Multi-Layer CCD

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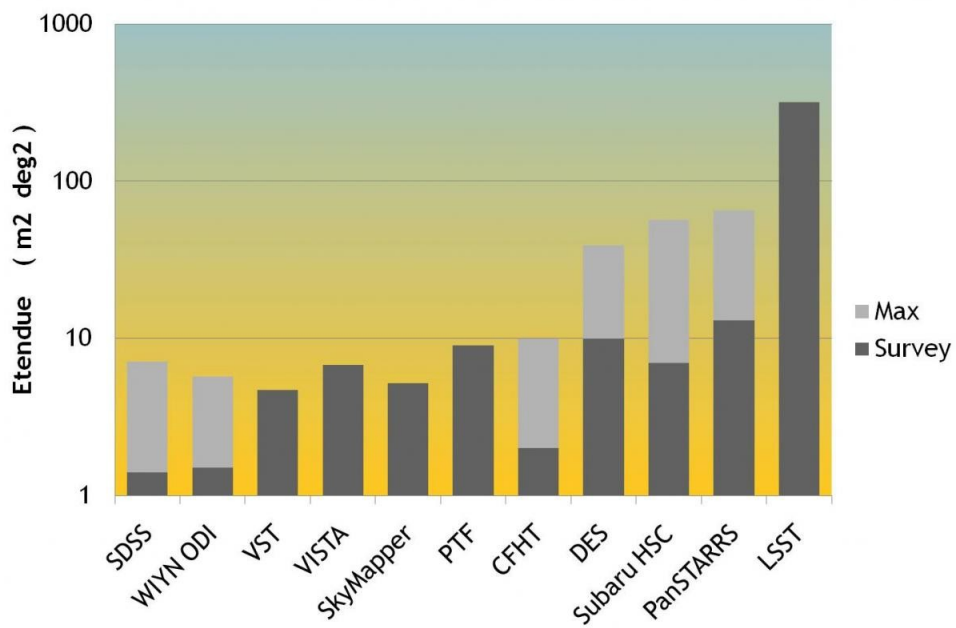
SLAC

Outline

- Telescope efficiency
- Multi-layer sensors
- Our approach

Telescope efficiency

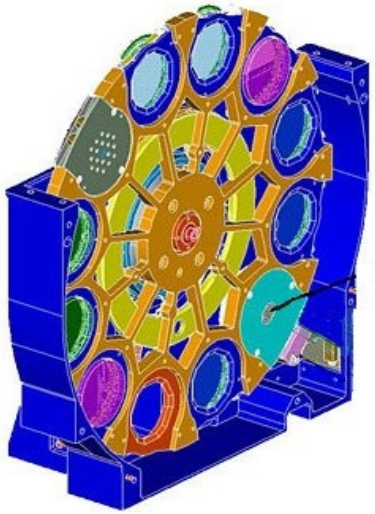
- Expensive facilities, lengthy surveys
- Speed ~ étendue = aperture area x FOV



lsst.org

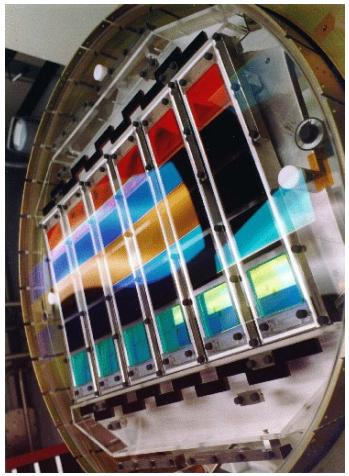
Telescope efficiency

- Color imaging

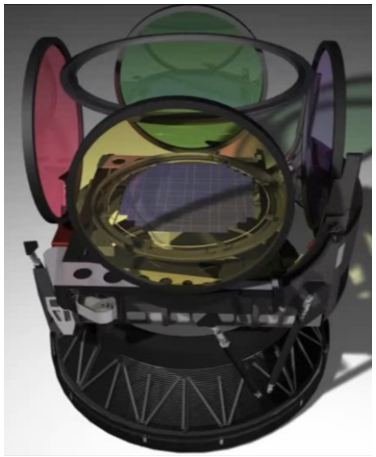


JWST NIRCAM

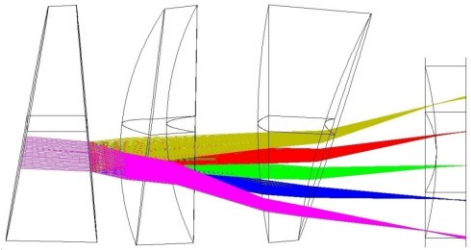
HST UVIS



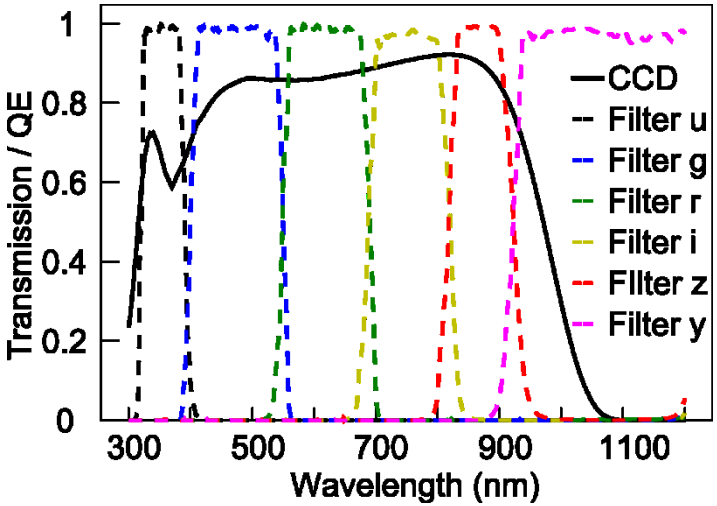
SDSS



LSST



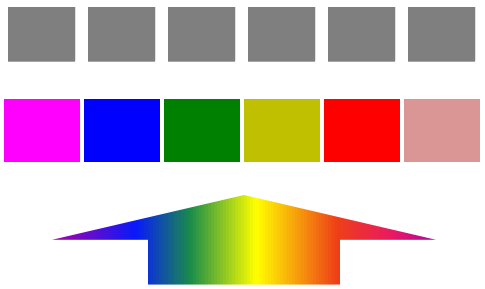
Swift UVOT



LSST

Telescope efficiency

- Color acquisition limits efficiency.



Telescope efficiency

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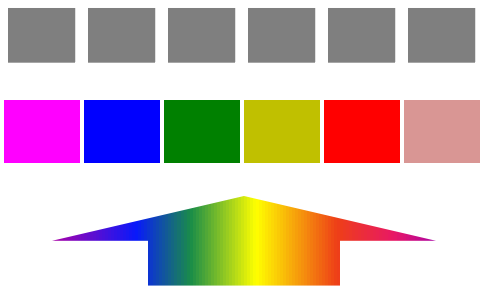
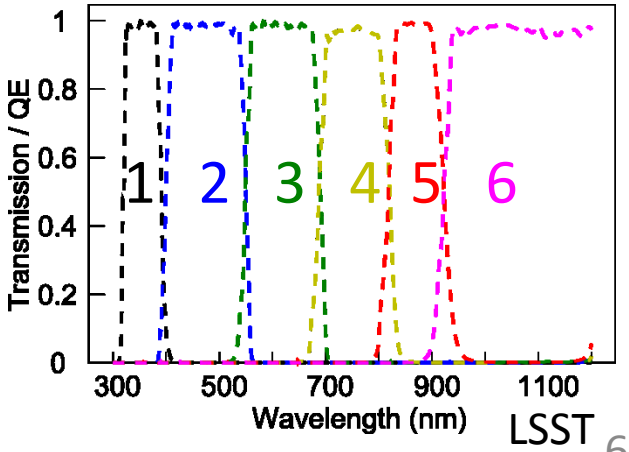


Monochromatic pixels

Wavelength selection

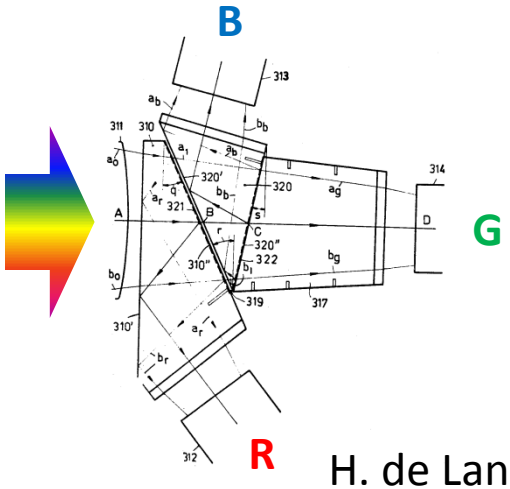
Broadband source

- How much is lost?
  - # of colors = N
  - Wasted photons (%) = $\frac{N-1}{N}$
  - Room for improvement = N

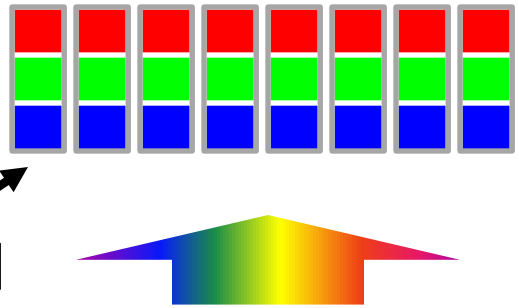


Telescope efficiency

- To utilize all incident photons
  - Multiple sensors
    - Hard to include more colors (multiple prisms, CCDs)
    - Bulky, expensive
  - Polychromatic pixels



H. de Lang 1965



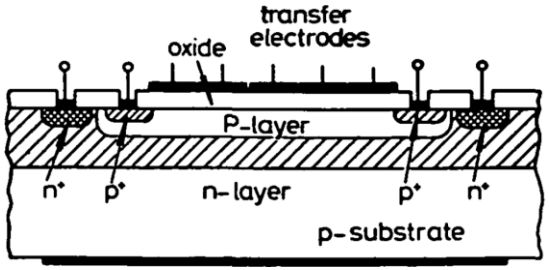
More info per pixel

Outline

- Telescope efficiency
- Multi-layer sensors
- Our approach

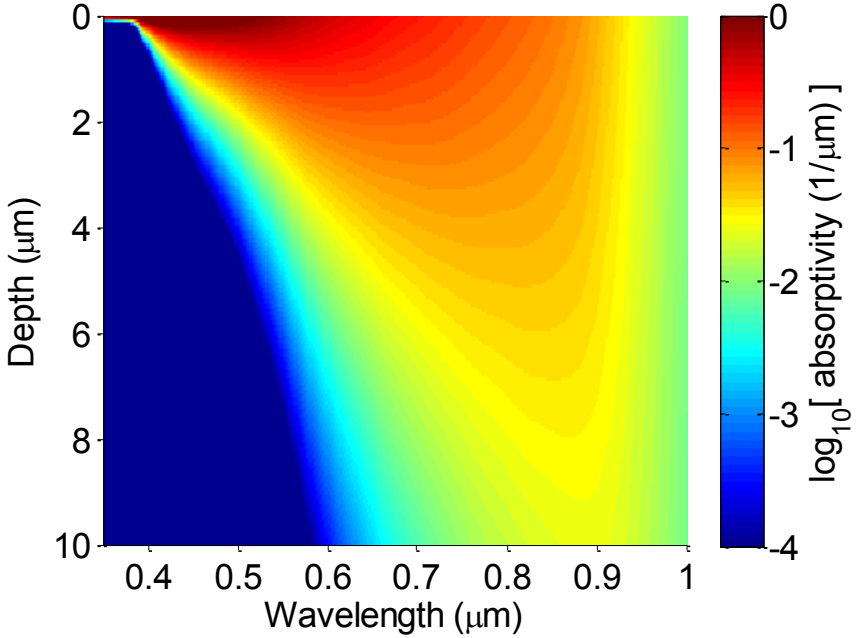
Multi-layer sensors

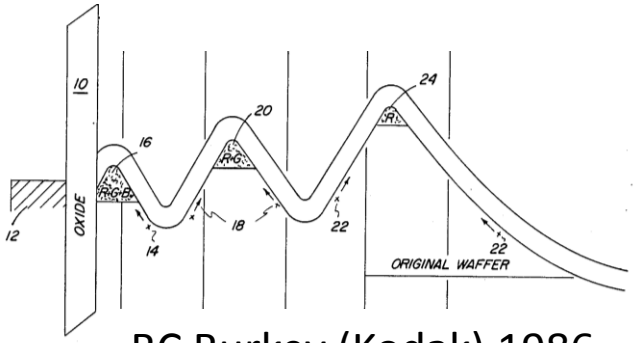
- Colors in the substrate



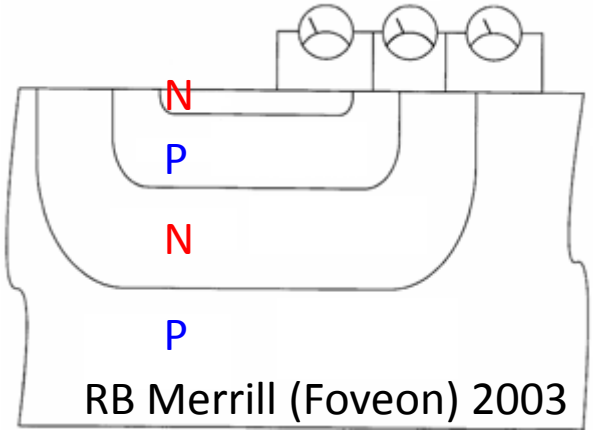
RM Barsan, 1978

Silicon absorptivity profile





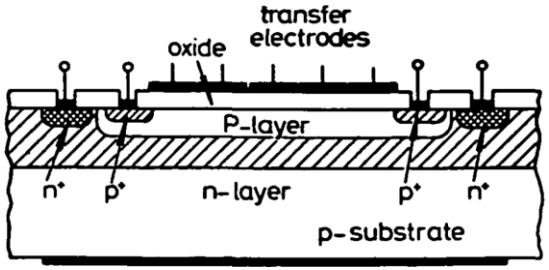
BC Burkey (Kodak) 1986



RB Merrill (Foveon) 2003

Multi-layer sensors

- Colors in the substrate



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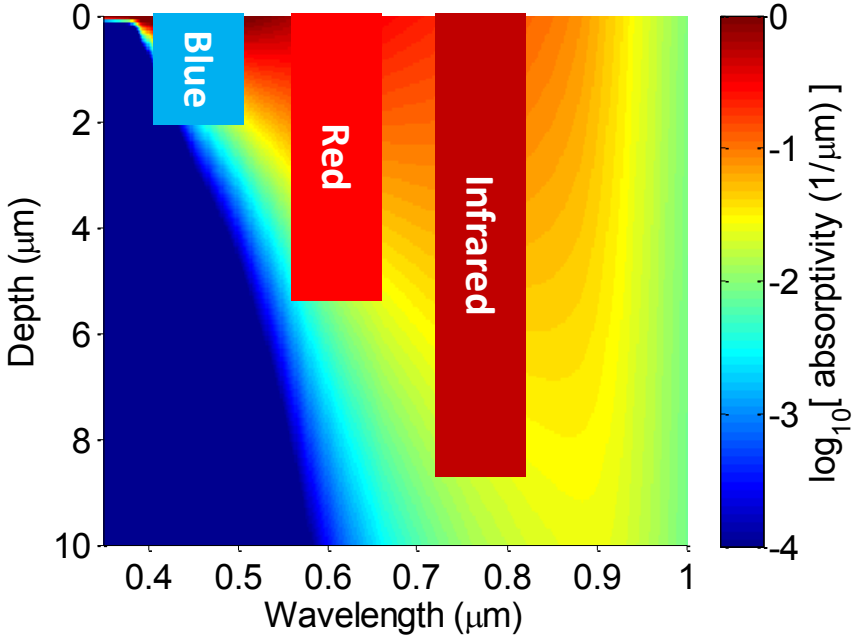

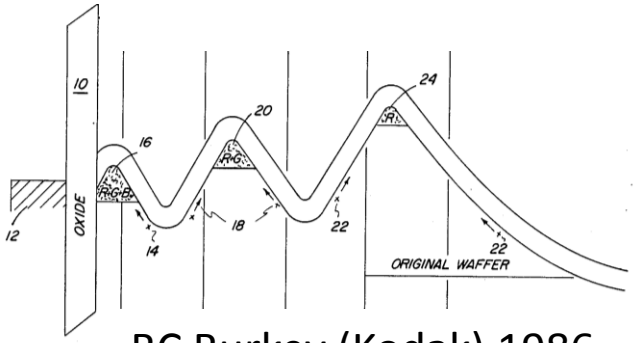

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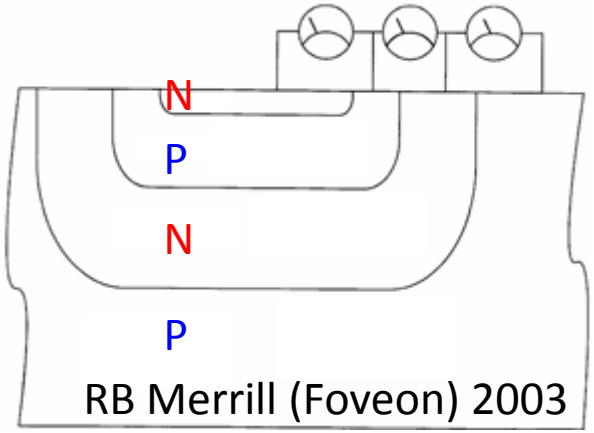
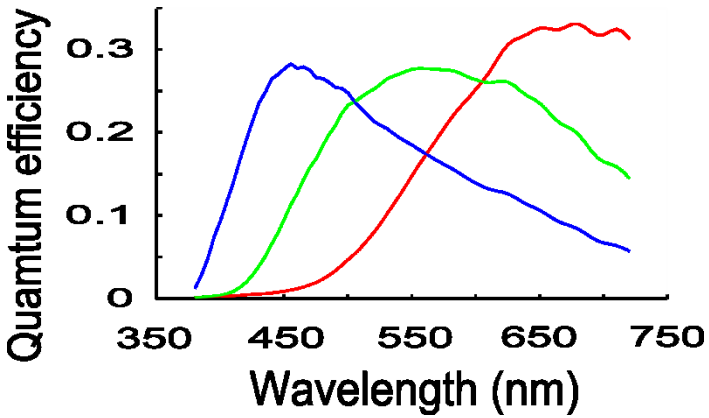


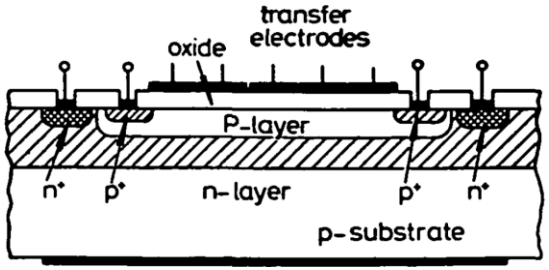
RB Merrill (Foveon) 2003

Multi-layer sensors

- PN-junction layers
  - Color crosstalk



  - Difficult to add layers
  - Blue-side connections
    - Limits fill factor (CMOS)



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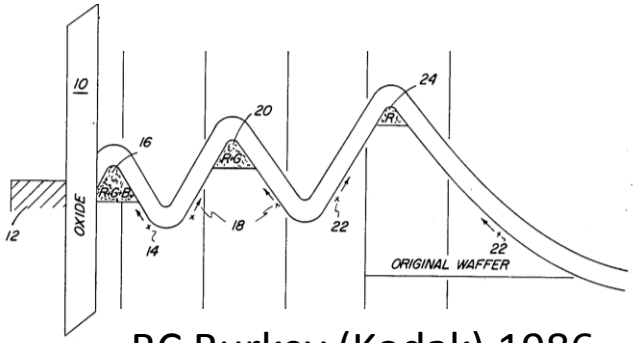

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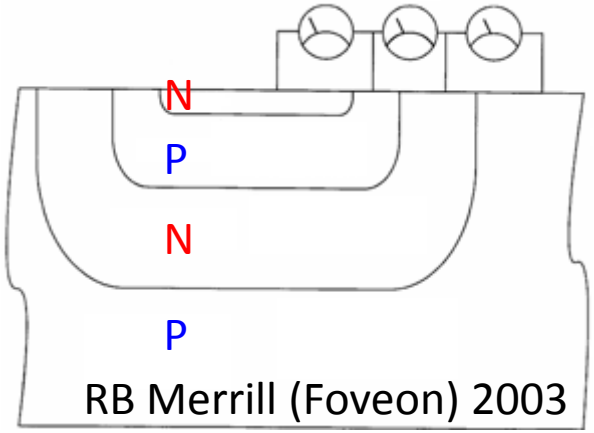

RB Merrill (Foveon) 2003

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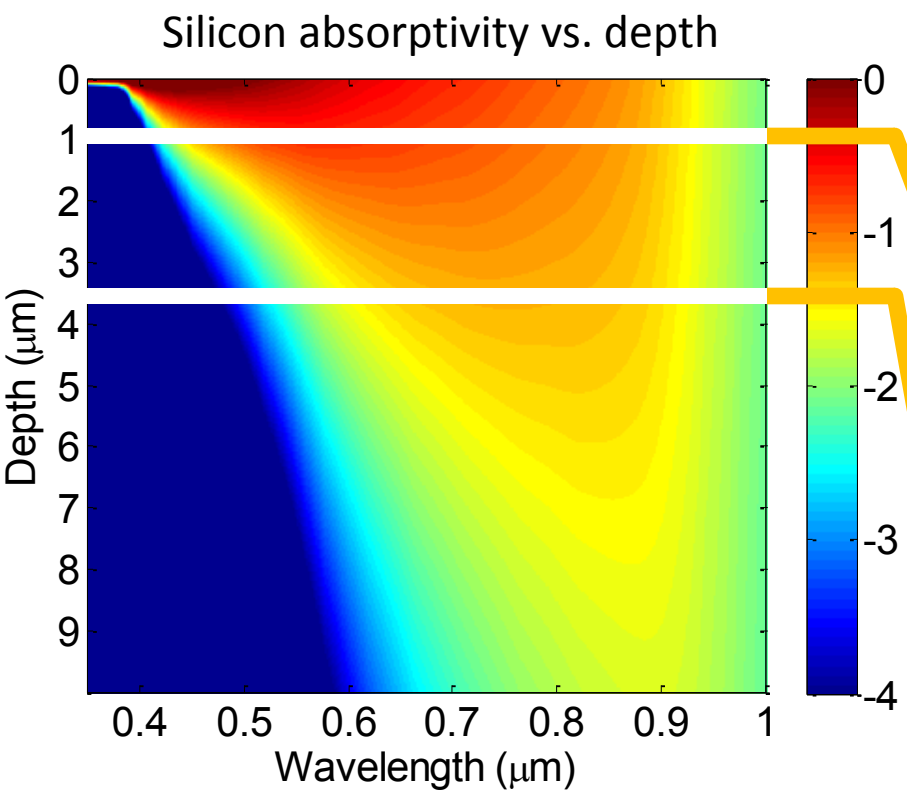
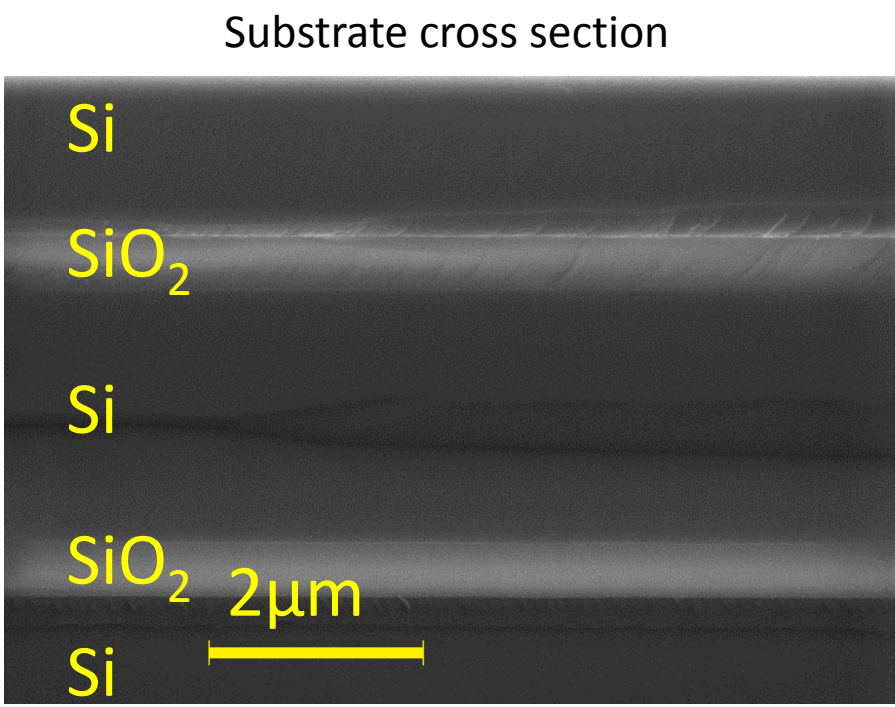
- Telescope efficiency
- Multi-layer sensors
- Our approach
  - Concept
  - Design
  - Experiment

Multi-layer SOI CCD

- CCD on silicon-on-insulator (SOI) substrates
- Each Si layer provides a color.

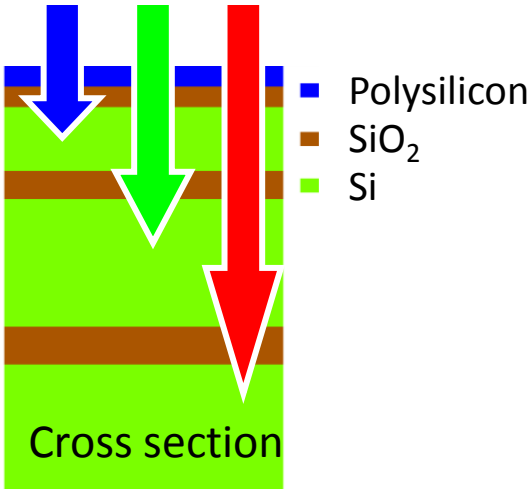


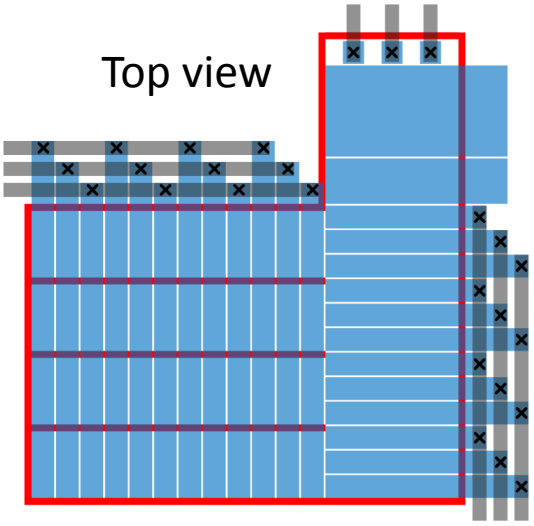


Multi-layer SOI CCD

- Features
  - Minimal waste of photons
  - Buried insulators
    - Optical/electrical separation
  - No in-pixel connections
  - Can stack more colors/layers
- CCD + buried optical filters

→Multifold faster color imaging





Outline

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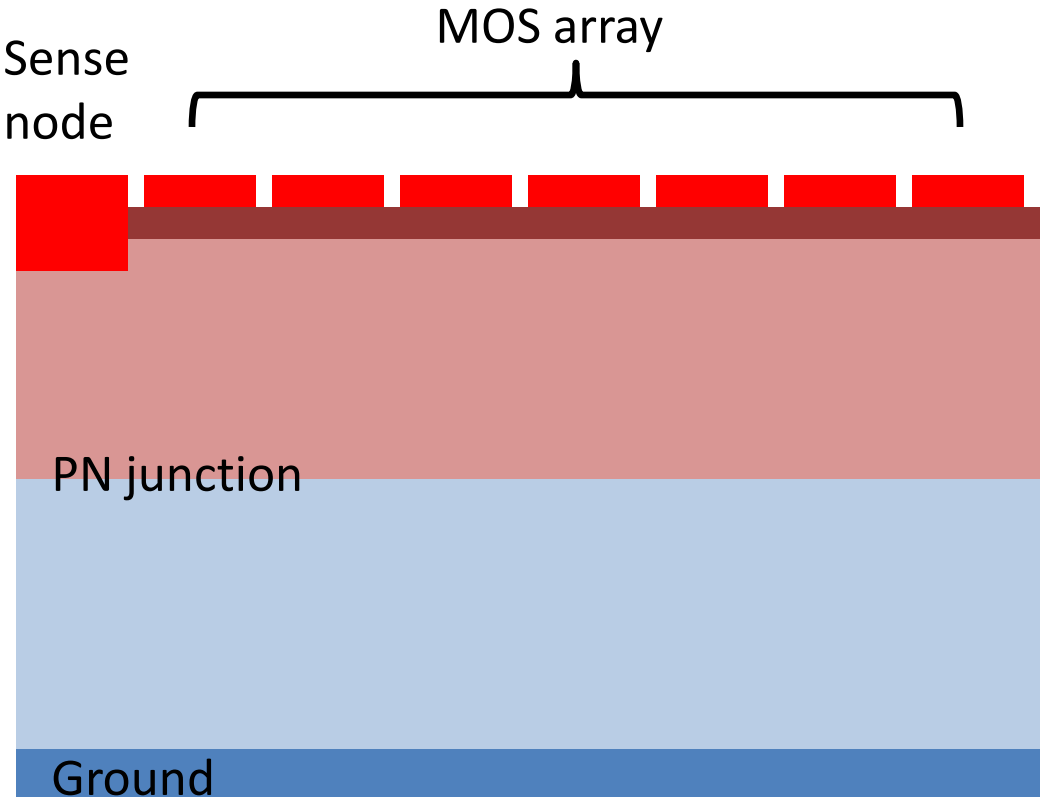
- Multi-layer sensors
- Multi-layer SOI CCD
  - Concept
  - Design
  - Experiment

CCD quick review

- Device operation
  - Equilibrium
  - Channel depletion
  - Optical absorption
  - Charge generation
  - Charge collection
  - Charge transfer
  - Charge measurement



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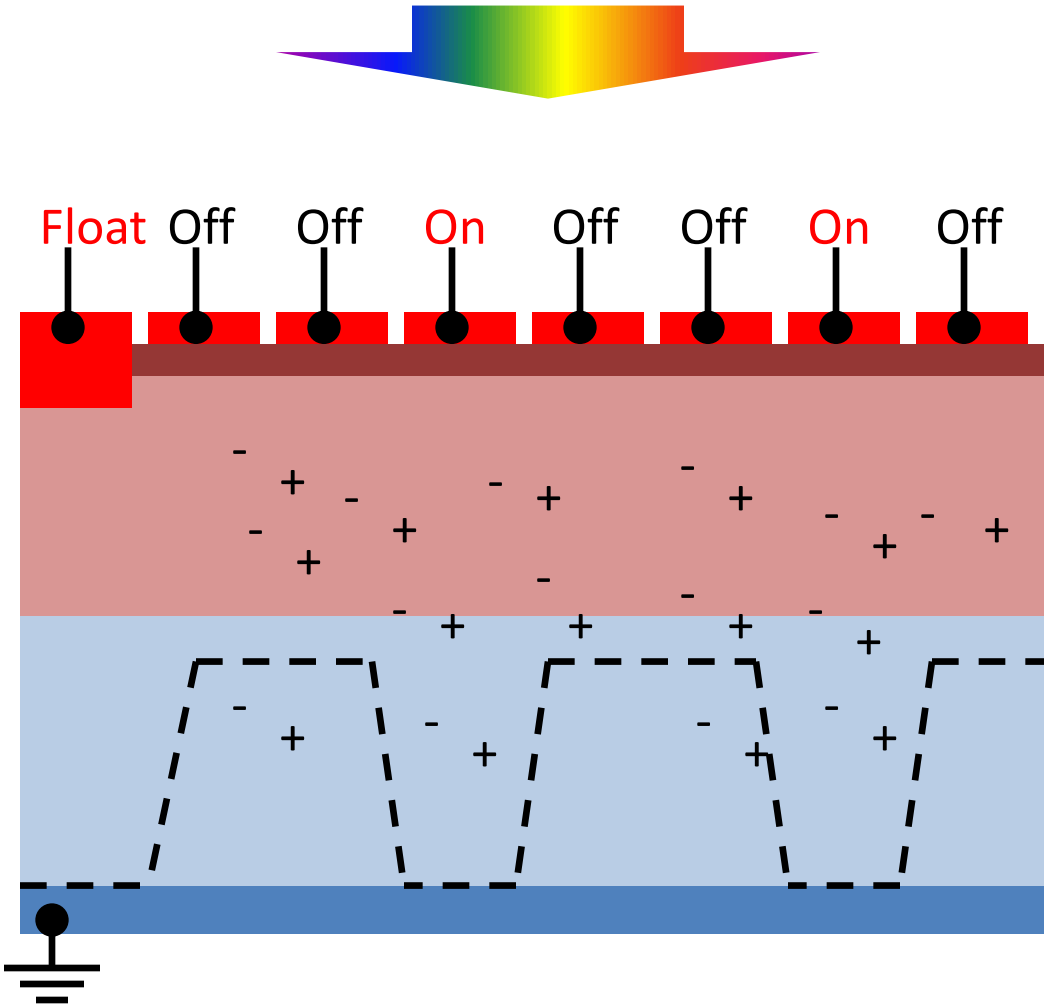

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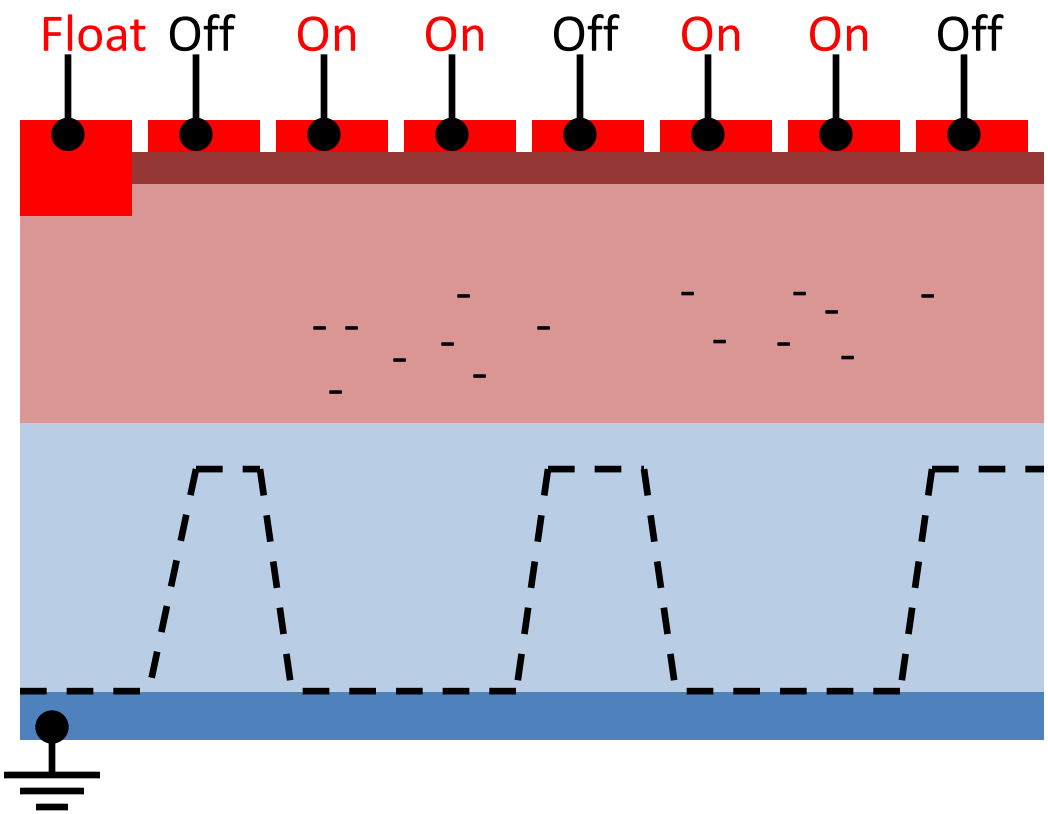

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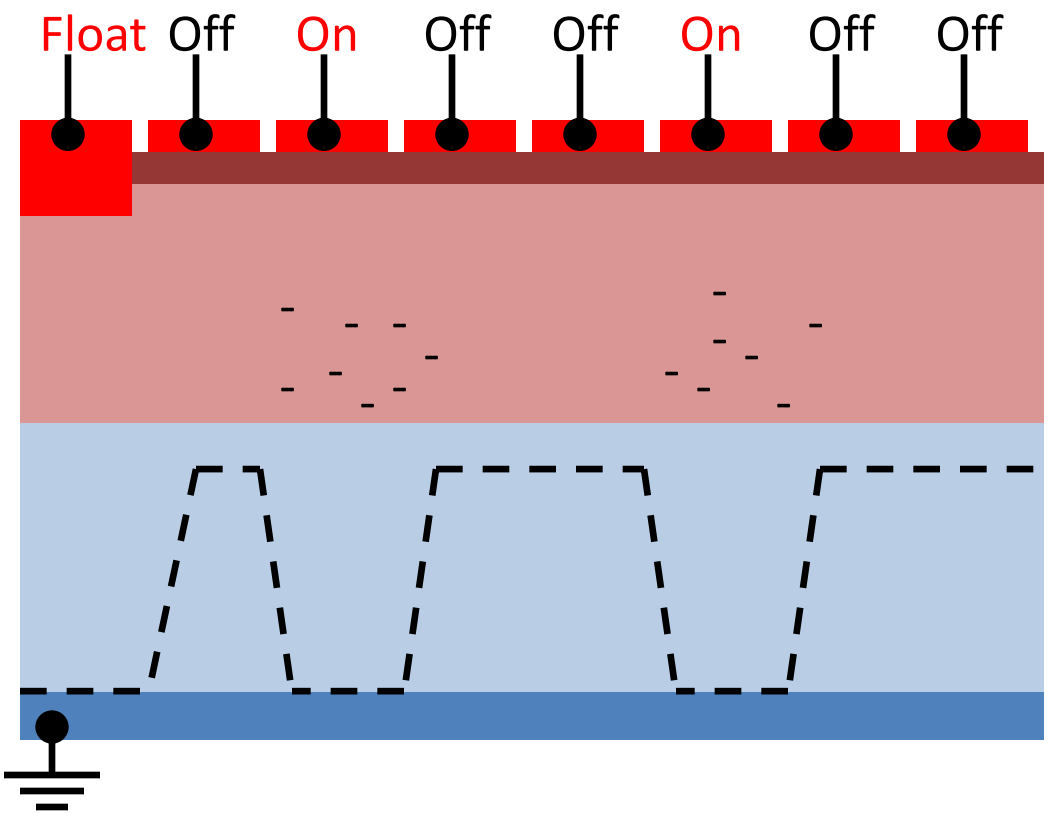
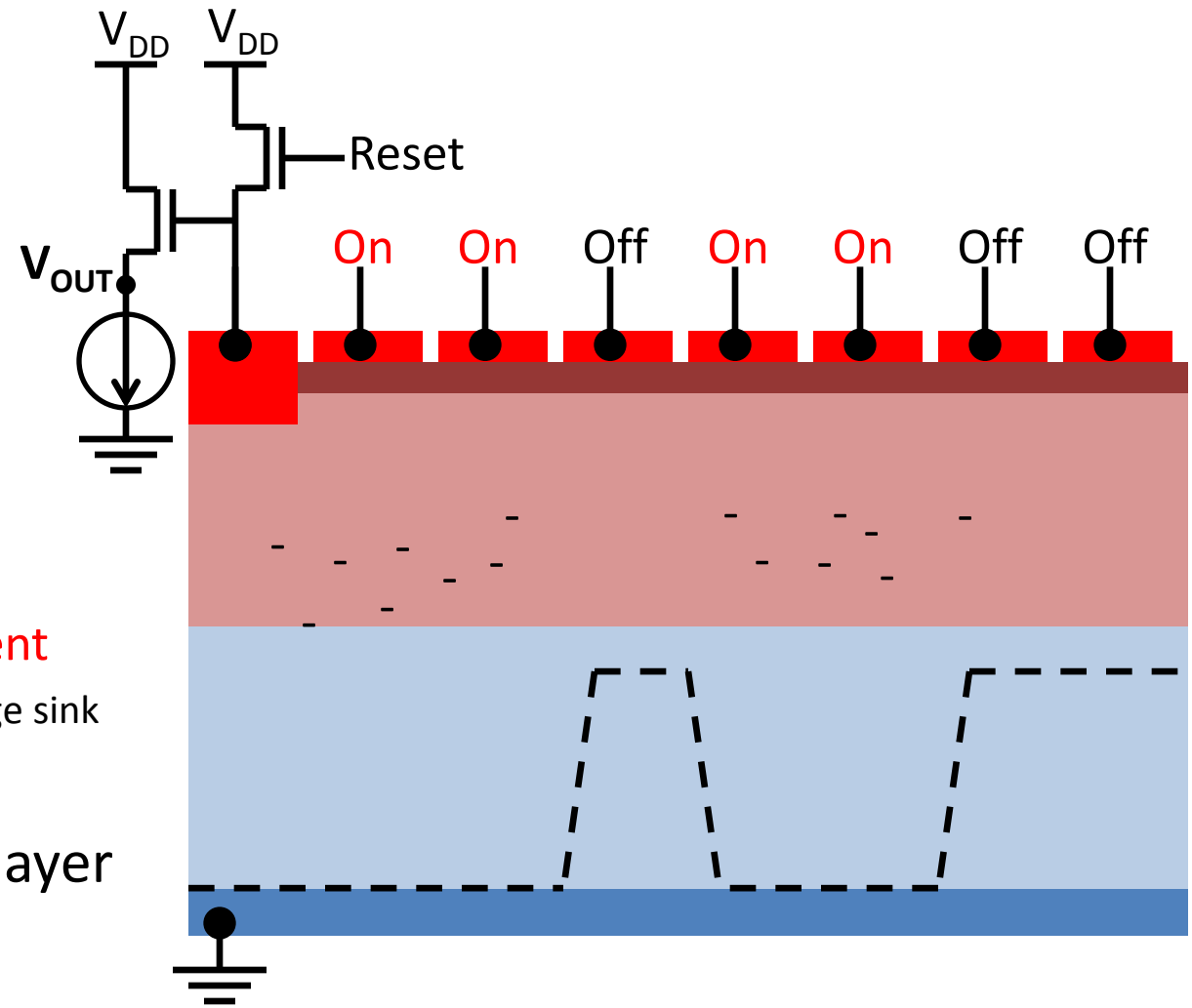


CCD quick review

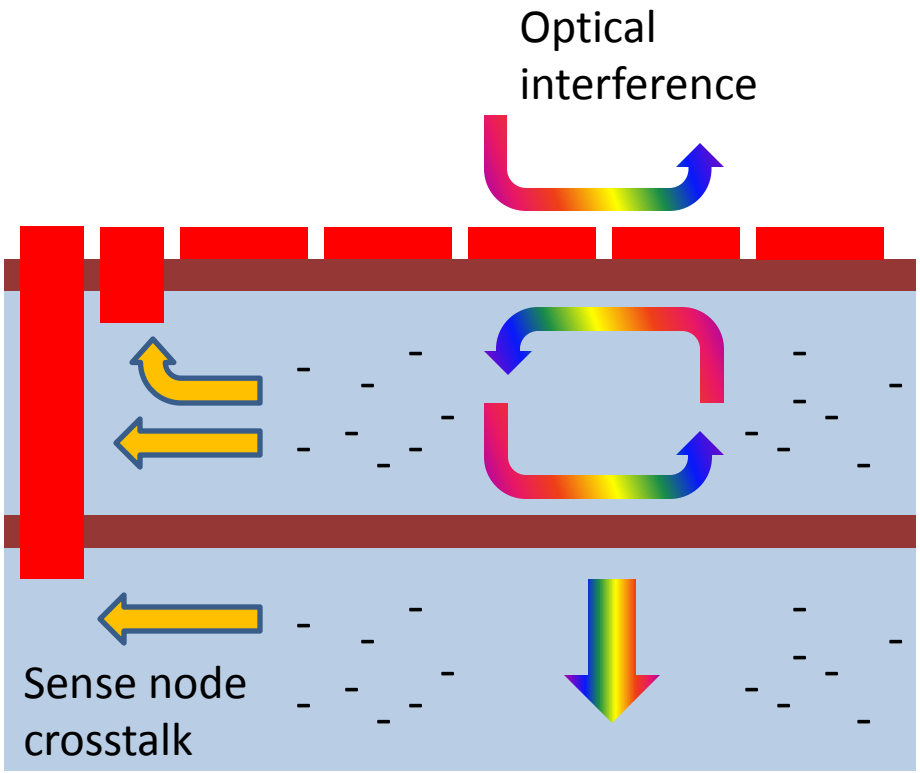
- Device operation
  - Equilibrium
  - Channel depletion
  - Optical absorption
  - Charge generation
  - Charge collection
  - Charge transfer
  - Charge measurement
    - Sense node ≈ charge sink

Different for multi-layer CCDs



Multi-layer SOI CCD

- Experimental demonstration
  - Optical absorption
  - Charge measurement
- Charge transfer

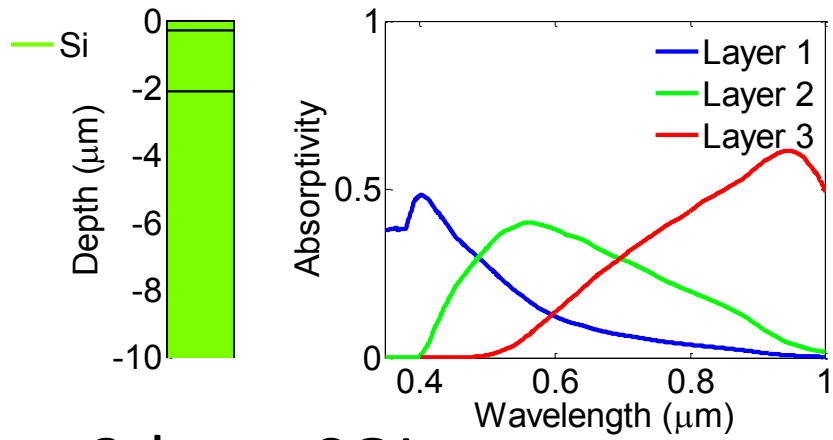


Optical design

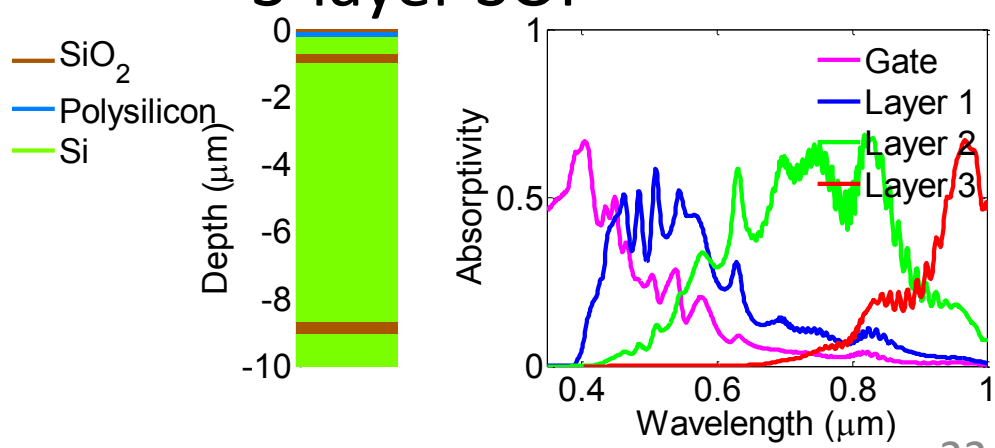
- Performance gain with simple designs
- Multi-layer dielectric for further improvements

- Bare silicon

1D S-matrix



- 3-layer SOI



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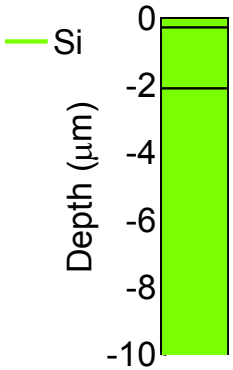

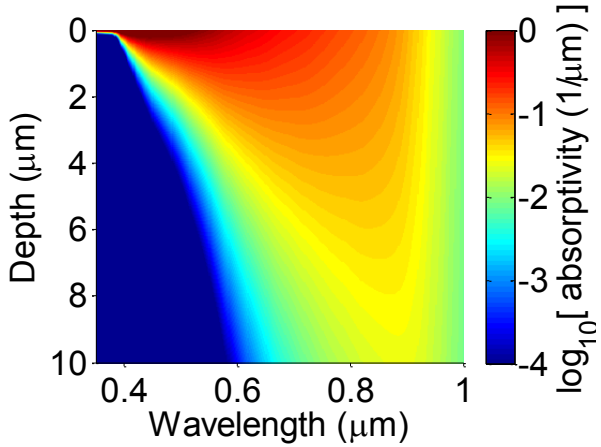

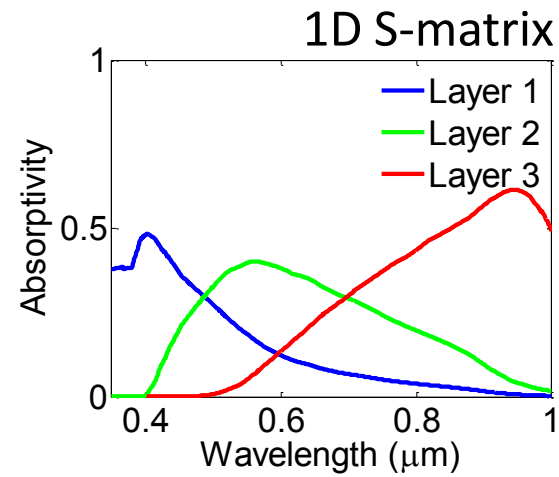

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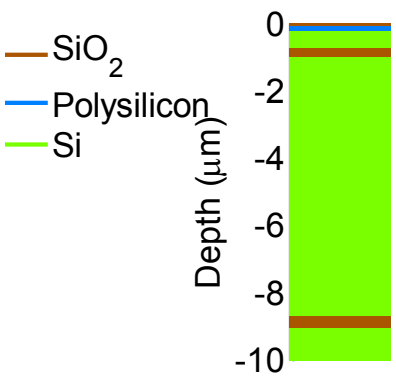

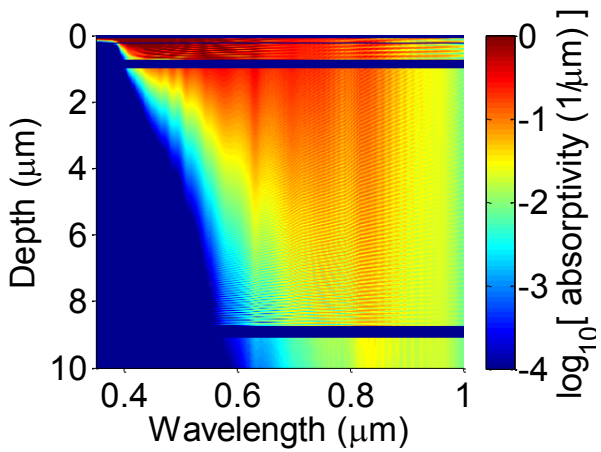

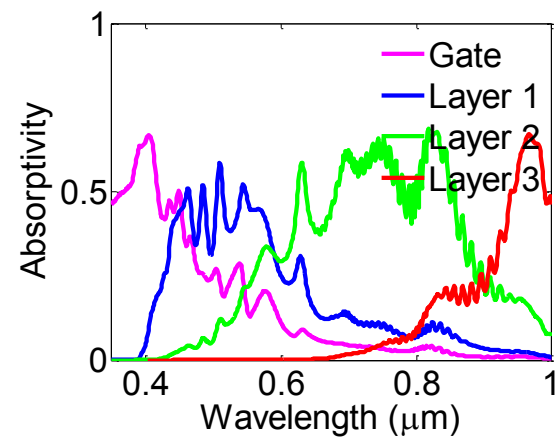

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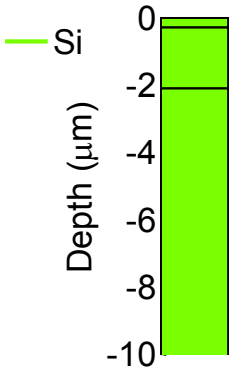

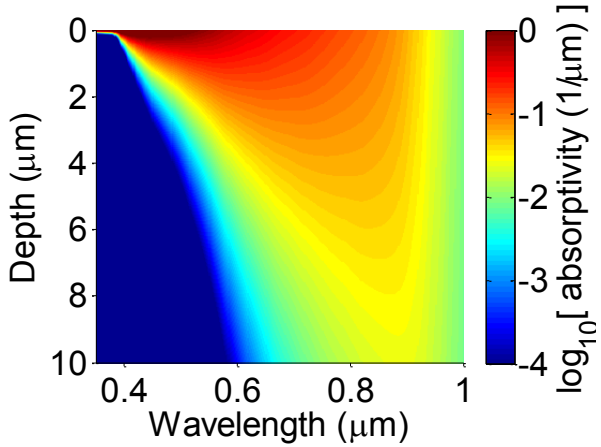

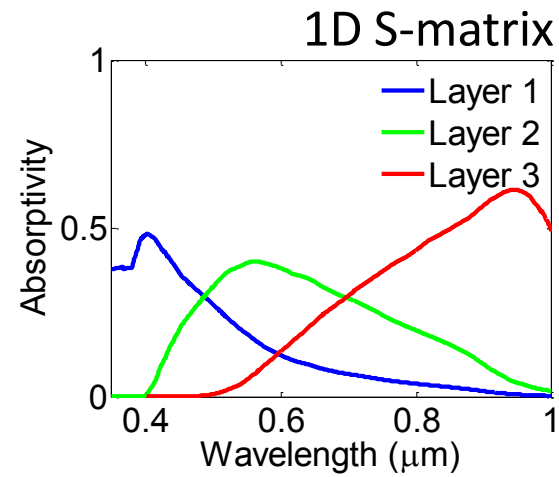

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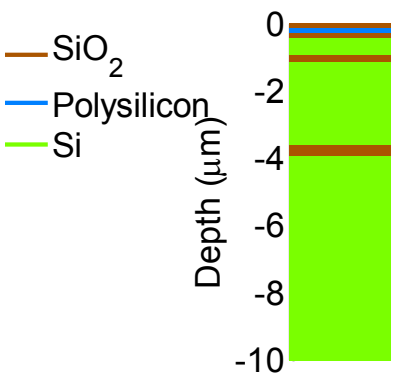

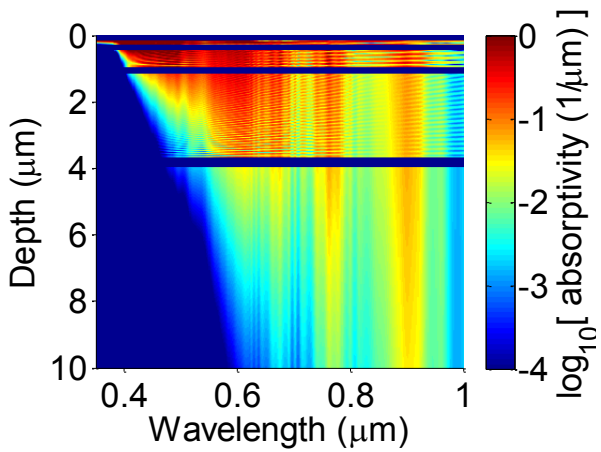

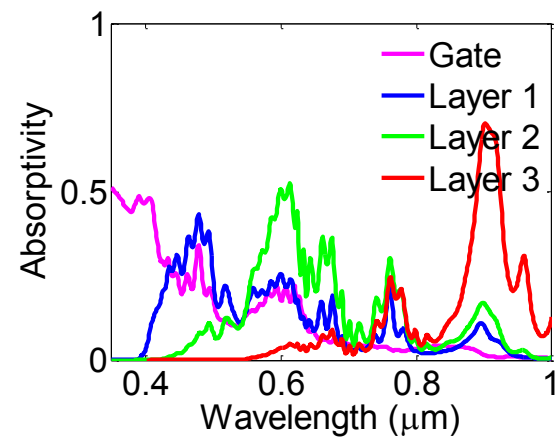

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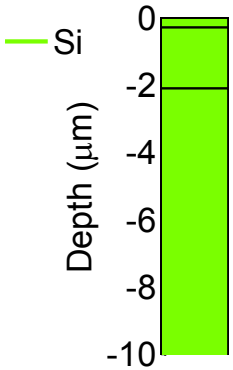

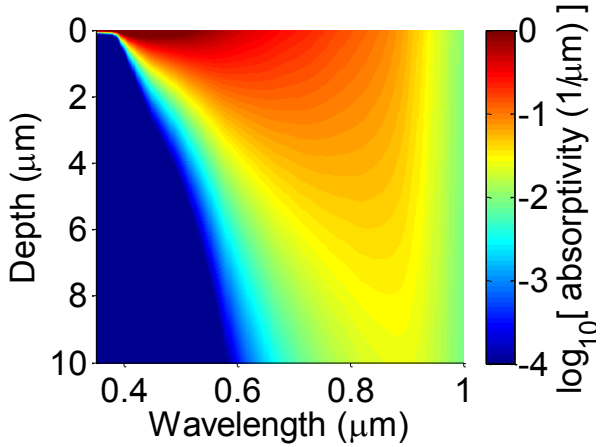

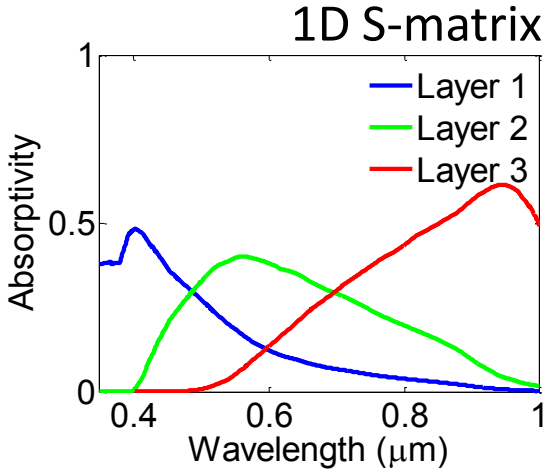

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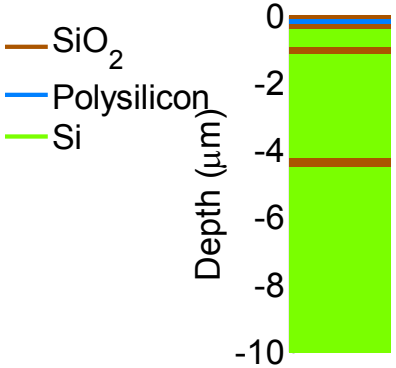
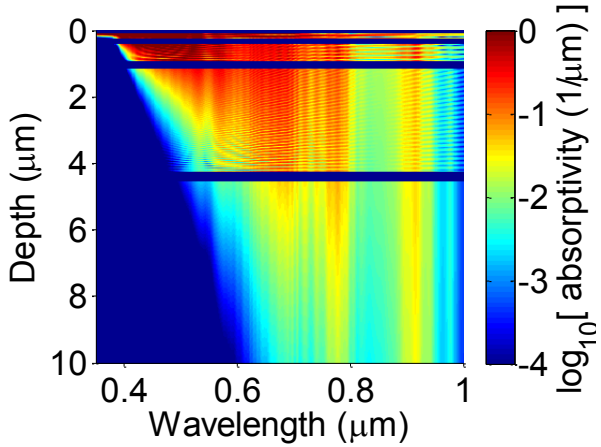
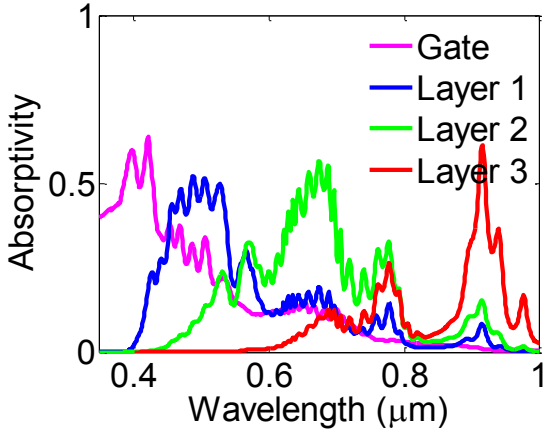


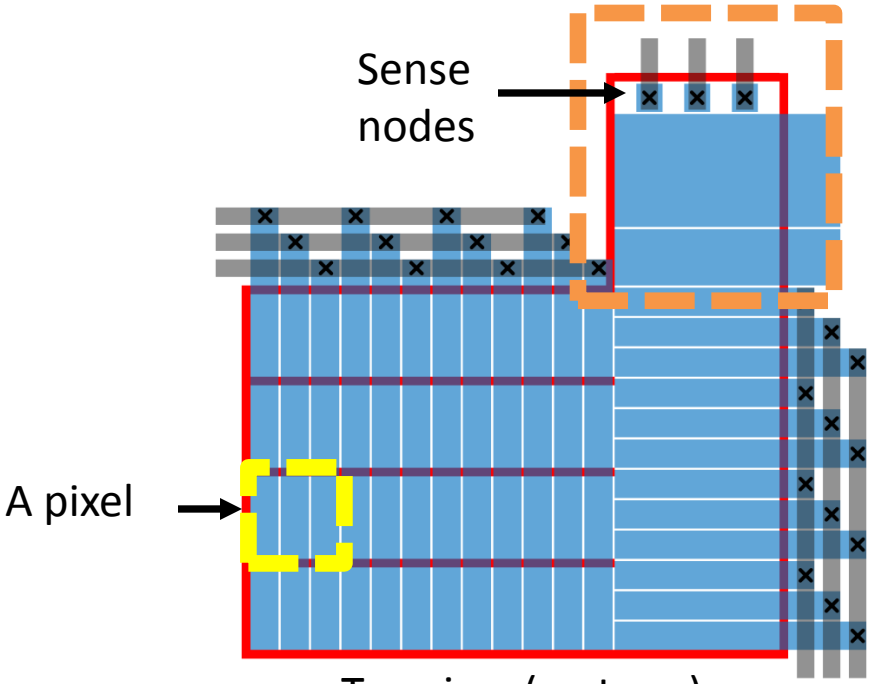




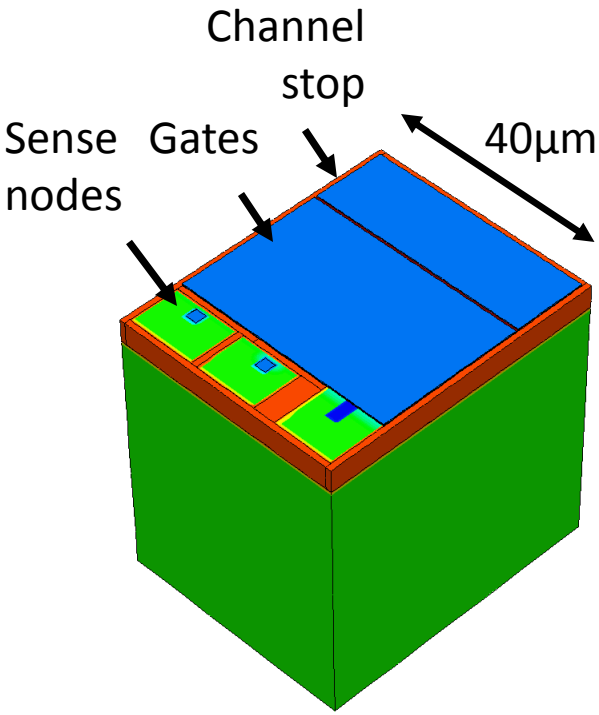
- Can we extract signals from these layers?

Device design

- Special sense nodes can extract charge with little crosstalk.

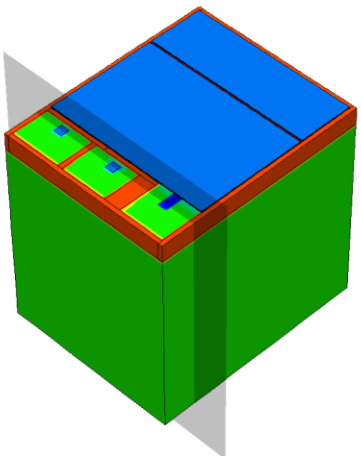


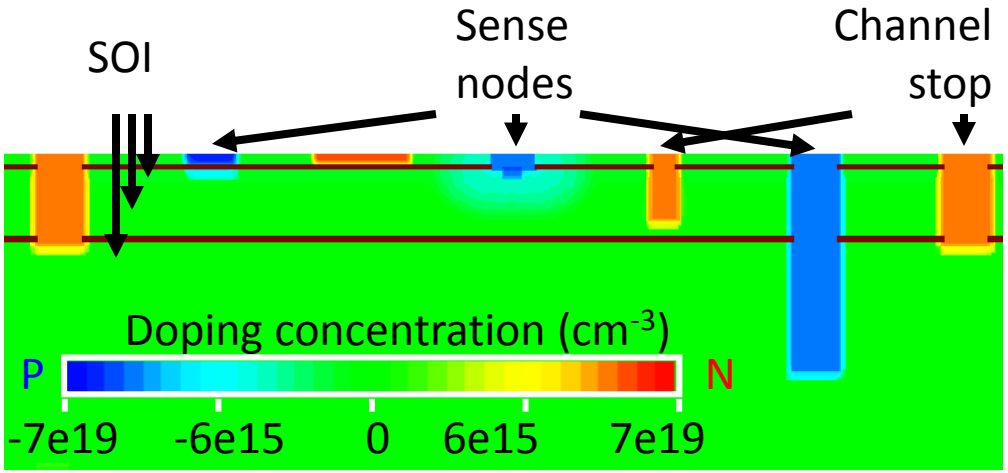
Top view (cartoon)

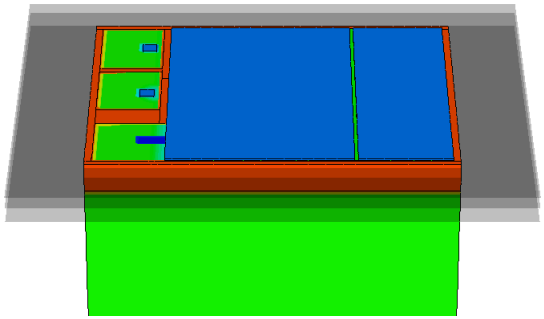


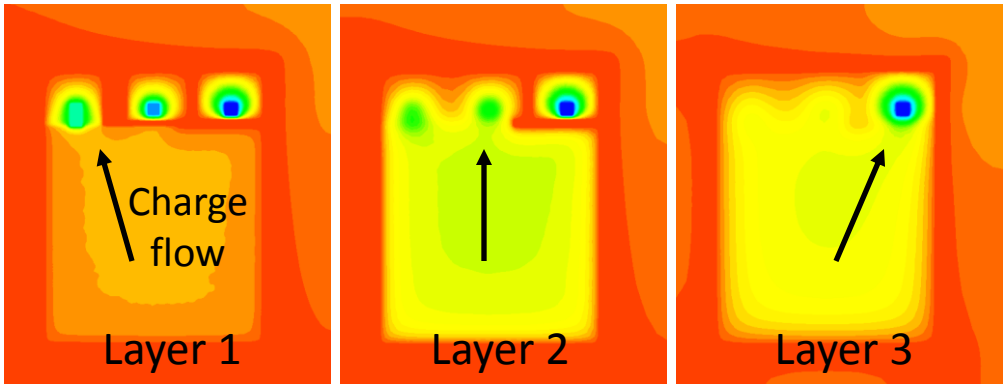
3D model in Synopsys Sentaurus

Device design

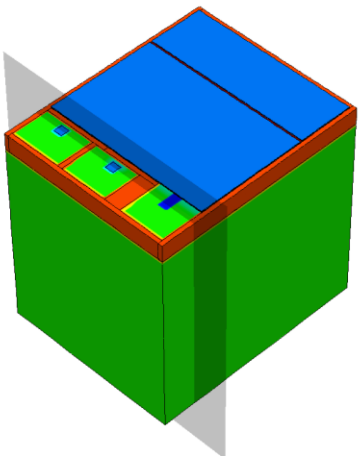


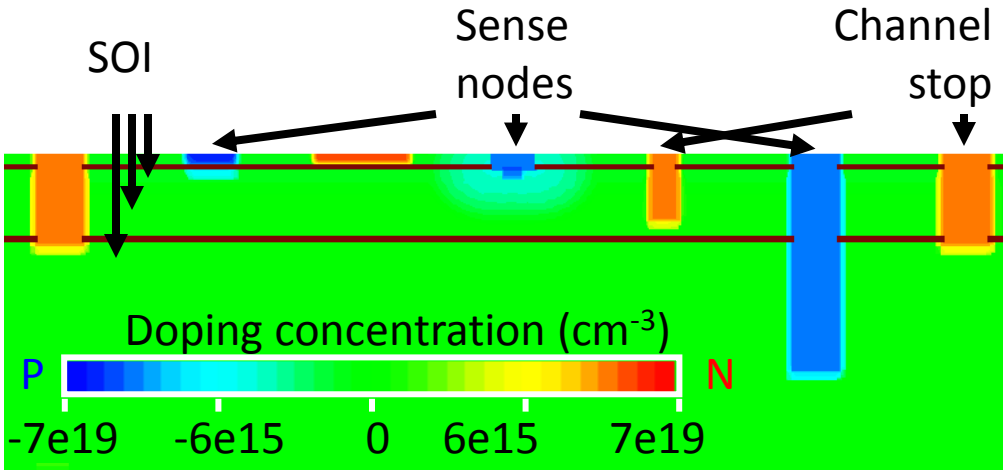


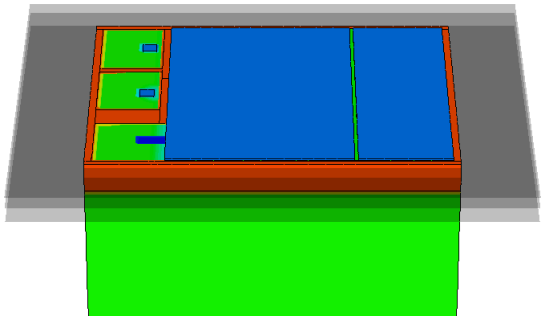


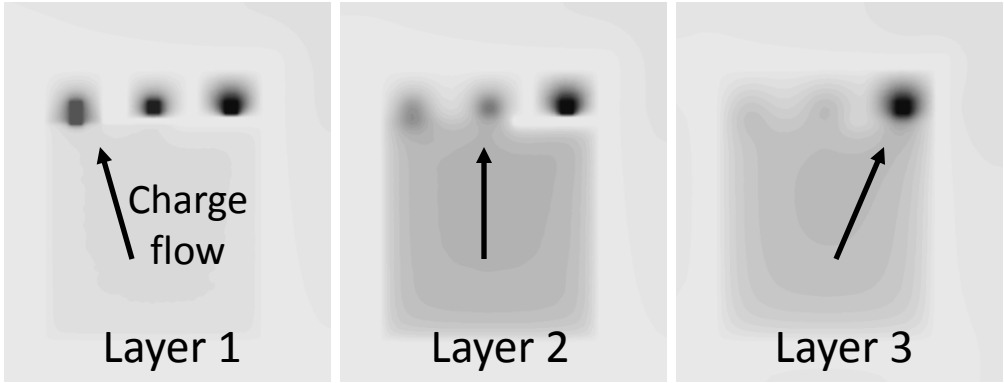


Device design





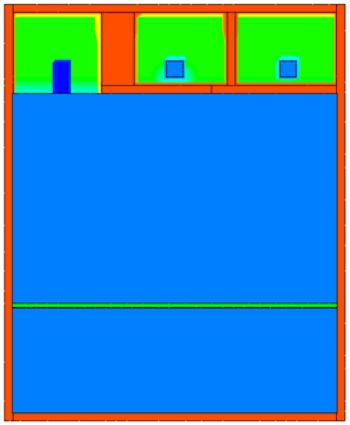


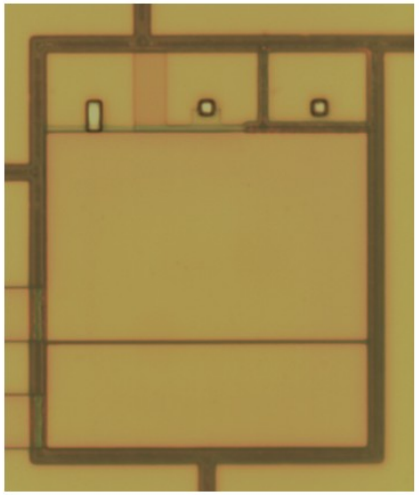


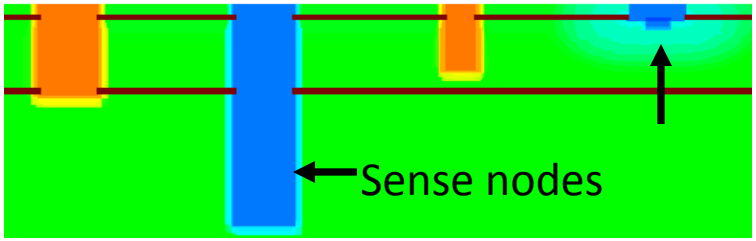
Outline

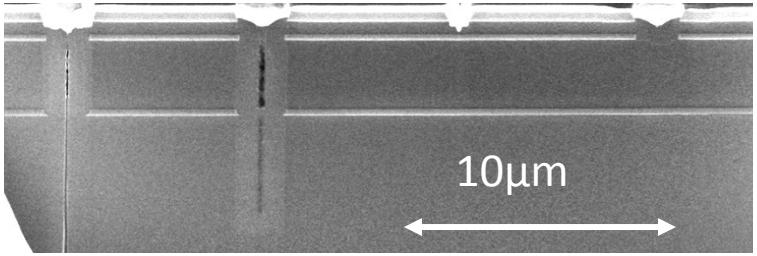
- Telescope efficiency
- Multi-layer sensors
- Multi-layer SOI CCD
  - Concept
  - Design
  - Experiment
- Future work

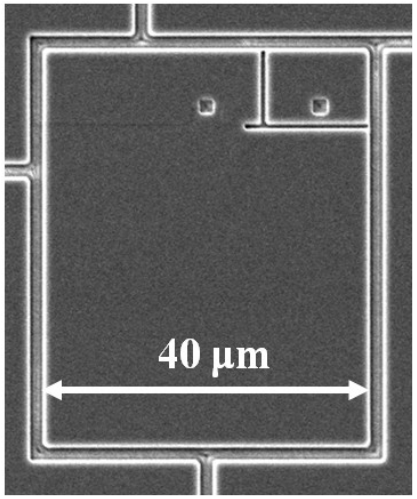
Experiment

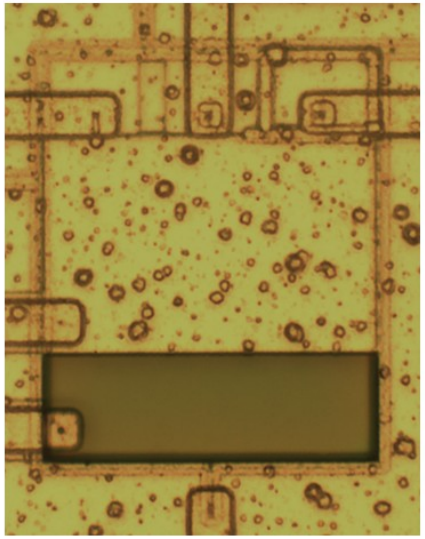


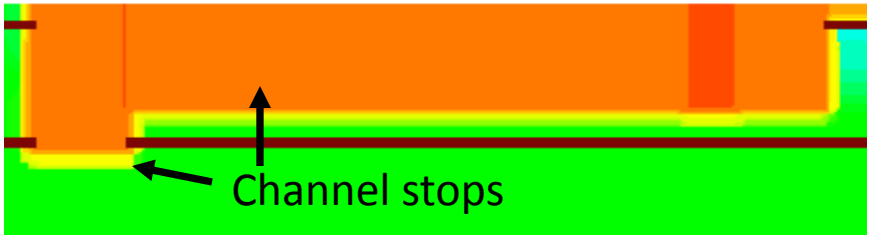


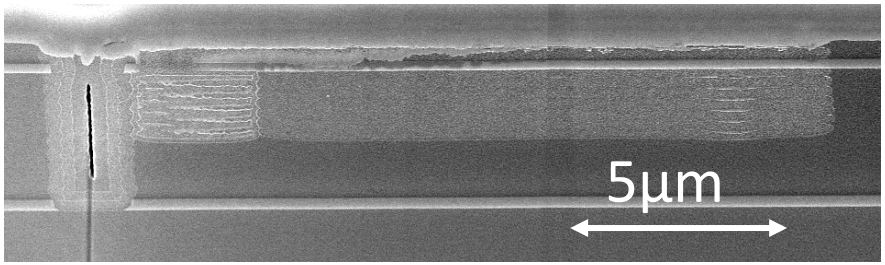










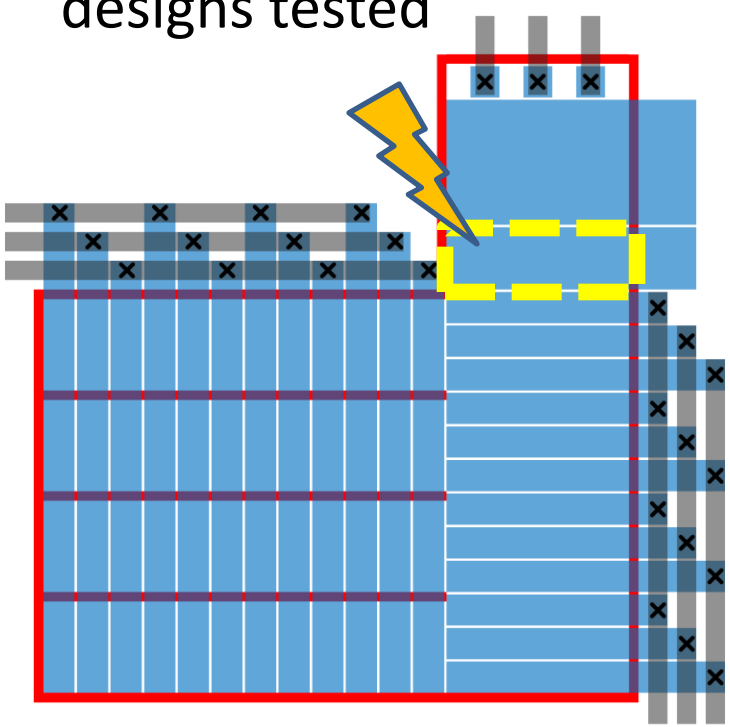


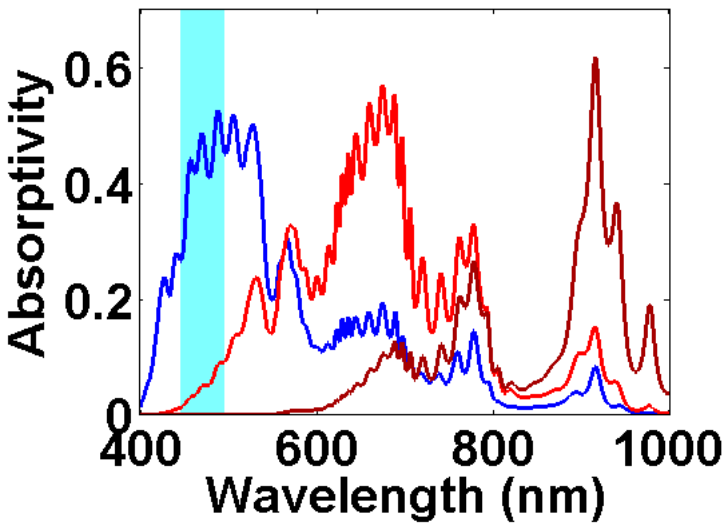
Top views

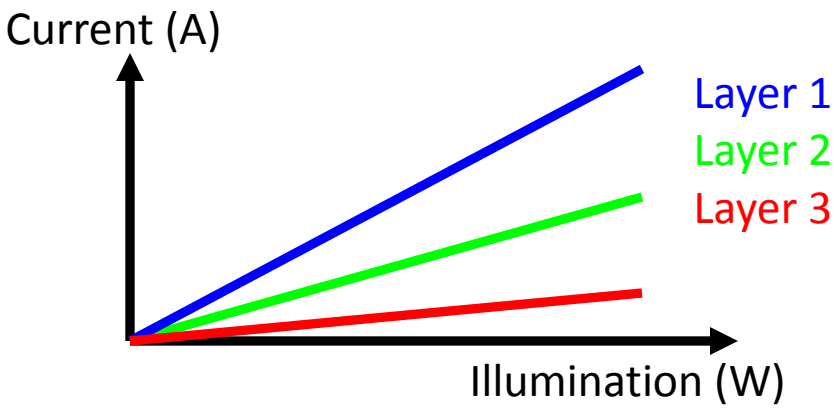
52° cross sections

Experiment

- Constant light, DC bias
  - $\text{Current}_{\text{layer}}(\lambda)$
  - Optical and sense node designs tested

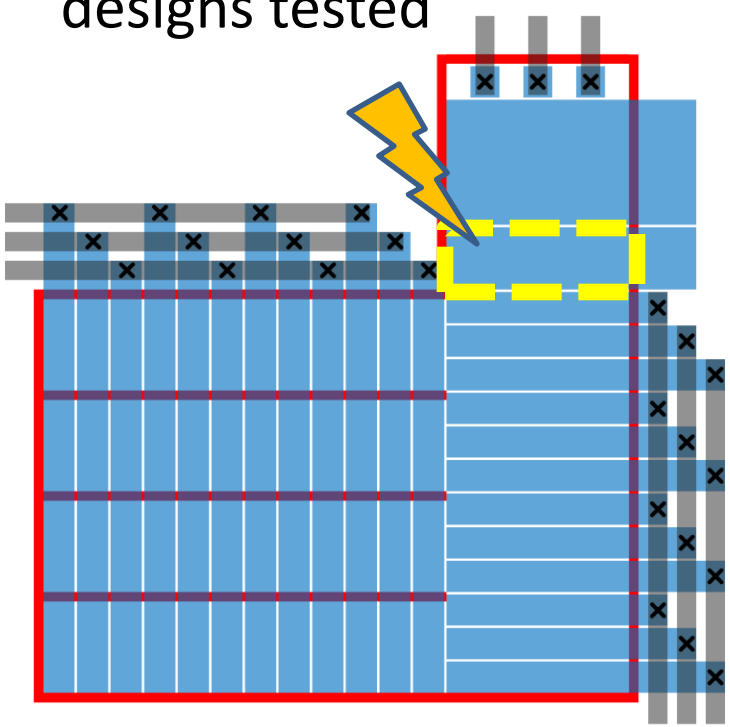


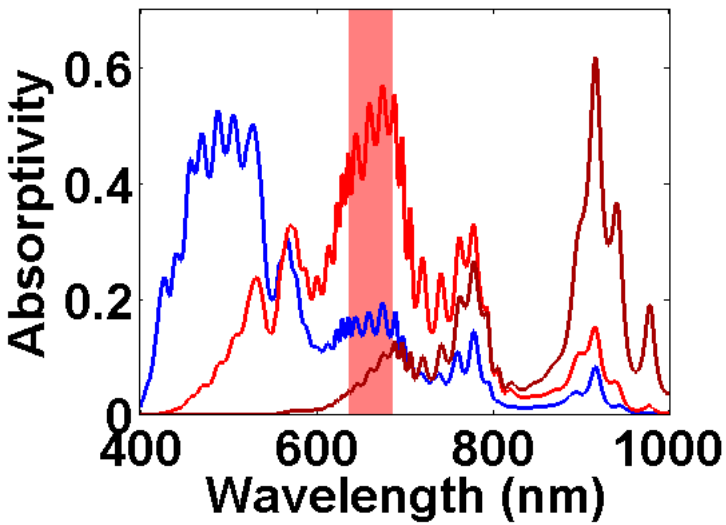


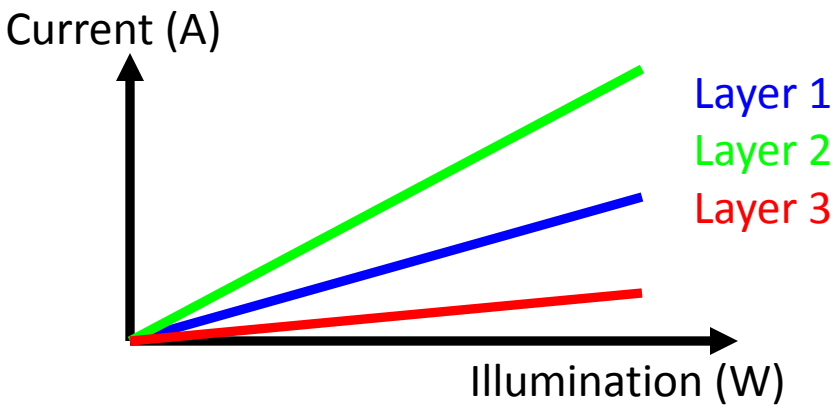


Experiment

- Constant light, DC bias
  - $\text{Current}_{\text{layer}}(\lambda)$
  - Optical and sense node designs tested

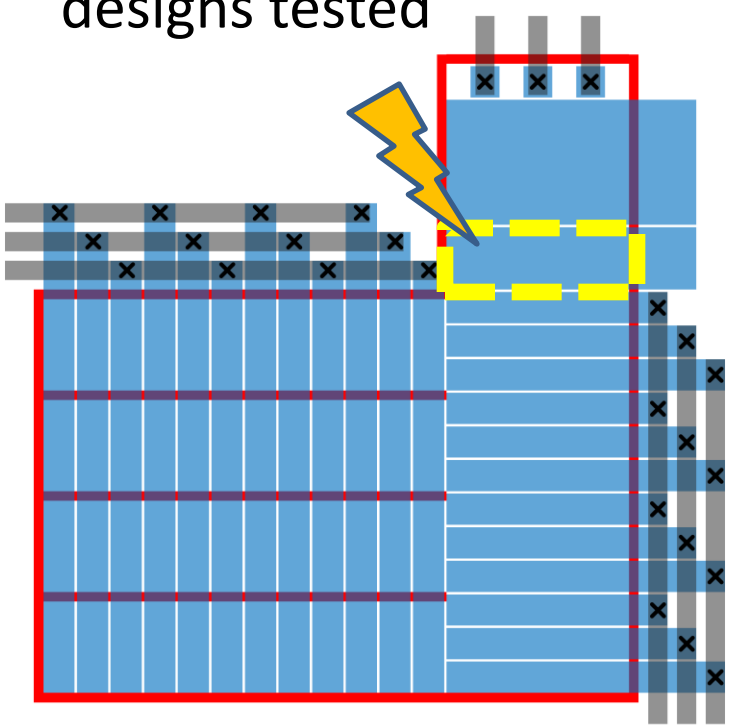


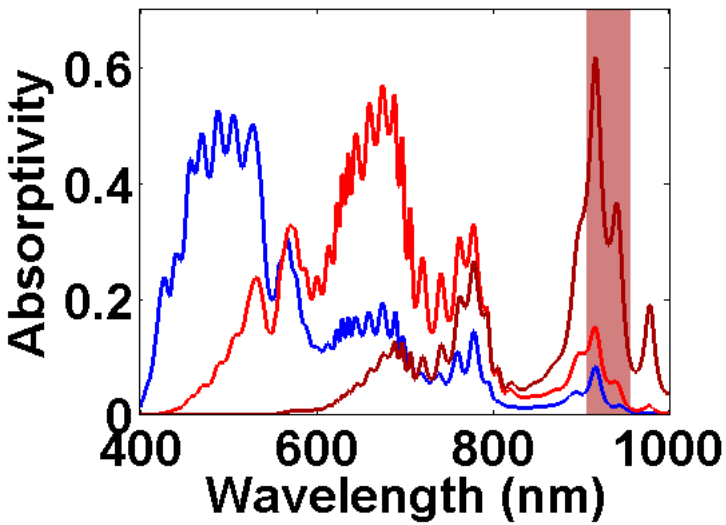


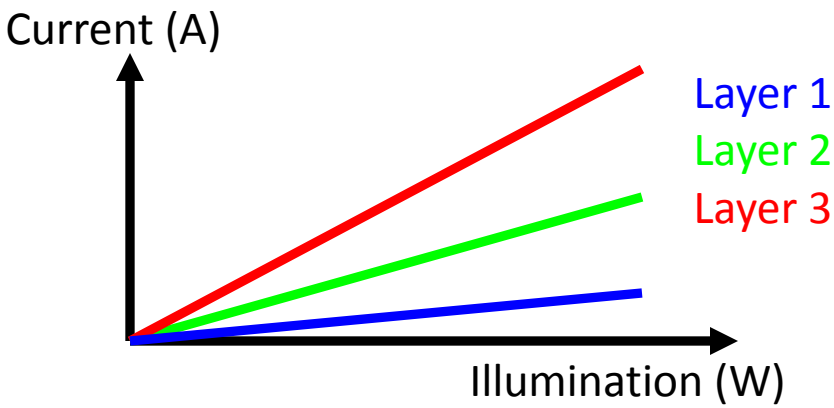


Experiment

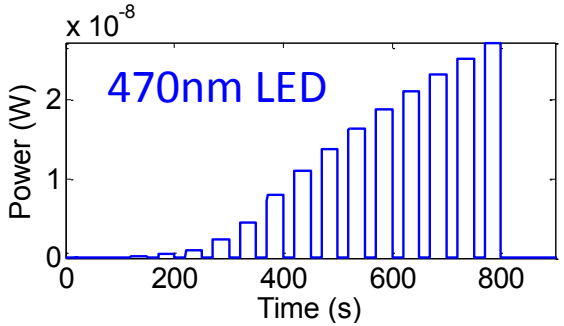
- Constant light, DC bias
  - $\text{Current}_{\text{layer}}(\lambda)$
  - Optical and sense node designs tested

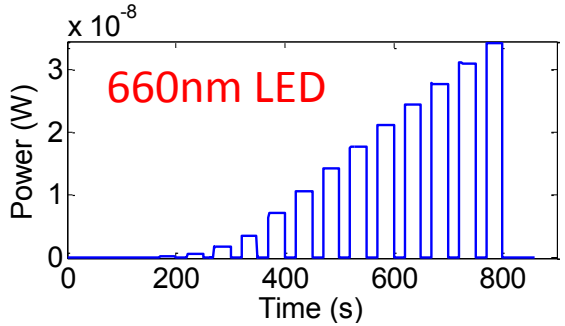


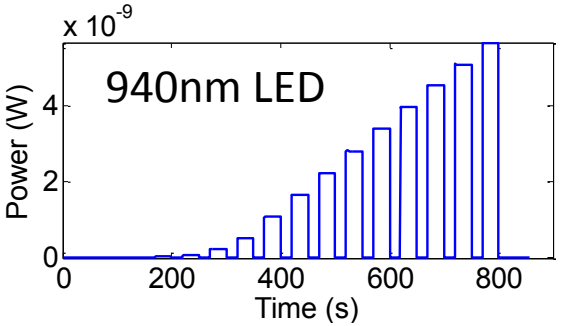




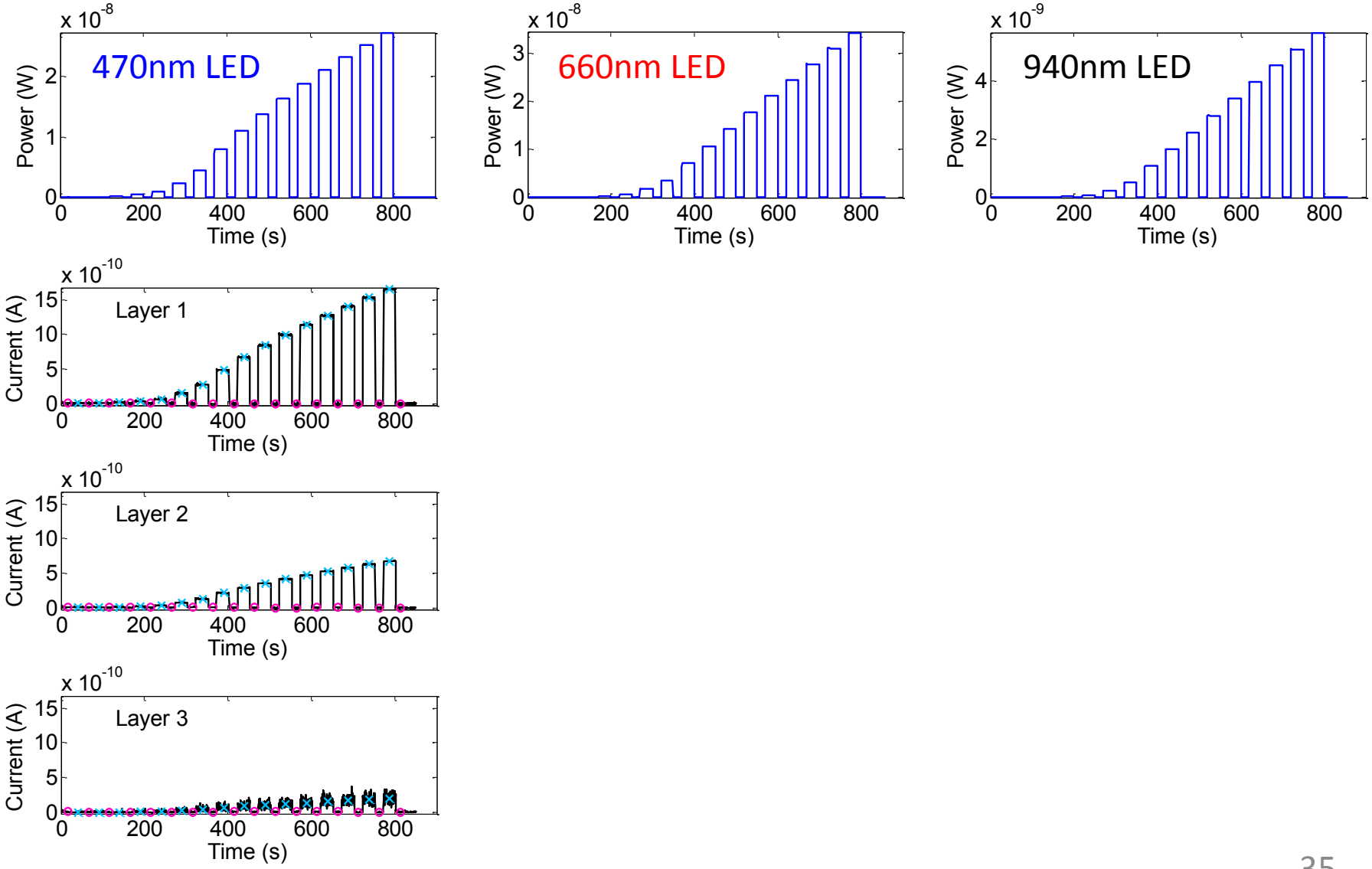
Experiment


x 10^-8
470nm LED
Power (W)
0
1
2
0
200
400
600
800
Time (s)

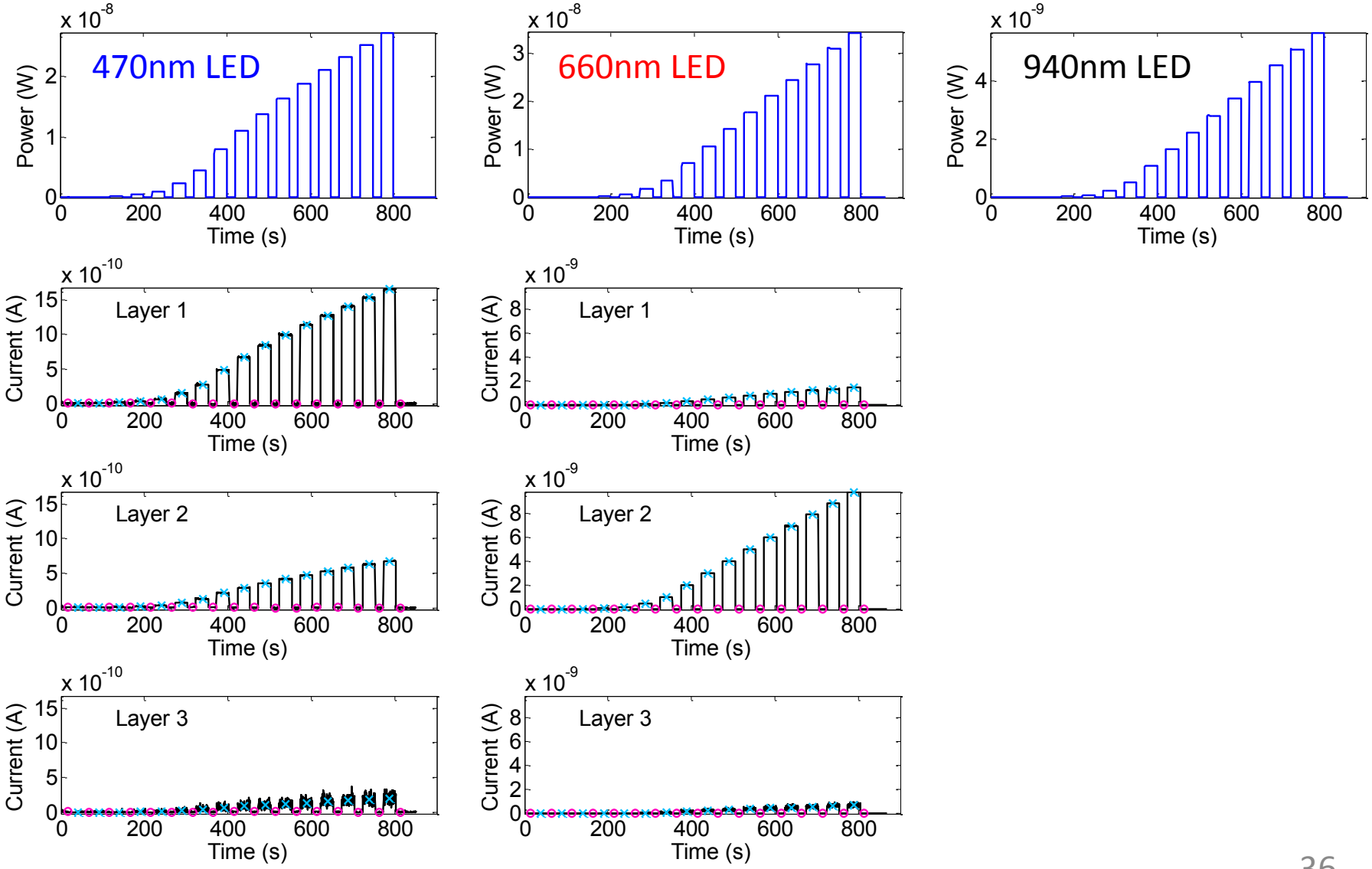

x 10^-8
660nm LED
Power (W)
0
1
2
3
0
200
400
600
800
Time (s)


x 10^-9
940nm LED
Power (W)
0
2
4
0
200
400
600
800
Time (s)

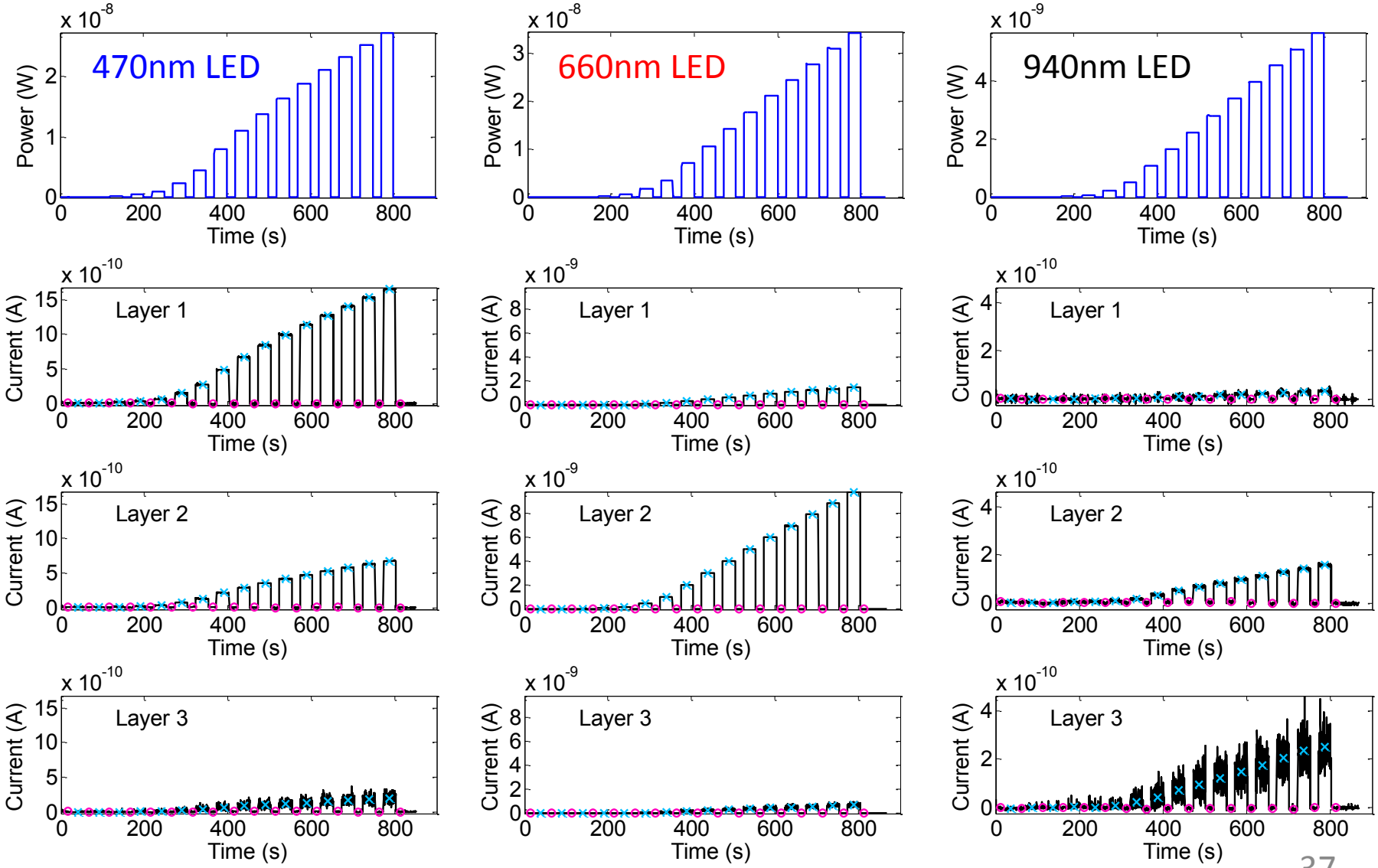
Experiment


470nm LED
660nm LED
940nm LED
Power (W)
Time (s)
Layer 1
Layer 2
Layer 3
Current (A)
x 10^-8
x 10^-9
x 10^-10

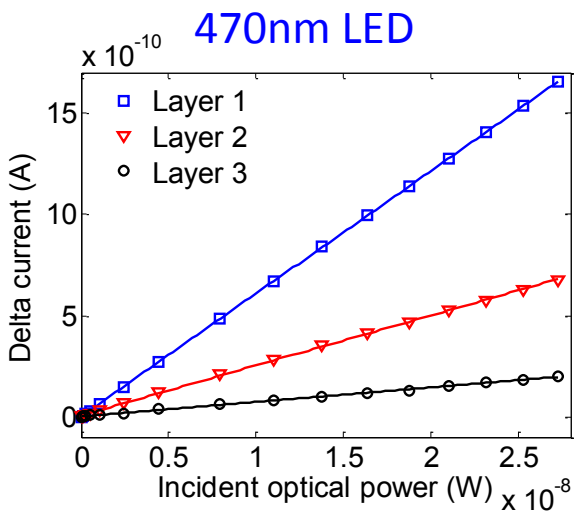
Experiment

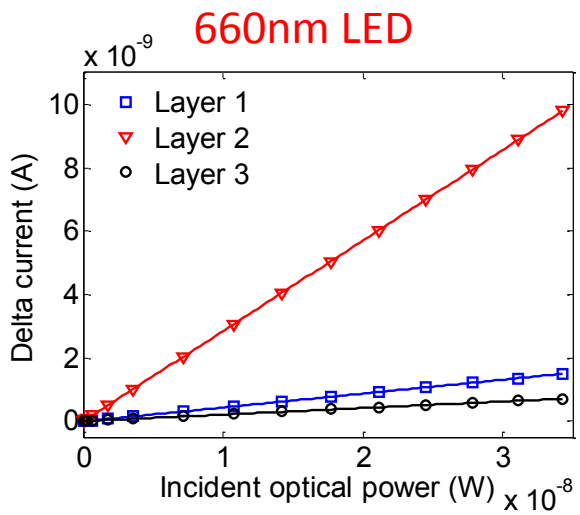

470nm LED
660nm LED
940nm LED
Power (W)
Time (s)
Current (A)
Layer 1
Layer 2
Layer 3
x 10^-8
x 10^-9
x 10^-10

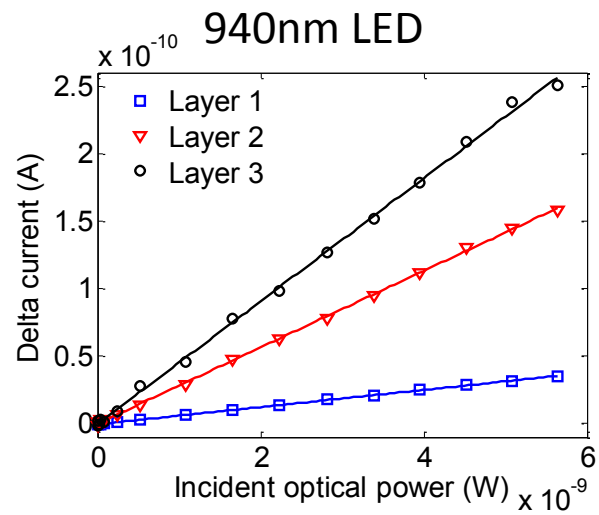
Experiment


470nm LED
660nm LED
940nm LED
Power (W)
Current (A)
Time (s)
Layer 1
Layer 2
Layer 3
x 10^-8
x 10^-9
x 10^-10

Experiment

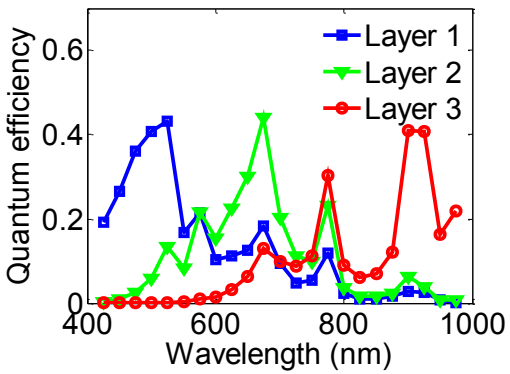

470nm LED
x 10^-10
Layer 1
Layer 2
Layer 3
Delta current (A)
Incident optical power (W)
x 10^-8

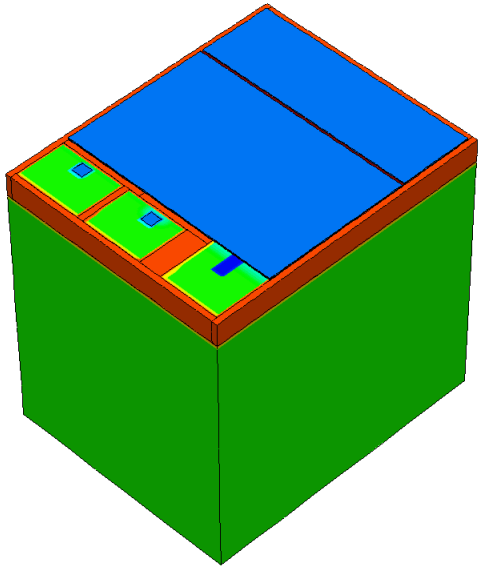

660nm LED
x 10^-9
Layer 1
Layer 2
Layer 3
Delta current (A)
Incident optical power (W)
x 10^-8


940nm LED
x 10^-10
Layer 1
Layer 2
Layer 3
Delta current (A)
Incident optical power (W)
x 10^-9

Conclusion

- Multi-layer SOI CCD design
  - Optical and sense node designs
  - First experiment demo
- Future work
  - Charge transfer
  - Multi-layer dielectric
  - Performance analysis
    - Full well, linearity, CDS, noise





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SNF Stanford Nanofabrication Facility

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