Electron detection

Lecture 5

Outline

Detector characteristics & definitions

- Gain, noise, DQE, resolution, PSF …

Types of electron detectors and how they work

- Viewing screen
- Photographic film
- CCD cameras
- There are several more (we'll discuss in MSE 640)

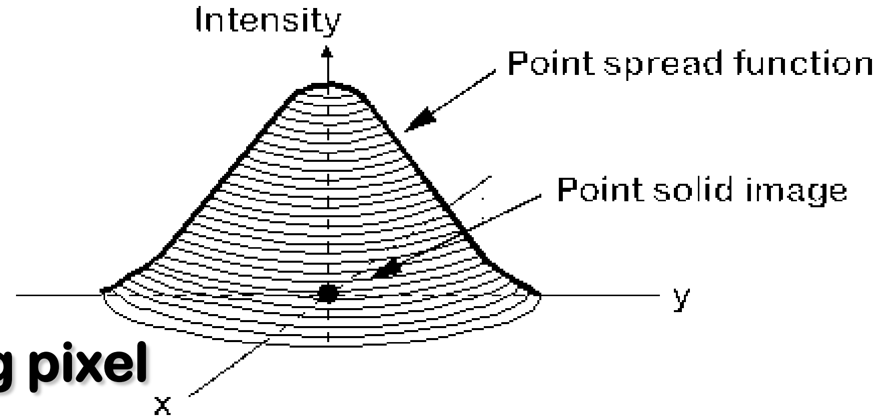
Detector characteristics

Gain:

- Magnitude of signal amplification

Shot noise:

- Random noise fluctuations
- Provides a natural limit



Resolution:

- "Related to" size of the imaging pixel

Point Spread Function - real resolution

- Measurable is the "MTF" - "modulation transfer function"

Dynamic range:

- Ratio of brightest possible pixel / to dimmest pixel

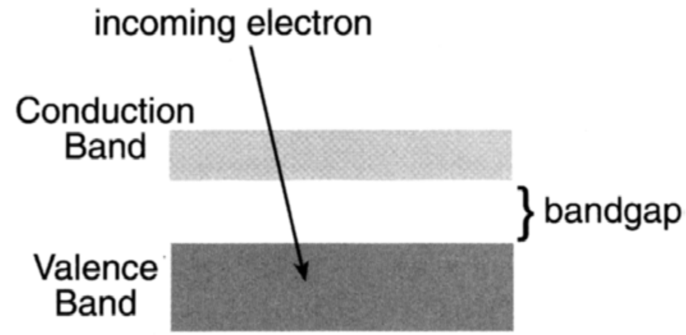
Detection quantum efficiency (DQE) (noise amplification):

$$DQE = \left(\frac{S_{out}}{N_{out}}\right)^2 \Bigg/ \left(\frac{S_{in}}{N_{in}}\right)^2$$

Some terms

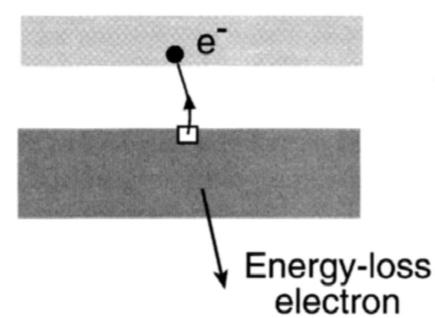
Cathodoluminescence (CL)

- Production of visible light from the impact of high energy electrons



Scintillation

- Light emission caused by ionizing radiation

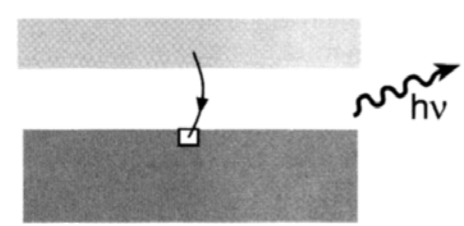


Fluorescence

- “Rapid” emission (nanosecs)

Phosphorescence

- “Slow” emission (secs)



Viewing screen
a.k.a. "fluorescent screen"

ZnS or ZnS / CdS powder on a backing plate

- Cathodoluminescence
- Dope to get to $\lambda \approx 550$ nm, best eye sensitivity
- Grain sizes on the order of 100 to 50 μm, 10 μm on the focusing screen

Intensity is proportional to current density

Time constant on order of 10^{-5} to 10^{-3} secs

- Phosphoresces for a second or so afterwards

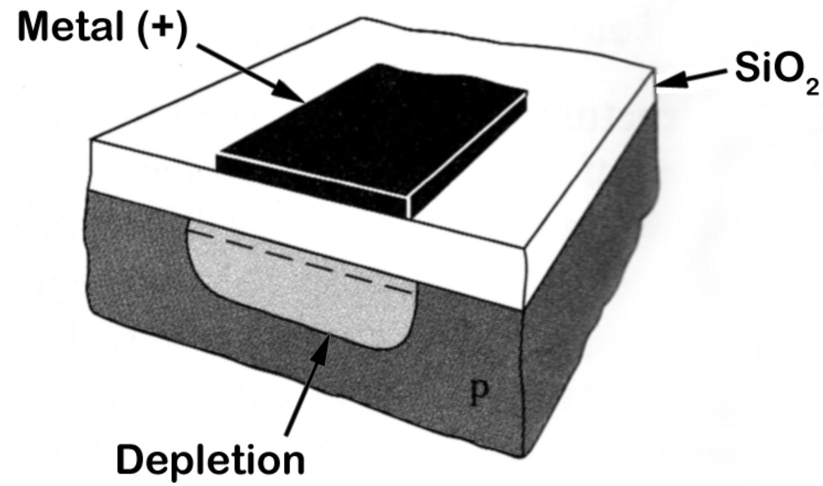
Very intense transmitted beam can damage the screen (over time) …

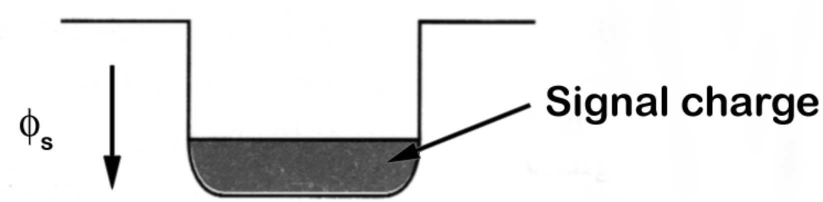
Photographic film

- "Emulsion" of silver halide in gel (AgBr; AgCl)
  - Presently use a polymer backing
  - Used to be glass -- hence the term "plates"
- Electrons strike silver halide grains, ionize the grain, convert to silver
  - Have to develop to create the negative
- Materials science - fast speed (Kodak SO-163)
  - Minimize drift during imaging
  - Larger grains (5 µm vs. 4 µm, but that's not a big deal)
- Resolution ≠ grain size ⇑ 'blooming' to 20µm size
- Advantages: large # of pixels 10^9; high DQE (0.85 - 0.9)
- Disadvantages: analog, low dynamic range; not linear …

Charge-coupled devices (CCD's)
operation principles

- **Based on accumulation of charge in a MOS capacitor**
- **Apply a steady-state positive gate voltage**
  - Surface potential well
- **Thermal generation w/ time**
  - Inversion condition
- **Instead, apply a voltage pulse**
  - Transient condition: "deep depletion"
  - Photo-injected electrons stored in this well





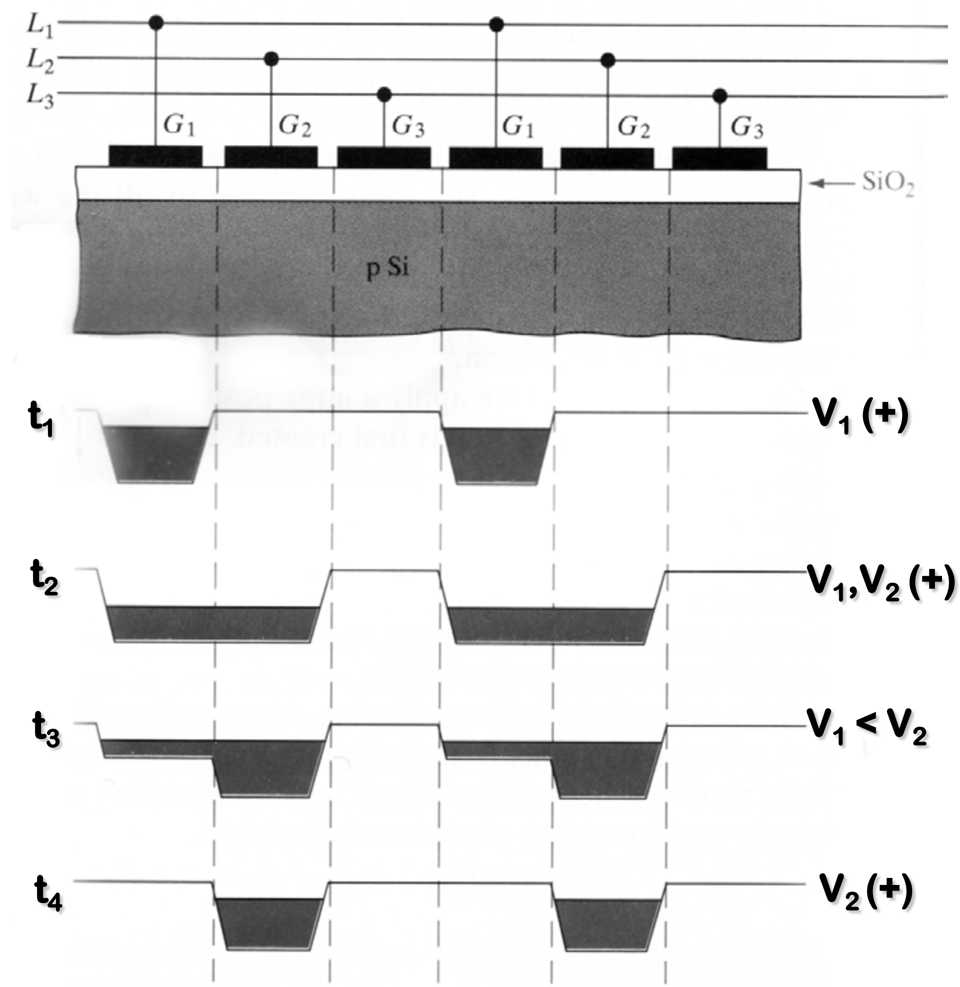
Charge-coupled devices (CCD's)

operation principles

Clocking scheme used to transfer charge from one MOS capacitor to the next

Must happen before thermal generation

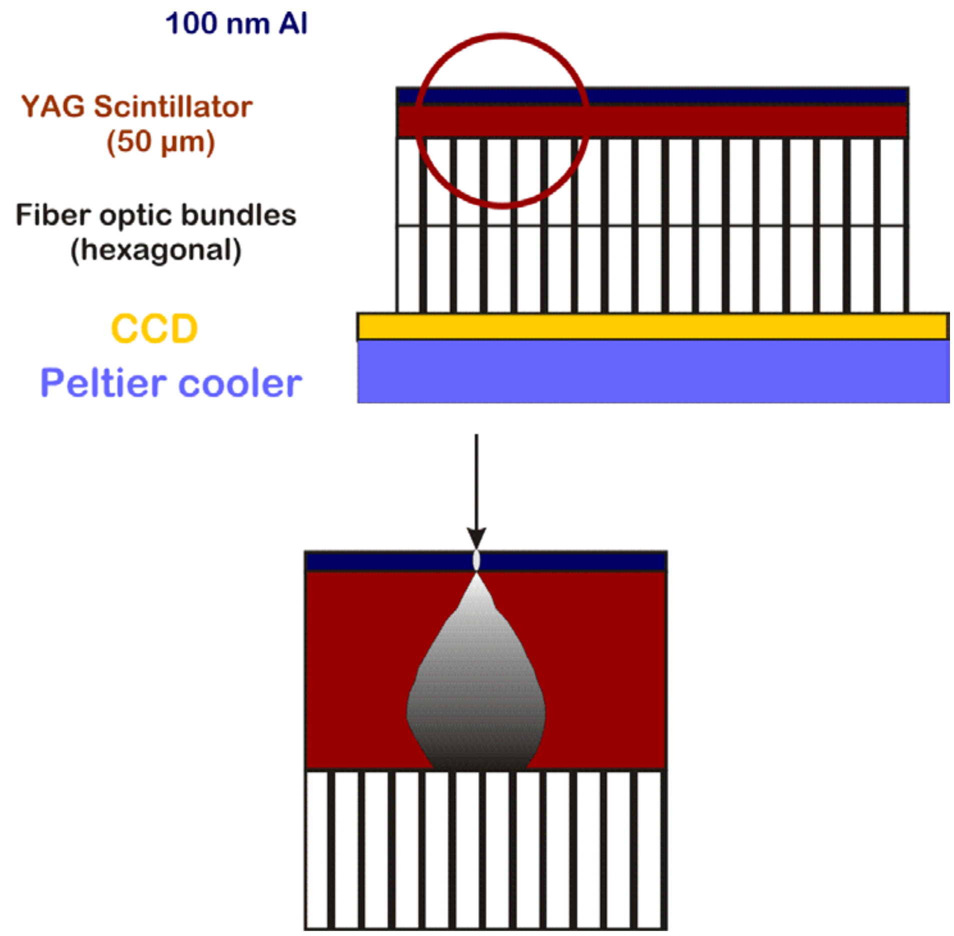
Can have either serial or full frame readout



Charge-coupled devices (CCD's)

camera setup

- Need to convert e^- to $h\nu$
- Thin aluminum to reflect any stray light (≈ 100 nm)
- YAG scintillator
  - Converts e^- to $h\nu$
  - Must be relatively thick to get enough conversion
  - Can result in a significant "blooming"
  - Measured as "point spread function"
- "Binning"
  - Average several pixels



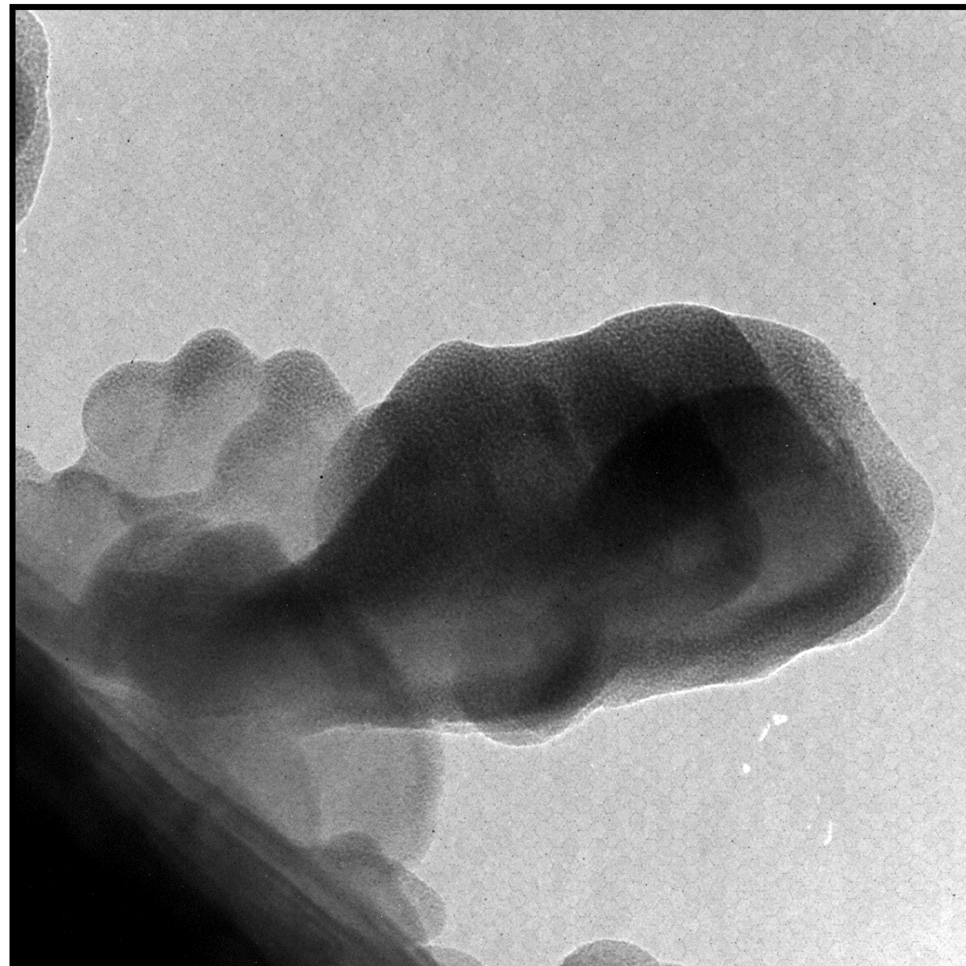
CCD Camera use

Need to prepare "Gain Reference"

- This is a good low noise picture of the camera
- Used to subtract out the fiber optic honeycomb, and defects
- This is stored and used with each image

Need to acquire "dark reference" image

- Even w. LN cooling, some shot noise present
- Allows subtraction of 'noise' image



This image was taken without 'gain subtraction'. Note the honeycomb pattern from the fiber-optic coupling & dead pixels

CCD Cameras

Advantages:

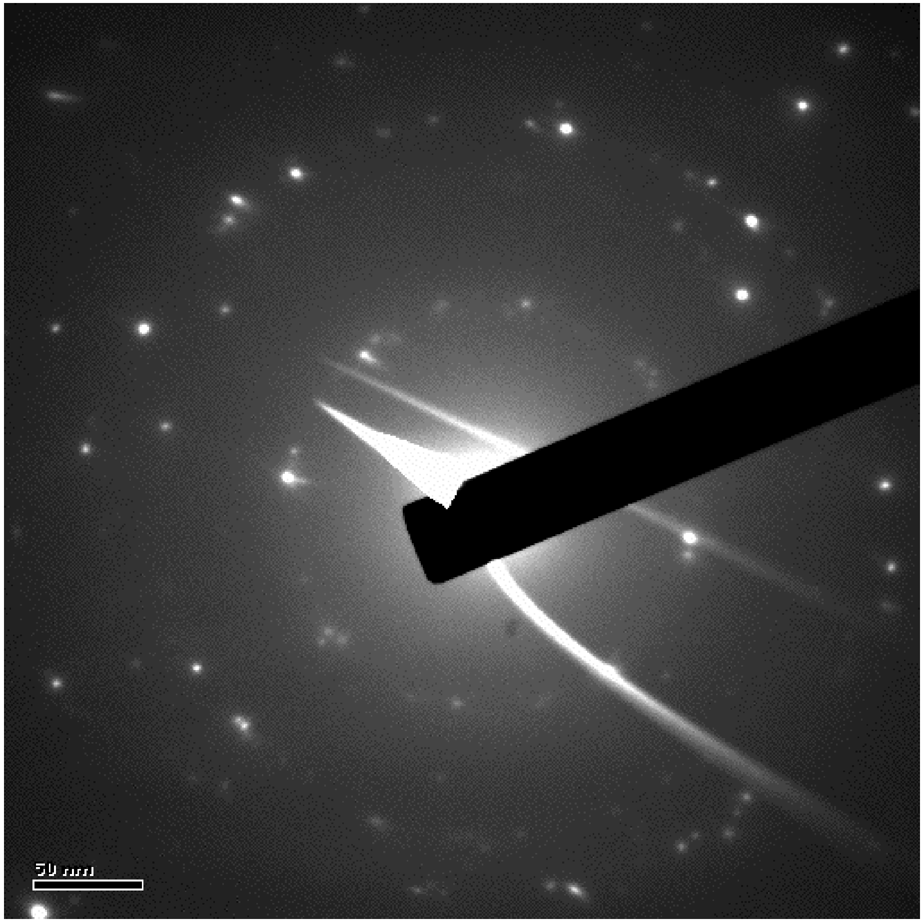
- Good DQE, even at low input signal levels
- High dynamic range
  - Diffraction patterns
- Linear
- Convenient

Disadvantages:

- Less resolution than film
  - Film - 6e9 image points
  - 1k x 1k - 1e6; 2k x 2k - 4e6; 4k x 4k - 1e7
- Expensive (initially - cheaper in the long run ...)
  - 1k x 1k - ≈$50k
  - 2k x 2k - ≈ $80k, 4k x 4k - ≈$150k
- Generally have slow readouts - 2 frames per sec at best
  - But, improving. I just bought a 1k x 1k with 15fps

CCD Cameras

- Individual pixels can handle only so many incident electrons
- Creates too many e^-/h^+ pairs, which spill over into adjacent pixels
  - Shows up as either a large intense region or a streak
- In addition to being ugly, it makes quantitative diffraction difficult



Which method for which experiment?

Film

- Large area images
- Diffraction contrast images
  - More dynamic range helps

CCD:

- Quantitative diffraction and imaging
- HREM, electron diffraction, most imaging