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Study of Geiger Avalanche Photo Diode applications to pixel tracking detectors

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Main Goal
The use of std CMOS tech. APD's in Geiger mode (that is reverse-biased above breakdown) as sensors with integrated logic, for direct particle detection in pixel tracking detectors

Tracking applications require:
- High Fill Factor (>90%)
- High Efficiency

Collateral (std) Application: Single photon detection for (astro-)particle physics, medical devices, etc..

Pros:
- Ionization production of Avalanche starting carrier –> Part. Detect.
- Std CMOS tech mature and supported for custom design
  - Integrated and Active Quenching (& active circuits) to minimize avalanche charge, cross-talk and after-pulsing
  - Gate mode (bunch crossing)
- Monolithic integration –> System on chip
- Moderate (low) cost
  - Very Low material budget: Depletion region ~1 μm ~80 e/h pairs!
- Very high SNR (but only binary detectors)

Cons:
- Fill factor limited to wells width
- Dark count rate (High Geiger eff. even at low excess bias V)
- Cross-talk (to handel lowering the excess bias V)
- After-pulsing (trapped carriers & delayed release; worse w/ cooling)

Approach

Device simulations
Edge breakdown / termination
Charge collection: sensitive area (?)
Quenching and recharge methods

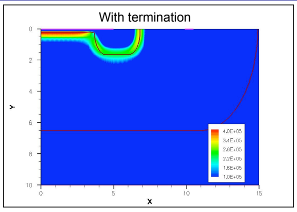
Tune simulations

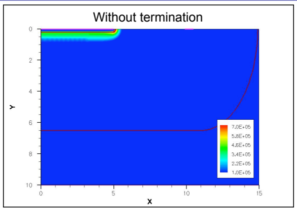
Test
I-V curves
Signal: LASER, particles
Dark count rate, After pulsing…
Crosstalk

Choose tech. and structure

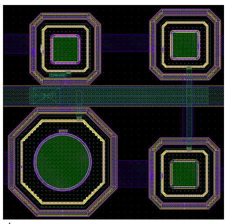
Design and proto
Basic structures
Pixel electronics
Matrices with digital readout

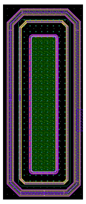
Device simulation at CNM-IMB–> Sentaurus T-CAD soft :
- AMS HV 350nm CMOS tech => PTUB termination allows breakdown at ~15V





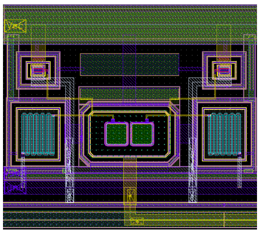
Proto's in HV CMOS:
- Test: tech layers, structure & shape.
- Layers for termination:
  - Deep p tub
  - Deep p tub and shallow n tub
  - No termination.
- Shape:
  - Classical circular shape (20 μm radius),
  - Square shape (20 μm side with rounded corners, curvature is 10 % of square side)
  - Rectangular pixels (20 μm x 100 μm, curvature is 10 % of 20 μm side).
- Rectangular pixel is optimized for ILC forward tracking



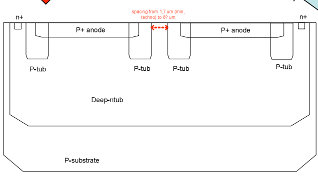


Deep SubMicron tech. proto
- Test: Integrated and Active Quenching

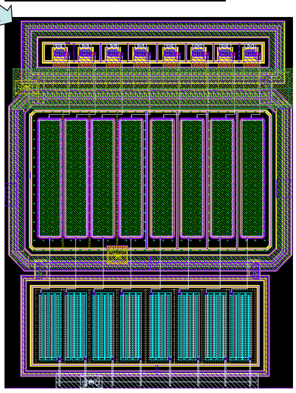
Proto's in HV CMOS:
- **APD's w/ output buffer**: To minimize output load (parasitic) capacitance which impacts performance: time response, after-pulsing, dark count, x-talk
- **Double APD and APD array:**
  - Fill factor ↑: pixel separation minimal (Min. DNTUB distance o(10 μm)).
  - Different pixels in the same DNTUB (common cathode).
    - Minimal separation is min. ptub distance (1.7 μm).
  - Problem sharing DNTUB: Electrons diffusing in the deep ntub could reach any pixel: electrical "crosstalk"…



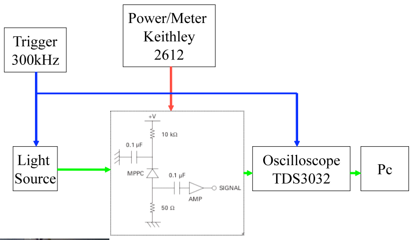
Double APD

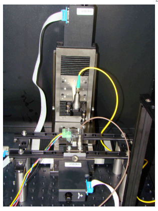


APD ARRAY



Test Setup
- 3D Traslation system: Newport ESP300
  - Resolution 0.1 μm
  - Absolute accuracy 5μm
- Black Box above isolation station
- Keithley 2612 power supply
- Oscilloscope: TDS3032 and TDS7154B
- Light source:
  - LED λ = 465nm, FWHM=850ps
  - Laser λ = 631nm, FWHM=50ps

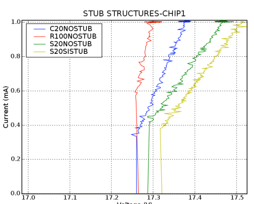




Key Measurements:
- Response to light and part.
- I-V characteristics
- Gain vs polarization
- Time resolution
- Dark current
- After-pulsing
- Cross-talk

Measurement Results

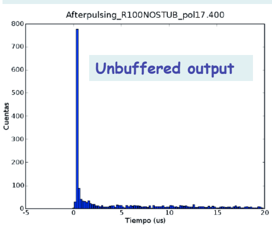
Termination works: Planar breakdown, close to simulations, stable

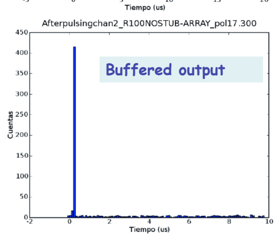


Structure	Breakdown Voltage(V)	$\sigma_V(V)$
C20NOSTUB	17.29	0.04
S20NOSTUB	17.30	0.04
R100NOSTUB	17.27	0.03
S20SISTUB	17.31	0.05

Preliminary measurements show that the unbuffered output channel shows signals with more counts after light signal. With buffered output the after-pulsing is almost suppressed

APD array pixel after-pulsing: Check the effect of a buffered output on after-pulsing





Laser light (631nm) scan on APD array