Optical and Infrared Detectors

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Outline

• Introduction
• History
• Charge Coupled Devices (CCDs)
  – Break
• CMOS imagers
• Hybrid CMOS imagers
• Other
Introduction

• Who am I?
• Why are detectors important?
• What is a detector?
• What information can we get?
• What causes imprecision?
History
History
History

Daguerreotype of the Moon taken by John William Draper in 1845.
Source: New York University Archives
Electronic detectors

- PMT (photoelectric effect)
Electronic detectors

Vidicon tube (Zucchino and Lowrance 1971)
Electronic detectors

Silicon photodiode vidicon target (McCord & Westphal, 1972)
CCDs

Willard Boyle and George Smith at Bell Labs
Charge coupling

Boyle & Smith, IEEE Spectrum, 1971
CCD sensitivity
CCD operation

- Charge detection
- Charge collection
- Charge transfer
- Charge measurement
- Signal processing
Charge detection

Burke et al, Lincoln Laboratory Journal, 2007
Backside illumination
Charge collection

Burke et al, Lincoln Laboratory Journal, 2007
Blooming
QE: -100°C  Basic Broadband response

- 16 um standard silicon - 100 ohm-cm.
- 40um deep depletion - 1500 ohm-cm.
- 70 um bulk silicon - 3000 ohm-cm.
- 150 um high-rho - 3000 ohm-cm.
- 300um high-rho - 3000 ohm-cm.
Fringing

a) 16um Std Si

b) 40um DD

c) 70um Bulk

Downing, 2009
Cosmic rays

20 minute dark exposure with Hamamatsu fully-depleted CCD
Charge transfer

buckets = capacitors

rain = photons

conveyors = shift registers

measuring station = output amplifier
Radiation damaged CCD showing CTE problems
Charge measurement

\[ V_{out} = A \left( \frac{q}{C_s} \right) \]

- \( A \): gain of transistor
- \( q \): charge
- \( C_s \): capacitance of sense node

Burke et al, Lincoln Laboratory Journal, 2007
Electron-multiplying (EMCCD)
Large mosaics

HyperSuprimeCam
116 CCDs
60cm focal plane

LSST
201 CCDs
64cm focal plane
3.2 GPixels
Large format CCDs

Semiconductor Technology Associates
10kx10k pixels
125mm wafer
Orthogonal transfer CCD

Burke et al, Lincoln Laboratory Journal, 2007
CMOS imagers
Anatomy of the Active Pixel Sensor Photodiode

- Microlens
- Red Color Filter
- Amplifier Transistor
- Reset Transistor
- Column Bus Transistor
- Photodiode
- Silicon Substrate
- Potential Well

Figure 3
Inter-Pixel Capacitance (IPC)

Finger et al. 2005
Correlated double sampling

signal = \( S_2 - S_1 = (T_{int} - t_s) \cdot F \)

\( F \) = flux (e/s)

\( T_{int} \) = total integration time

\( t_s \) = sample time

\( t_s = \frac{\text{pixels}}{\text{outputs} \times \text{pixel rate}} \)

noise = \( \sqrt{2\sigma^2} \)

\( \sigma \) = read noise (e)
Fowler sampling

\[ \text{signal} = S_2 - S_1 = (T_{int} - nt_s) \cdot F \]

\( F = \text{flux (e/s)} \)

\( n = \text{number of samples (4)} \)

\[ \text{noise} = \sqrt{\frac{2\sigma^2}{n}} \]

\( \sigma = \text{read noise (e)} \)
Up-The-Ramp sampling

signal = $F$
F = flux (e/s)

noise = $\sqrt{\frac{12N}{N^2-1} \cdot \frac{\sigma^2}{T_{int}^2}}$

$\sigma$ = read noise (e)
N = number of samples (13)
Cosmic rays/saturation
Hybrid CMOS

ReadOut Integrated Circuit (ROIC) Multiplexer (mux)
Dark Current

Electrons per pixel per sec

18 micron square pixel

Typical InSb Dark Current

~9 μm

~5 μm

~2.5 μm

~1.7 μm

HgCdTe

λ_{co} (μm)
Diffusion
Sub-pixel scale defects