Silicon Avalanche Photodiode (APD) X-Ray Detectors

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Silicon Avalanche Photodiodes

Fast Single Photon Detector

Si Diode + Internal Gain

Good Points:

Fast -> Good Time Resolution (0.1-2 ns)

& High Rates > 10^7 easy, 10^8 Done (10^9 ?)

Good Pulse Height Resolution (10-30%)

Low Noise (<0.005 - 0.05 Hz)

Reasonable Efficiency (~50%) < 10 keV

Small, Rugged (relative to a PMT)

Less Good Points:

Small Area (< ~1 cm^2)

Poorer Efficiency at High Energy

Other:

Arrays Available (Minimum Pitch ~0.1mm)

What are APDs good for?

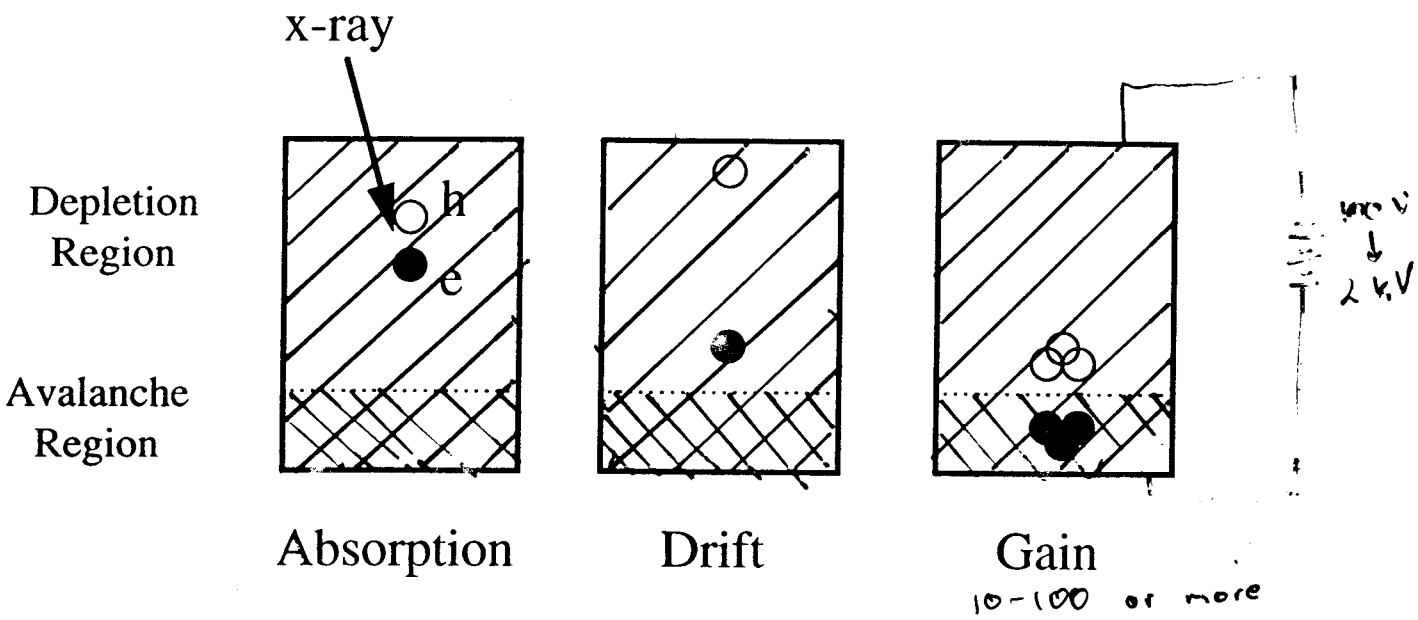
Fast Photon Counting

- High Rates
- Low Noise
- Good Energy Resolution

Time Resolved Measurements:

- Nuclear Resonant Scattering
- X-Ray Correlation Measurements
- Ultrasound
- General Time Resolved Scattering
- X-Ray Time of Flight Measurements
- Pump/Probe Measurements

Silicon APD Operation



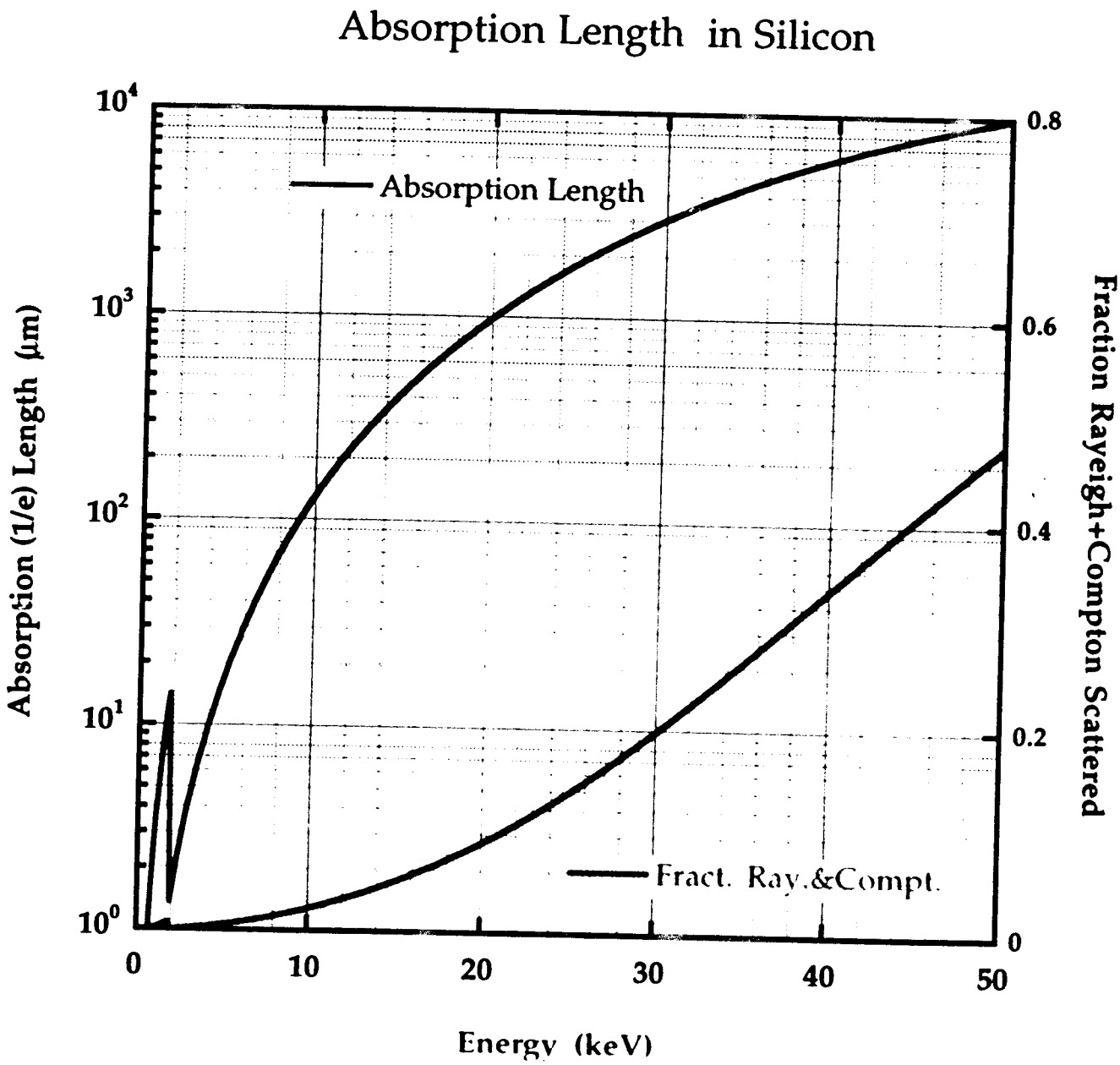
Important Points:

Lots of carriers to start - 1 eh pair/ 3.6 eV

Efficiency determined by "active thickness" of Si before the gain region

Drift to gain region takes time (~10 ps/μm)

Trade Off: Higher efficiency -> Poorer time resolution



Efficiency for 100 μm Device

8 keV → 80%

14 keV → 25%

20 KeV → 10%

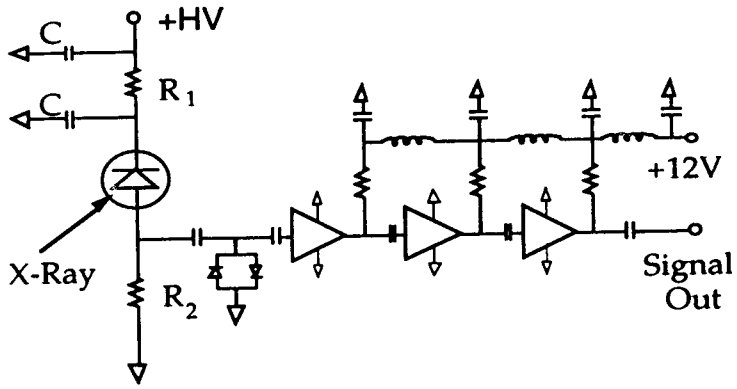
30 keV → 3%

Electronics

Wide-Band (~GHz) Amplifier (near the diode)

~50 Ohm Input Impedance

(Minicircuits, Phillips, Ortec....)



Signal Shape:

Leading Edge (rise time)

Amplifier Bandwidth and Carrier Transport Time

Trailing Edge (fall time)

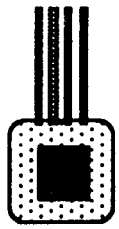
Amplifier Bandwidth and

Input Impedance & Diode Capacitance

Fast Discriminator (NIM levels) (Ortec, Phillips, ...)

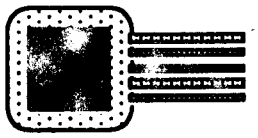
3 APDs

Perkin-Elmer 5x5 mm^2 x 100μm
"Old Faithful"
Reasonably Efficient, Reliable
Good Pulse Height Spectrum
Note : RCA->EG&G->P.E.



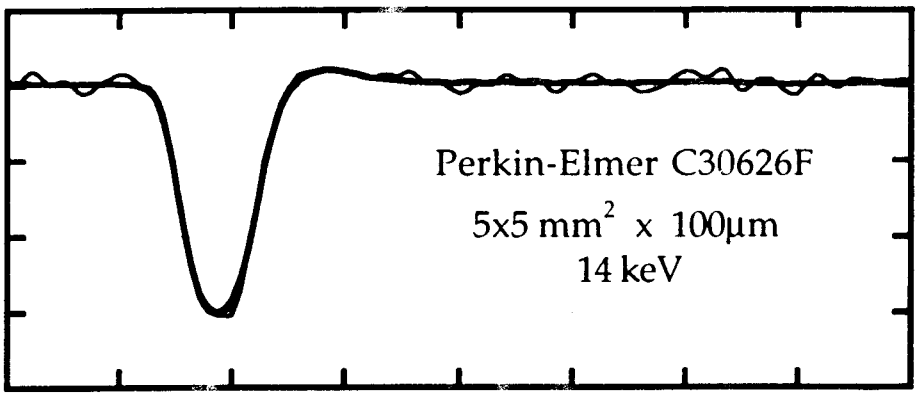
Hamamatsu S5343 LC - ϕ1 or ϕ3 mm x 20 μm
Fast -> ~150 ps time resolution, short tail
Good Signal to Noise (1keV for ϕ1mm?)

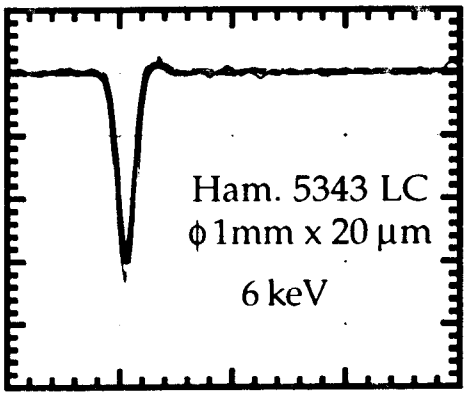
Perkin-Elmer "200 μm" 10x10 mm^2 x 180μm
Large Area
Thick -> High Efficiency
Reasonable S/N (<5 keV)

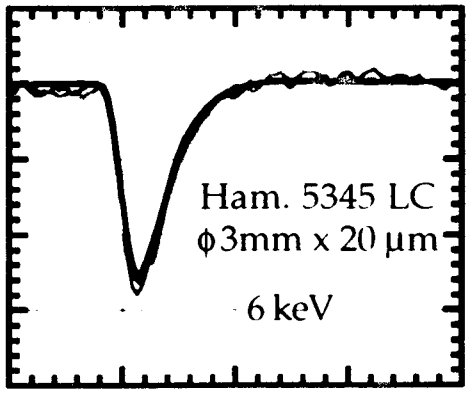


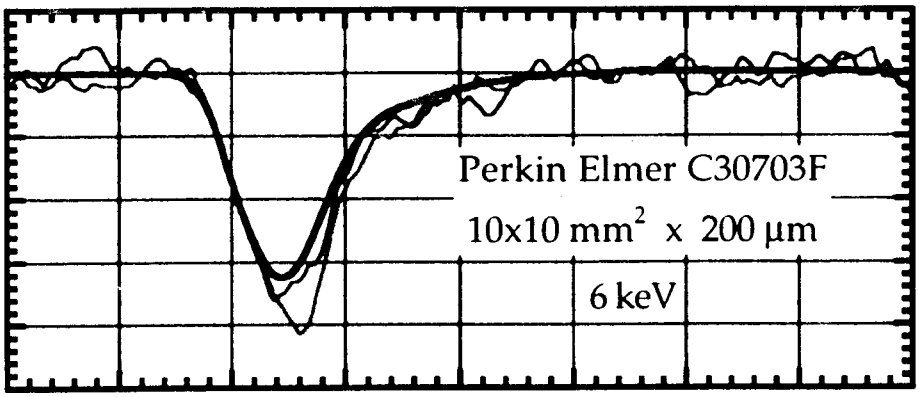
Recent Review of Available Devices:
A. Baron, Hyp. Int. 125 (2000) 29

Signal Shapes



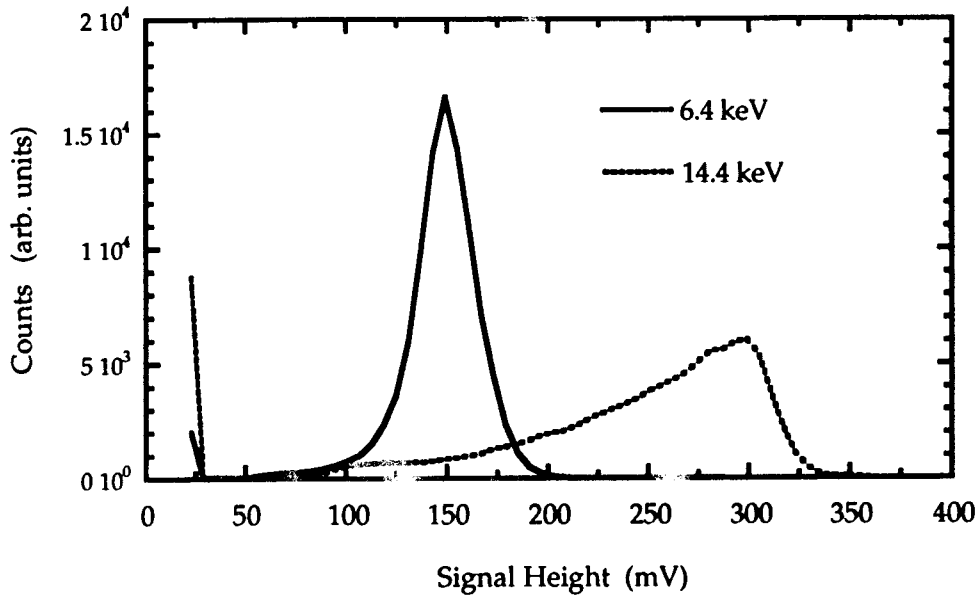


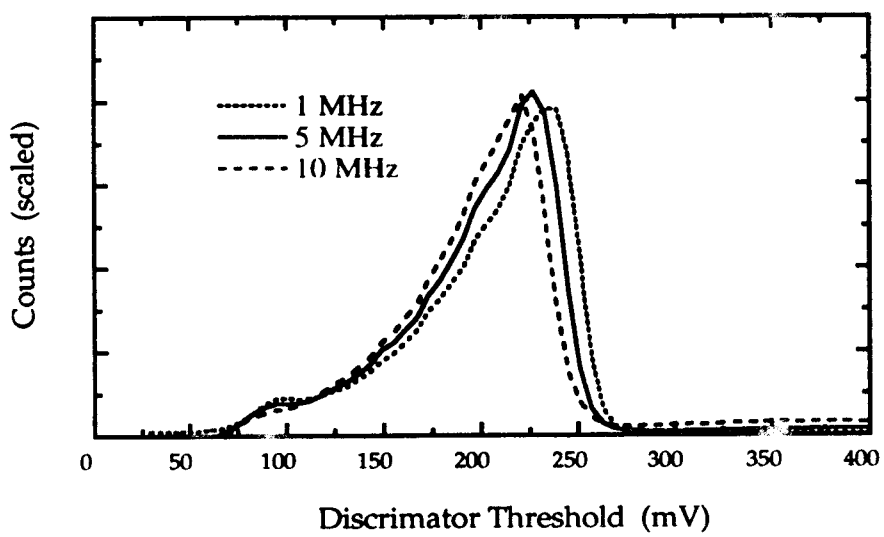


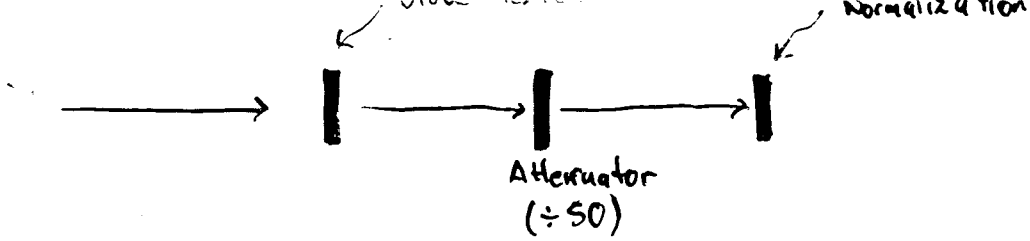


50 mV / Division 5 ns / Division

Pulse Height Resolution
(Fast Amplifier!)

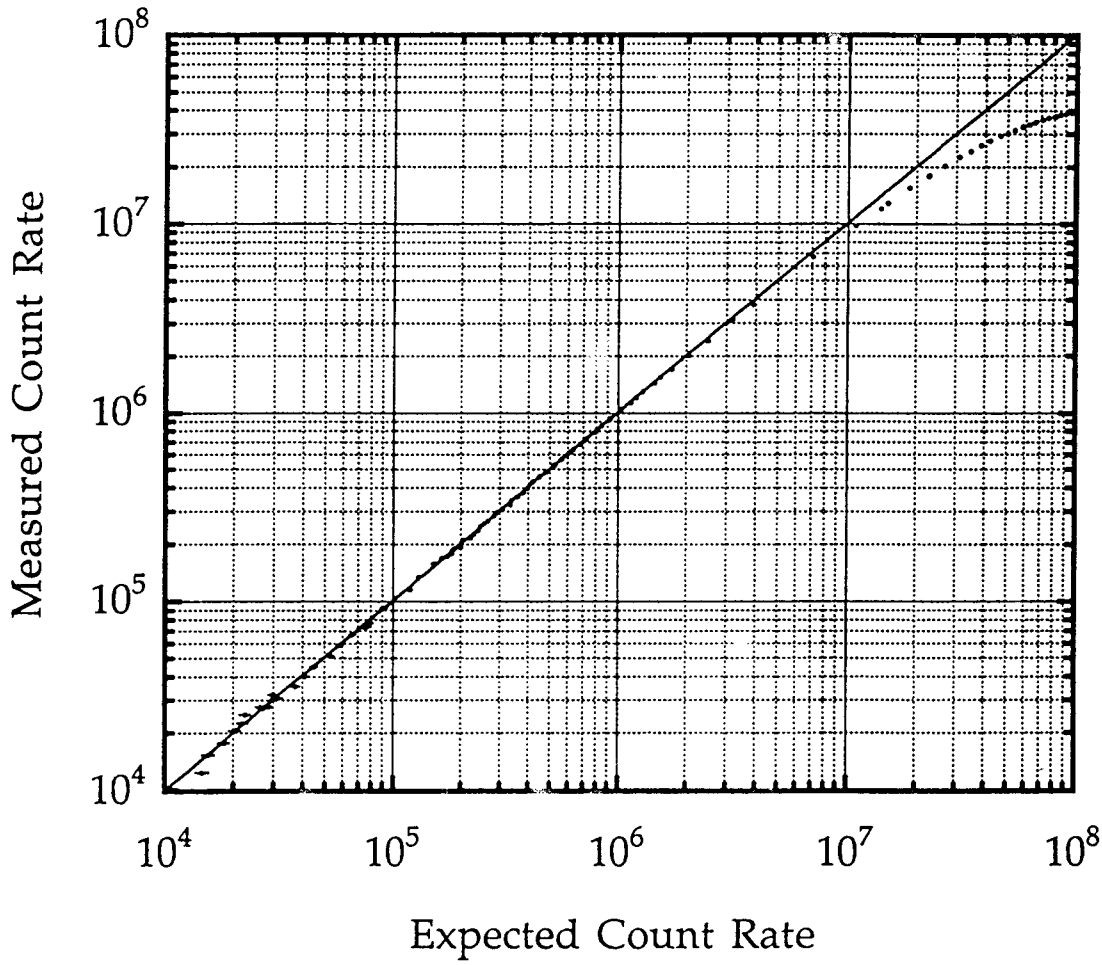






Linearity of 5x5 Diode (2/3 fill)

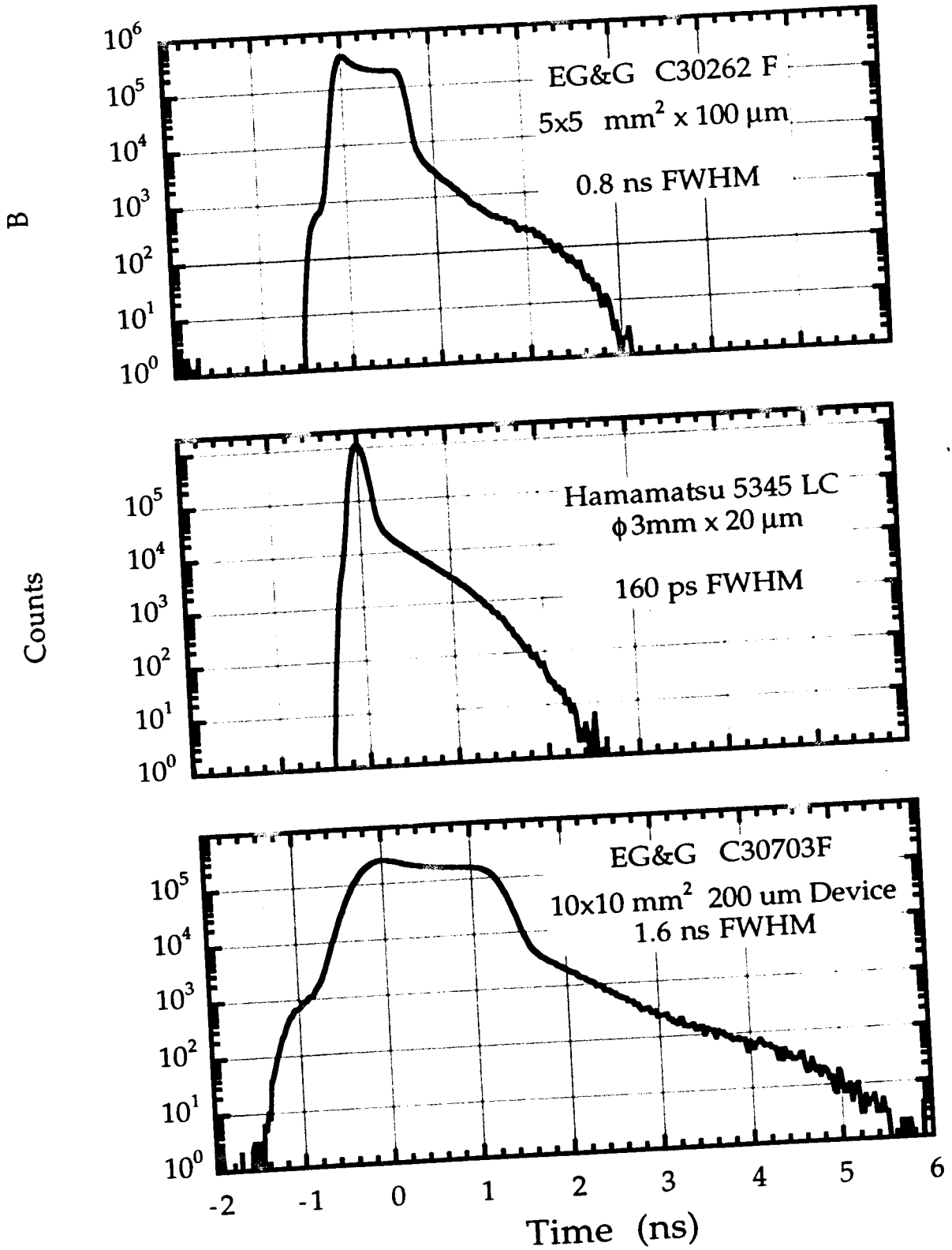
(ESRF)



Noise Rate : 10^{-2} Hz
10% Loss Rate : 10^{+7} Hz

Dynamic Range $\geq 10^9$

APD Time Resolution



Array Devices

Hamamatsu -> Close packing of standard devices

Linear arrays

ϕ1 mm elements

1x1mm^2 elements

1x2.5 mm^2 elements

2x2 arrays of ϕ1 mm elements

16x2 array of 3x5mm^2 elements

PE/EG&G/RCA -> Special Structures

Linear arrays with 300 or 150 μm pitch

Note also "Stacked Arrays" (P.E.& Ham.)

Multiple thin detectors in series.

Improves Efficiency at Higher Energies

(Baron *et al*, NIMA 400 (1997) 124)

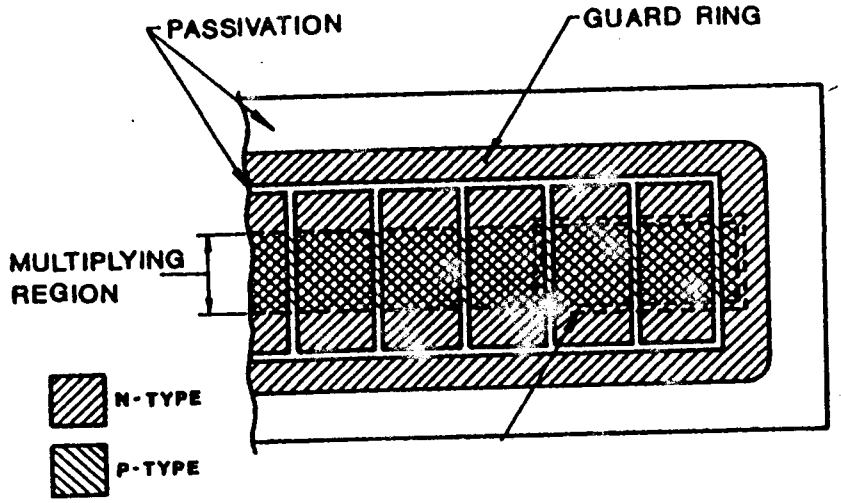
Improves Dynamic Range (Higher Energies)

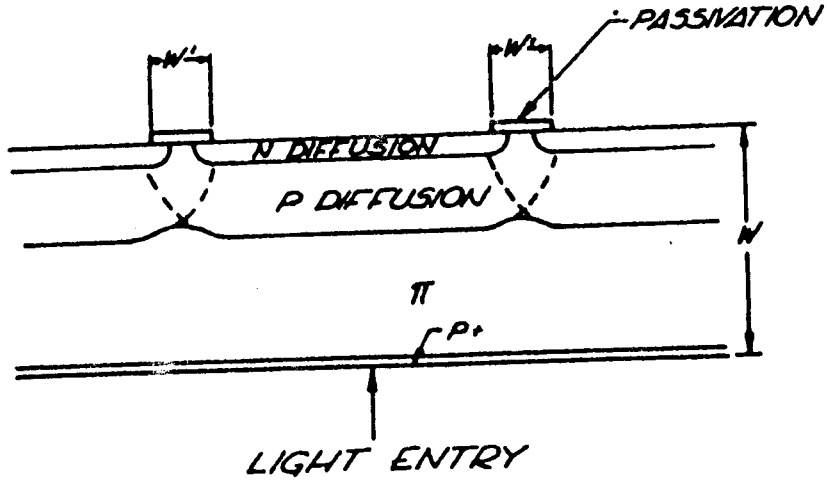
(Kishimoto et al, RSI 69 (1998) 384)

C30985 Linear Array

(Perkin-Elmer)

25 Elements, 300 μm Pitch, 100 μm Thick.

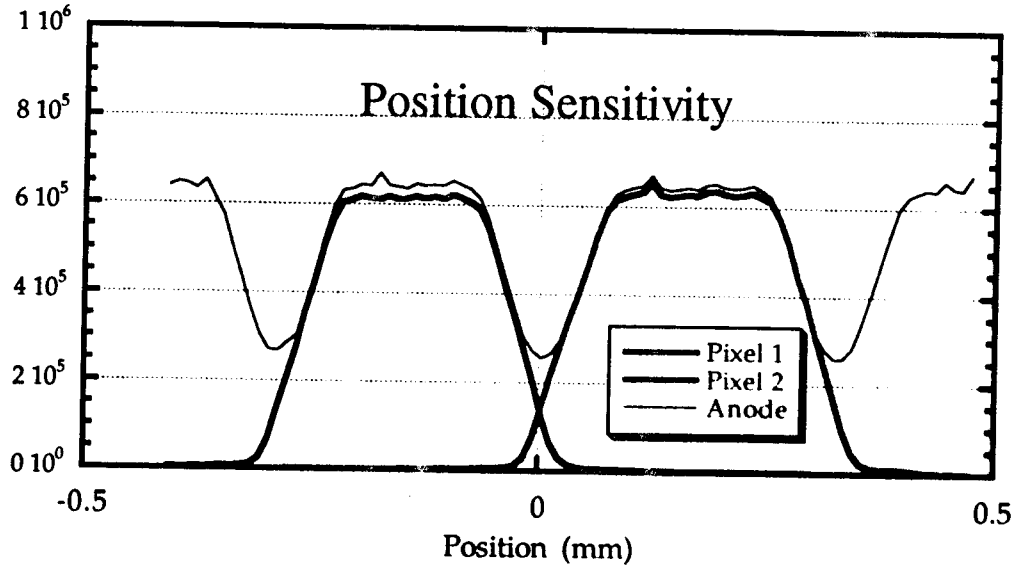


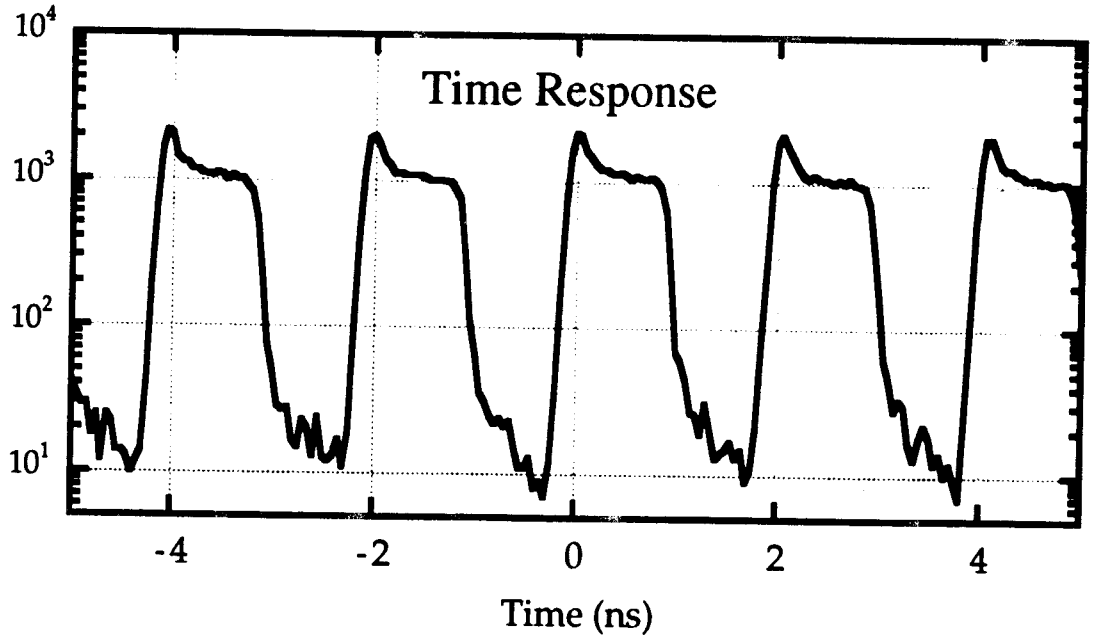


Webb & McIntyre

IEEE Trans. Electron Dev. ED31 (1984) 1206

C30985 Array - 25 Elements, 300 um Pitch,





APD Reliability
(*This Speakers Experience*)

Some Sensitivity to Moisture

- Sealed devices are usually OK
  - EG&G (PE) 5x5 mm^2 -> No Problem
    - 10x10 mm^2 Sometimes dark current rises
- Hamamatsu: No sealed devices available.
  - Some structures seem to be fine.
  - Others sometimes die.

Recovery possible on baking

- (e.g. 24 Hours in Vacuum Oven at 80C)

Bevelled Edge Devices (API, RMD)

- Large area device lifetime: minutes to months.
- Failure usually irreversible.
- Smaller devices tend to be better.

What Next?

1. NaI/PMT Replacement for E < 20 keV

   Consider the EG&G 200 um structure
   in either a 5x5 mm^2 or 10x10mm^2 package.

2. Arrays -> Integrate amplifier.

   There is some general tendency toward
   using array detectors.
   Possibly some room for standardization
   Immediate facilitation possible if there were
   some IC amplifier customized for APDs

3. Improved Time Resolution

   20 ps time resolution demonstrated with visible
   light in Geiger mode (Cova, *et al.*,RSI 60 (1989) 1104)
   Same should be possible with x-rays.

Acknowledgements

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