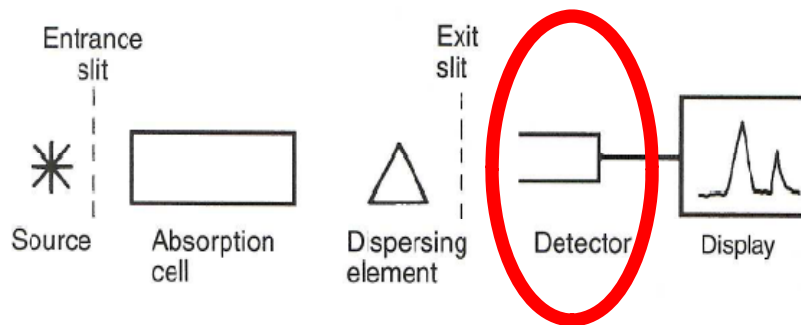


Detectors and Signal-to-Noise

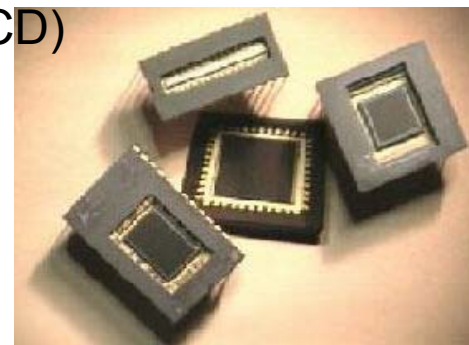


1) Photon transducers:

- Photodiodes
- Photomultiplier tubes
- Vacuum phototubes

2) Multichannel photon transducers:

- Photodiode Arrays
- Charge Transfer Devices (CID, CCD)



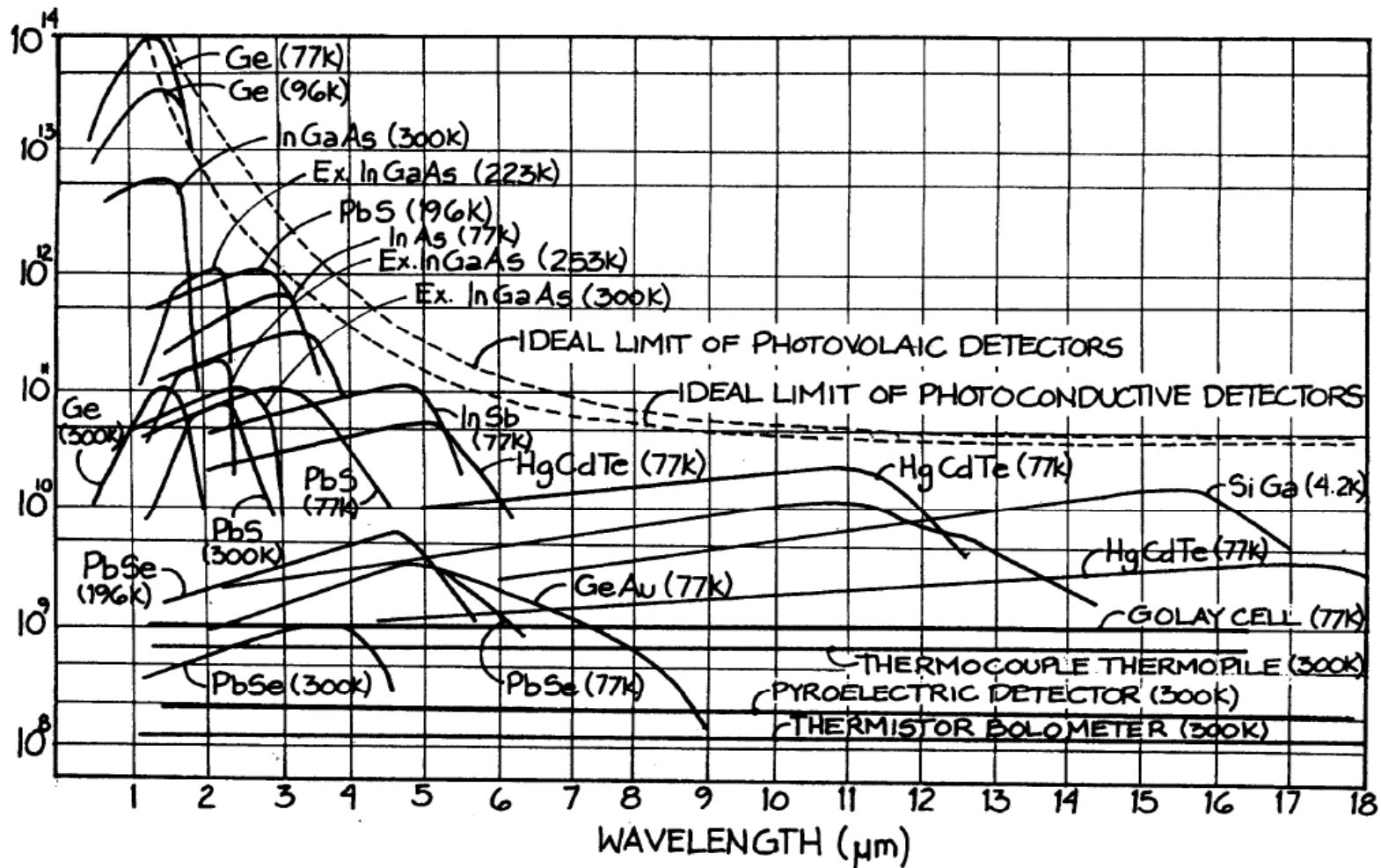
3) Photoconductivity transducers (FTIR)

4) Thermal transducers

Oct 23 2008

CHEM 5161

Wavelength region (mid and far IR)



Source: "Building Scientific Apparatus" by Moore, Davis and Coplan 3rd Edition

Detectivity D^*

- What signal will be obtained for unit irradiance ?
- Spectral Detectivity D^* (λ , 900, 1)
- Units: [$\text{cm Hz}^{1/2} \text{W}^{-1}$]

For a thermal detector of absorptivity and emissivity ϵ , at absolute temperature T_1 , completely enclosed by an environment at temperature T_2 , the photon-noise-limited detectivity can be shown to be

$$D^* = \frac{4.0 \times 10^{16} \epsilon^{1/2}}{(T_1^5 + T_2^5)^{1/2}} \text{cmHz}^{1/2} \text{W}^{-1} \quad (4.313)$$

For a photon detector, the limiting spectral detectivity is

$$D^*(\lambda) = \frac{c_0 \eta(\nu)}{2h\nu\pi^{1/2} \left[\int_{\nu_0}^{\infty} \frac{\eta(\nu') \nu'^2 e^{h\nu'/kT_2} d\nu'}{(e^{h\nu'/kT_2} - 1)^2} \right]^{1/2}} \quad (4.314)$$

Ideal limit of D^*

Ideal limit of D^* assumes thermal coupling as radiation only

Thermal detectors: $D^*_{\max} = 1.8 \times 10^{10} \text{ cm Hz}^{1/2} \text{ W}^{-1}$

When the limiting noise is temperature noise, there is no way to distinguish a signal-induced temperature change from a noise-induced temperature fluctuation. Therefore an improvement of the temperature sensitive phenomenon of the detector will not improve its signal-to-noise ratio.

Ghan 1984 J. App. Phys. 55(5) 1243

Photoconductive detectors: $5 \times 10^{10} < D^*_{\max} < 10^{14} \text{ cm Hz}^{1/2} \text{ W}^{-1}$

The maximum D^* of a cooled photoconductive detector is limited by the noise in the photons from 300 K background radiation.

Photoconductive and photovoltaic transducers (Photodiodes)

<i>Material</i>	<i>Bandgap (eV)</i>
ZnS	3.6
CdS	2.41
CdSe	1.8
CdTe	1.5
Si	1.12
Ge	0.67
PbS	0.37
InAs	0.35
Te	0.33
PbTe	0.3
PbSe	0.27
InSb	0.18

- Semiconductor based: Resistance decreases upon absorption
- Applied in the near IR (0.75 – 3 μm)
- Materials: sulfides, selenides, stibnides of lead, cadmium, gallium, indium (most popular: PbS, InSb, HgCdTe)
- Cooling to suppress noise level can also be used to extend spectral range

Thermal transducer

- Applied in the IR (where photons lack energy to cause photoeffect)
- Absorption by a small backbody
- Temperature rise is measured (few 1/1000 K)
- Low heat capacity (small size and thickness)
- Examples:
 - Golay Cell
 - Thermocouple
 - Bolometer
 - Pyroelectric Transducer

Table 3.1 Elements of an absorption experiment in various regions of the spectrum

Region	Source	Absorption cell window	Dispersing element	Detector
Microwave	Klystron; backward wave oscillator	Mica	None	Crystal diode
Millimetre wave	Klystron (frequency multiplied); backward wave oscillator	Mica; polymer	None	Crystal diode; Golay cell; thermocouple; bolometer; pyroelectric
Far-infrared	Mercury arc	Polymer	Grating; interferometer	Golay cell; thermocouple bolometer; pyroelectric
Mid- and near-infrared	Nernst filament; globar	NaCl or KBr	Grating; interferometer	Golay cell; thermocouple; bolometer; pyroelectric; photoconductive semiconductor
Visible	Tungsten filament; xenon arc	Glass	Prism; grating; interferometer	Photomultiplier; photodiode; photographic plate
Near-ultraviolet	Deuterium discharge; xenon arc	Quartz	Prism; grating; interferometer	Photomultiplier; photodiode; photographic plate
Far-ultraviolet	Microwave discharge in noble gases; Lyman discharge	LiF (or no windows)	Grating	Photomultiplier; photodiode; photographic plate

Signal-to-Noise

- Sources of Noise
 - Photon Shot Noise (White noise)
 - Dark Current Noise ($1/\nu$ dependence)
 - Read Out Noise (Electronics)
 - Thermal Noise (White noise)
 - Generation Recombination Noise

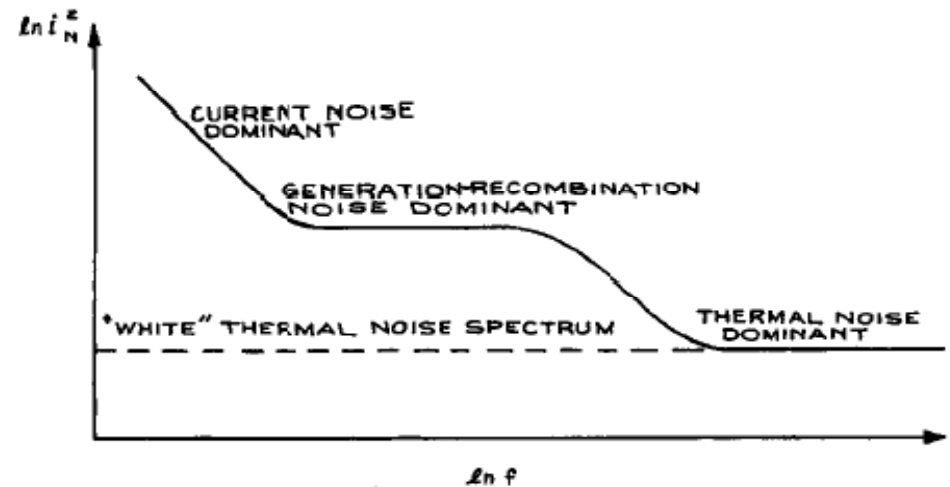


Figure 4.162 Schematic frequency dependence of noise in semiconductor detectors; i_N is the noise current.

$$\Delta N_i = \sqrt{N}$$

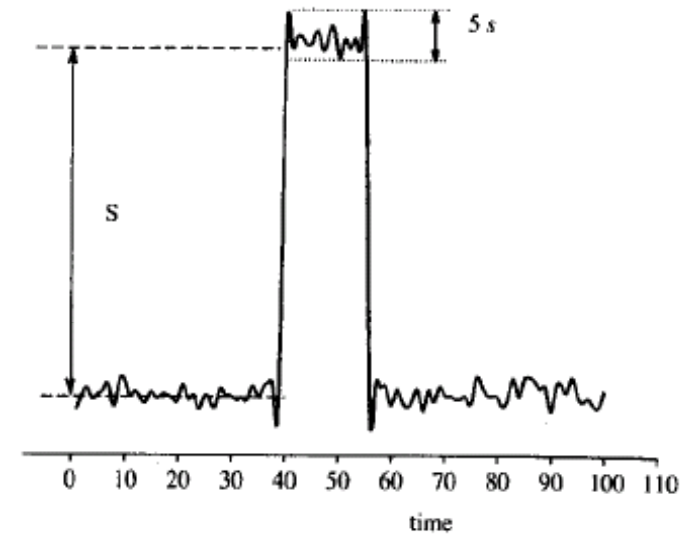
$$\frac{\Delta N_i}{N_i} = \frac{1}{\sqrt{N_i}}$$

$$\Delta N = \sum_i \Delta N_i$$

Signal-to-Noise ratio S/N

- Noise is photon-noise limited:

$$\frac{N}{\Delta N} = \frac{N}{\sqrt{\sum_i \Delta N_i^2}} \propto \sqrt{N}$$



- Means to enhance S/N
 - Signal averaging: internally or externally
 - Signal smoothing: boxcar averaging, moving average, polynomial smoothing (keyword: convolution)
 - Filtering in the frequency domain:

Question

- Readout Noise: $N_{RO} = 20 e^-$
- Dark Current Noise: $N_{DC} = 3 e^-$
- Output Saturation: $10^6 e^-$
- At what “saturation level” is noise dominated by photon-noise ?
- What is the minimum detectable optical density for 1 scan, and 100 scans ?