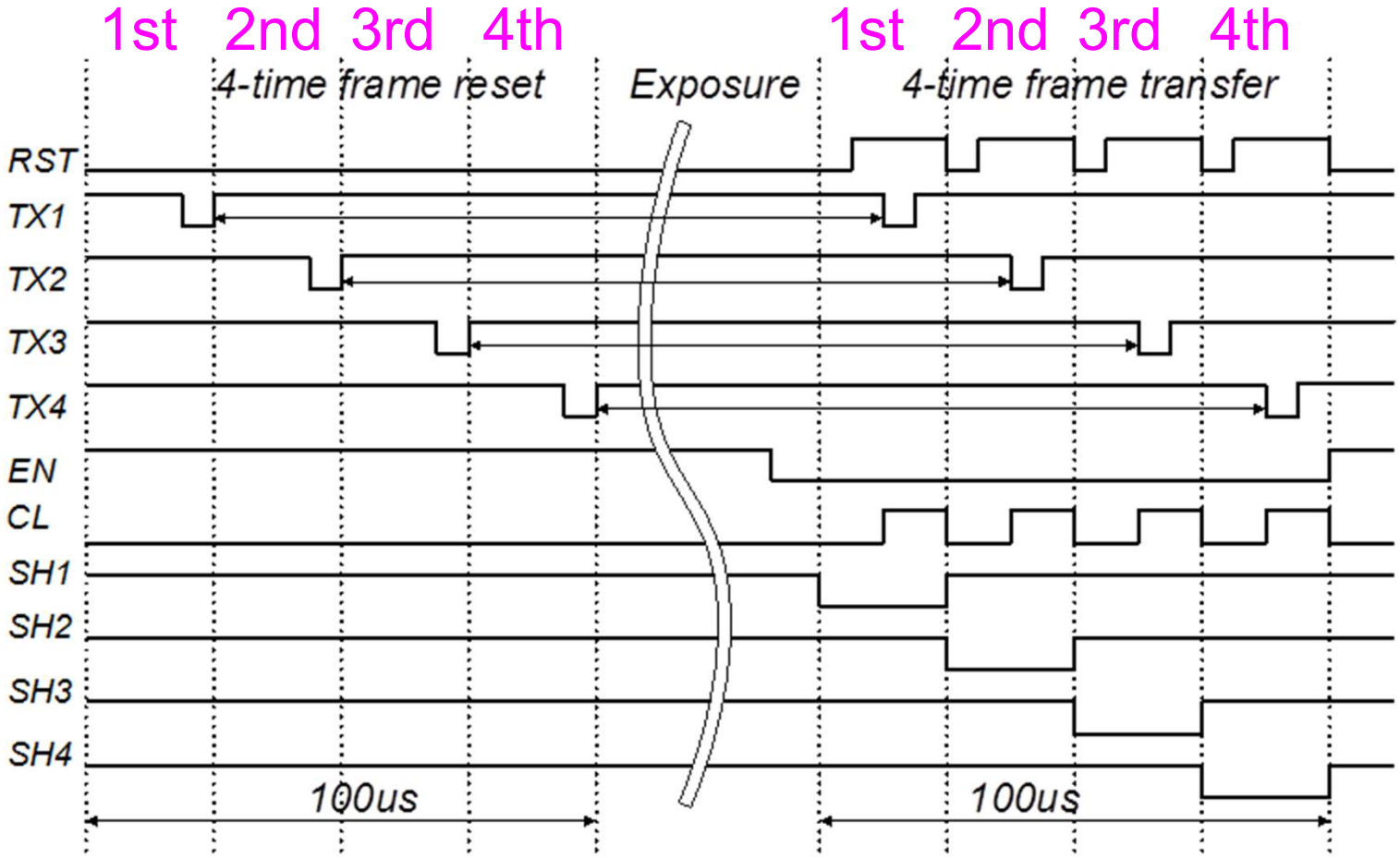


Timing Diagram of Image Sensor

Timing from PD to storage node in GS mode

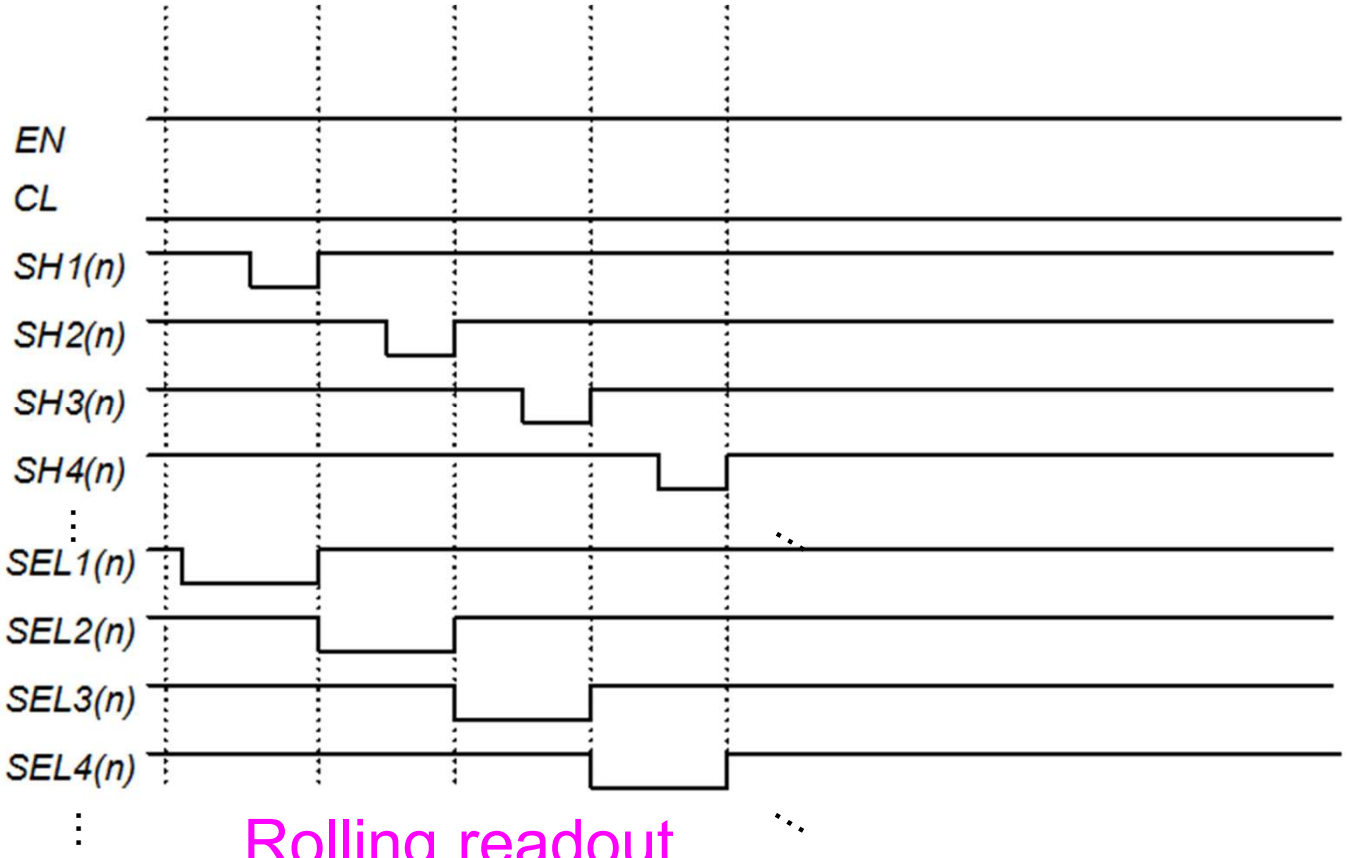
=> 4-time frame reset & transfer

Reset and signal levels are readout for pixel CDS.



Timing Diagram of Image Sensor

Timing from storage node to column circuit in GS mode
=> Rolling readout at 5 fps
Ref. and signal levels are readout for column CDS.



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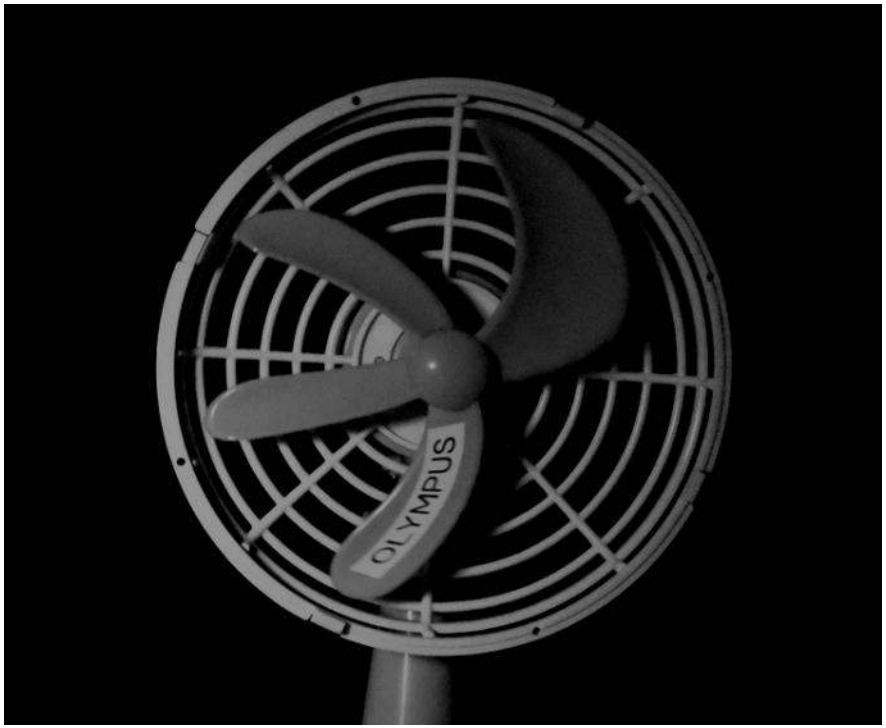
Captured Image : Color sample

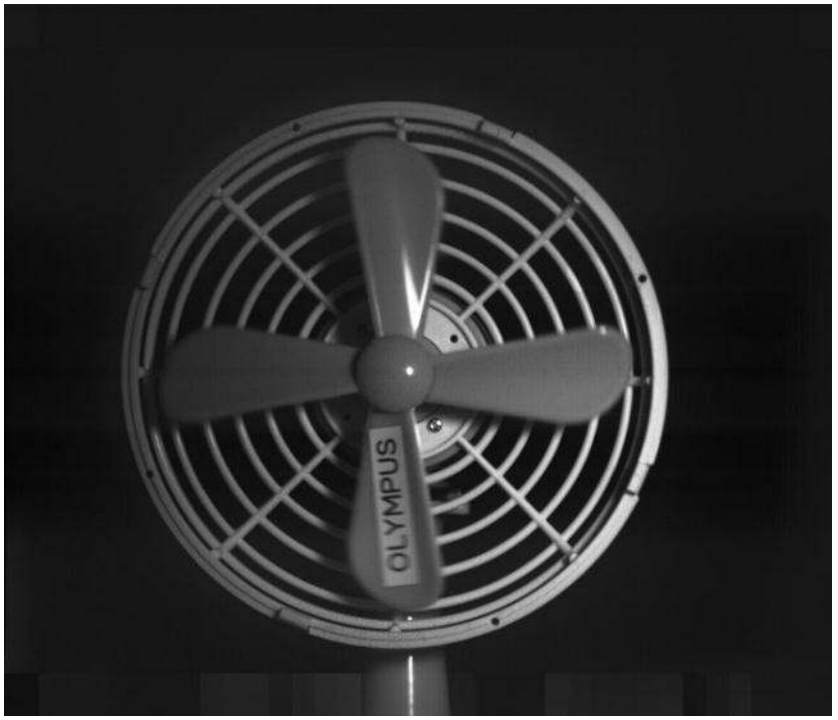
16Mpixel high resolution image with On-chip color filter

Captured Image : B/W sample

Scene: A target (a fan) moving very fast
Tint:125us



Captured in RS 60-fps mode with a commercially available camera



Captured in GS mode with our image sensor

Specifications

	This work	Previous work
Fabrication process of top substrate	0.18-μm 1P6M	0.18-μm 1P6M
Fabrication process of bottom substrate	0.13-μm 1P6M	0.18-μm 1P6M
Chip size	20.1 × 19.66 mm	6.5 × 6.5 mm
Pixel area size	17.51 × 13.22 mm	3.03 × 2.20 mm
Effective pixels	4608 (H) × 3480 (V)	704 (H) × 512 (V)
Pixel size	3.8 × 3.8 μm	4.3 × 4.3 μm
Read out rate	5 fps	30 fps
Supply voltage	3.3 V	3.3 V
Number of interconnections in pixel array area	4,008,960	90,112
Minimum pitch of interconnection	7.6 μm	8.6 μm

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Supply voltage	3.3 V	3.3 V
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Bigger

Higher

Finer

Higher

Finer

Measurement Results

	This work (Pixel Size: 3.8 × 3.8 μm)	Previous work (Pixel Size: 4.3 × 4.3 μm)
Conversion gain	35 μV/h+	26 μV/h+
Full well capacity	35,000 h+	30,000 h+
Sensitivity with 3200-K light source (B/W sample)	35,000 h+/lxs	60,000 h+/lxs
Dark current at 60°	50 h+/s	1000 h+/s
Parasitic light sensitivity (PLS)	-180 dB	-160 dB

Photodiode process and pixel layout were optimized

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Conclusion

◆ Key technology

- Wafer on wafer bonding
- Interconnection at 7.6-μm pitch
- 4 million interconnections in pixel area

◆ Achievements

- 16Mpixel global-shutter function with -180-dB PLS
- High image quality

Future Work

◆ Technology

- Finer pitch interconnection
- Improvement sensor specs for global shutter (frame rate, random noise)

◆ Applications

- Advanced image sensor using pixel level interconnection (minimum chip size, in-pixel ADC, WDR)
- 3D stacked image sensor with other chips (DSP, memory)


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