CCD/IR Array Detectors

Obs Tech
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What's a CCD?

- CCD = charge coupled device
- Silicon-based 2-dimensional array of picture elements (pixels)
- Quantum efficiency much higher than photographic plates
- Permanent record with quantitative output (versus human eye)
CCD Arrays

- Typical formats
  - 2Kx2K
- Large CCDs 2Kx4K or 4Kx4K
- Edge-buttable mosiacs
  - $\Rightarrow$ 32Kx32K pixels
- 1 billion pixels (and beyond)!
- Pixel size $\sim$4-50 $\mu$m
How CCDs Work ...

- Each pixel = MOS structure (metal, oxide, semiconductor)
- Voltage bias creates a well of capacitance
- Photon excites $e^-$ into conduction band, then $e^-$ trapped in well
- Thus, pixel integrates photoelectrons
How CCDs Read Out ...

1 biased gate creates well for integration
For readout, 2 gates biased ⇒ broader well
Next, 2nd gate stays low while 1st rises ⇒ e- shift
1st gate de-biased ⇒ e- have moved 1 pixel (hurray!)
Repeat ...
CCD Readout (cont.)

- Shift all columns down 1 pixel
- Bottom-most row is in shift register
- Shift it out quickly to amplifier and output
- Repeat for next row, etc.
- Readout times ~few seconds
CCD Quantum Efficiency

- Quantum efficiency = fraction of photons converted to e-
- High QE = good
- QE depends on wavelength
- CCDs (Si) work out to \( \sim 11000 \text{ Å (1100 nm)} \)
- Modern CCDs have peak QE >80%

![Figure 8.1: Pre-flight QE Measurements on WFPC2 CCDs. The differences between the chips are probably due to systematic measurement error and do not reflect a real difference in sensitivity.](image-url)
CCD Dark Current

- Thermal motions of $e^-$ can bump them into conduction band
- Thus $e^-$ generated even without light $\Rightarrow$ dark current
- $I_d \sim e^{(-a/kT)} \Rightarrow$ strongly temperature-dependent
- CCDs usually cooled to $<-30^\circ C \ (-100^\circ C)$
CCD Output

- Signals shifted to on-chip amplifier
- Amplifier has some gain and offset: $V_{out} = g\times N_e + V_{off}$
- $V_{out}$ digitized into ADU (analog-to-digital units)
- Amplifiers are not perfect, and pixel capacitance add read noise to the system
- Good CCDs have $<5$ e$^-$ read noise $\Rightarrow <25$ e$^-$ charge added (plus or minus!)
Things that mess CCDs up:

- QE <100%
- QE varies pixel to pixel
- QE varies versus wavelength
- $I_d$
- $I_d$ varies pixel to pixel
- $I_d$ not perfectly repeatable
- Temp change $\Rightarrow I_d$ drift
- $V_{\text{offset}}$
- Read noise
- Amplifiers not perfectly linear
- Cosmic rays deposit $e^-$ in wells
- Charge transfer efficiency <1
What about CMOS?

- QE <100%
- QE varies pixel to pixel
- QE varies versus wavelength
- $I_d$
- $I_d$ varies pixel to pixel
- $I_d$ not perfectly repeatable
- Temp change $\Rightarrow I_d$ drift
- $V_{offset}$
- Read noise
- Amplifiers not perfectly linear
- Cosmic rays deposit $e^-$ in wells
- Fill factor issues, etc.
**Infrared Array Detectors**

- Non-Si to reach long wavelength
  - InSb $\Rightarrow \lambda < 5 \ \mu\text{m}$
  - HgCdTe $\Rightarrow \lambda < 2.4 \ \mu\text{m}$
  - HgCdTe $\Rightarrow \lambda < 10 \ \mu\text{m}$
  - Si:As $\Rightarrow \lambda < 28 \ \mu\text{m}$
  - Si:Sb $\Rightarrow \lambda < 40 \ \mu\text{m}$
Hybrid Arrays

- Most IR materials can't work as CCDs
- IR absorbing layer connected to multiplexer (switch; usually CMOS technology)
- In bump bonds connect them
- Thermal contraction mismatch $\Rightarrow$ major constraint for arrays currently
IR Array Properties

- More susceptible to $I_d \Rightarrow$ run colder (77K-4K)
- Read noise usually higher ($\sim$10 e-), but non-destructive reads possible
- QE $\sim$ same as CCDs
- QE varies more from pixel to pixel
- Cosmetically much worse than CCDs (hybrid more complex; non-Si technology lags)
- Si mux $\Rightarrow$ $\sim$same effects important as CCDs