Recent Advances of Planar Silicon APD Technology

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RMD

OVERVIEW

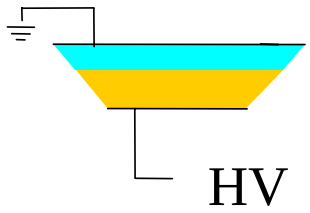
- Planar Process for Deep Diffused Silicon APDs
- Position Sensitive APDs (PSAPDs) and APDs of Various Active Areas
- Positron Emission Tomography (PET) Studies
- Single Photon Emission Computerized Tomography (SPECT) Studies
- High-Energy Physics Experiments
- APDs for Optical Communications
- Hybrid PSAPD-PMT Detector

Planar Process for APD Fabrication

Standard Wafer

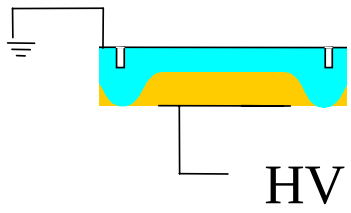
Deep Diffusion into Si wafer, p-n-p

Si Removal



Bevel Formed

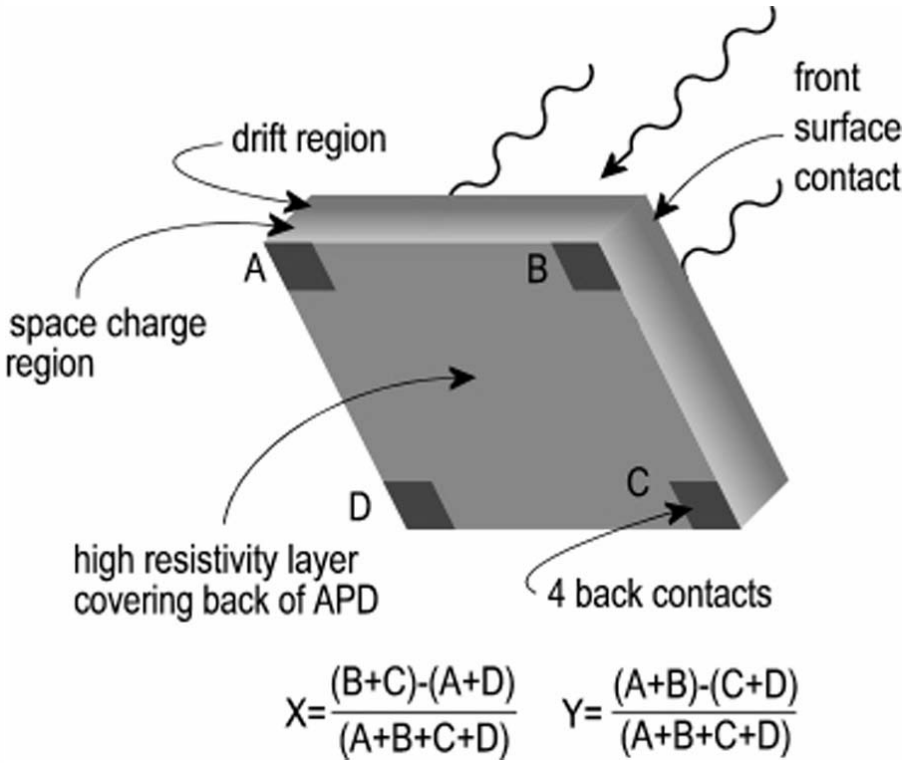
Grooved Wafer

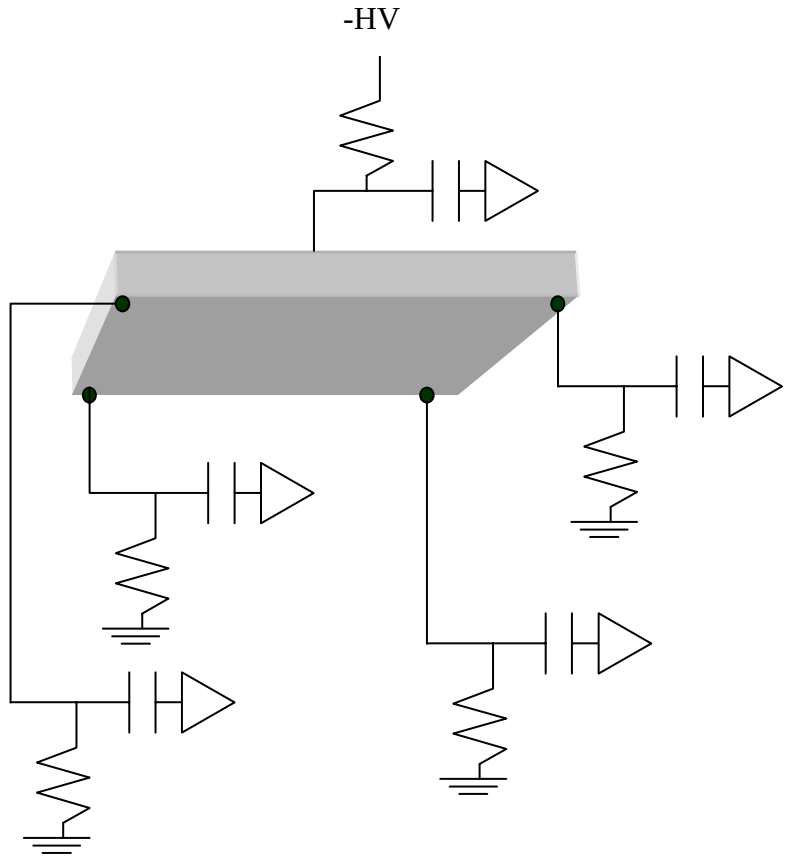


Wafer Diced

R. Farrell, K.S. Shah, K. Vanderpuye, R. Grazioso, R. Myers, G. Entine "APD arrays and large-area APDs via a new planar process," *Nuc. Inst. Meth. Phys. Res. A*, Vol. 442, pg. 171, 2000.

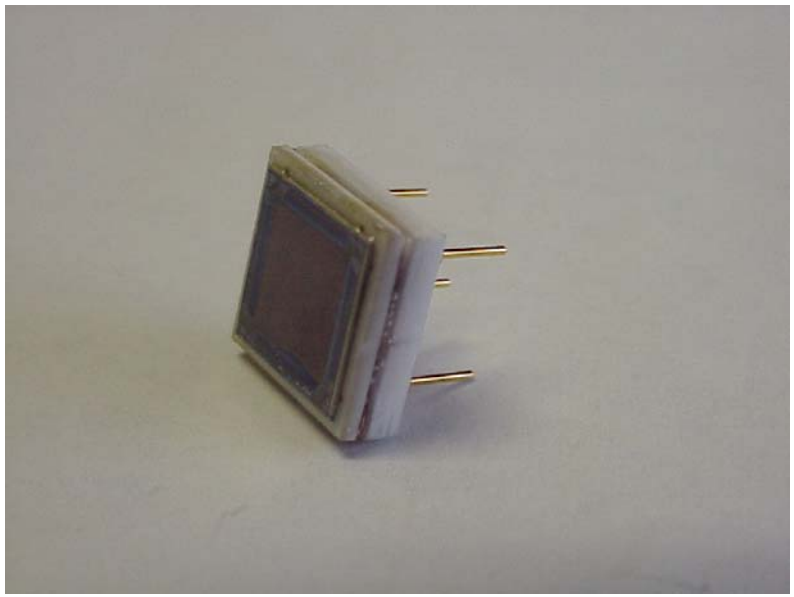
Fabrication for Position Sensitivity



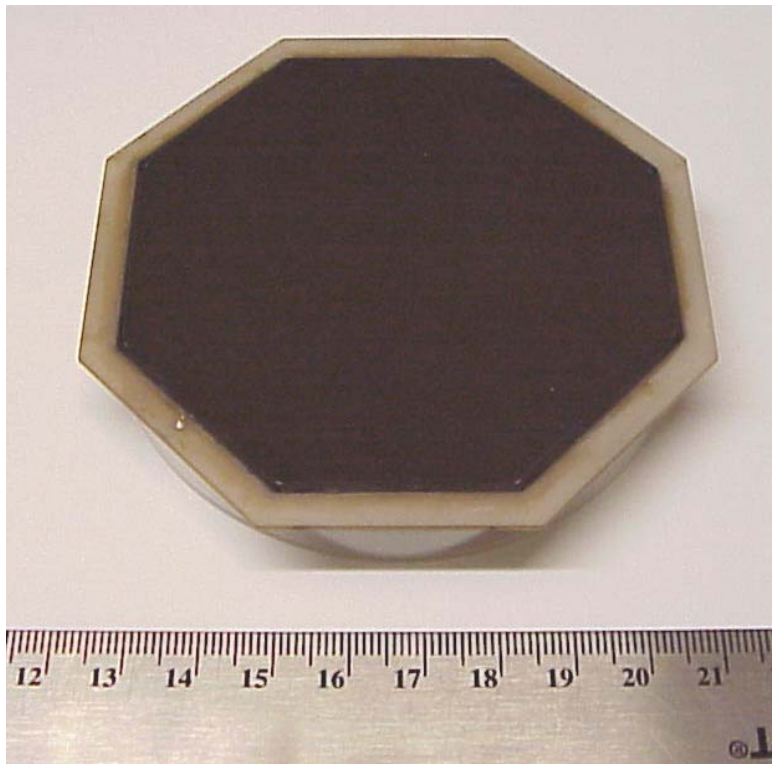


K.S. Shah, R. Farrell, R. Grazioso, E. Harmon, E. Karplus, "Position-sensitive avalanche photodiodes for gamma-ray imaging," *IEEE Trans. Nuc. Sci.*, Vol. 49, No. 4, August 2002

Position Sensitive and Discrete APDs

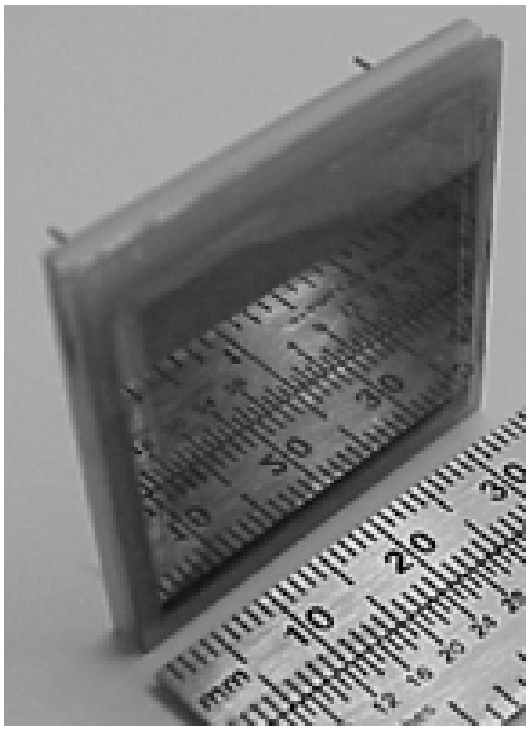


8 x 8 mm^2 PSAPD

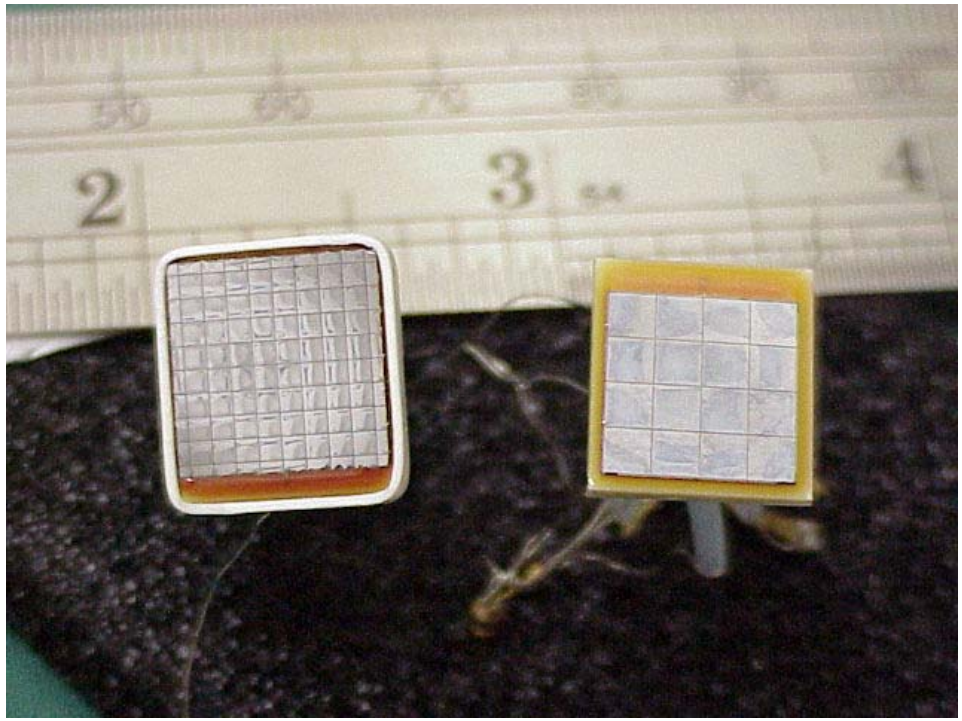


45 cm^2 Planar APD

Position Sensitive and Discrete APDs

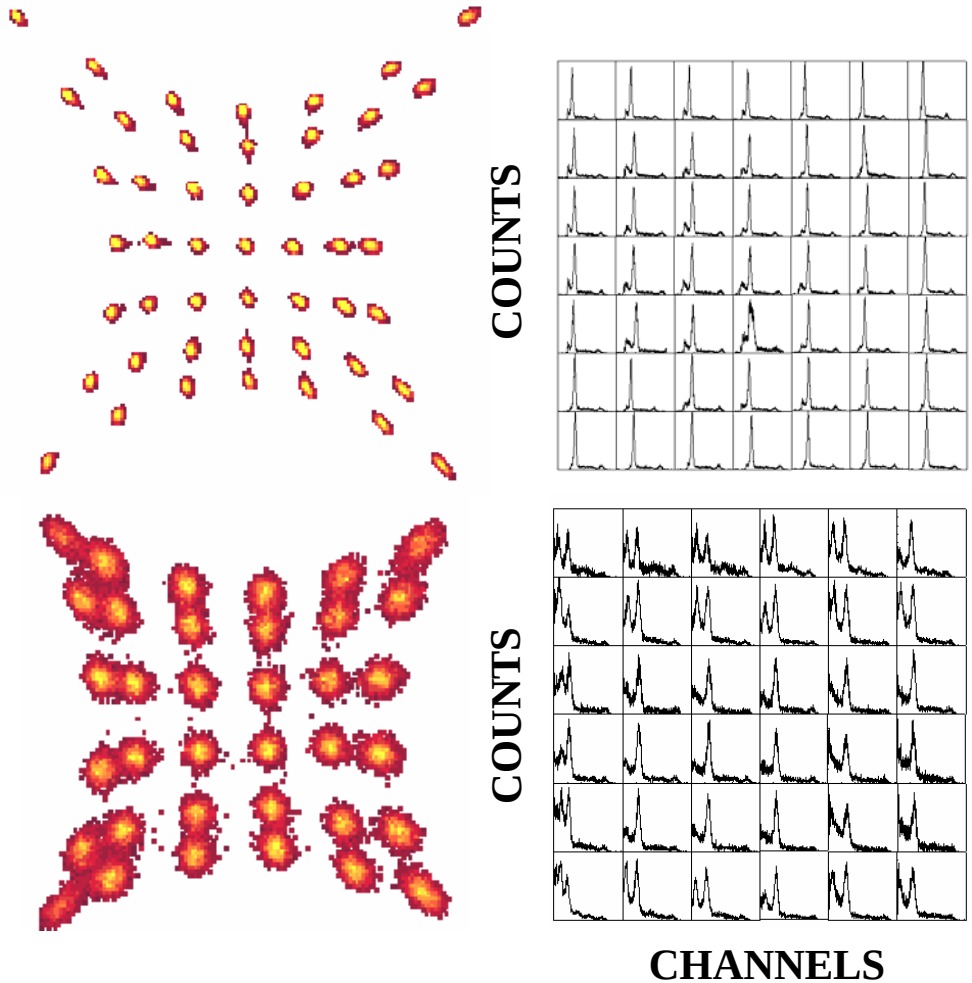


28 x 28 mm^2 PSAPD



APD Arrays

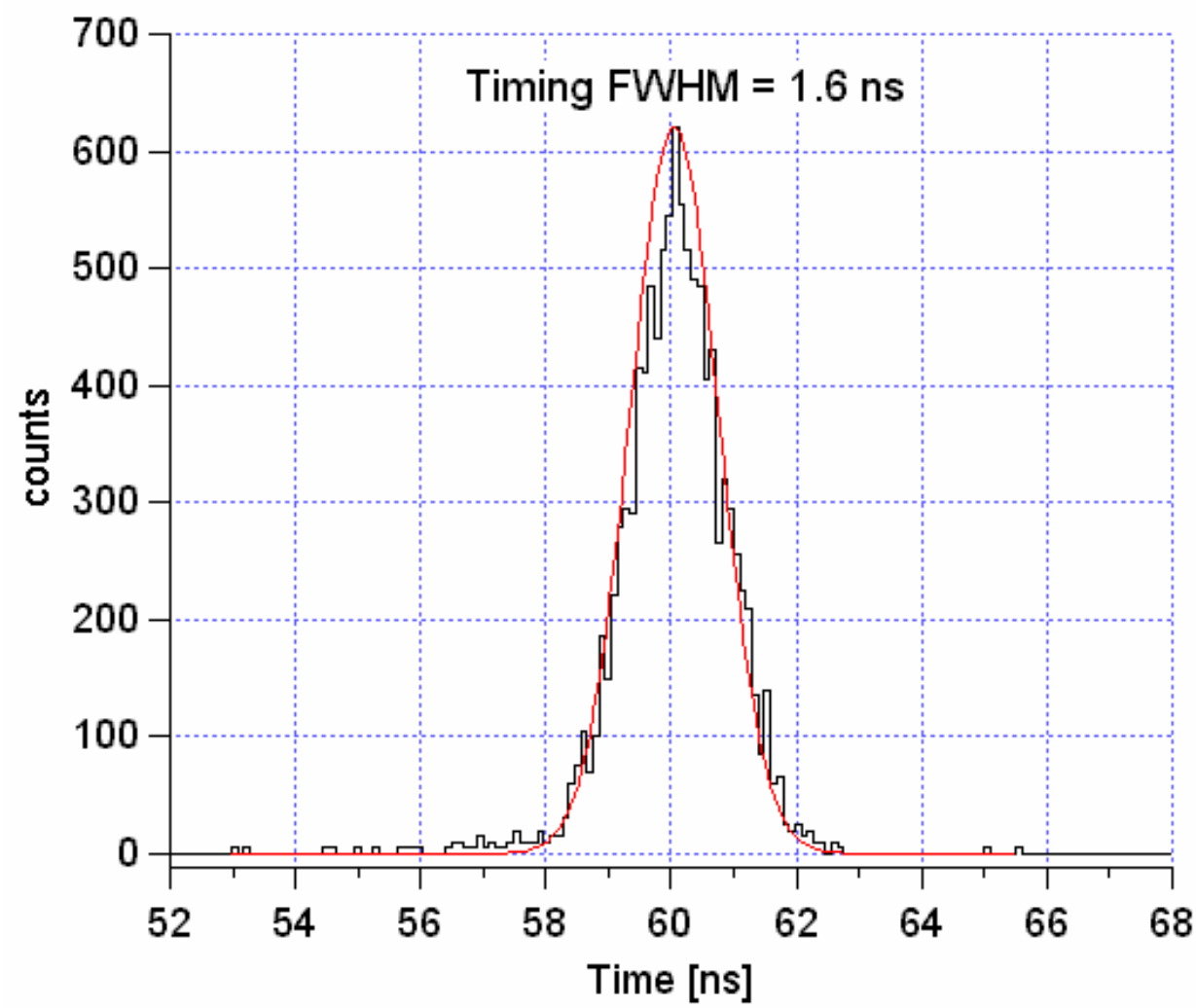
PET Applications



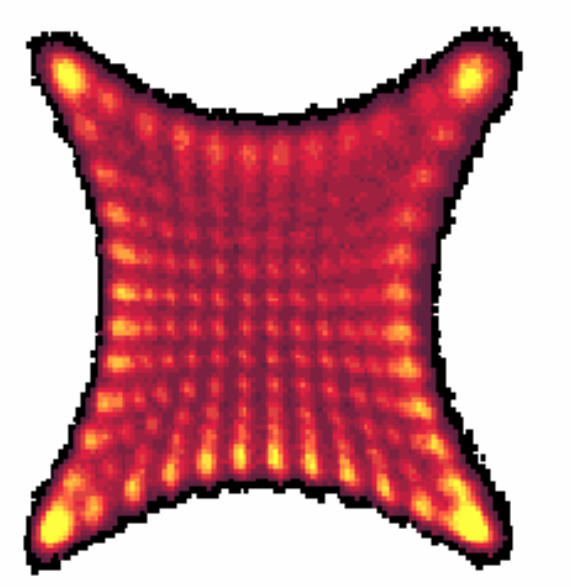
28 x 28 mm^2 PSAPD coupled to 7 x 7 LSO array with 3 mm pixels at –20 °C. Average energy resolution = 15.5% at 511 keV.

8 x 8 mm^2 PSAPD coupled to 6 x 6 LSO array with 1 mm pixels at 23 °C. Average energy resolution = 16% at 511 keV.

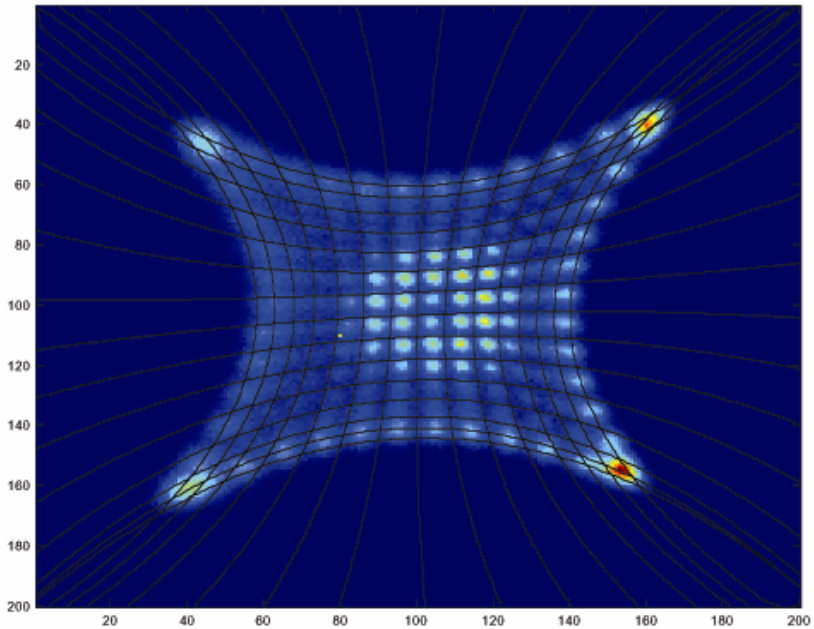
PET Applications



SPECT Applications



16 x 16 CsI:Tl array coupled to 8 x 8 mm^2 PSAPD at –40 °C, 60 keV.



A mouse myocardial perfusion phantom imaged with ^{99m}Tc (140 keV).

High-Energy Physics Applications

Brookhaven National Laboratory (**apd.phy.bnl.gov**)

www.kopio.bnl.gov

KOPIO experiment seeks to identify kaon "charge parity symmetry violations". Experiment needs various sized APDs for the calorimeter. APDs will be coupled to WLS fiber bundles.

meco.ps.uci.edu

MECO experiment will search for muons that convert into an electrons without neutrinos. 13 x 13 mm^2 APDs needed for the calorimeter. APDs will be coupled to $PbWO_4$ blocks.

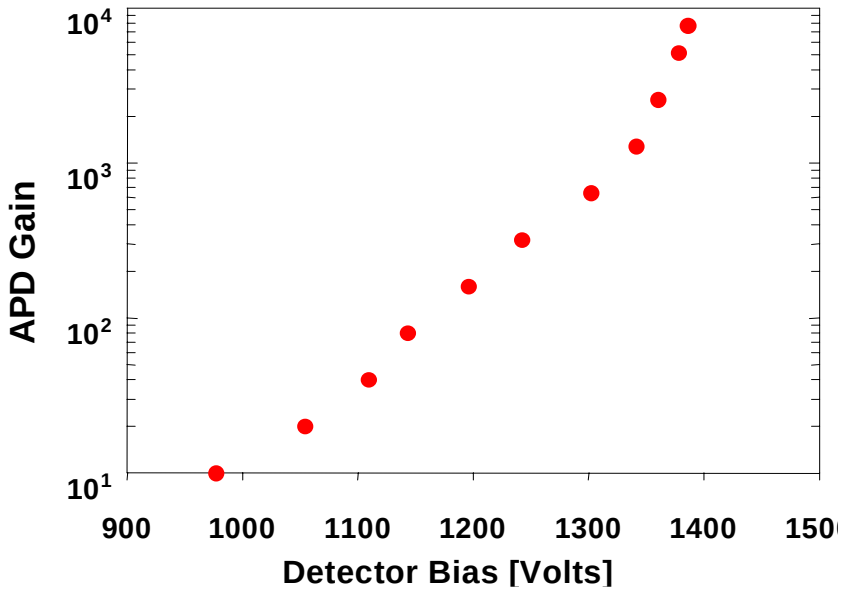
High-Energy Physics Applications

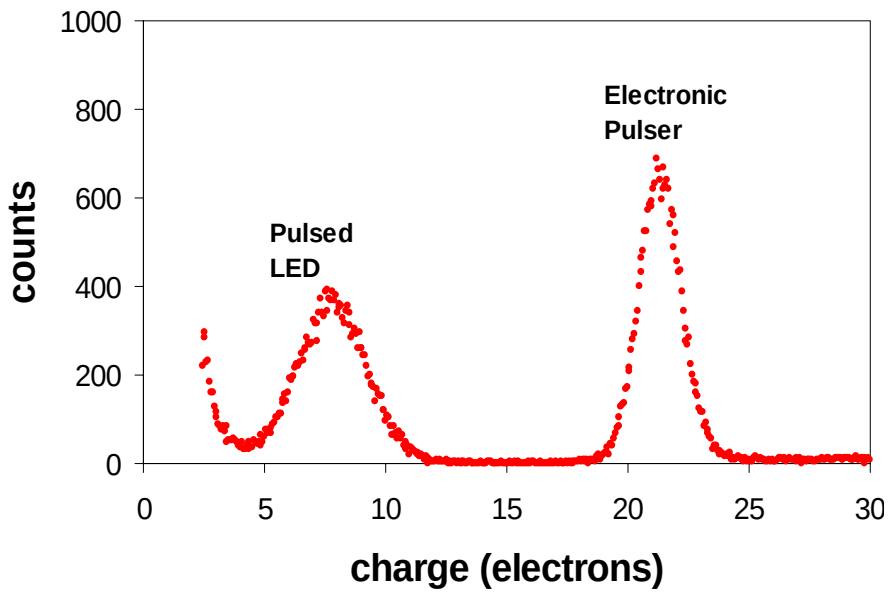
Brookhaven National Laboratory

Water Cherenkov tank has been assembled.
An array of APDs will be used.

Prototype immersible 14 x 14 mm^2
APDs have been fabricated and tested.

High-Energy Physics Applications



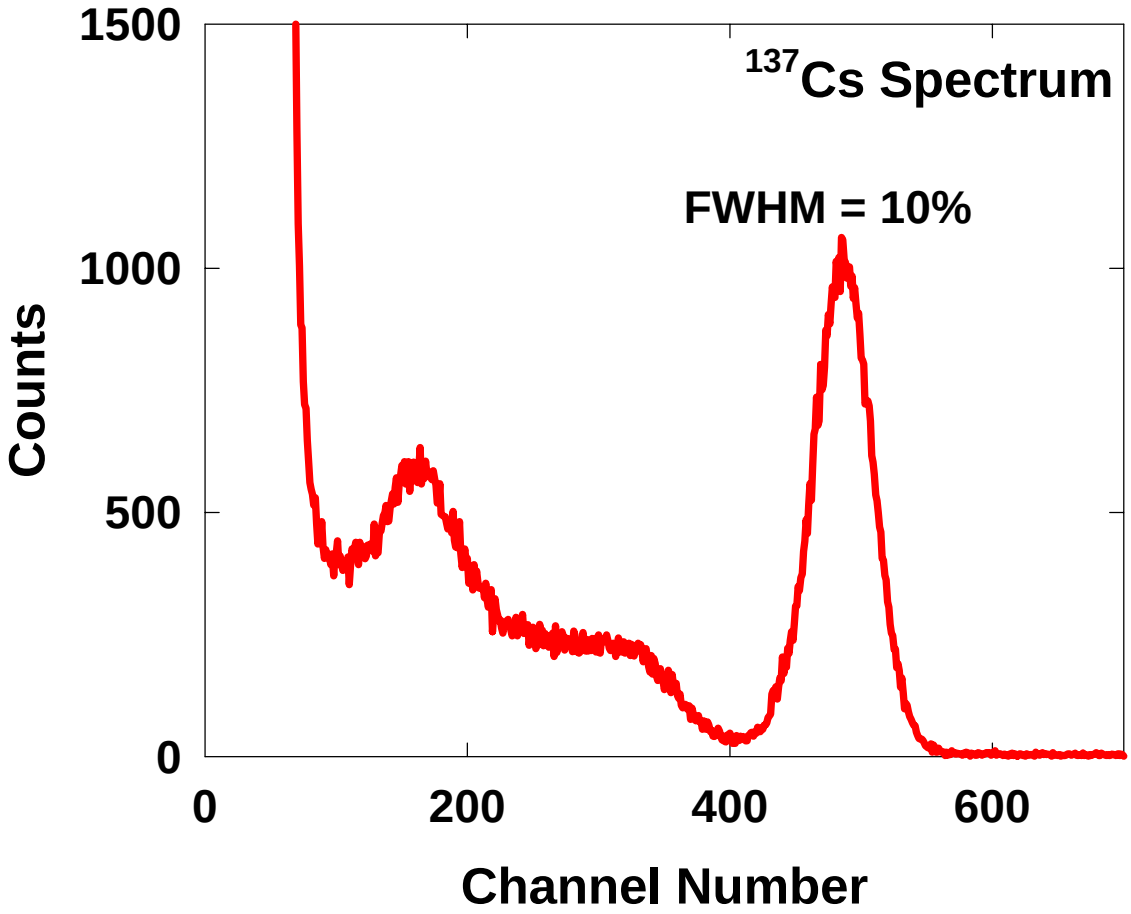


45 cm^2 APD gain vs. bias at 77 °K.

45 cm^2 APD noise and optical detection at 77 °K. Noise = 0.8 electrons-RMS.

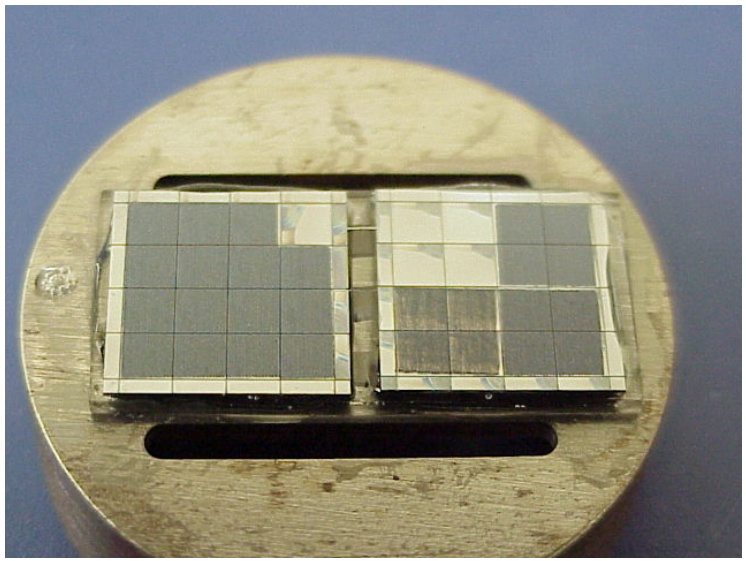
M. McClish, K.S. Shah, R. Farrell, F. Olschner, M. Squillante, "Characterization of very large silicon avalanche photodiodes," *IEEE NSS Conf. Rec.*, Oct. 16-24, 2004, Rome, Italy.

High-Energy Physics Applications



45 cm^2 APD coupled to CsI:Tl scintillator while cooled to –40 °C.

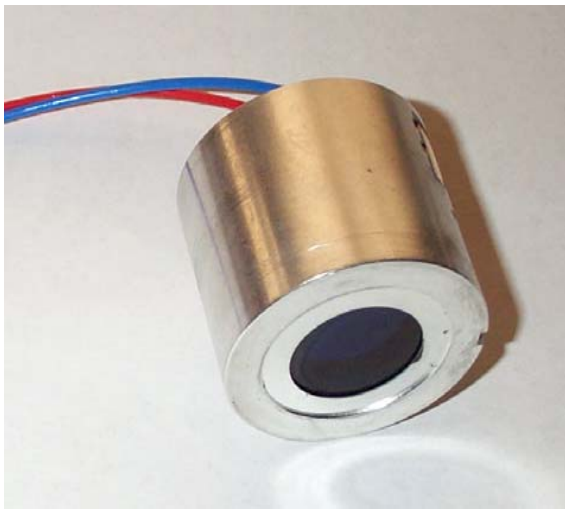
APDs For Optical Communications

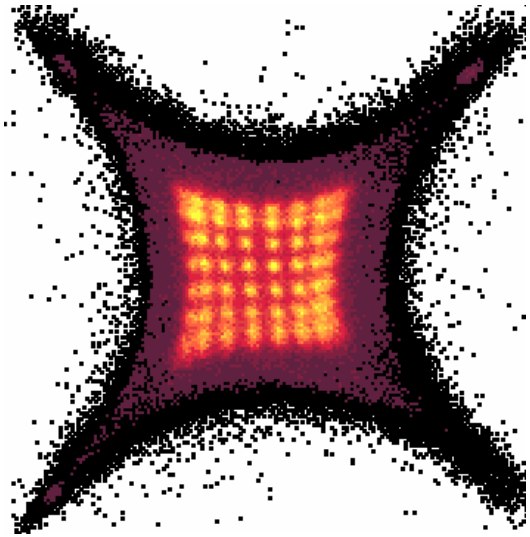


Intersatellite global and planetary near-IR (1064 nm) high-speed digital link. Arrays can also act as a pointing system to maintain laser alignment.

Device	QE at 450 nm	QE at 1064 nm
Si Photodiode	64	33
RMD APD (standard)	61	26
Textured APD	0.2	45
Textured APD with post-texturing processing	0.9	59
Standard APD with "post-texturing" processing	56	33

Hybrid Position Sensitive APD





- Proximity design
- 14 x 14 mm^2 PSAPD
- High gain 10^6 to 10^7
- 320 μm with ~5 photons/pulse

8 x 8 CsI:Tl, 1 mm pixel CsI:Tl imaged at 23 °C with ^{241}Am (60 keV).

M. McClish, K.S. Shah, R. Grazioso, J. Glodo, R. Farrell, E. Karplus, R. Benz, "A hybrid position sensitive avalanche photodiode detector for scintillation spectroscopy and imaging," *IEEE NSS Conf. Rec.* Oct. 19-25, 2003, Portland, OR.

Summary

- RMD now fabricates APDs and position sensitive APDs with various sensing areas, 1 mm^2 to 45 cm^2
- Devices posses high gain, low noise, with relatively high QE with good energy & spatial resolution
- Devices are being implement in several diverse projects
  - PET and SPECT
  - Calorimeter, water Cherenkov, and LXe instruments
  - Hybrid PSAPDs and optical communications

RMD

Acknowledgements

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