SOI技術を用いたイメージセンサ

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内容

- Pinned Depleted Diode 構造

  ～光、X線起因のキャリアを高速かつ低ノイズで検出する
  ためのSOIピクセルの基本構造～

- X線エネルギースペクトルイメージセンサへの応用
- 高近赤外感度TOFイメージセンサへの応用

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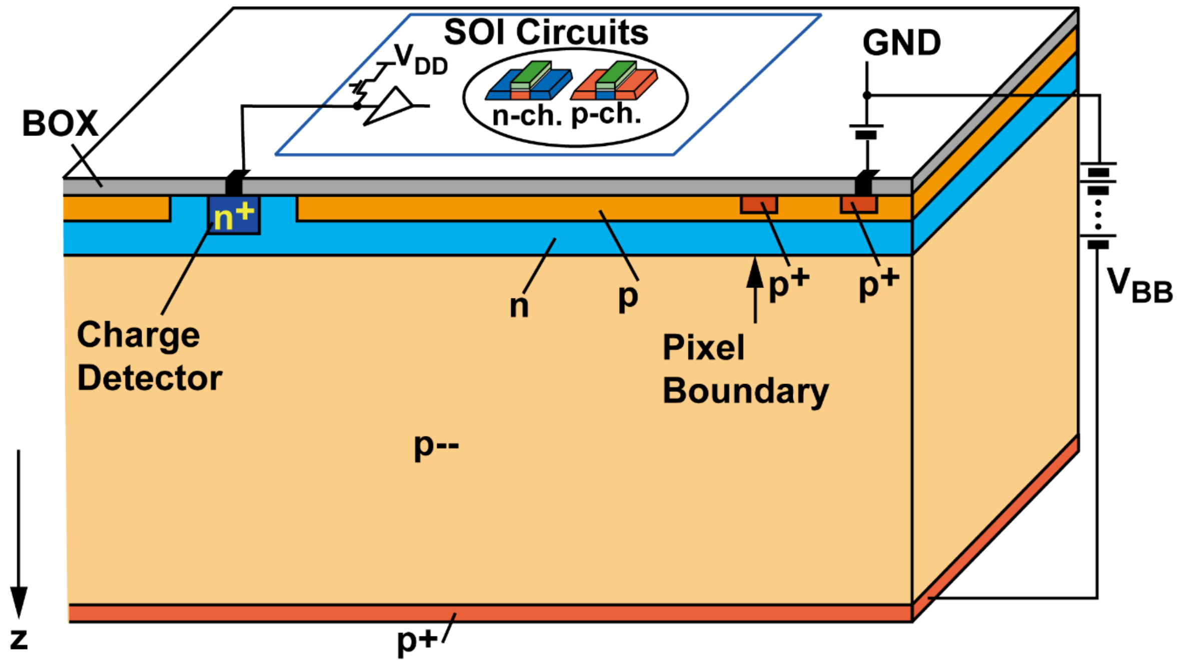
A SOI Pixel Detector Using Pinned Depleted Diode Structure (SOIPIX-PDD)



- Pinned Surface of Si Substrate with High Density Holes
  → Very Low R-G Dark Current
- Buried Channel → No Carrier Loss Due to Si-SiO_2 Interface Traps
  → Nearly 100% Charge Collection Efficiency
- Lateral Electric Field to Gather Electrons into an n^+ Sensing Node
  → High Sensitivity and Low Noise Due to Small Sensing Capacitance

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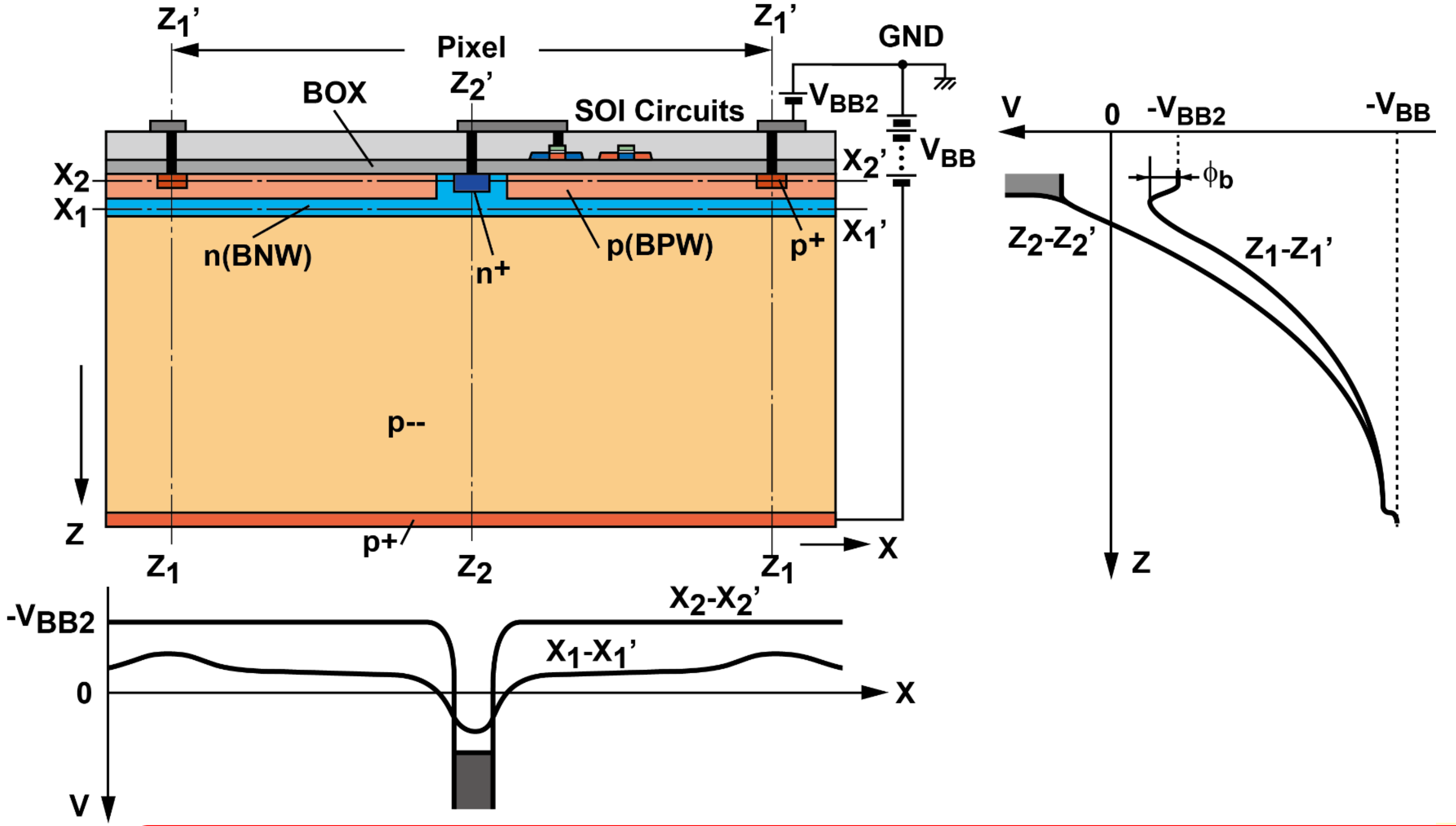
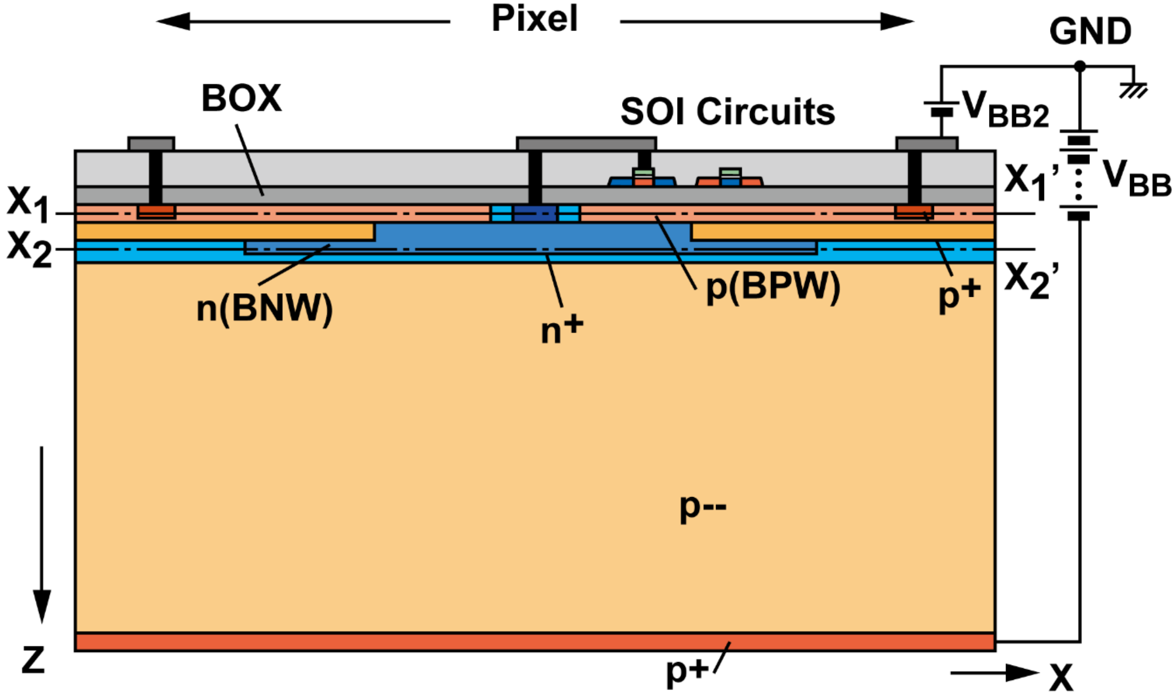


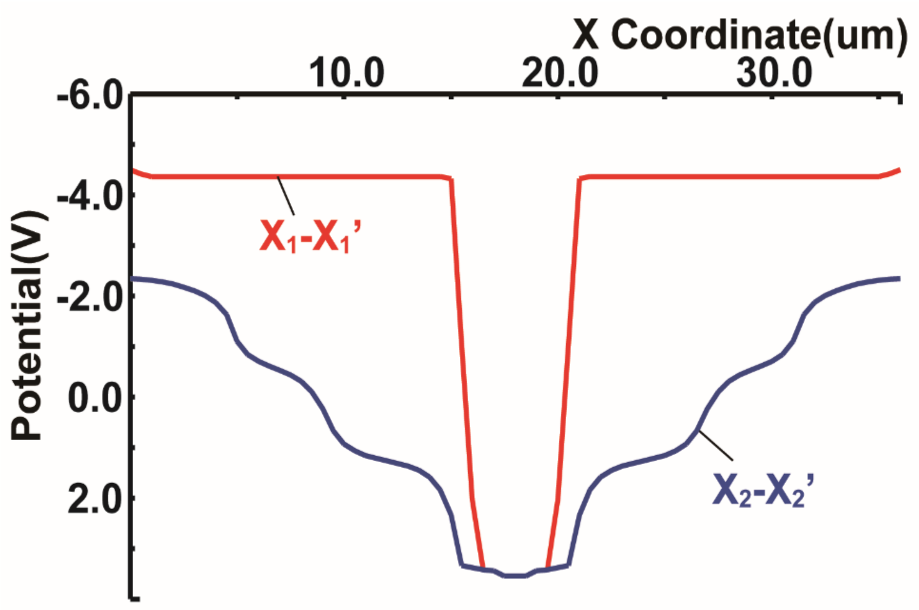
(Design Issues)

- Pinned Neutral BPW/Depleted BNW
  → Sufficient Potential Barrier (ϕ_B) to Prevent Hole Injection from BPW
- Sufficient Lateral Electric Field for High-Speed Charge Collection
  → Multiple BNW/BPW Structure Can Be Used.

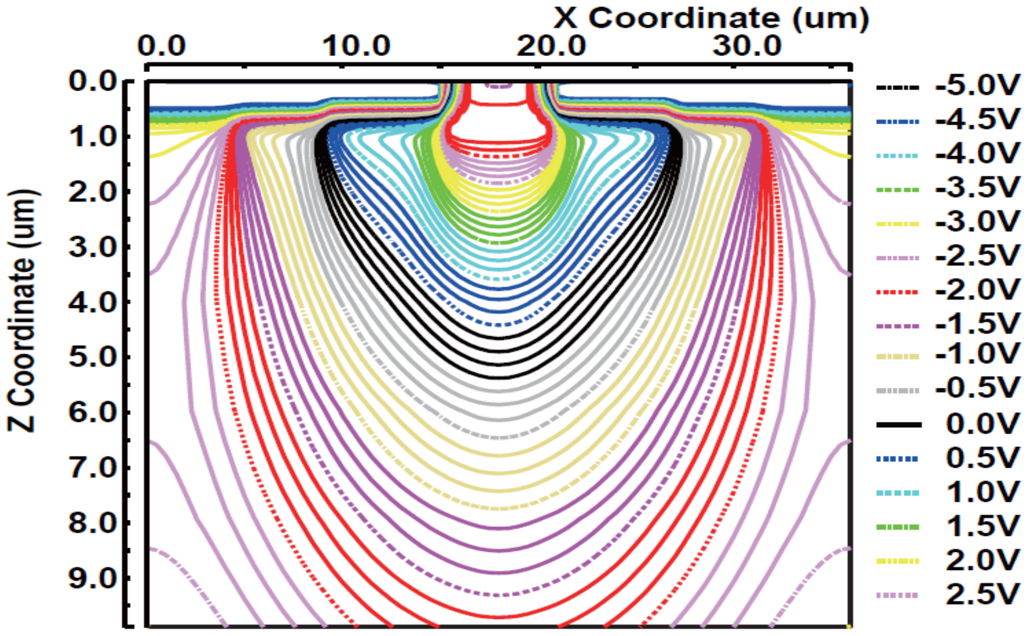
SOIPIX-PDD with Multiple BPW/BNW

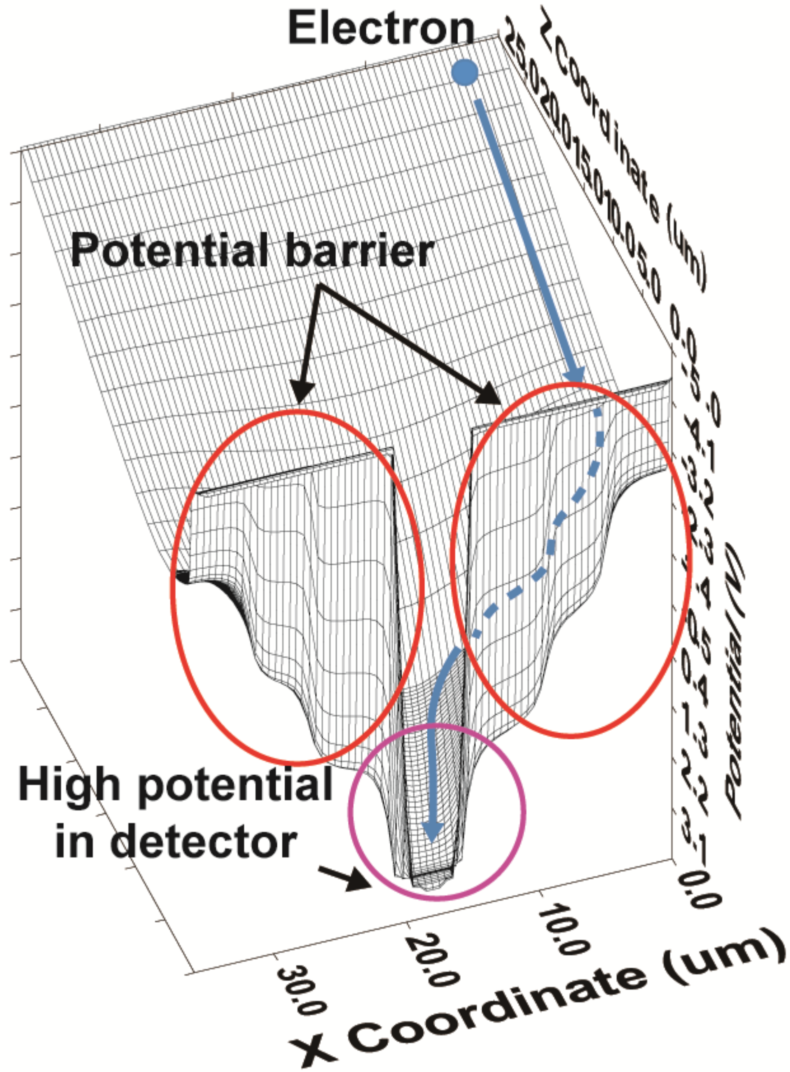


VBB=-15V
VBB=-4V
25kΩcm, 200μm
36μm x 36μm



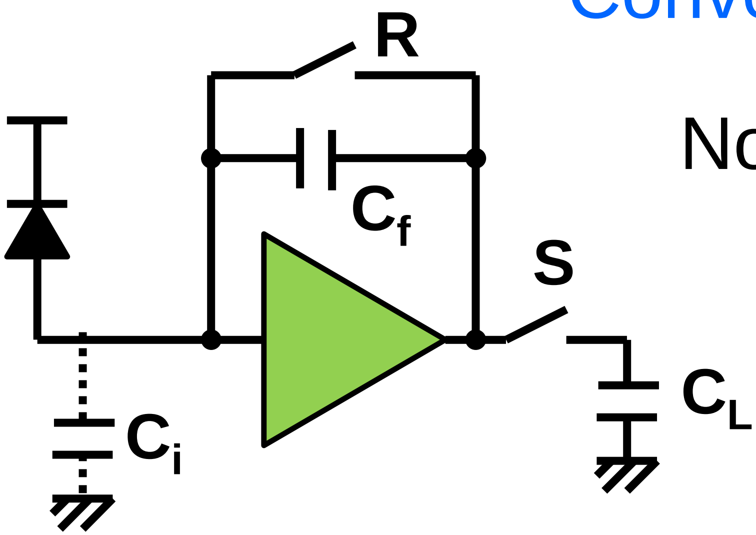
Simulated 2D Potential Profiles of SOIPIX-PDD with Multi BPW/BNW



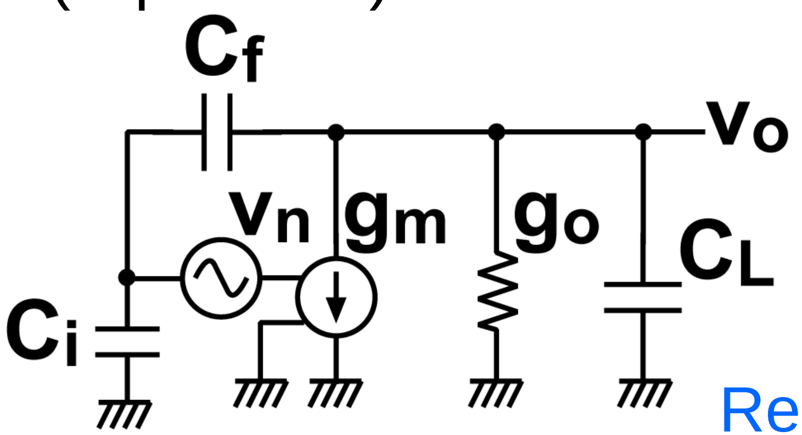


Low-Noise Charge Amplifier

(Charge Amp.)



(Equivalent)



Conversion Gain: $C.G. = \frac{q}{C_f}$

Noise (after CDS):

$$\overline{v_o^2} \cong 2\frac{k_B T}{C_L}\xi\left(1+\frac{C_i}{C_f}\right)$$

(Thermal noise)

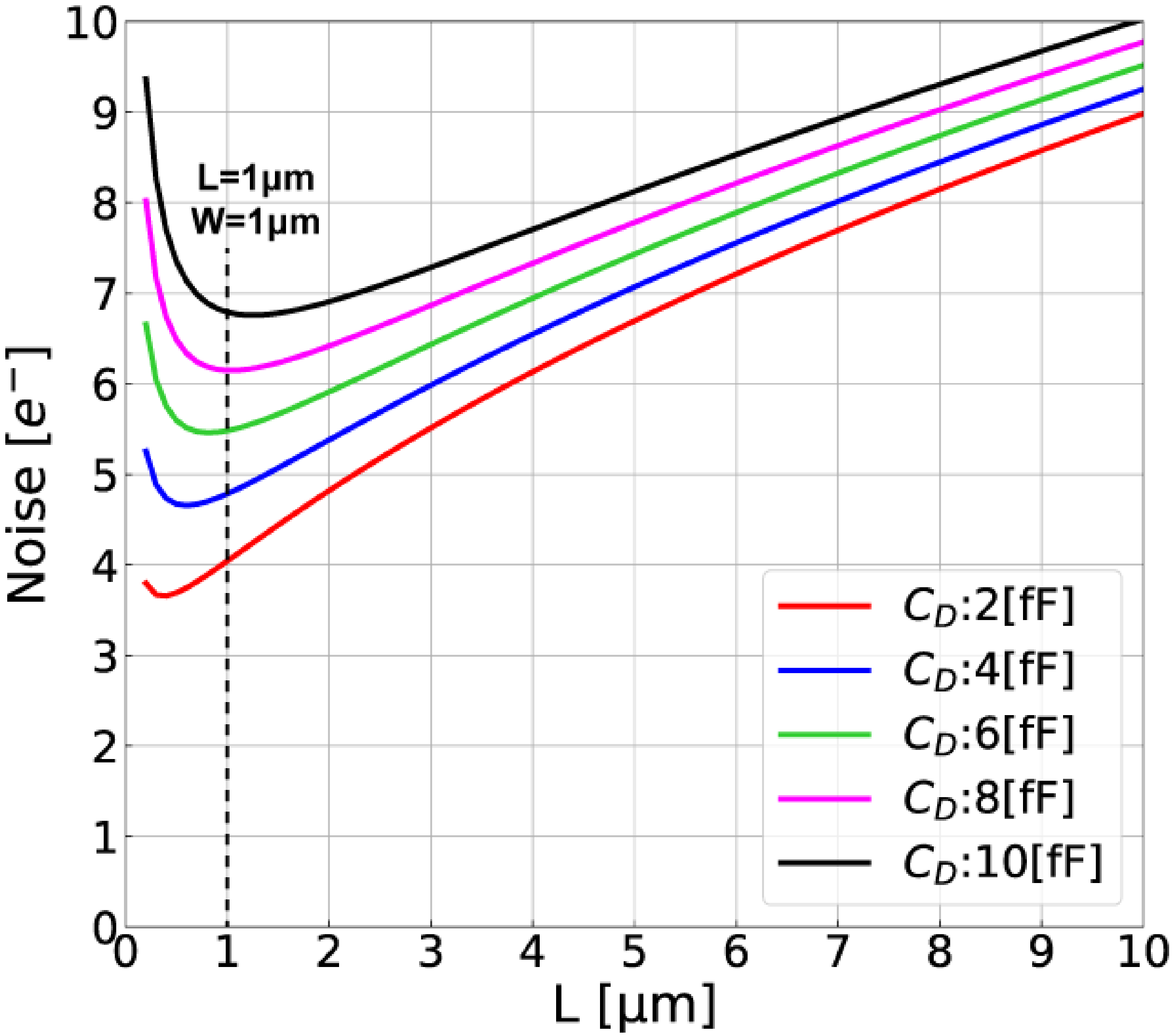
$$+2N_f\left(1+\frac{C_i}{C_f}\right)^2(\varepsilon+\ln\omega_{cA}T_{CDS})$$

(1/f noise)

$$C_i = C_{SENS} + C_{IN,AMP}$$

Reduction of C_{SENS} (Sensing Node Cap.) and $C_{IN,AMP}$ (Amp. Input Cap.) is important.

Optimization of Charge Amp. Noise



1/f Noise Coefficient of MOSFET:

$$N_f = \frac{k_f}{C_{ox}^2 LW}$$

$C_D = C_{SENS}$

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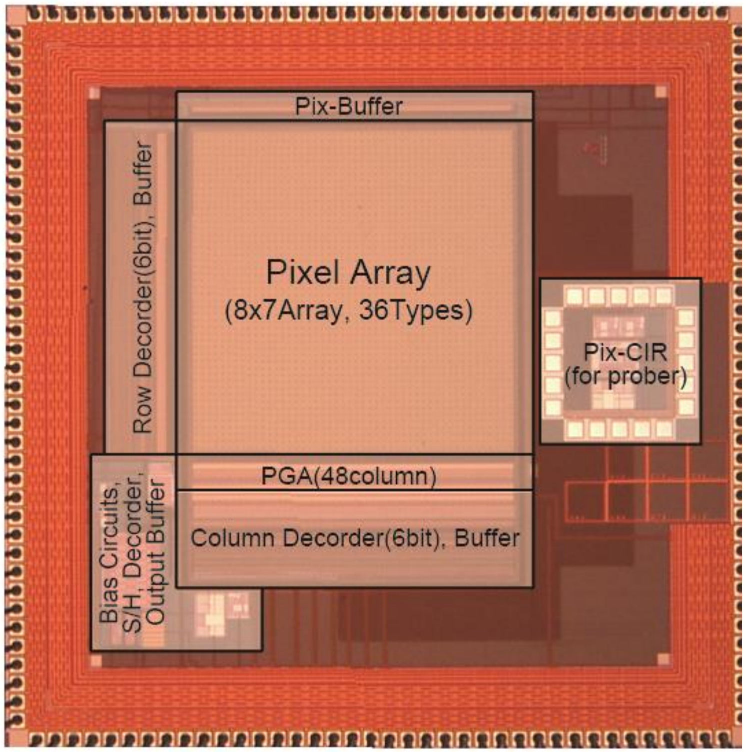
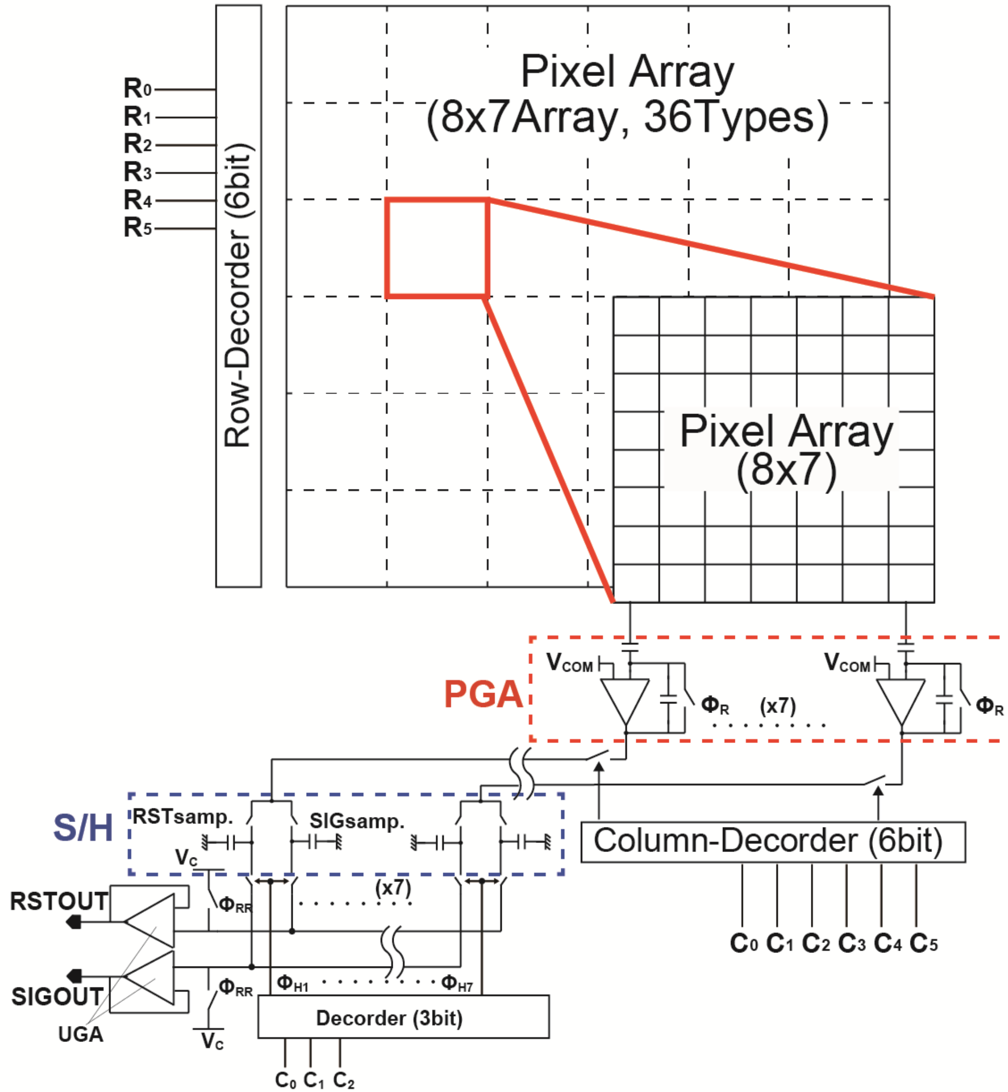
Implemented SOIPIX-PDD chip



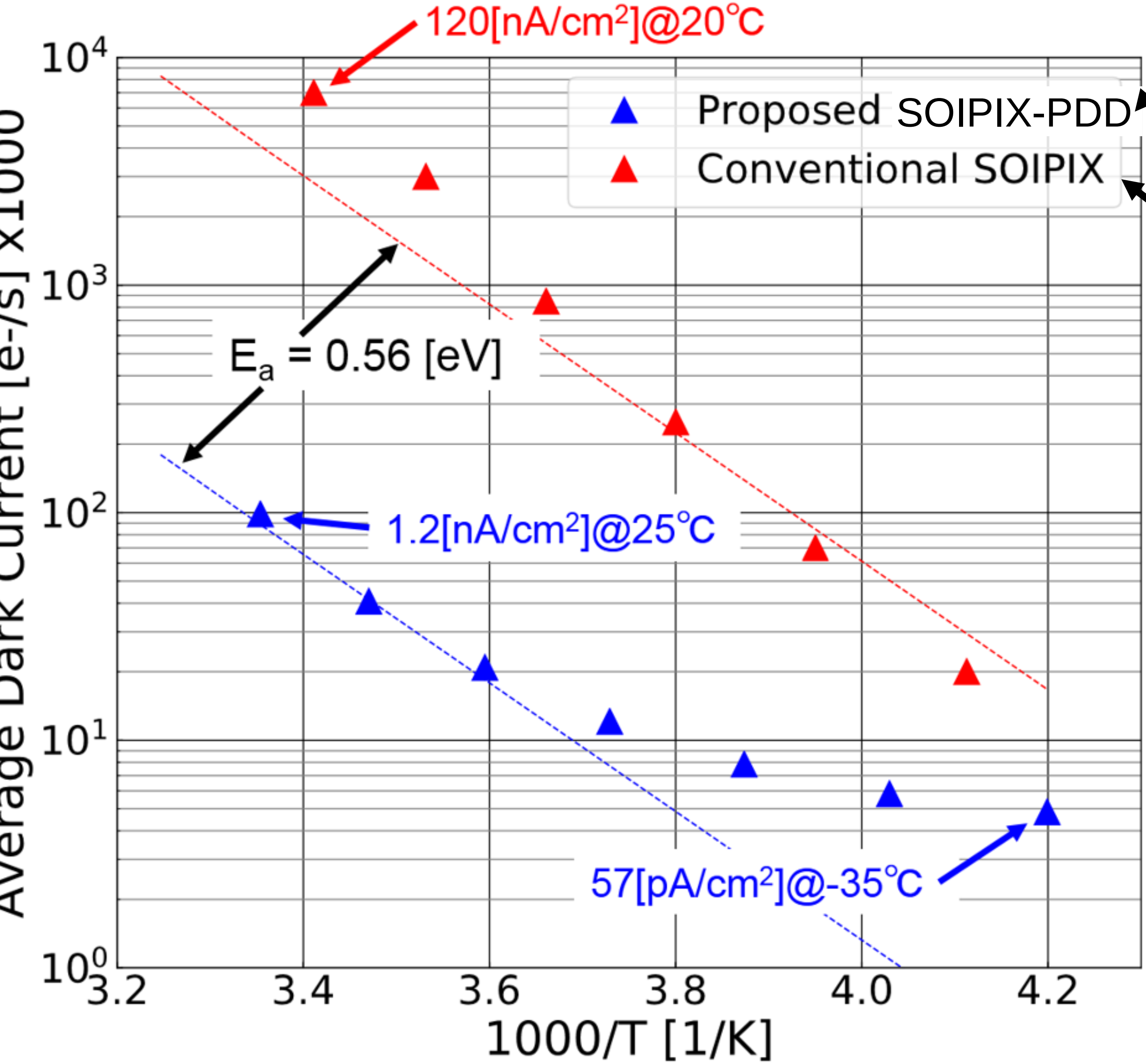


Chip Spec.

Technology :0.2μm FD-SOI CMOS
Chip Size：4.45mm×4.45mm
Pixel Size：36μm× 36μm
Convertion Gain：59μV/e⁻
Target Pixel Noise：3.4e⁻
Dynamic Range:0.1keV-37keV
Event-Driven Detection

Sensors 2018, 18, 27;doi:10.3390/s18010027

Dark Current



(36 µm x 36 µm, V_{BB} = -60 [V])

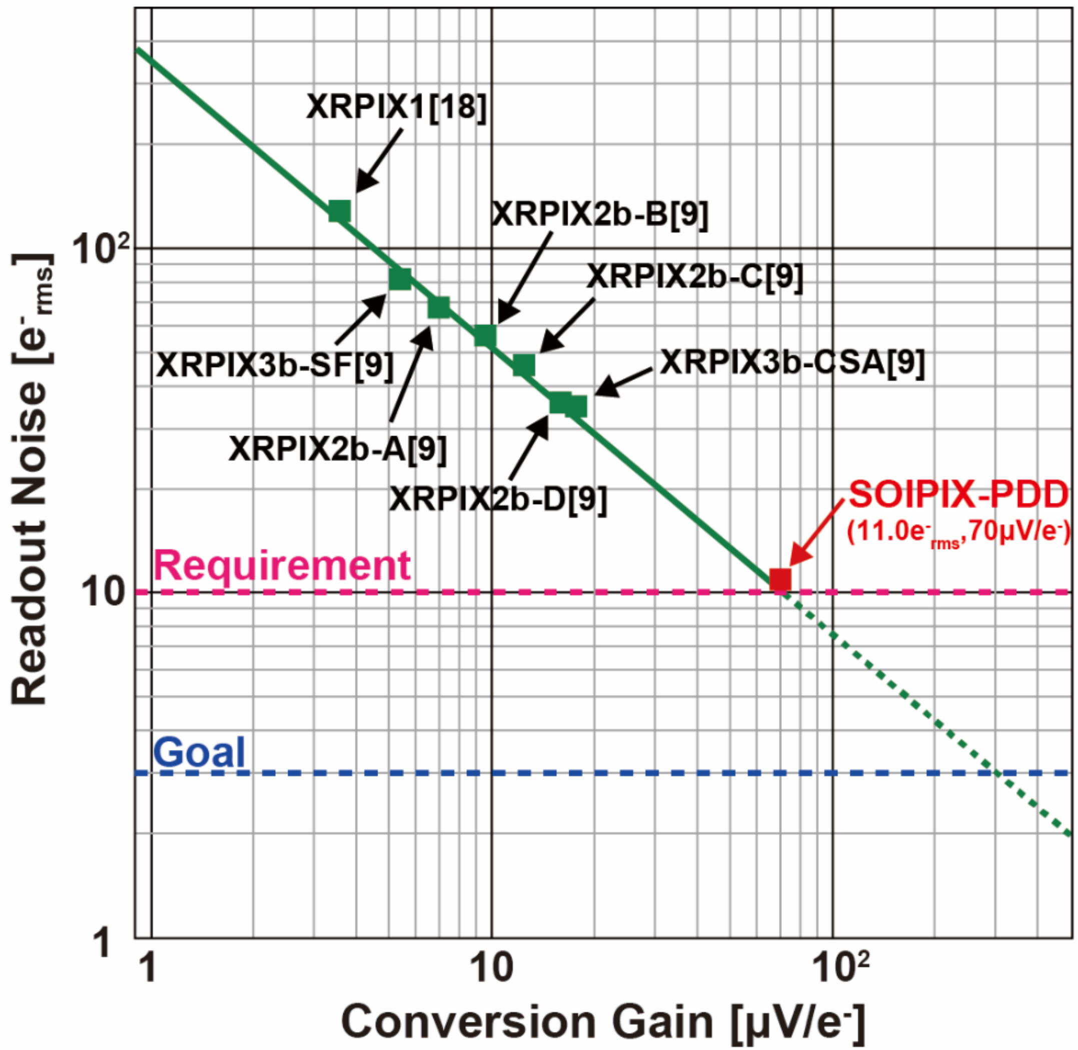
(36 µm x 36 µm, V_{BB} = -30 [V])

Readout Noise @-35℃, Gain=1

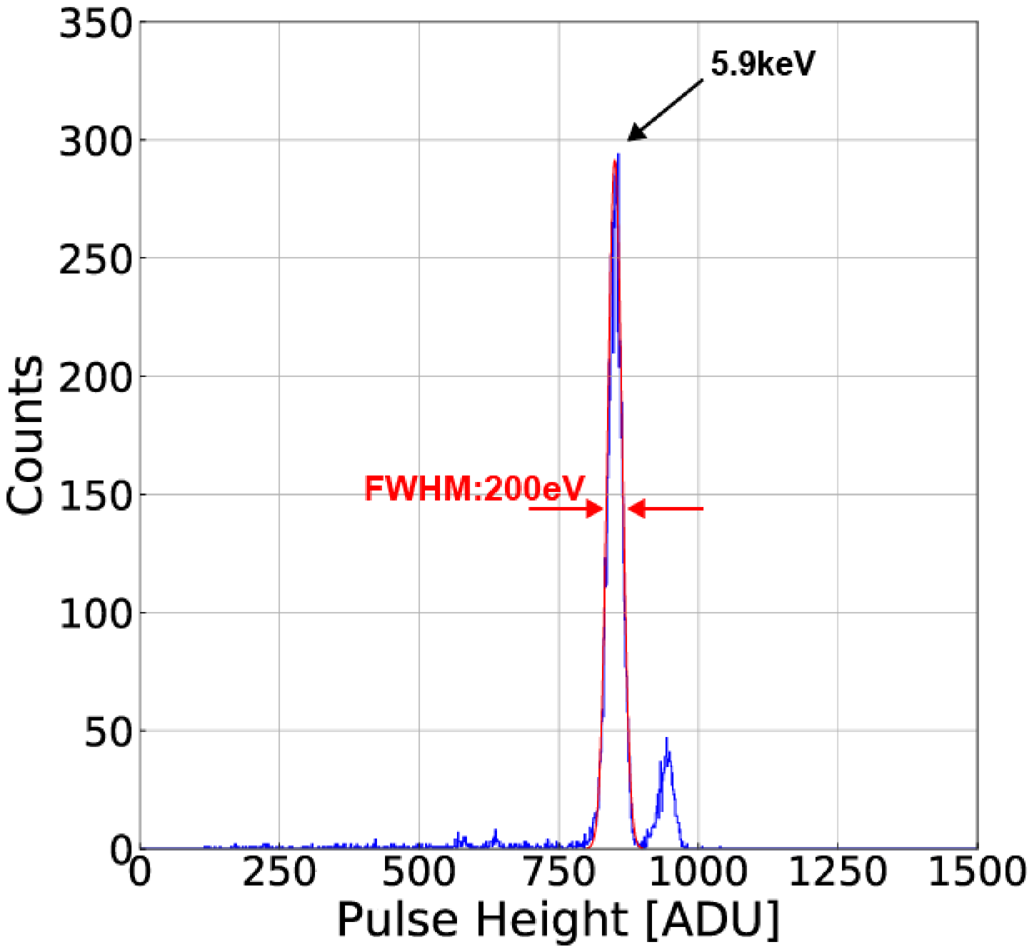
Noise Plot $[e^-]$ of 8 × 7 Pixel Array

y \ x	1	2	3	4	5	6	7
1	9.6	8.6	9.3	10.3	10.7	10.0	13.9
2	10.6	9.0	9.7	10.8	10.8	10.4	13.2
3	9.2	10.9	11.1	11.0	10.6	10.2	12.6
4	11.7	13.3	13.2	9.8	10.7	11.4	13.7
5	11.1	11.0	11.7	10.1	10.9	9.7	13.4
6	10.3	11.2	10.0	9.1	10.5	10.1	12.7
7	12.3	11.3	9.8	10.0	11.1	11.3	14.3
8	11.6	11.1	10.4	10.7	10.7	10.6	12.6

Comparison with Conventional SOIPIXs



^{55}Fe X-Ray Spectrum with SOIPIX-PDD



- FZ-p, 25kΩ・cm, 200μm
- Temp = -35[℃]
- V_{BB} = -60 [V]
- Conversion Gain = 70 [μV/e-]
- 1 [LSB] = 122 [μV]
- Bin =5[LSB]
- Vt=100 [LSB] (=174e-)
- Single Pixel Event

FWHM:200eV(3.3%)
@5.9keV

Very Small Tailing
→ High Charge Collection Efficiency

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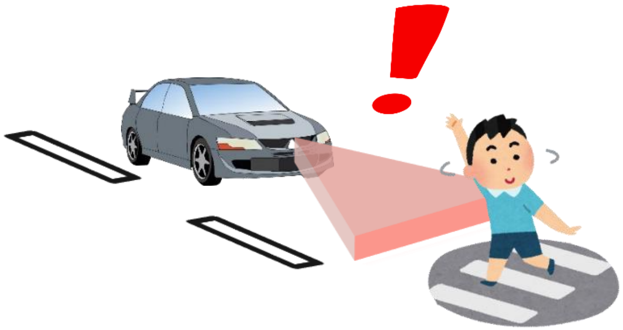
Challenge

Long-range TOF imager application: Automobile, Security, Drone, etc.

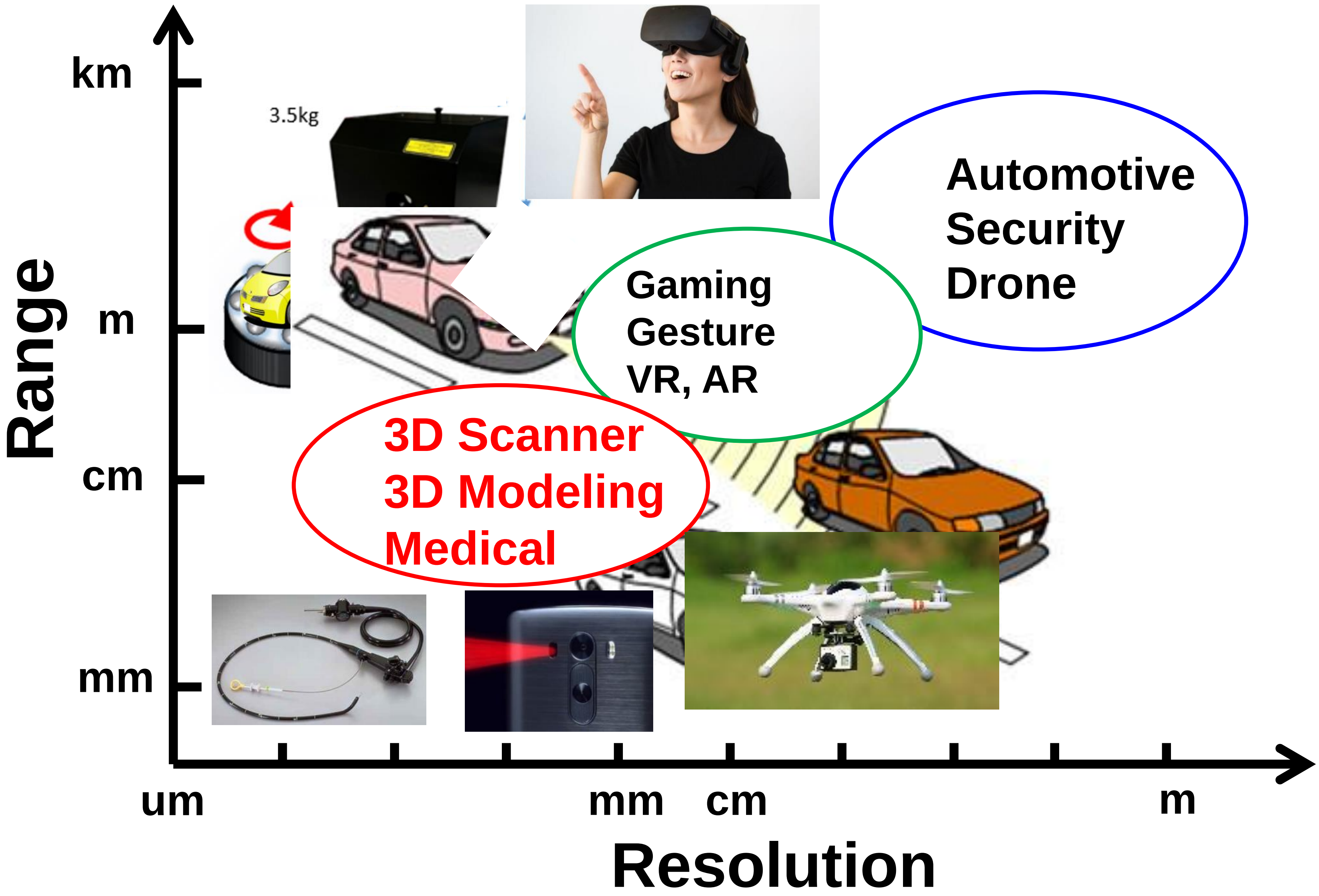
- **Long range (10~100m)**
  → Signal can be very weak
- **Outdoor use**
  → High tolerant to **Sun light**
  (Strong background light)



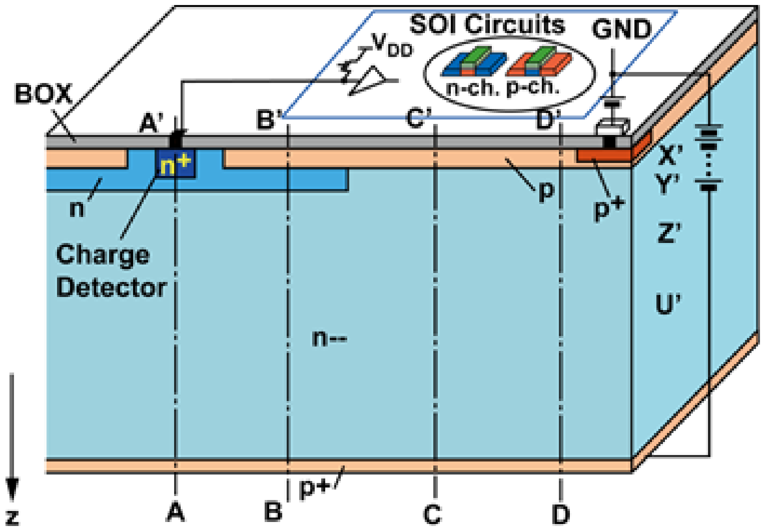
Target of ToF Range Imager

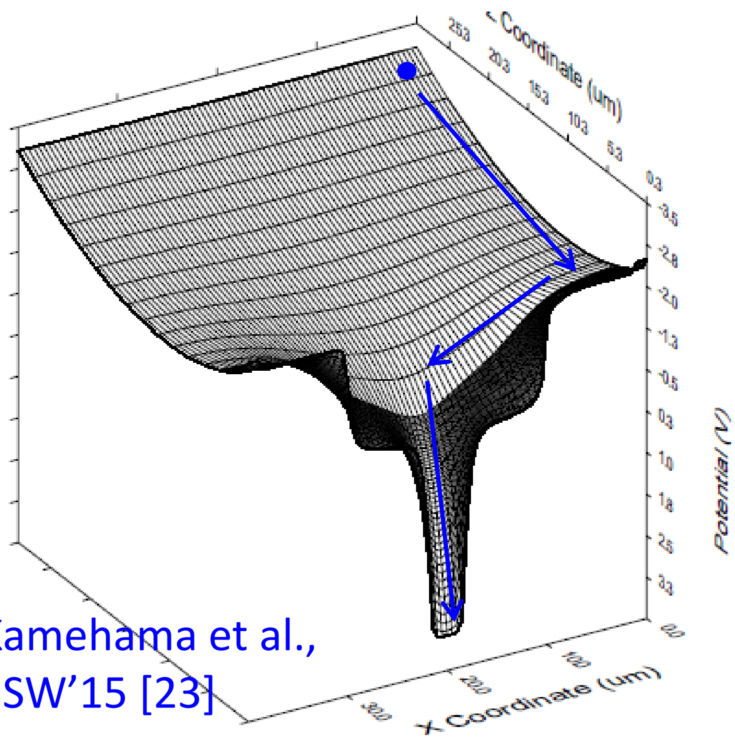
- Realizing lock-in TOF pixels based on SOI detector (fully depleted substrate)
- Near-infrared wavelength 940 nm, Q. E.> 80%
- Hybrid TOF sensor technique (Range shift method) with 4-tapped modulator is used. → Highly tolerated to strong sun light and having high resolution,.

TOF Camera Application

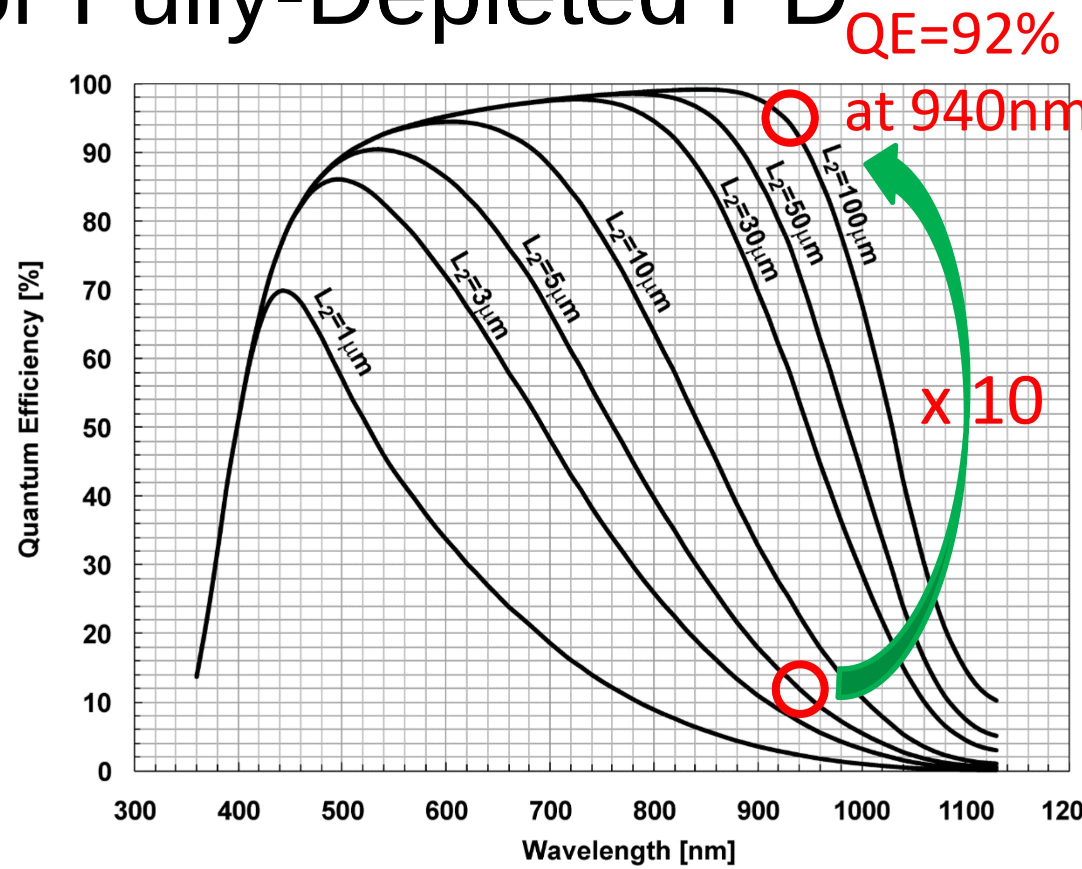


SOI Pixels for Fully-Depleted PD



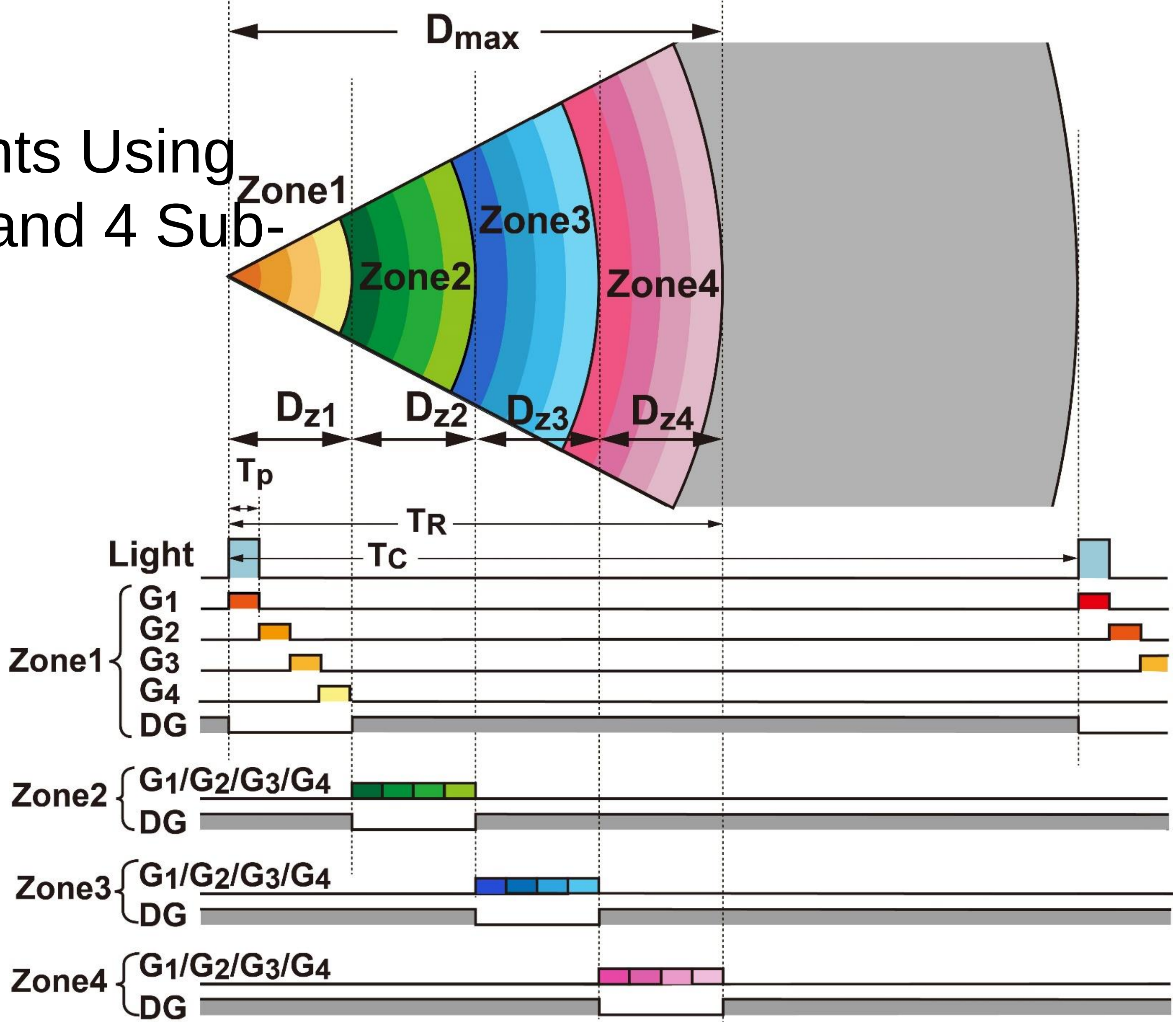


Kamehama et al., IISW'15 [23]



- High QE (>80%) at 940nm using 100μm-thick Sub.
- It can be used for Indirect TOF Detectors
- QE of 92% at 940nm is demonstrated.

Hybrid TOF Measurements Using 4-Tap Pixel and 4 Sub-frames



Efficient Measurement Time Assign. to Far & Near is possible.