IONIZING RADIATION TRANSDUCERS

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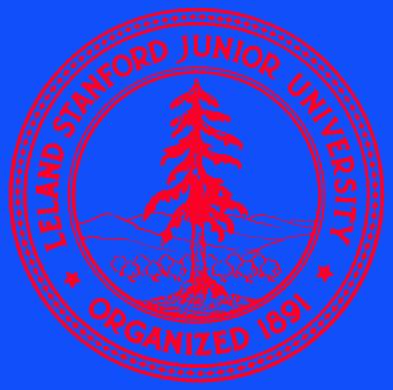
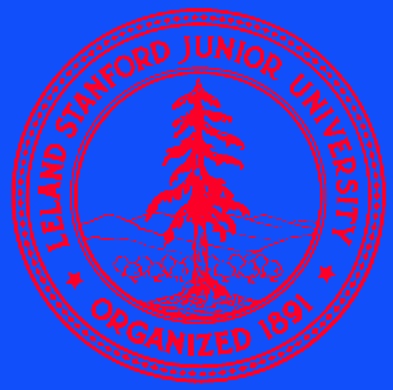




RADIATION TRANSDUCERS

- **Ionization-based detectors (Geiger-Muller)**
- **Scintillation detectors**
- **Direct solid-state detectors**

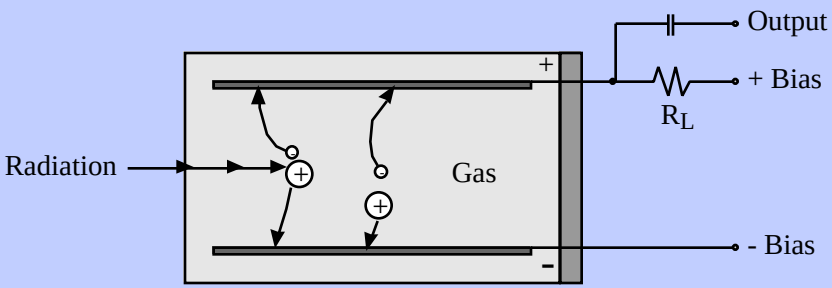
TYPES OF IONIZING RADIATION

Type of Radiation	RBE
β^-, β^+, x, γ (E < 0.03 MeV)	≈ 1
β^-, β^+, x, γ (E > 0.03 MeV)	≈ 1.7
Slow (Thermal) Neutrons	≈ 3
Fast Neutrons, Protons	≈ 10 to 20
α-Particles	≈ 10 to 20
Recoil Ions (heavy ions)	up to 30

RBE = relative biological effectiveness

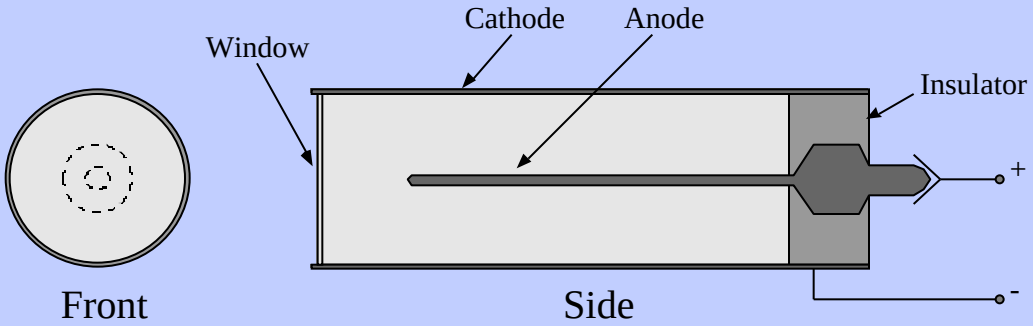
COMPARISON OF DETECTORS

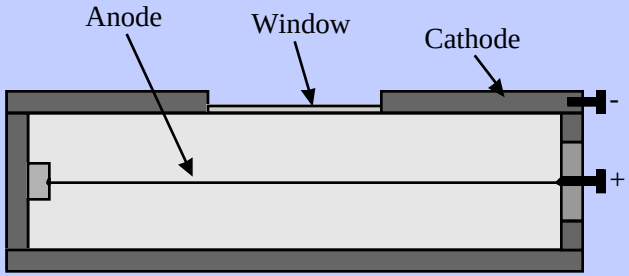
Sensor Type	Energy Required to Form e/h or e/ion Pair	Response Time
Geiger-Müller (gas-filled tube)	≈ 25 to 40 eV	≈ 0.1 to 1.0 ms
Scintillator (example NaI(Tl))	≈ 50 eV for pair, ≈ 1 keV for photoelectron at cathode of photomultiplier	≈ 0.01 to 1.0 μs
Semiconductor	1.12 eV (Si), 0.66 eV (Ge)	≈ 1 ns



G-M TUBE DESIGNS

- **Particles ionize gas, ions and electrons are attracted to cathode and anode, respectively, generating a current.**
- **No micromachined versions at present.**





Reference: Norton, H. N., "Handbook of Transducers," Prentice-Hall, Inc., 1989.

RADIATION TO LIGHT TRANSDUCTION

- **Scintillators convert incident ionizing radiation into light using an intermediate phosphor (e.g. doped ZnS).**
- **The light is detected using a conventional detector such as a CCD, photomultiplier, avalanche diode, etc.**
- **The Cerenkov Effect (radiation has higher velocity than light in a particular material, giving rise to light emission) can be used instead of phosphors.**

SCINTILLATOR MATERIALS

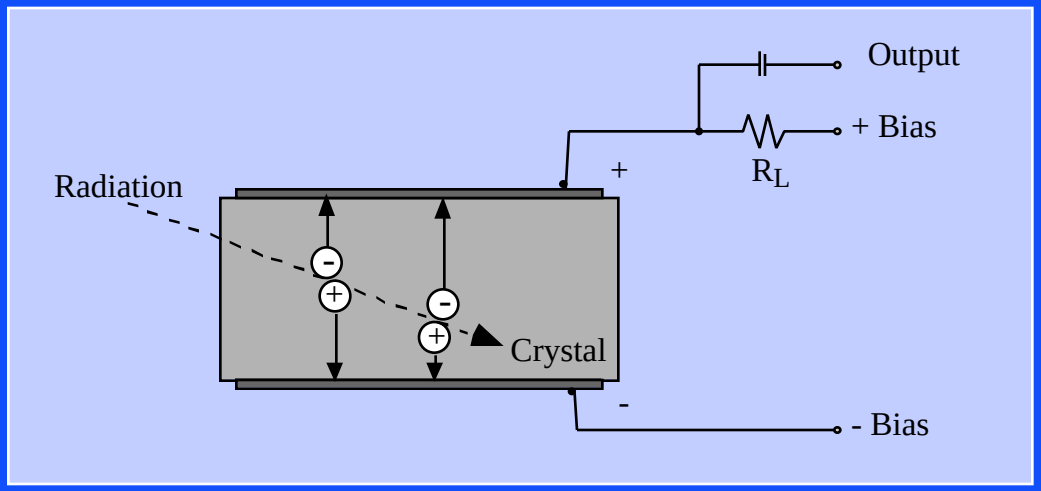
Material	Peak Emission	Cutoff Emission	Time Constant	Refractive Index	Density	γ Scintillation Efficiency
* NaI(Tl)	410 nm	320 nm	230 ns	1.85	3.67	100%
CaF_2(Eu)	435 nm	405 nm	940 ns	1.44	3.18	50%
* CsI(Na)	420 nm	300 nm	630 ns	1.84	4.51	85%
CsI(Tl)	565 nm	330 nm	1.0 µs	1.80	4.51	45%
* LiI(Eu)	470 to 485 nm	450 nm	1.4 µs	1.96	4.08	35%
* CsF	390 nm	220 nm	5 ns	1.48	4.11	5%
$Bi_4Ge_3O_{12}$	480nm	350 nm	300 ns	2.15	7.13	8%
* KI(Tl)	426 nm	325 nm	≈ 1 µs	1.71	3.13	24%

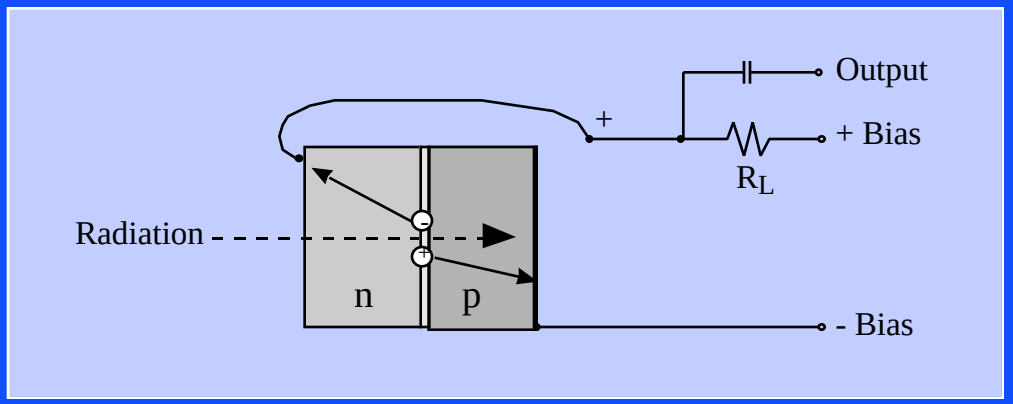
Reference: Padikal, T. N., "Medical Physics," Section 14 in "A Physicist's Desk Reference: The Second Edition of Physics Vade Mecum," Anderson, H. L. [ed.], American Institute of Physics, New York, NY, 1989, pp. 226 - 237.

DIRECT SEMICONDUCTOR DETECTORS

- **Electron-hole pair generation occurs at an average of 3 eV versus 30 eV for ionization detectors, giving higher sensitivity and SNR.**
- **Typical structures are PIN diodes, reverse biased to widen depletion region and collect carriers.**
- **Often, it is desired to track the paths of particles, so arrays of detectors are used.**
- **Fully integrated arrays with on-chip amplifiers, multiplexer and read-out circuitry have been implemented.**

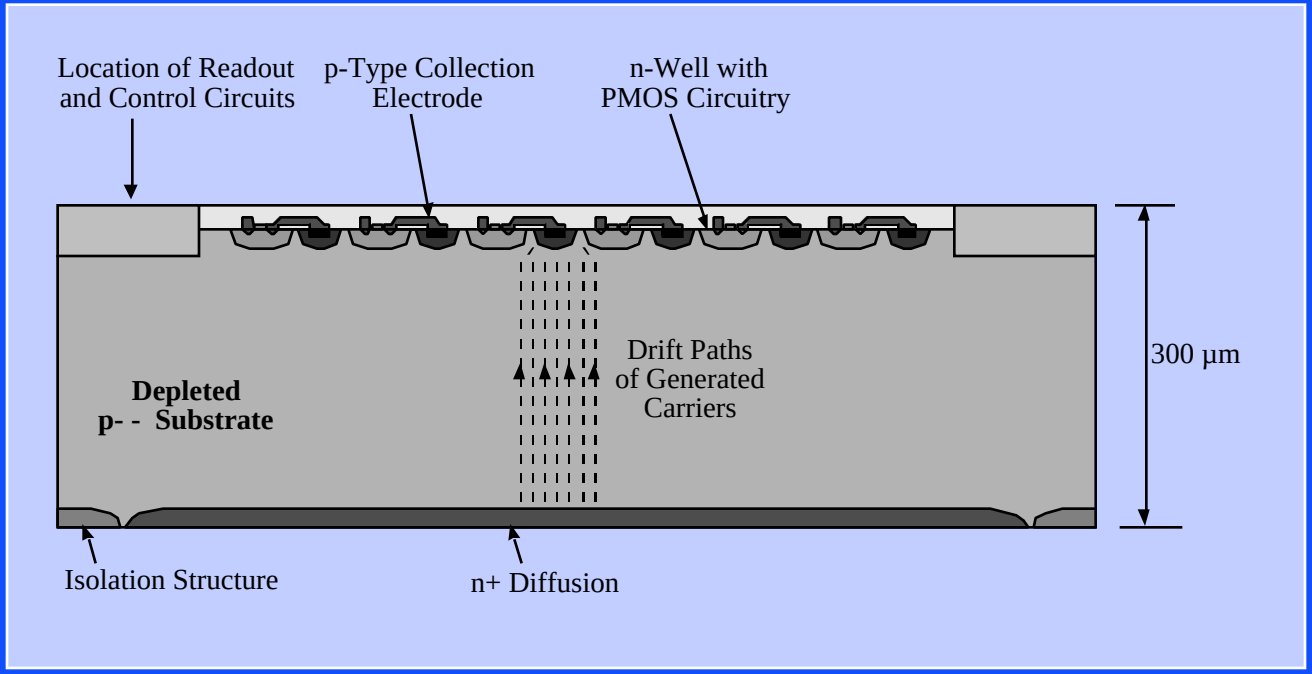
DIRECT SEMICONDUCTOR DETECTORS



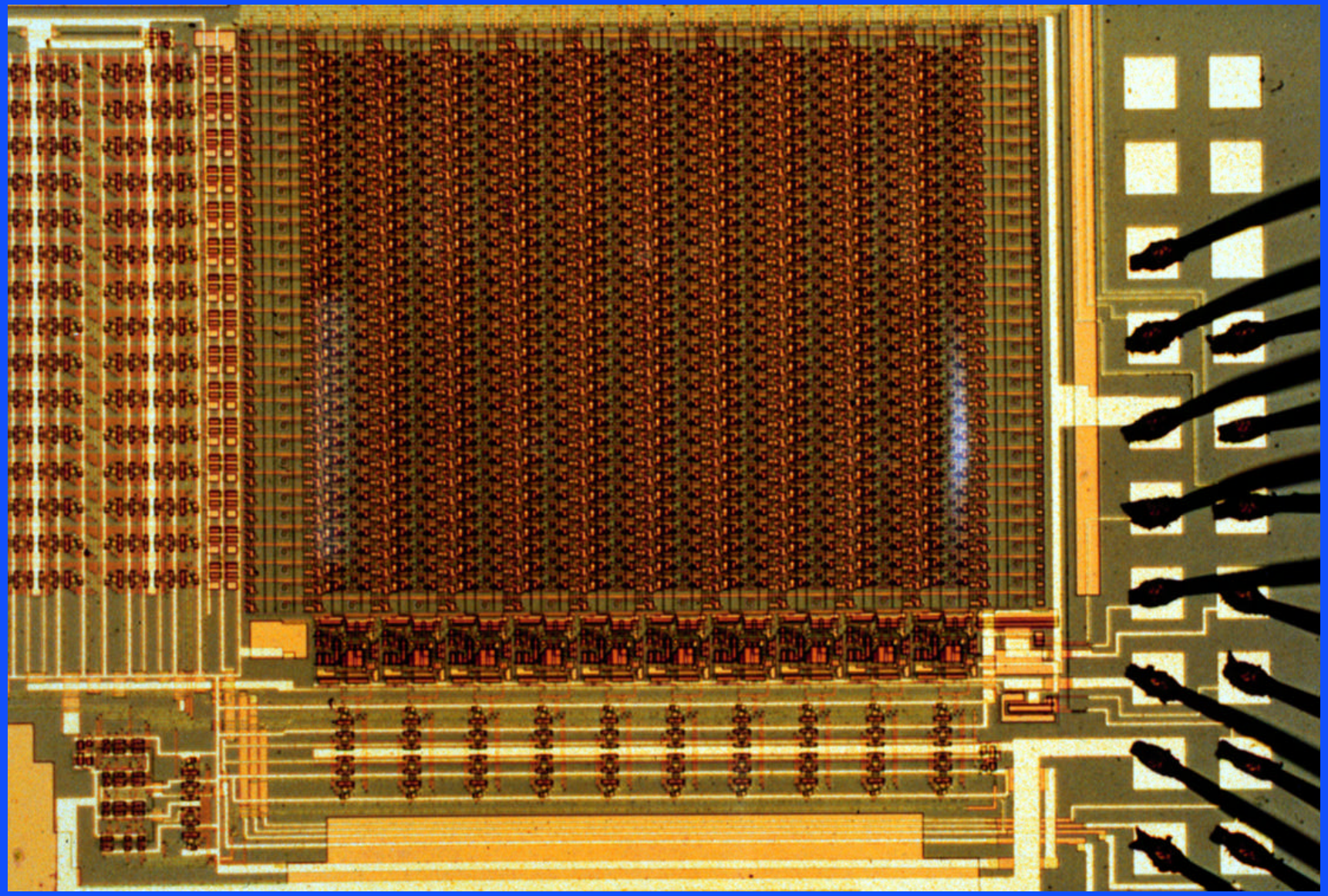


Reference: Norton, H. N., "Handbook of Transducers," Prentice-Hall, Inc., 1989.

INTEGRATED CMOS DETECTOR



Reference: Snoeys, W., Plummer, J., Parker, S., and Kenny, C., "A New Device Structure and Process Flow for a Low-Leakage P-I-N Diode-Based Integrated Detector Array," summary of conference paper, in IEEE Transactions on Electron Devices, vol. 38, no. 12, Dec. 1991, pp. 2696 - 2697.



Courtesy Dr. W. Snoeys.

POTENTIAL MICROMACHINING APPLICATIONS FOR IONIZING RADIATION

- **Heavy metal collimators (e.g. electroplated lead or gold).**
- **Integrated ionization sensor arrays with on-chip high-voltage source.**
- **Stacked 3-D detector arrays.**
- **Actuated heavy metal containing micro-shutters with radiation sources for calibration of detector arrays.**
- **Others?**