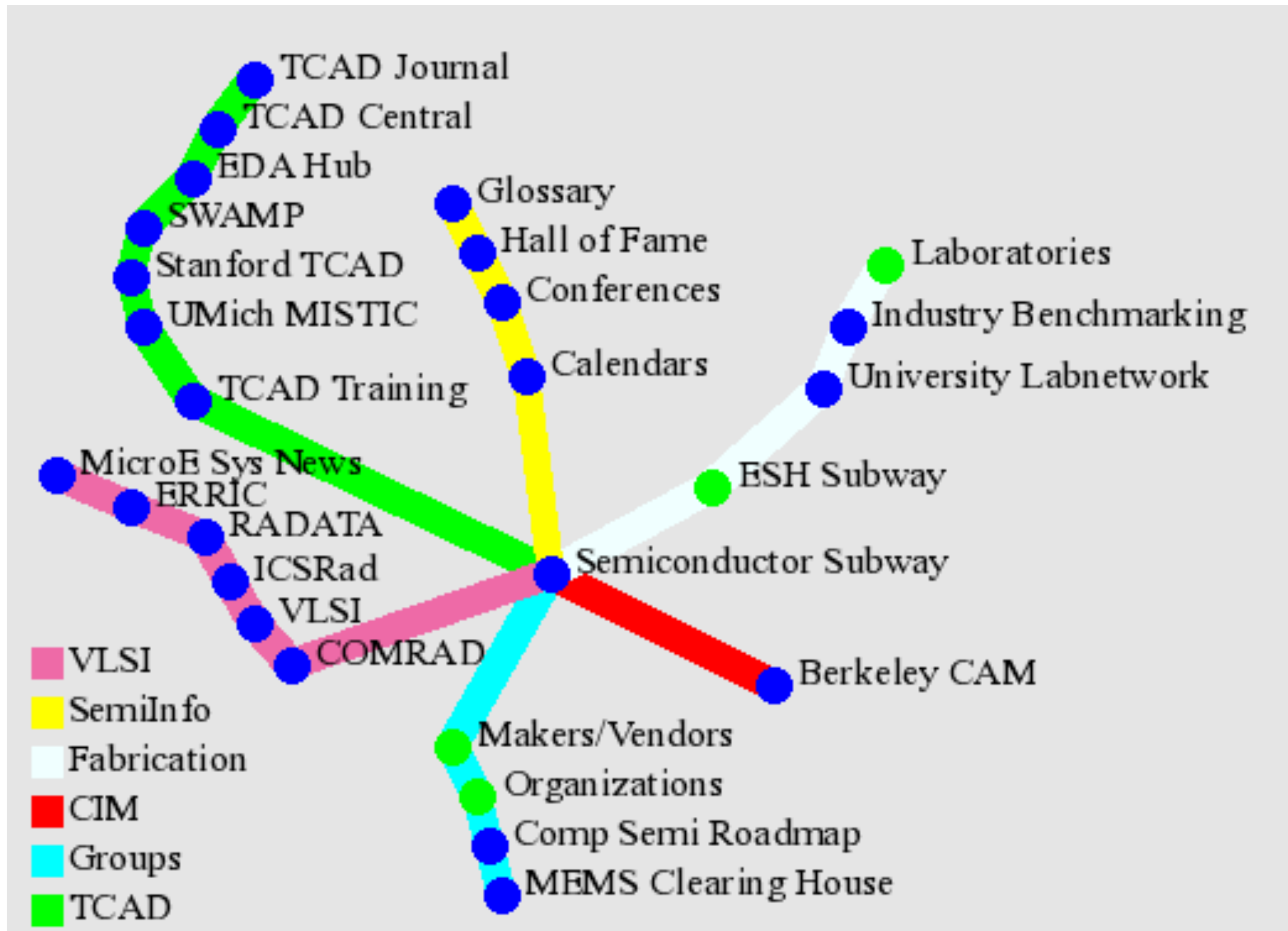
Week 9: Chap.13 Other Semiconductor Material

MICHIGAN STATE UNIVERSITY

Germanium Diodes

Other Semiconductors and Geometries …
-- Why
--- CZT properties
-- Silicon Structures
--- CCD's
--- SiPM's

Gamma ray Backgrounds



[The MIT Semiconductor Subway (of links from 2007)]

Chap. 13 – Other Semiconductors - Motivation

MICHIGAN STATE UNIVERSITY

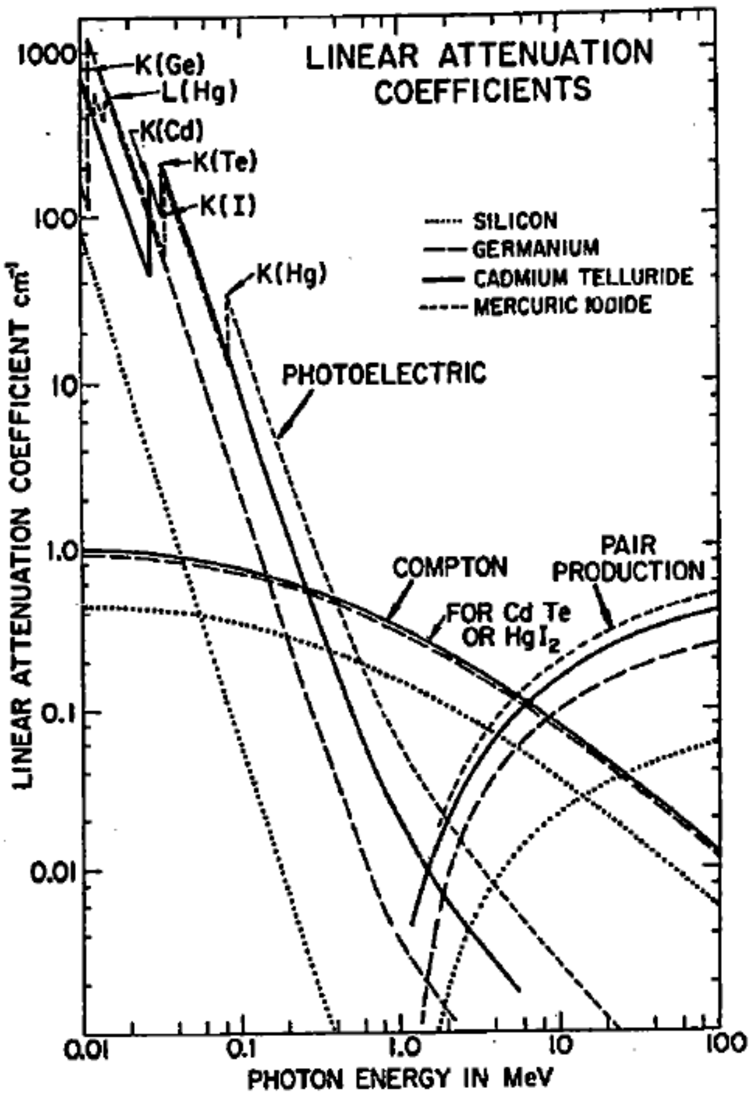


Fig. 13.22 Knoll, 3rd 4th Eds.

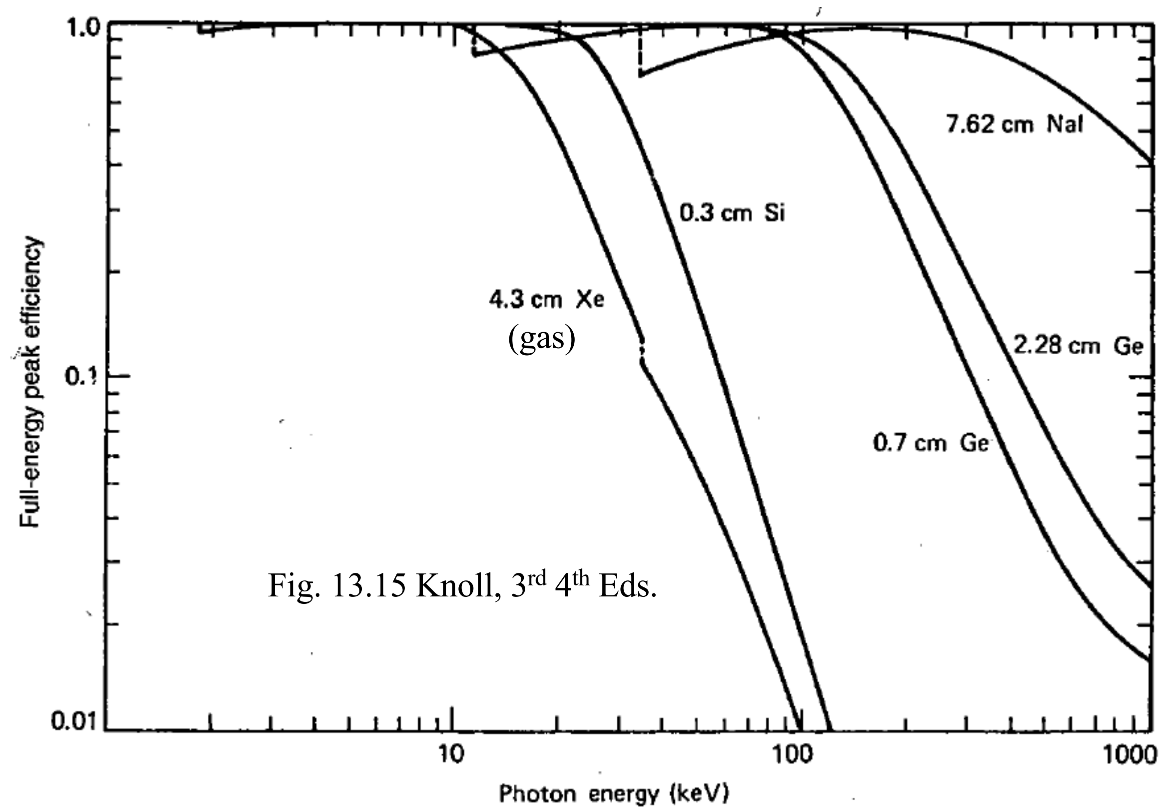


Fig. 13.15 Knoll, 3rd 4th Eds.

Detector comparison, (thickness given)

NaI(Tl) has a significantly higher stopping power for ~MeV gamma rays than Ge and especially Si, thus significant effort has been applied to finding other semiconducting materials with higher atomic numbers.

Other Semiconductor Properties

MICHIGAN STATE UNIVERSITY

Material	Z	Bandgap [eV]	Mobility [cm^2/Vs]		Density g/cm^3
			electrons	holes	
Si	14	1.1	1350	480	2.3
Ge	32	0.7	3800	1800	5.3
Diamond	6	5.5	1800	1200	3.5
GaAs	31-33	1.5	8600	400	5.4
AlSb	13-51	1.6	200	700	4.3
GaSe	31-34	2.0	60	250	4.6
CdSe	48-34	1.7	50	50	
CdS	48-16	2.4	300	15	4.8
InP	49-15	1.4	4800	150	
ZnTe	30-52	2.3	350	110	
WSe_2	74-34	1.4	100	80	
BiI_3	83-53	1.7	680	20	
Bi_2S_3	83-16	1.3	1100	200	6.7
Cs_3Sb	55-51	1.6	500	10	
PbI_2	82-53	2.6	8	2	6.2
HgI_2	89-53	2.1	100	4	6.3
CdTe	48-52	1.5	1100	100	6.1
CdZnTe	48-30-52	1.5-2.4	1350	120	5.8

NaI(Tl) 11-53-81 5.8 – 6.3 (0 , 0 scintillator) 3.7

[NaI from Poole, et al. Chem.Phys.Lett.26 (1974) 514]

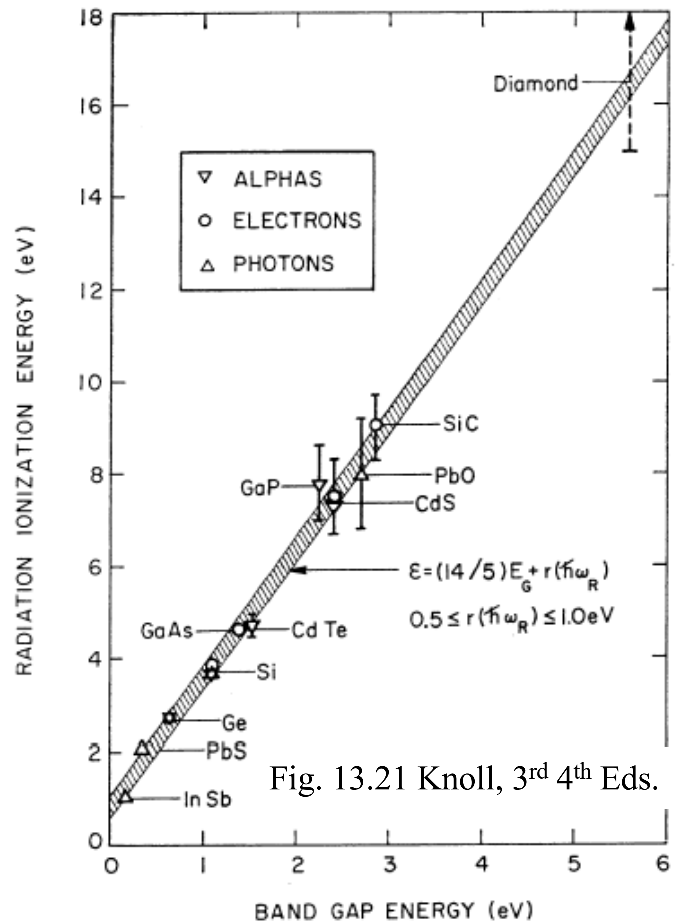


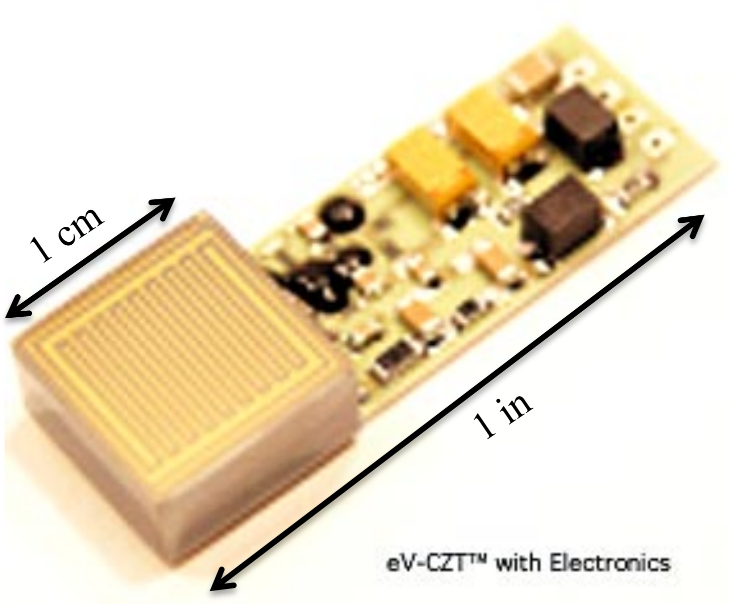
Fig. 13.21 Knoll, 3rd 4th Eds.

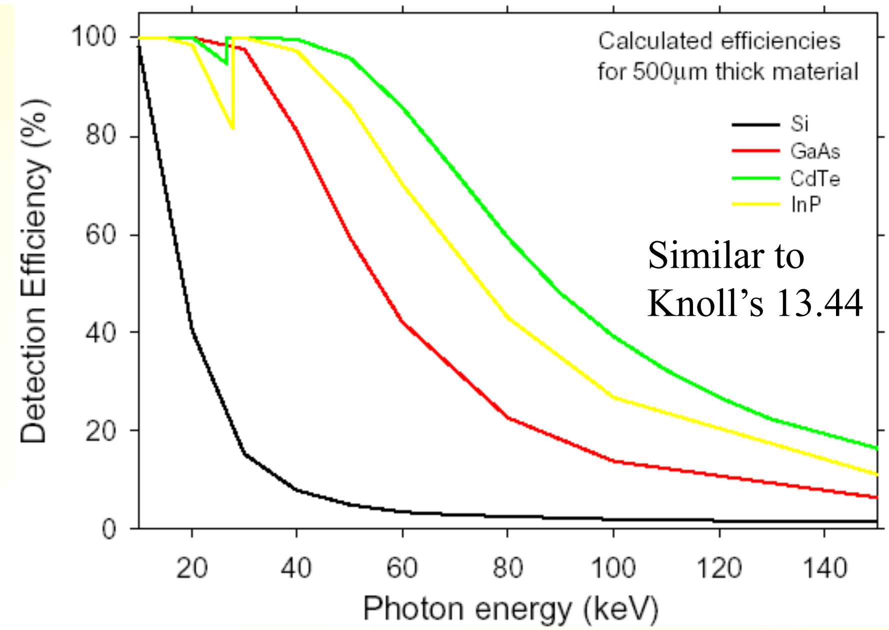
C.A.Klein, J.App. Phys. 39 (1968) 2029

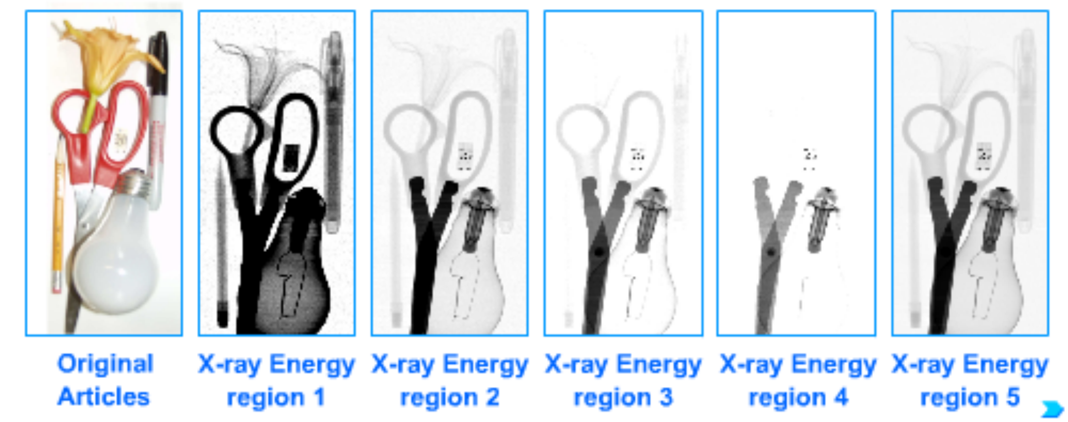
Recall correlation of W with band gap – higher W leads to lower signal but also lower thermal noise.

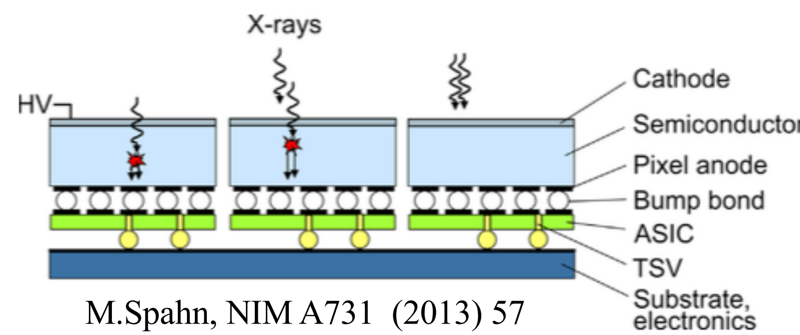
Other Semiconductors – CZT

MICHIGAN STATE UNIVERSITY

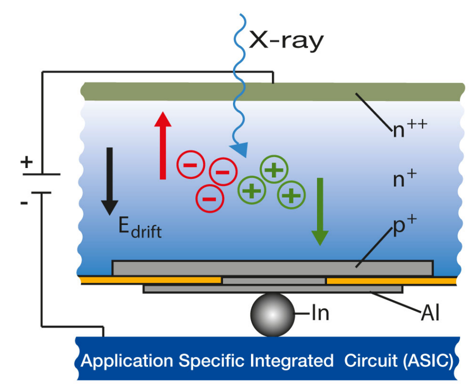








M.Spahn, NIM A731 (2013) 57



Typical sensitivity of integrated device:

0.1 mRem/hr to 1 Rem/hr

Q: How much power is this in a 10x10x0.5 mm^3 crystal?

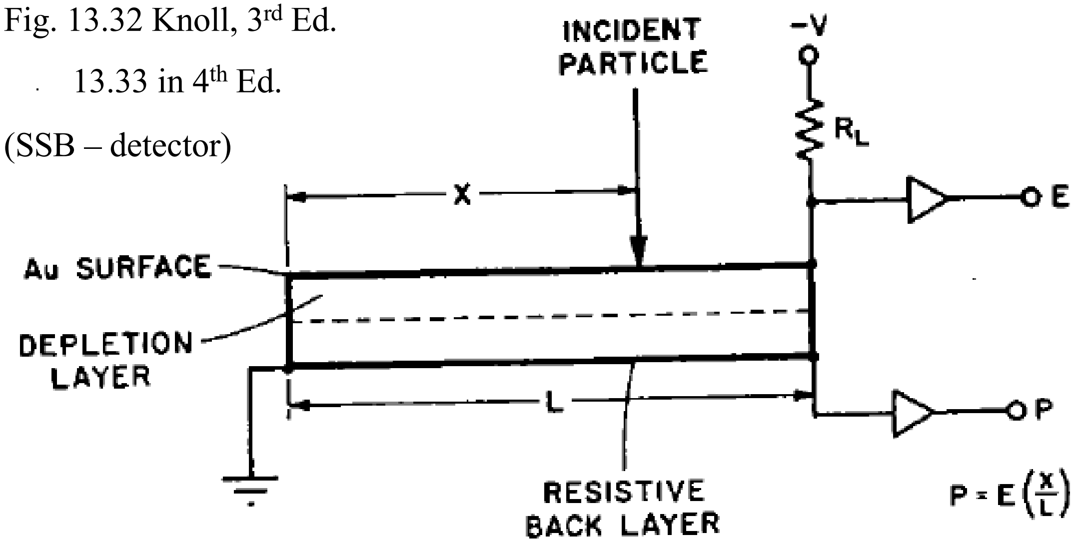
[max: 5.0 GeV/s]

Position Sensitivity [Simple]

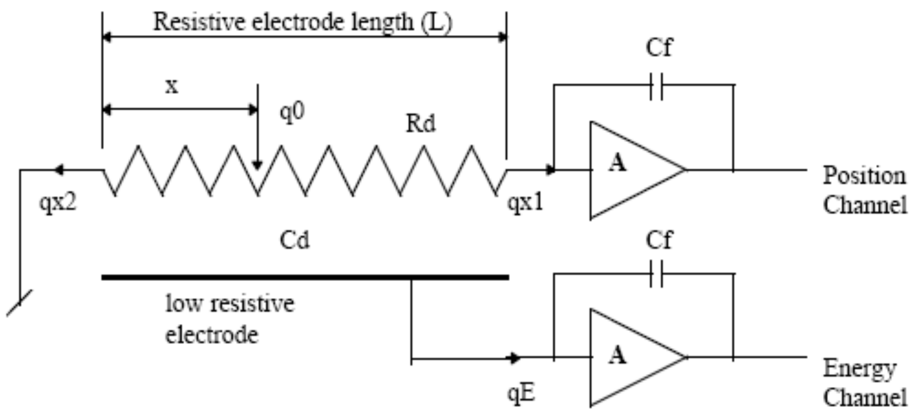
Fig. 13.32 Knoll, 3rd Ed.

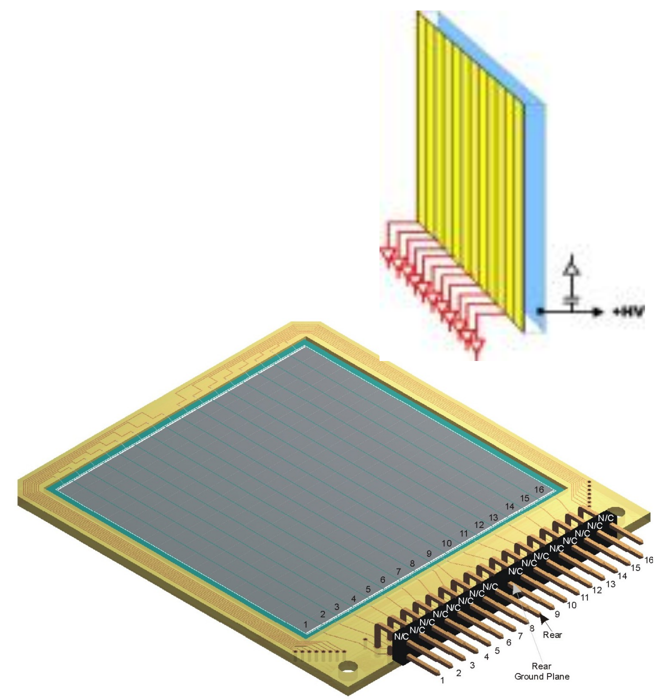
13.33 in 4th Ed.

(SSB – detector)



ORTEC PSD n-type, B-contact

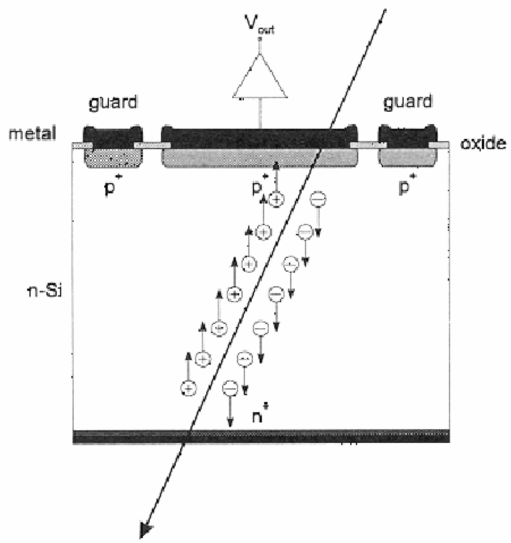


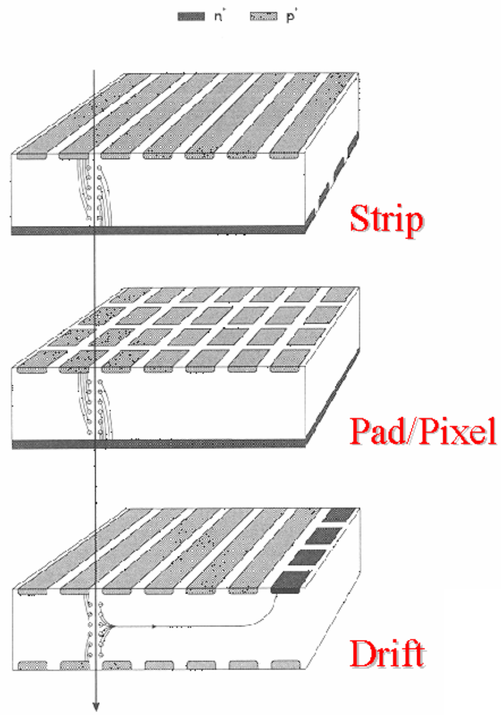


Charge division:

q0 = qx1 + qx2 + qE

Position Sensitivity [Patterns]





One readout channel / strip

One readout channel / pad

One readout channel / pad & Time

Drift detectors .. Continuous readout
Very low capacitance due to small anode

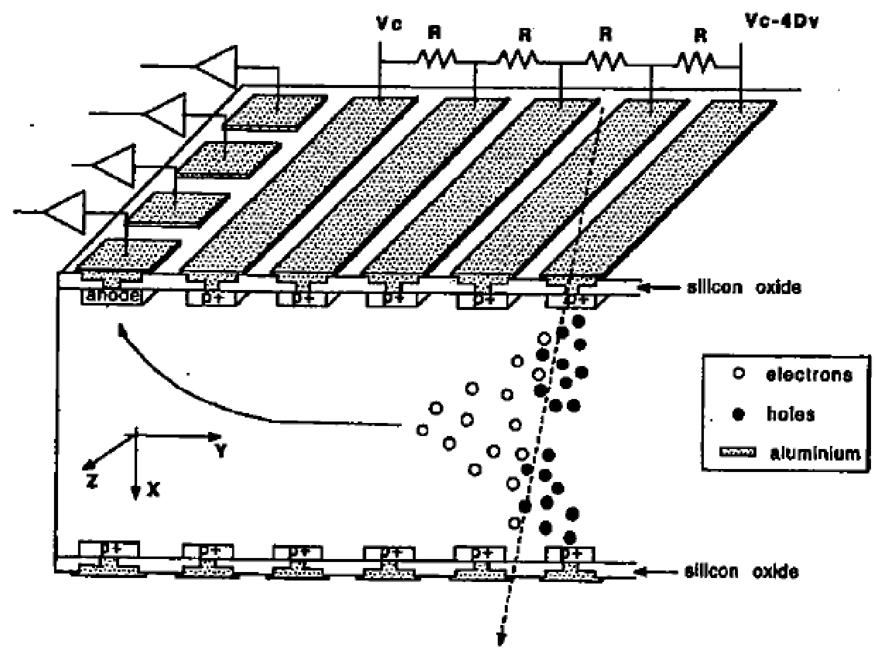


Fig. 13.37 Knoll, 4th Ed.

Position Sensitivity [CCD]

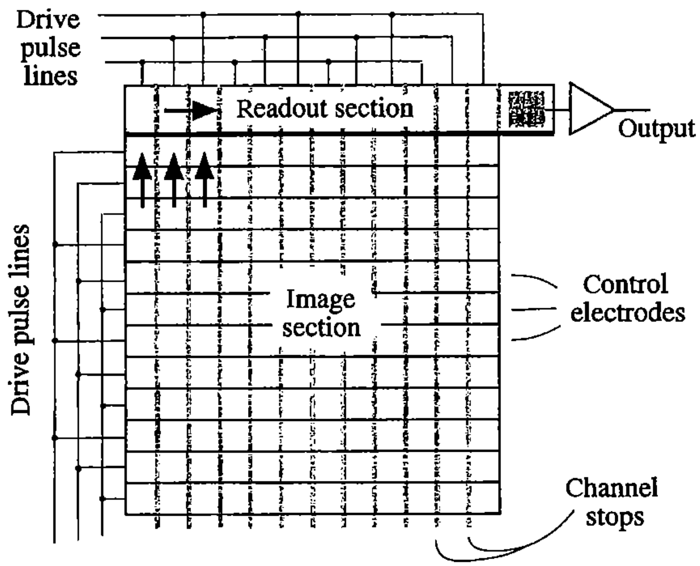


Fig. 13.38 Knoll, 3rd Ed.

13.39 in 4th Ed.

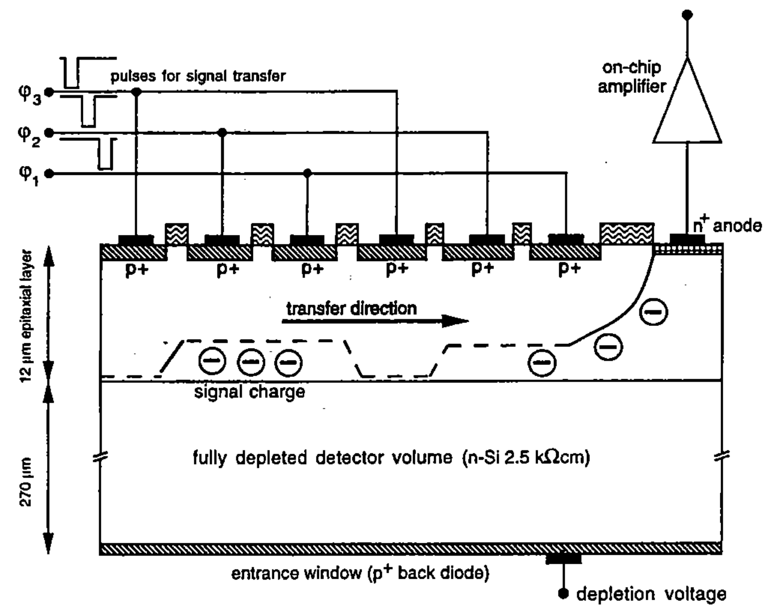


Fig. 13.39 Knoll, 3rd Ed.

13.40 in 4th Ed.

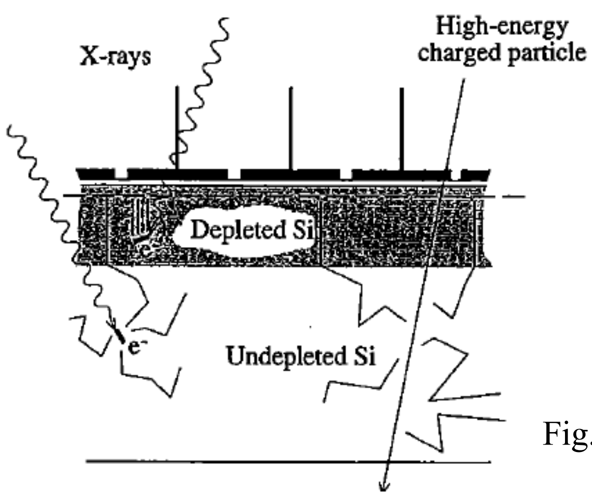


Fig. 13.40 Knoll, 3rd Ed.

13.41 in 4th Ed.

New Application – SiPM

(1) Recall that NaI(Tl) and other scintillators emit ~tens of thousand photons per MeV deposited in the crystal and of order ½ make to the photocathode and then ¼ create photoelectrons. Thus, one has ~thousands information carriers per MeV → few % resolution.

(2) A Silicon diode will "break down" or discharge if it is over biased. If the discharge can be terminated then only a large pulse is passed. Such a device that breaks down when exposed to light: avalanche photodiode (APD).

(3) Extremely small structures (circuits) can be created in silicon, e.g., thousands

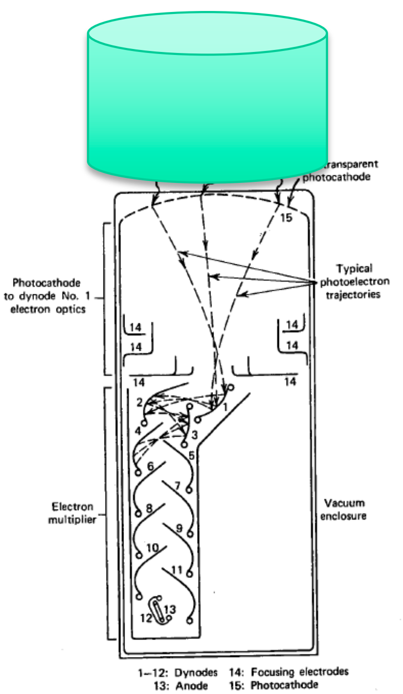
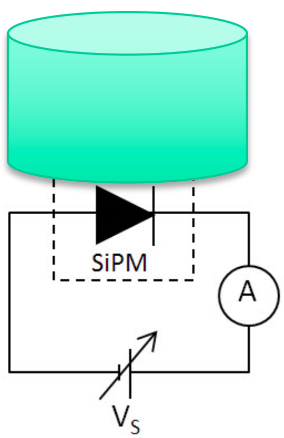
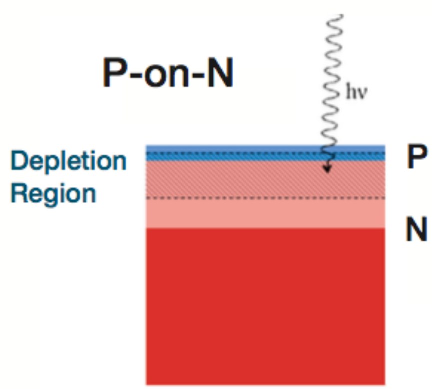


Fig.9.1 Knoll, 3rd,4th Eds.

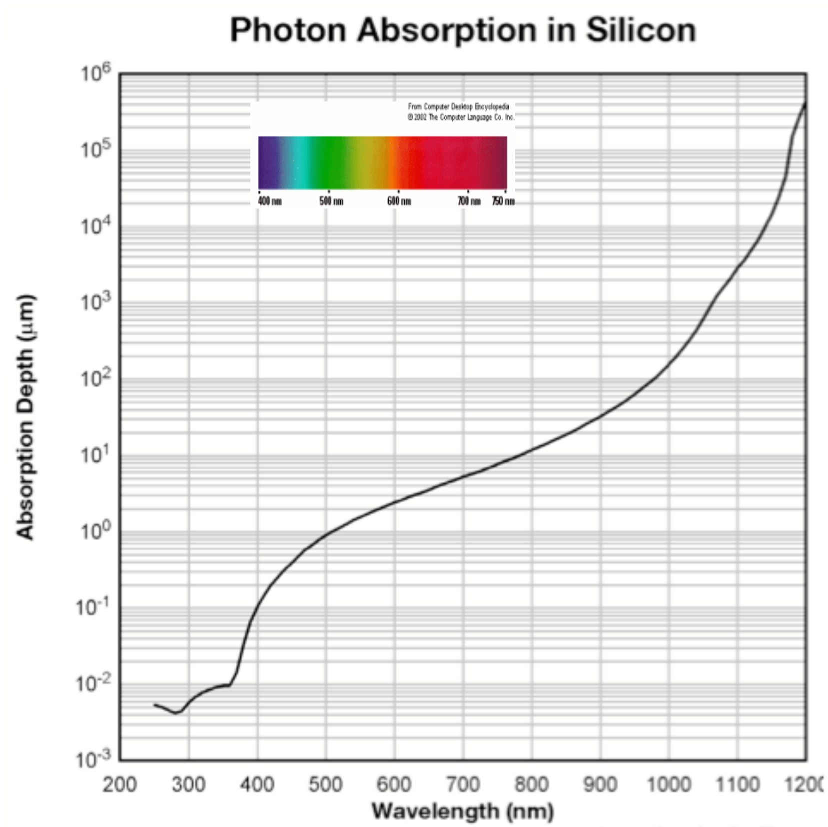




KETEK SiPM

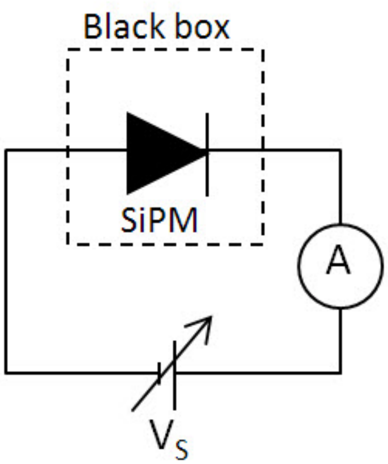
Hamamatsu SiPM

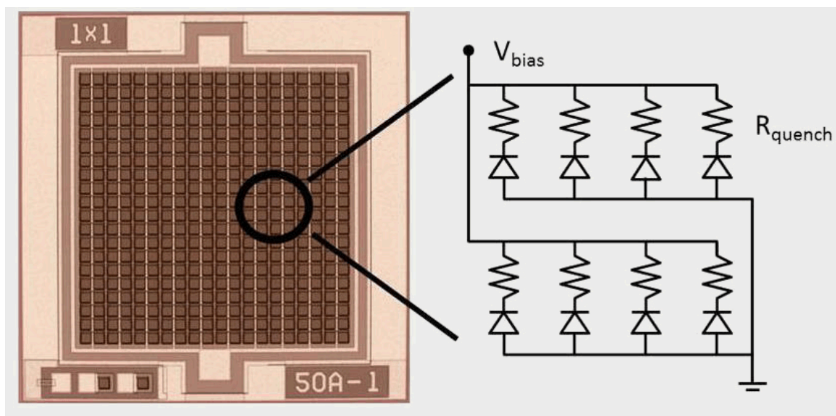
SensL Documentation

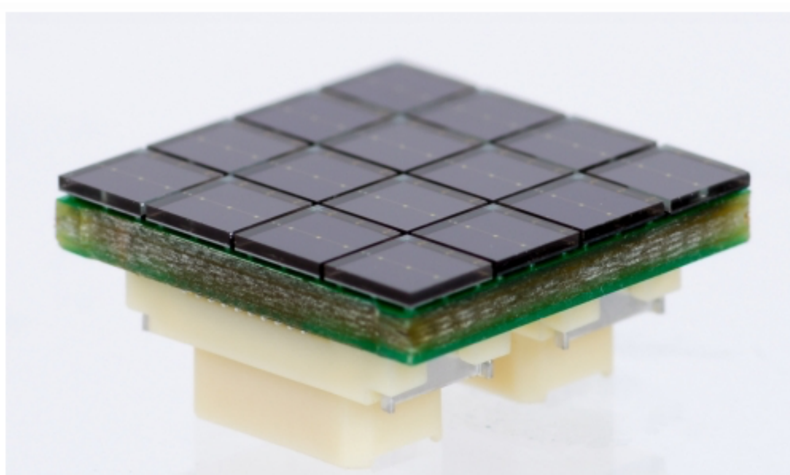


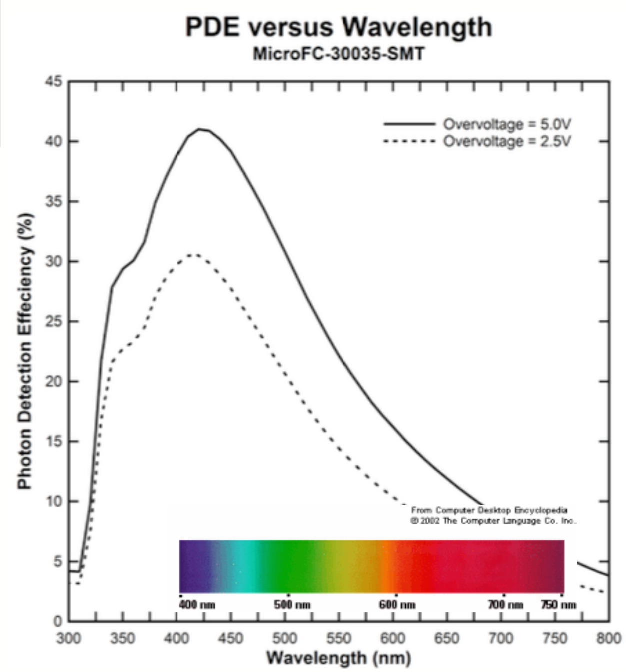
New Application – SiPM

SensL: A typical SiPM has a few macroscopic cells (~10) each with microcell densities of between 500 (10 μm) and several 1000 per mm^2, depending upon the size of the microcell. Each microcell is an APD that detects photons identically and independently. The sum of the breakdown currents from all of these individual microcells combines to form a *quasi-analog output*, and is thus capable of giving information on the magnitude of an instantaneous photon flux.









[KETEK SiPM]

[Hamamatsu SiPM]

[SensL Documentation]

MICHIGAN STATE UNIVERSITY

Problem 13.8 – A fully depleted silicon CCD is 300 μm thick and used to form a recorded image of of incident x-rays whose energy is 10 keV. It has an array of 256 x 256 pixels per frame and is operated in a simple mode of alternating exposure and readout. The readout frequency is 100 kHz. The exposure time per frame is to be kept at least 20 times the total readout time. The same measurement is designed to measure the energy deposited by each individual x-ray so that probability of multiple hits should be less than 5% per pixel during exposure.

a) Determine the maximum x-ray interaction rate in the full image.

b) Find the minimum required storage capacity for electrons in one pixel.

c) If the charge due to leakage is to be kept less than 10% of of the signal charge due to a single x-ray interaction in a pixel, estimate the maximum leakage current for the entire device.

Chap. 13 – CCD Readout Question

MICHIGAN STATE UNIVERSITY

Problem 13.8 – A fully depleted silicon CCD is 300 μm thick and used to form a recorded image of of incident x-rays whose energy is 10 keV. It has an array of 256 x 256 pixels per frame and is operated in a simple mode of alternating exposure and readout. The readout frequency is 100 kHz. The exposure time per frame is to be kept at least 20 times the total readout time. The same measurement is designed to measure the energy deposited by each individual x-ray so that probability of multiple hits should be less than 5% per pixel during exposure.

a) Determine the maximum x-ray interaction rate in the full image.

$t_{Readout} = 256*256 / 10^5 /s = 0.655$ s $\qquad t_{Exposure} = 20 * t_{Readout} = 13.1$ s

5% chance of more than one per pixel ..

$P(0) = e^{-rt}$

$P(1) = rt\ e^{-rt}$

$P(>1) = 1 – [P(0)+P(1)] = 1 - rt\ e^{-rt} - e^{-rt} = 1 - e^{-rt} (rt + 1)$

$0.05 = 1 - e^{-rt} (rt + 1)$

$e^{-rt} (rt + 1) = 0.95 \qquad e^{-x} \sim 1 – x + \ldots$ for small x

$(1 – rt) (rt + 1) = 0.95$

$1 – (rt)^2 = 0.95 \rightarrow rt = (0.05)^{1/2} \rightarrow r_1 = (0.05)^{1/2} /t$

$rate_{device} = 256*256*rate_1 = 256*256* (0.05)^{1/2} /13.1 = 1120 /s$

Chap. 13 – CCD Readout Question

Problem 13.8 – A fully depleted silicon CCD is 300 μm thick and used to form a recorded image of of incident x-rays whose energy is 10 keV. It has an array of 256 x 256 pixels per frame and is operated in a simple mode of alternating exposure and readout. The readout frequency is 100 kHz. The exposure time per frame is to be kept at least 20 times the total readout time. The same measurement is designed to measure the energy deposited by each individual x-ray so that probability of multiple hits should be less than 5% per pixel during exposure.

a) Determine the maximum x-ray interaction rate in the full image.

$t_{Readout} = 256*256 / 10^5 /s = 0.655$ s $\qquad t_{Exposure} = 20 * t_{Readout} = 13.1$ s

$rate_{device} = 256*256*rate_1 = 256*256* (0.05)^{1/2} /13.1 = 1120 /s$

b) Find the minimum required storage capacity for electrons in one pixel.

c) If the charge due to leakage is to be kept less than 10% of of the signal charge due to a single x-ray interaction in a pixel, estimate the maximum leakage current for the entire device.