Thin-Film Semiconductor Technology Applied to Large Area Radiation Detectors

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UT Dallas

Flexible Electronics Research Group at UTD

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  - Mike Perez, Ph.D. – n-type flexible TFTs (NSF)
  - John Murphy Ph.D – Large Area Neutron Detectors (ARL, FUSION)
  - Martha Rivas – Pulsed Laser Deposition of Chalcogenides
  - Dewan Lutful Kabir – Reliability and Electrical Characterization
  - Lindsey Smith – Neutron converter layers (DNDO)
  - Kevin Larosa – Backplane electronics (DNDO)
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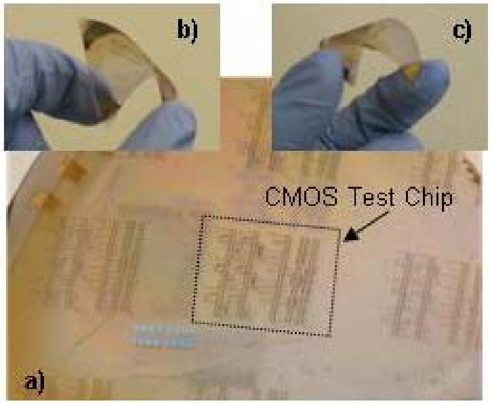
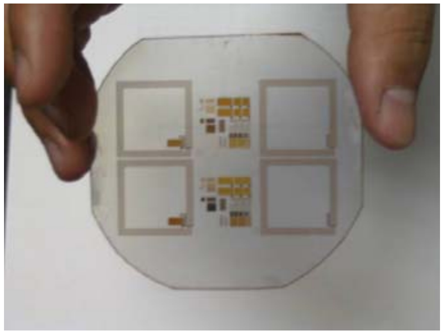
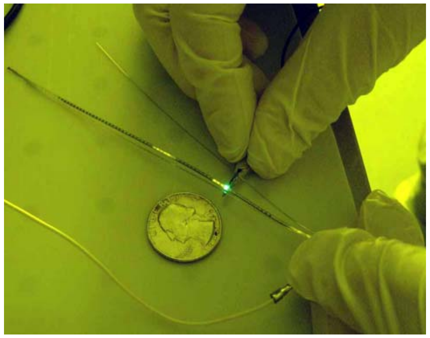
- **Collaborators**
  - Dr. David Allee (ASU), Dr. Eric Forsythe (ARL), George Kunnen (ASU)
- **FUNDING**
  - U.S. Army Research Labs,Military Tech, DOE, UT Dallas, Texas MicroPower, NSF, Texas instruments, FUSION, DNDO, AFOSR, DARPA

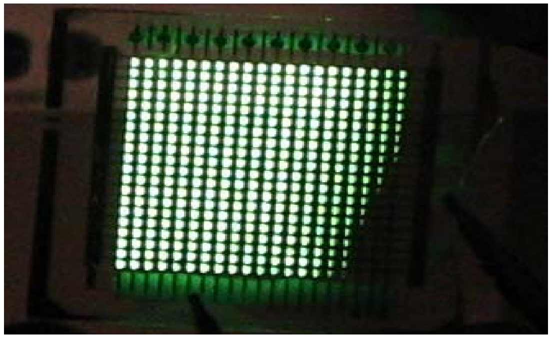
Agenda

- **Large Area Radiation Detectors**
  - **Why thin-film devices**
  - **Large area neutron detector project**
- **Current state of thin-film semiconductor devices**
  - **Transistors**
  - **Memory**
  - **CMOS**
  - **Circuits**

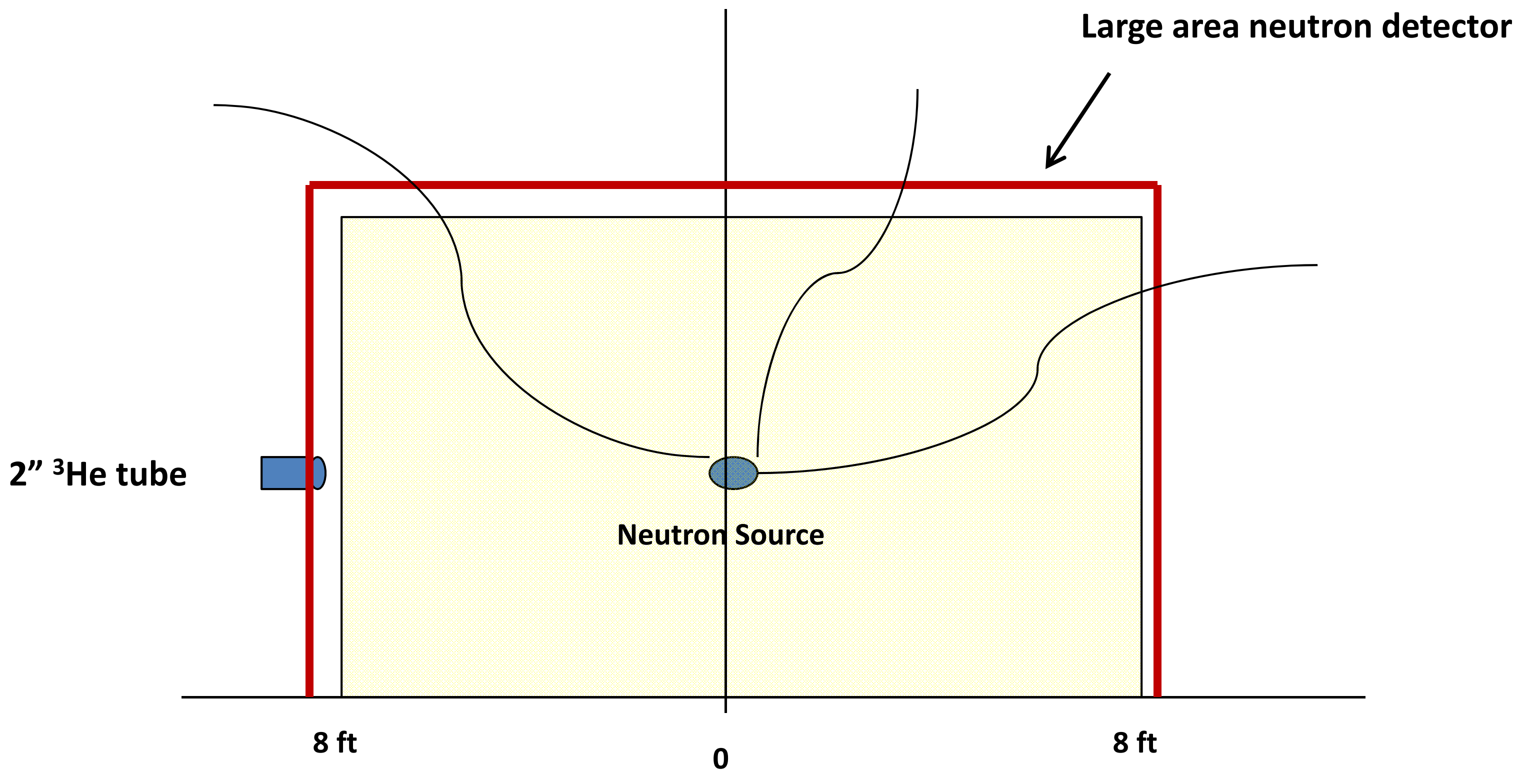






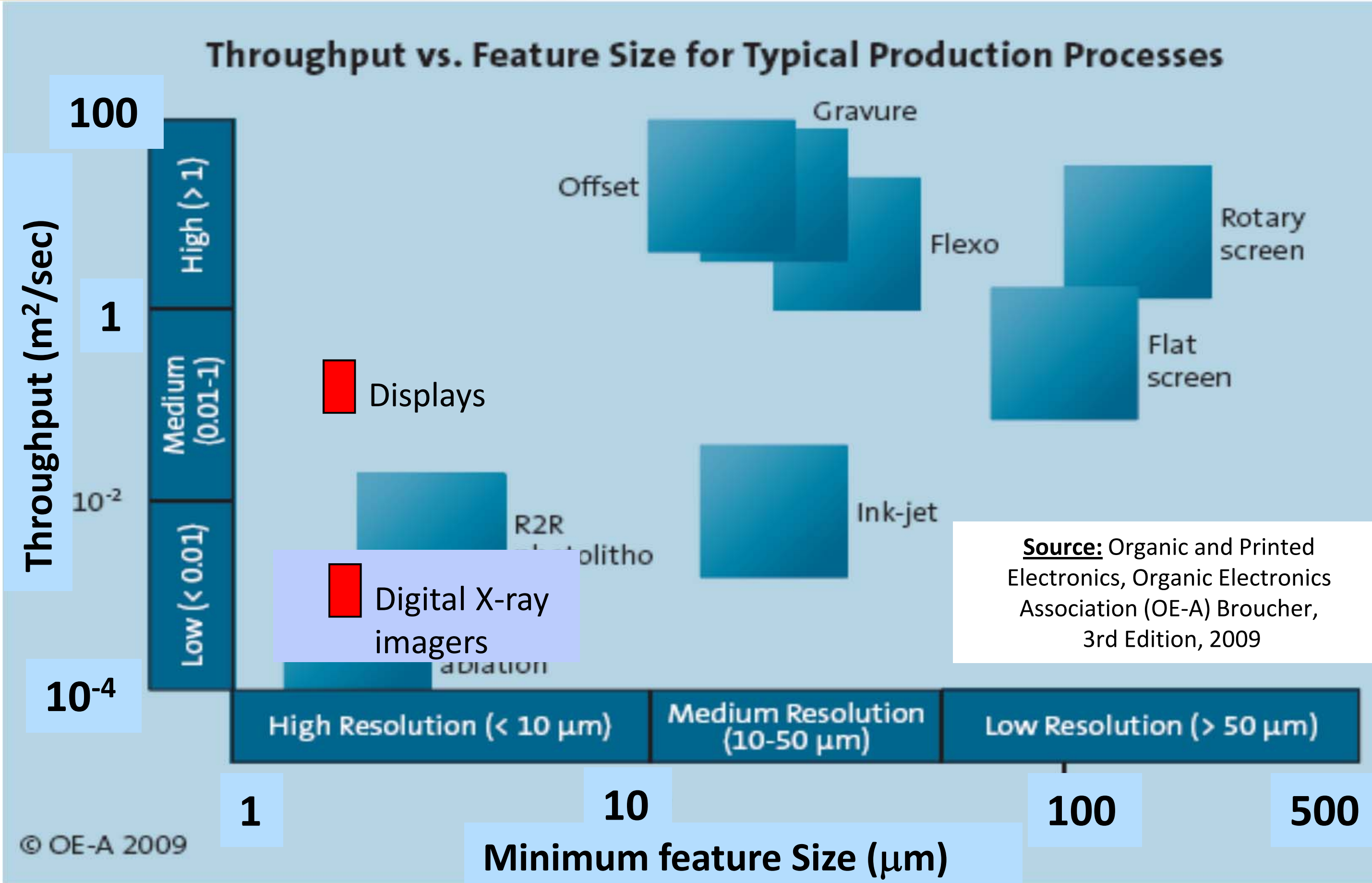


Why large area detectors?



Probability of neutron hitting 2” tube ~ 1 part in 36000
Probability of neutron hitting large area detector ~ 1 part in 3

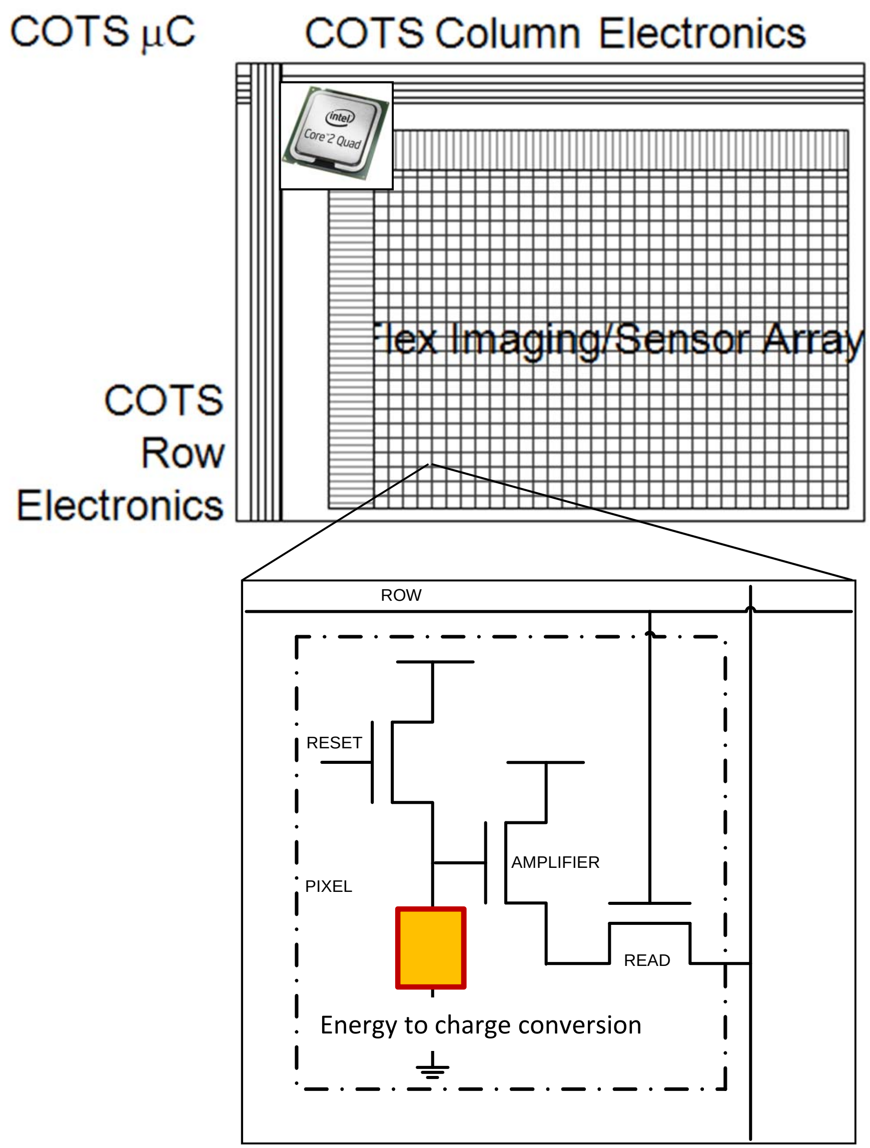
Future Flexible Electronics
Throughput vs cost / cm²



# of TFTs per min	Area per min	Yield zero redundancies	Display ~cost/cm²	Si-CMOS ($5k/wafer)	Digital X-ray 1-up/subs	Digital x-ray 4-up/subs
~10^8/min	4m²/min	99.99997%	$0.05/cm²	$6.86/cm²	$29/cm²	$7/cm²

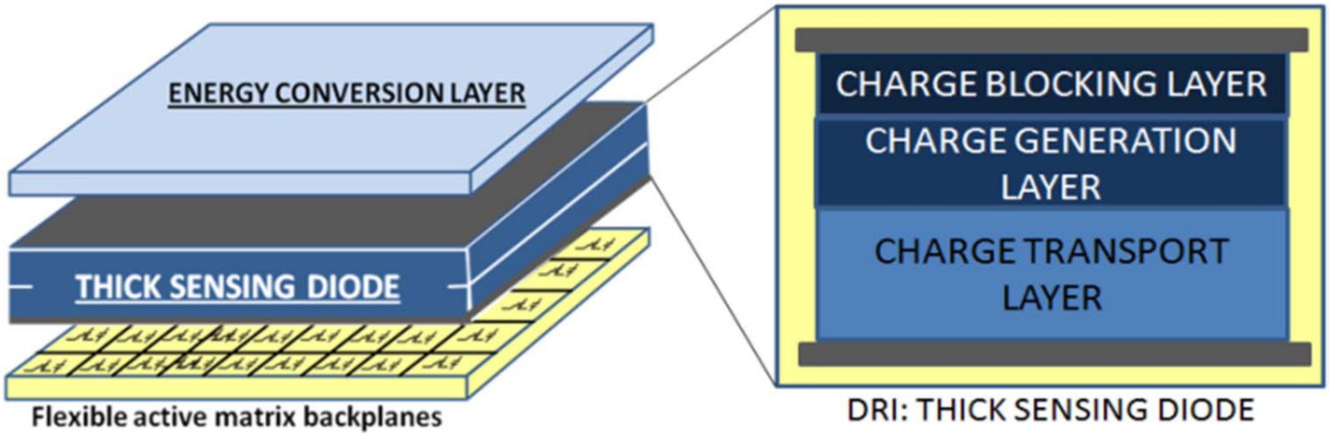
Thanks to Dr. Eric Forsythe – Army Research Laboratory

Large Area Sensor Arrays: The Concept with ASU



- ***Neutron Detection***
- VIS / IR Imager
- Millimeter Wave
- *MEMs*
  - *Blast*
  - *Acoustic*
- Electronic Textiles

Very large area, flexible, low power neutron detectors

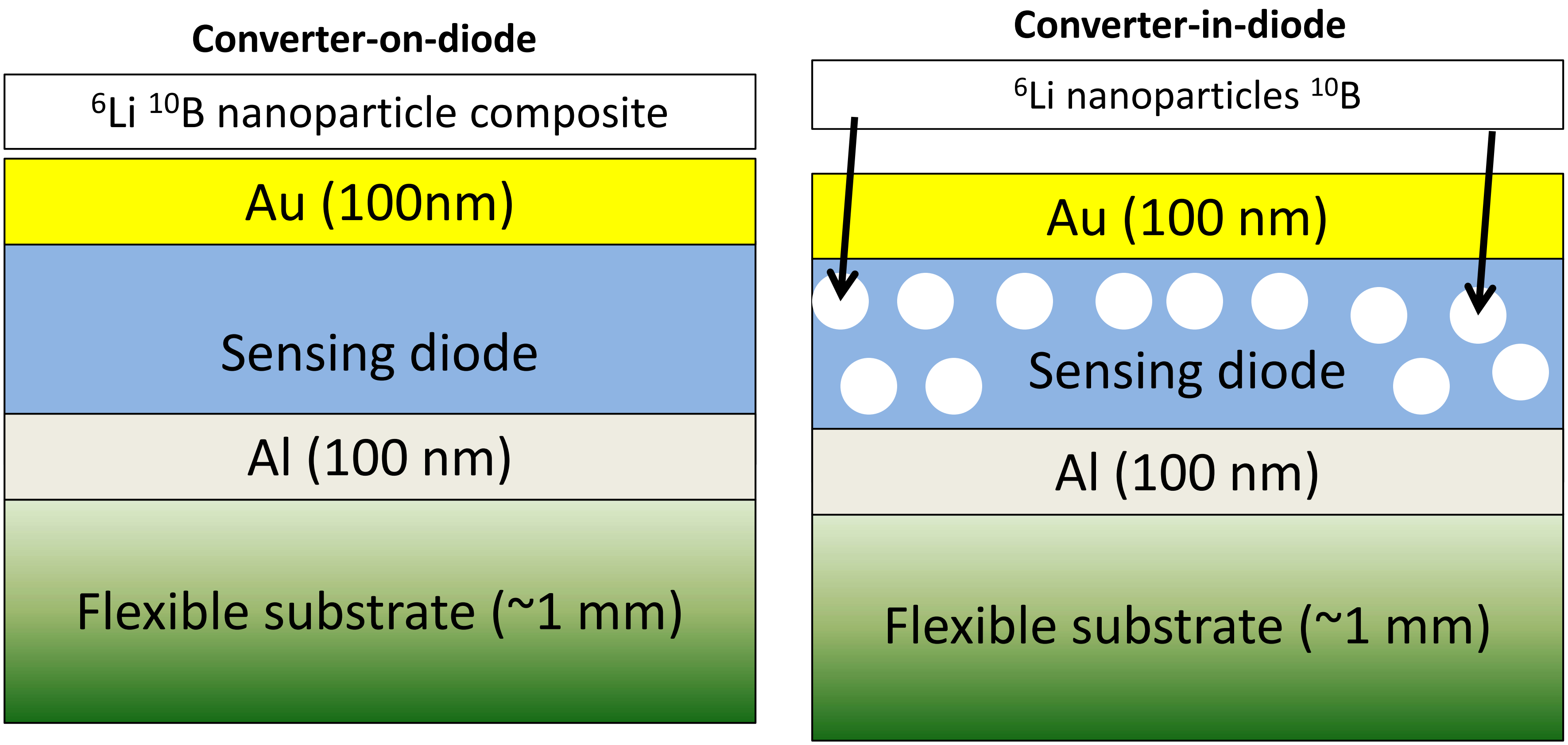


Three main pieces

- energy conversion layer
- sensing diode
- backplane electronics

Neutron conversion layer strategies

Isotope	Reaction	Thermal σ (barns)	Charged particles and energies (keV)
^{3}He	$^{3}He(n,p)^{3}H$	5333	p: 573, 3H: 191
^{6}Li	$^{6}Li(n,\alpha)^{3}H$	940	3H: 2727, α: 2055
^{10}B	$^{10}B(n,\alpha)7Li$	3835	α: 1472, 7Li: 480
^{nat}Gd	$^{nat}Gd(n,\gamma)$	49700	Conversion e-: 29-191
^{157}Gd	$^{157}Gd(n,\gamma)$	259000	Conversion e-: 29-182
^{235}U	$^{235}U(n,f)$	681	Various fission products



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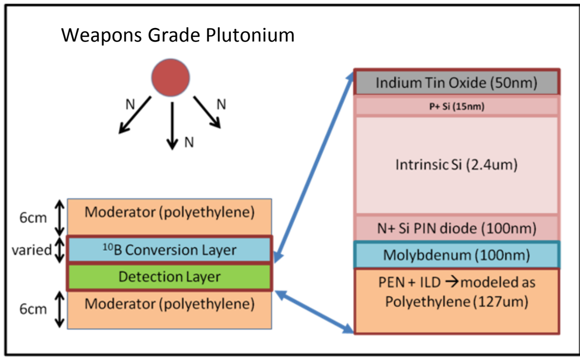
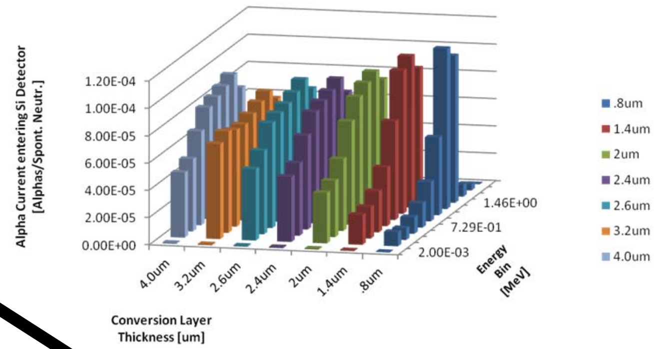
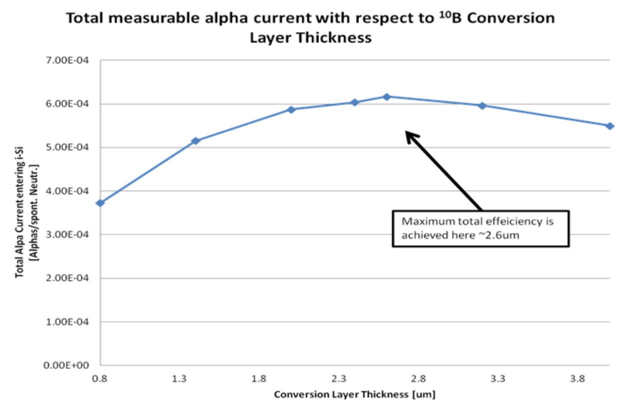
Neutron Detector Modeling in MCNPX and MATLAB

Detector Layers simulated in MCNPX:



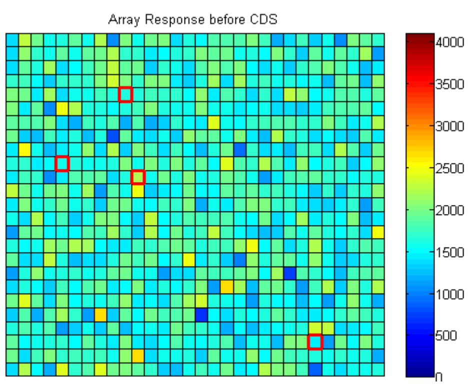


→ Example neutron conversion layer optimizations result in 2.6um ^{10}B thickness

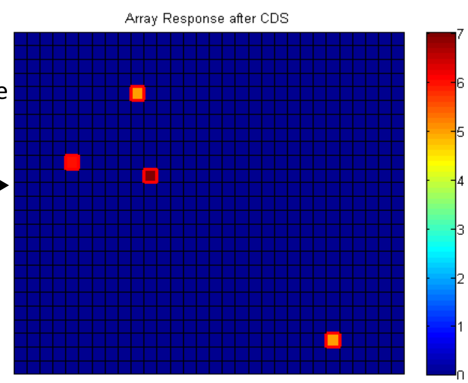


- Front end captures Neutron and emits charged alpha particle,
- Alpha detected with PIN diode and active pixel sensor circuit
- MCNPX used to model and optimize detector front-end layers
- Detector layers capable of being fabricated with FDC process

MATLAB model of arrayed pixel sensors with simulated alpha particle exposure (Red Boxes):

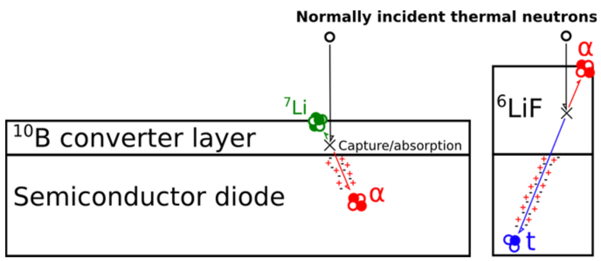


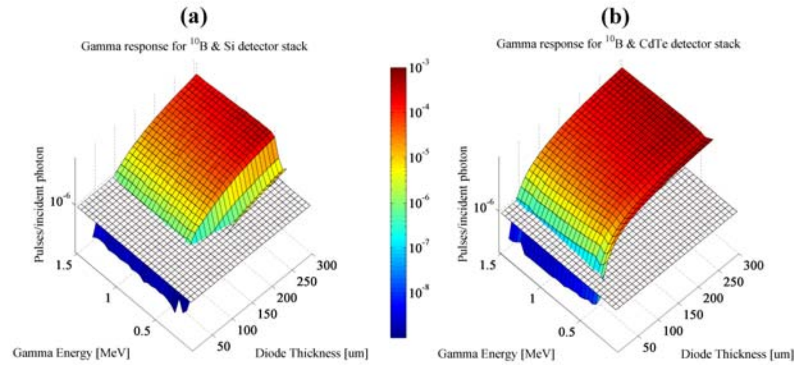
With Correlated Double Sampling applied:



- Each cell represents an active pixel sensor
- Sensors modeled to reflect FDC process variations.
- CDS dramatically improves ability for detector to resolve alpha particle strikes

Thin-film diode optimization - MCNPX





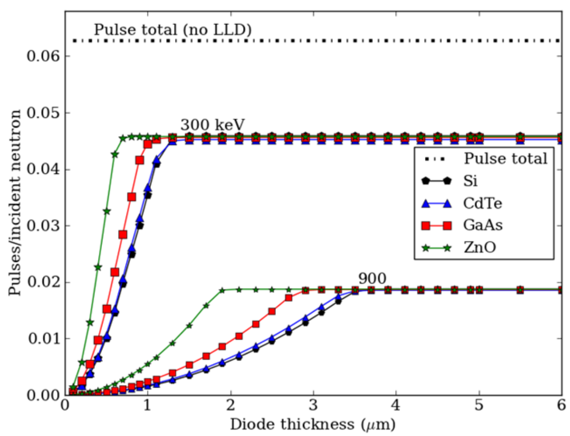
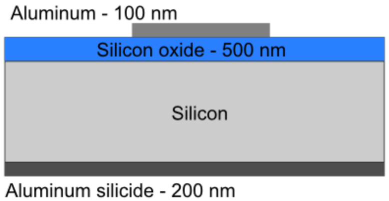
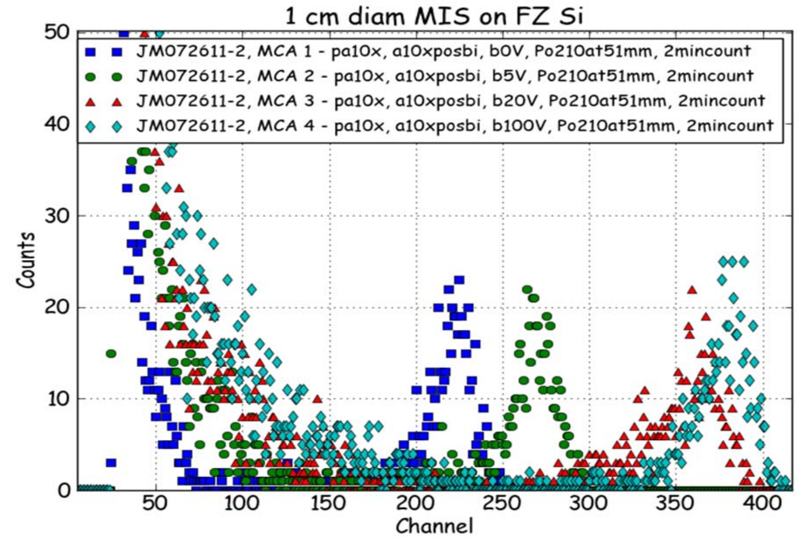


TABLE II. Intrinsic gamma efficiencies for selected thicknesses and gamma energies. (LLD = 300keV and a 2.8 μm ^{10}B conversion layer)

Thickness (μm)	***γ energy (keV)***	***Si***	***CdTe***	***GaAs***	***ZnO***
3	511	0	0	0	0
	1460	0	9×10^{-14}	0	8×10^{-14}
10	511	0	6×10^{-13}	0	1×10^{-12}
	1460	1×10^{-13}	9×10^{-12}	2×10^{-12}	8×10^{-12}
30	511	6×10^{-11}	6×10^{-7}	1×10^{-7}	3×10^{-7}
	1460	1×10^{-10}	2×10^{-7}	6×10^{-8}	2×10^{-7}
100	511	3×10^{-6}	4×10^{-4}	2×10^{-4}	2×10^{-4}
	1460	2×10^{-6}	1×10^{-4}	6×10^{-5}	9×10^{-5}
300	511	3×10^{-4}	4×10^{-3}	2×10^{-3}	2×10^{-3}
	1460	2×10^{-4}	3×10^{-3}	2×10^{-3}	2×10^{-3}

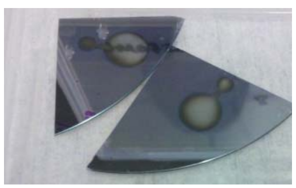
Sensing Diode Optimization: Schottky vs. MIS

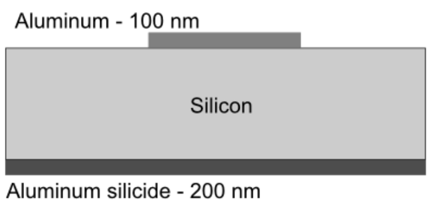


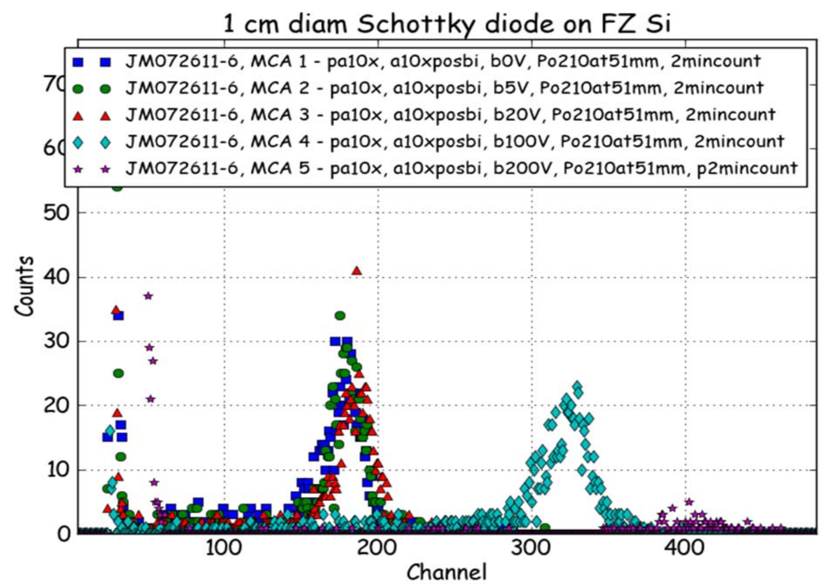


Integrating over channels for peak

Detector bias (V)	0V	5V	20V
Particles detected	562	595	651
Measured source strength	1,938	1,954	2,245
Efficiency	**60%**	**60%**	**69%**



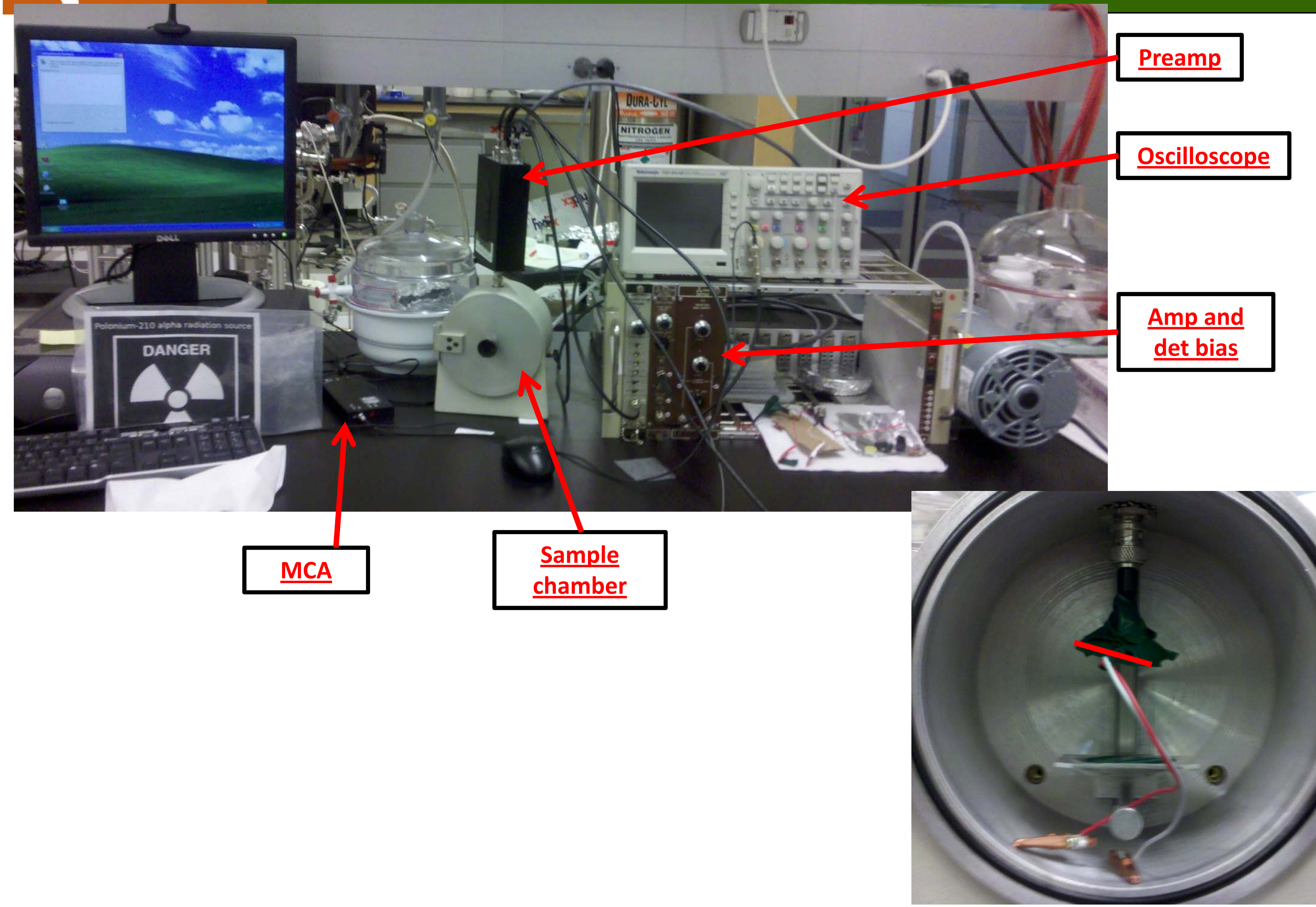




Integrating over channels 100-450

Detector bias (V)	0V	5V	20V	100V
Particles detected	785	772	752	869
Measured source strength	2,486	2,445	2,382	2,752
Efficiency	**77%**	**76%**	**74%**	**85%**

Radiation measurement setup



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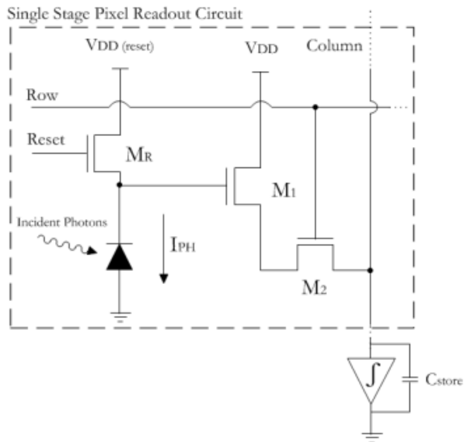
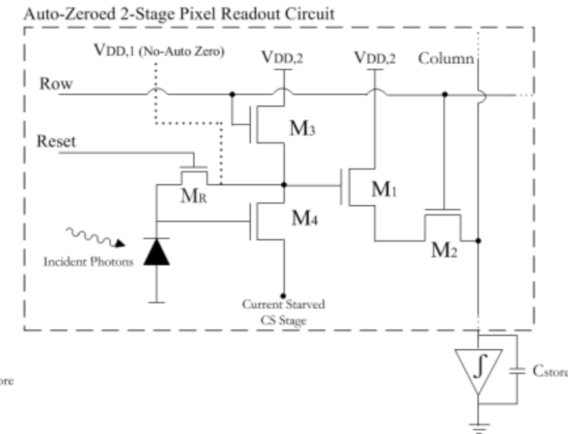
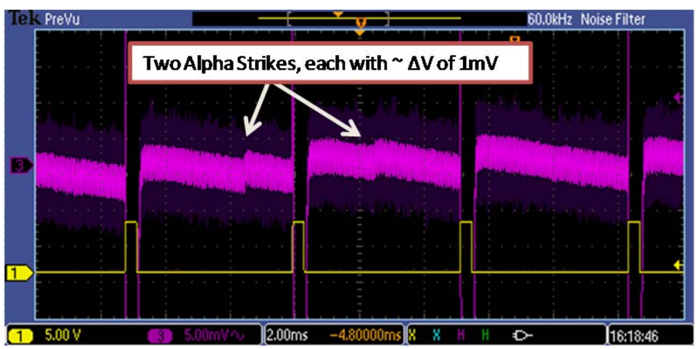
TFT-based Active Pixel Sensors



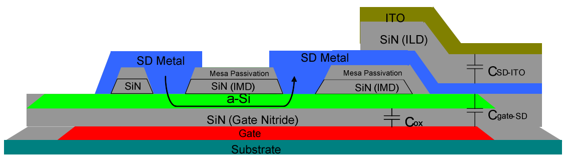


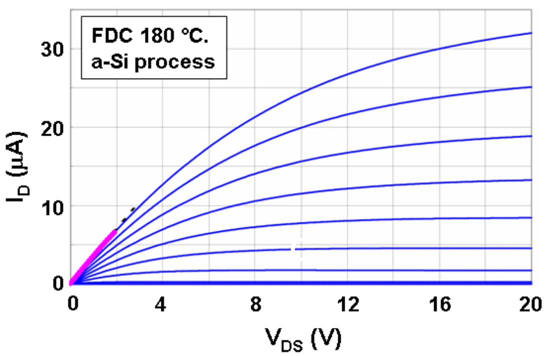


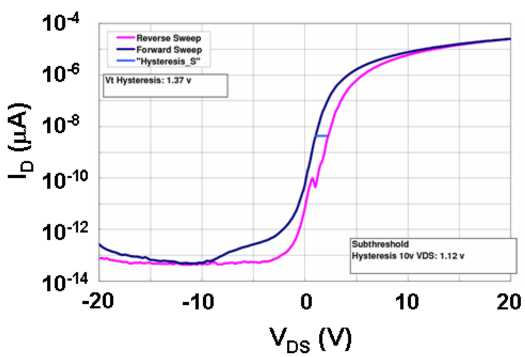
The detection of two alpha particle strikes on a commercial diode and amplified with the two stage low noise thin film transistor amplifier.

Flexible CMOS

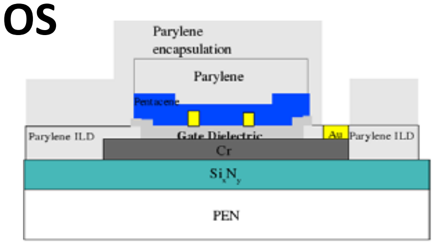
NMOS

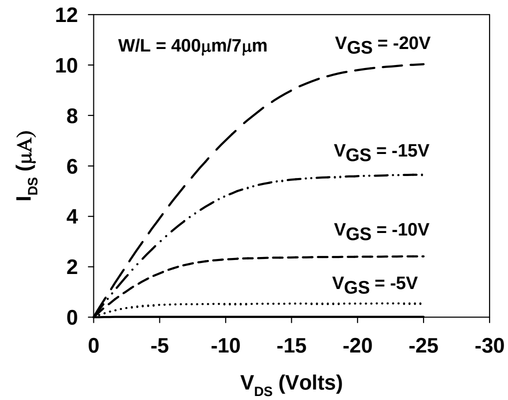


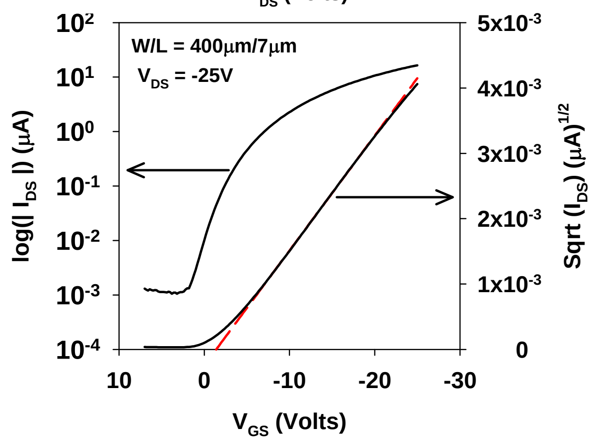




PMOS







Why CMOS

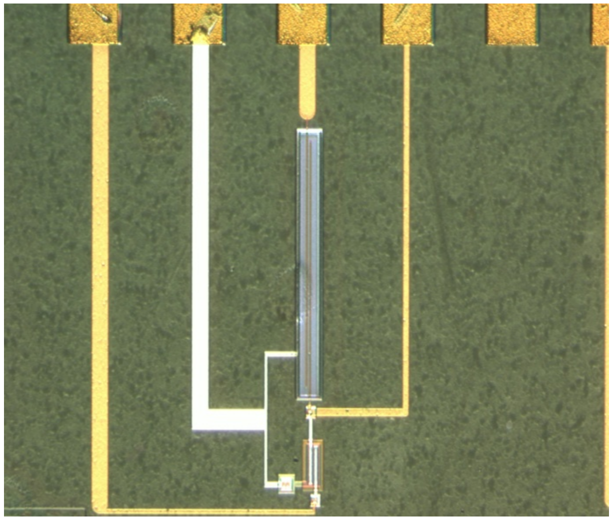
- Dramatically reduced power consumption
- Analog circuitry possible
- Sensor applications

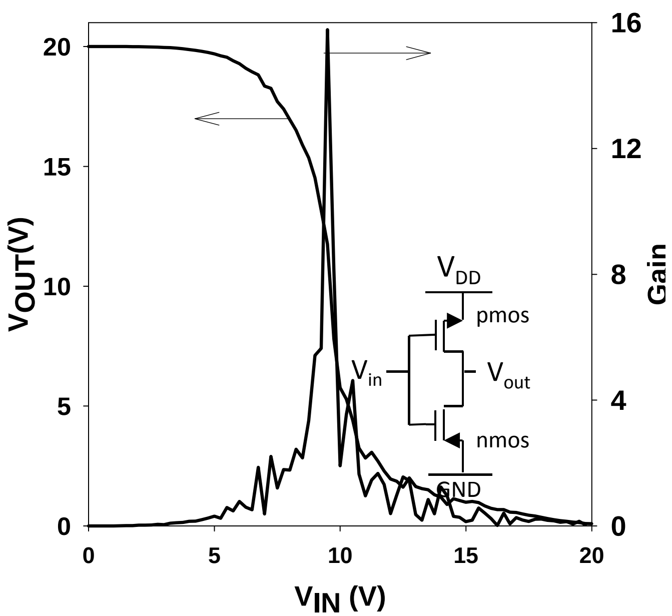
How to do F-CMOS

- Combine Processes
  - N-Type a-Si:H TFTs
  - N-Type inorganic TFTs
  - P-Type Organic TFTs
- Standard Cell Approach

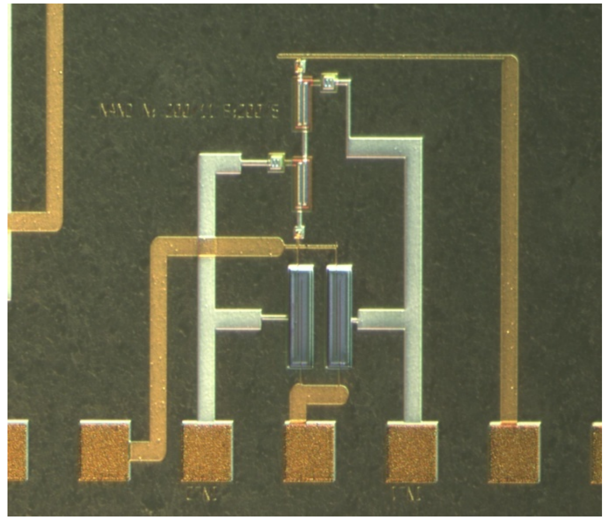
a-Si / pentacene CMOS Devices – with ASU

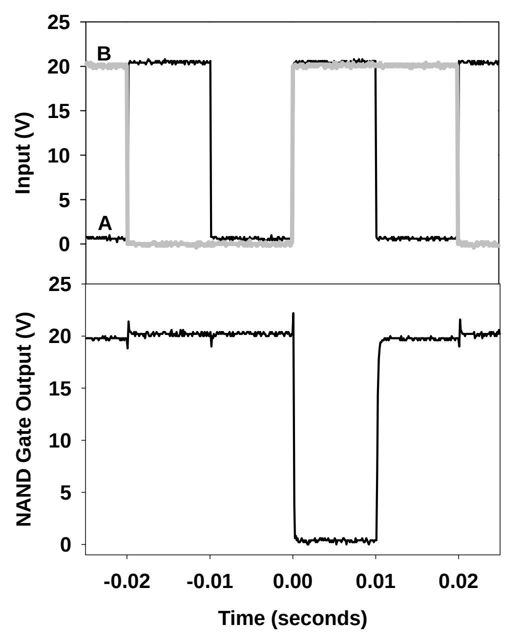
Inverters



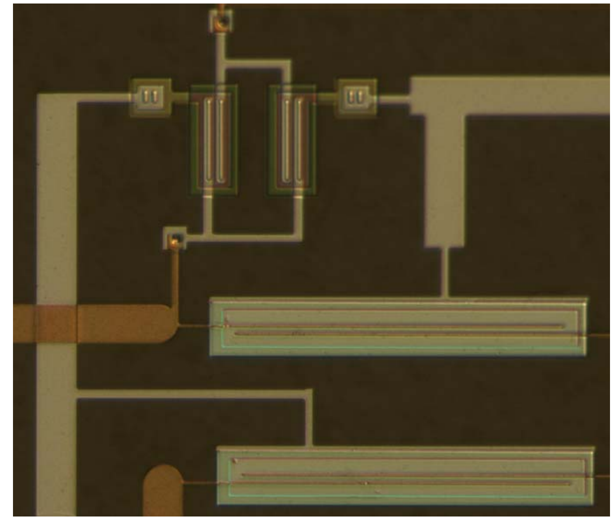


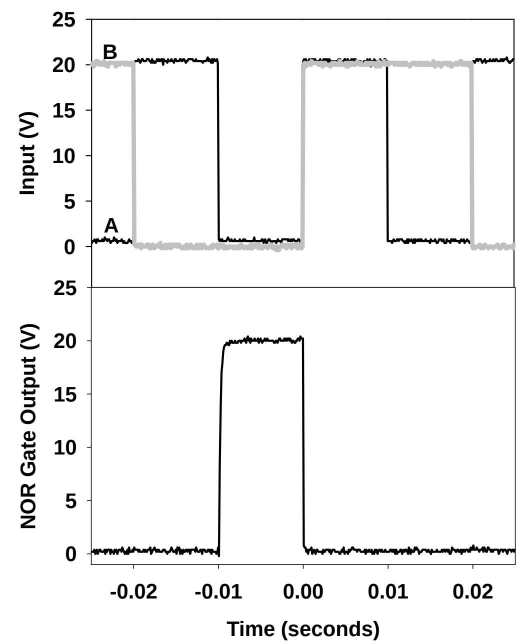
NAND Gates





NOR Gates

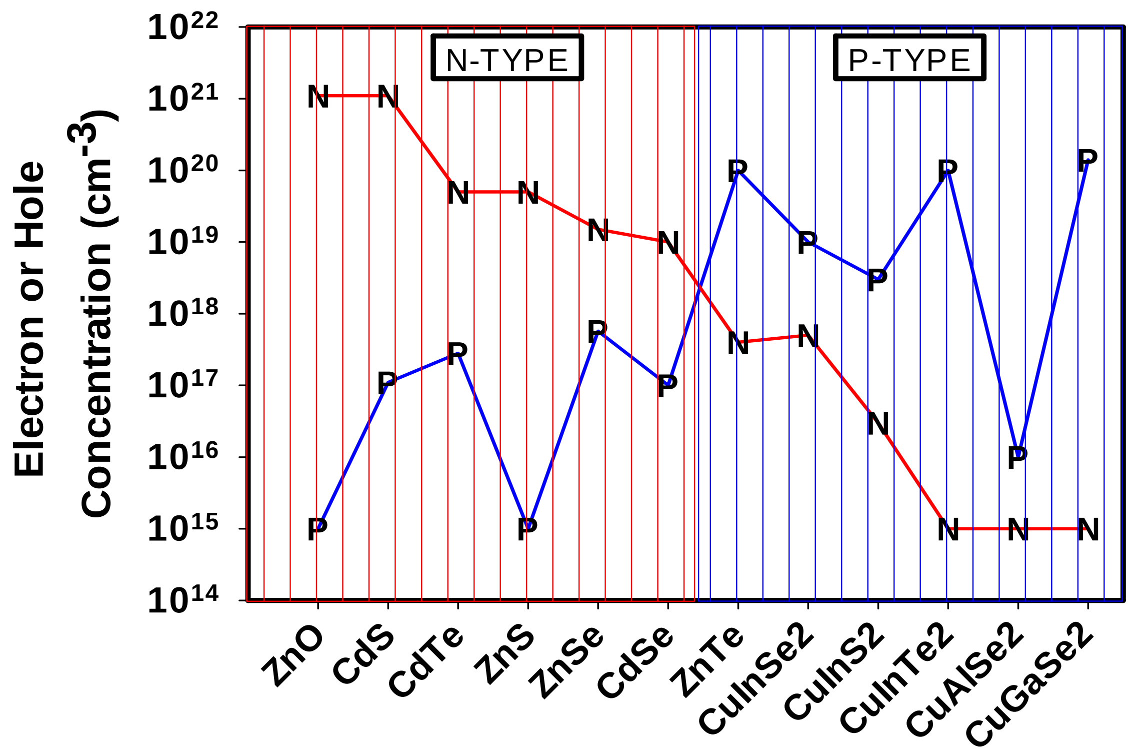




Technology Comparison

Chalcogenides

Semiconductor	Mobility (cm²/V-s) e⁻	h⁺
CdS	250	
CdSe	650	
ZnSe	600	
$SnSe_2$	27	
InS	50	
SnS_2	18	
$CuGaS_2$		20
$CuInS_2$		15
ZnTe		100
PbS		5
Cu_2S		10

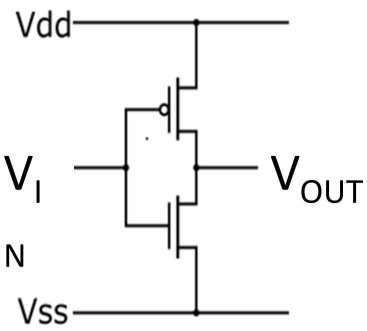


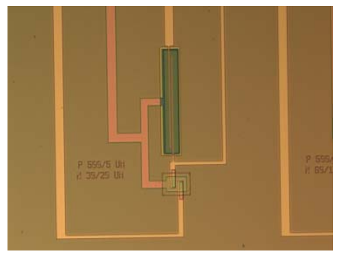
Organic semiconductors $\mu \sim 6\times10^{-2}$ **to 1** $cm^2V^{-1}s^{-1}$

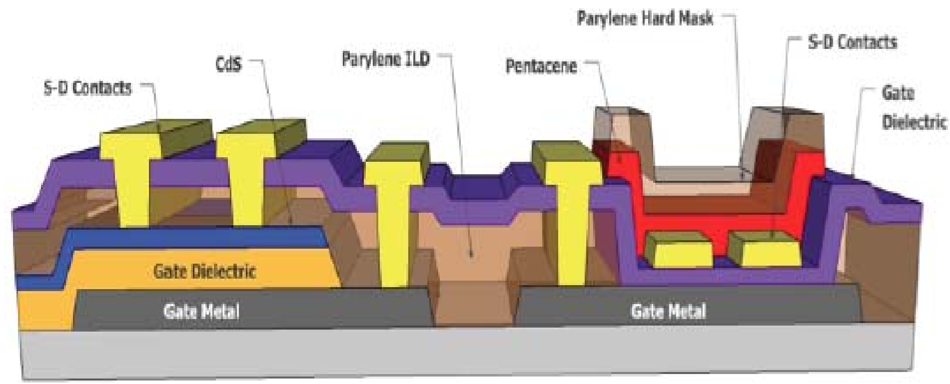
Amorphous silicon: $\mu \sim 0.01$ **to 1** $cm^2 V^{-1} s^{-1}$

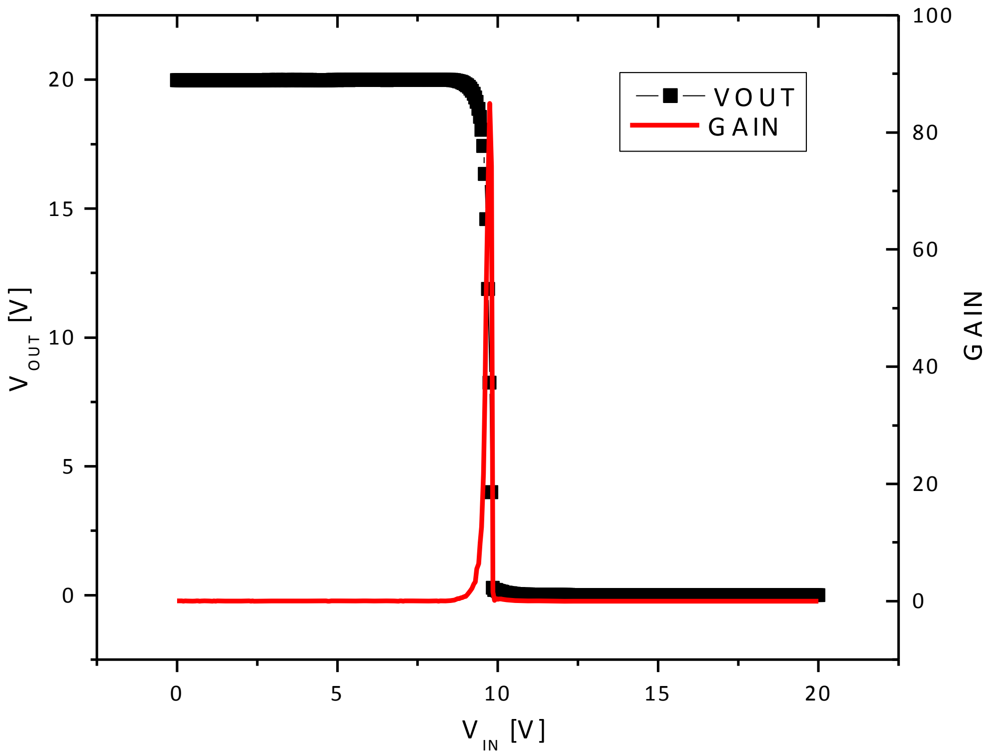
Inorganic semiconductors: $\mu > 100\ cm^2 V^{-1} s^{-1}$

CBD CdS/ Evaporated Pentacene Inverters





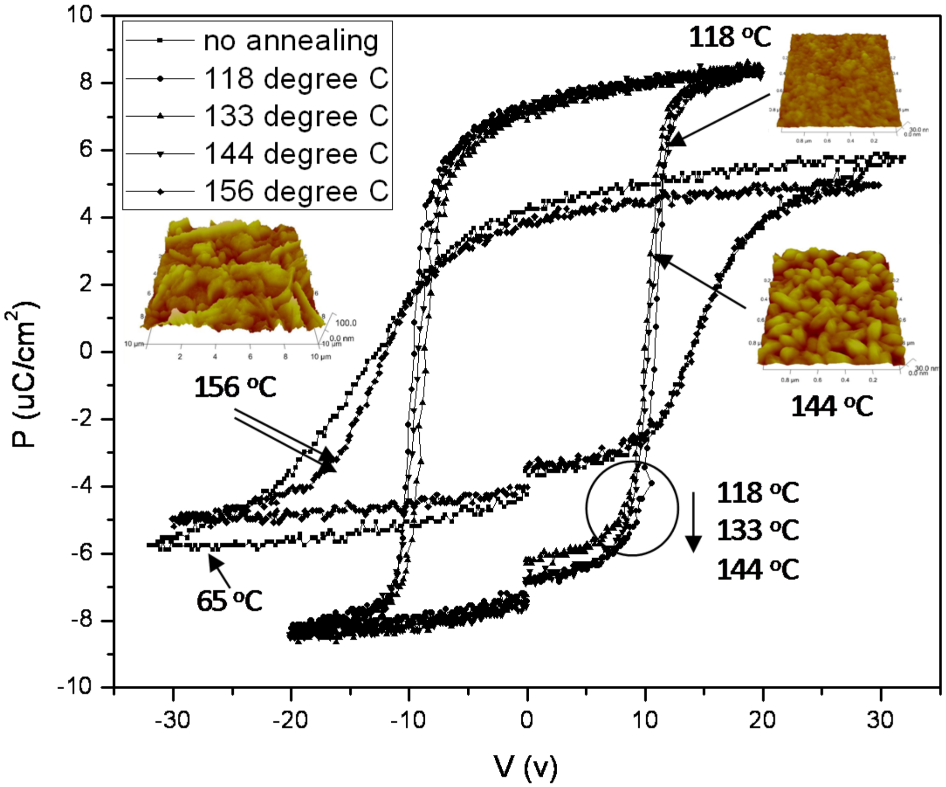


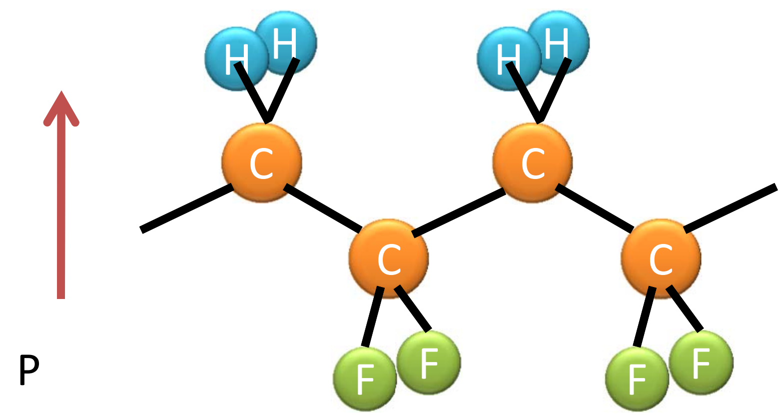


- **Optimized pentacene and CBD CdS deposition**

- **Inverters yield gains of about 80**

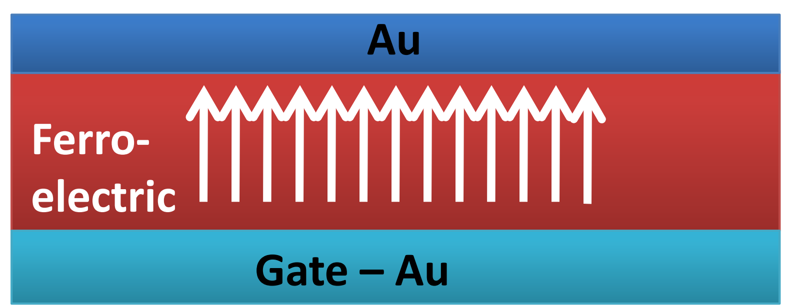
Ferroelectric-based organic Memory (FeRAM)
PVDF - TrFe



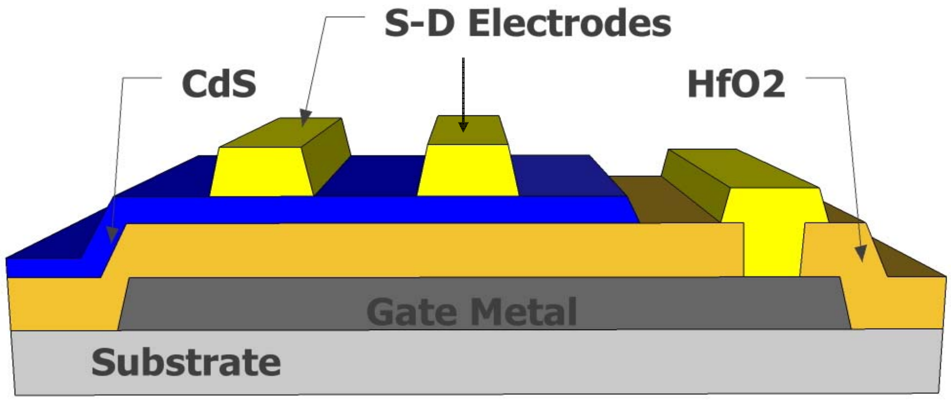


MFM Capacitor – 1T-1C memory cell

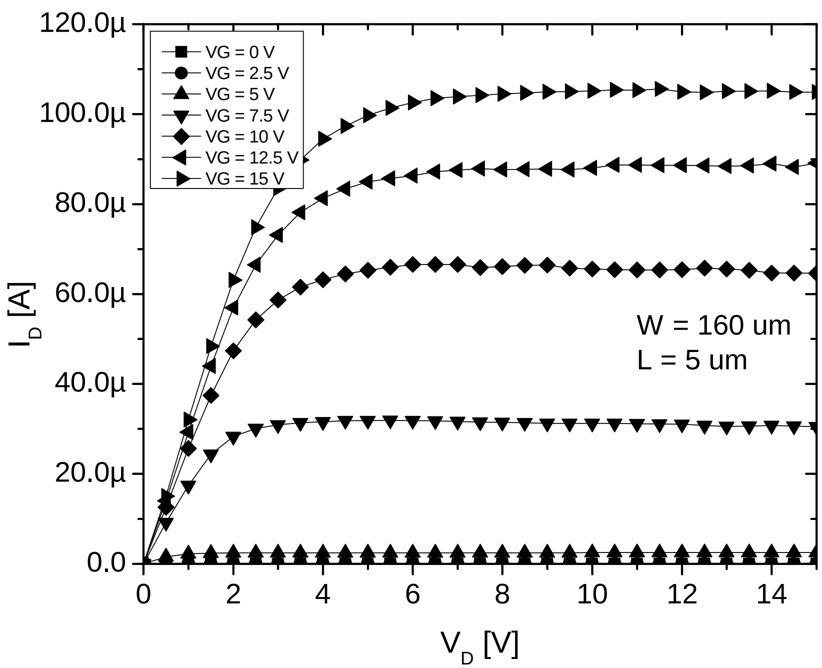
- relatively easy to fabricate
- destructive read
- complicated read / write circuitry

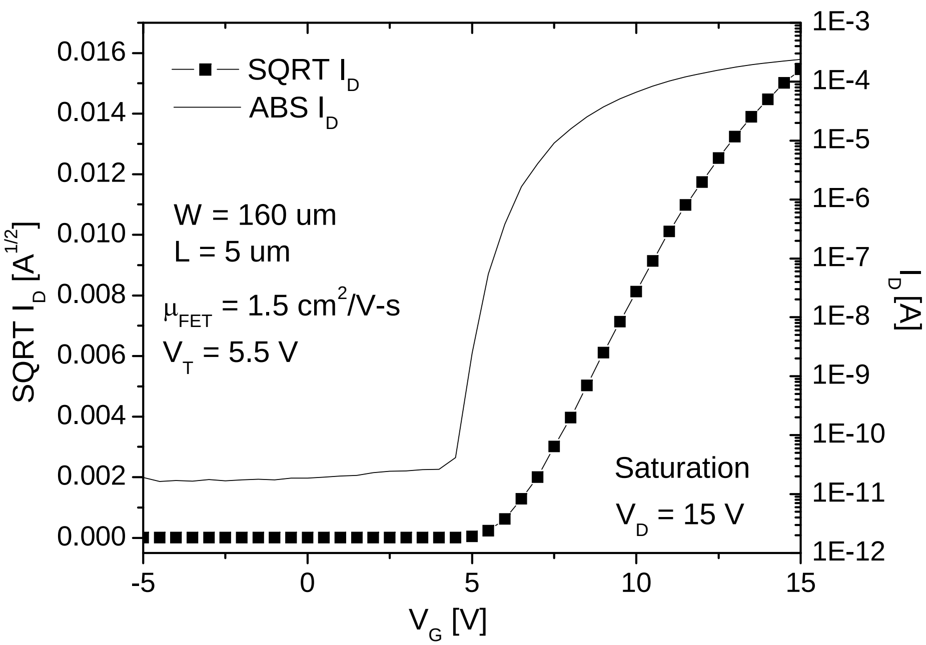


Fully integrated TFT used for 1T1C

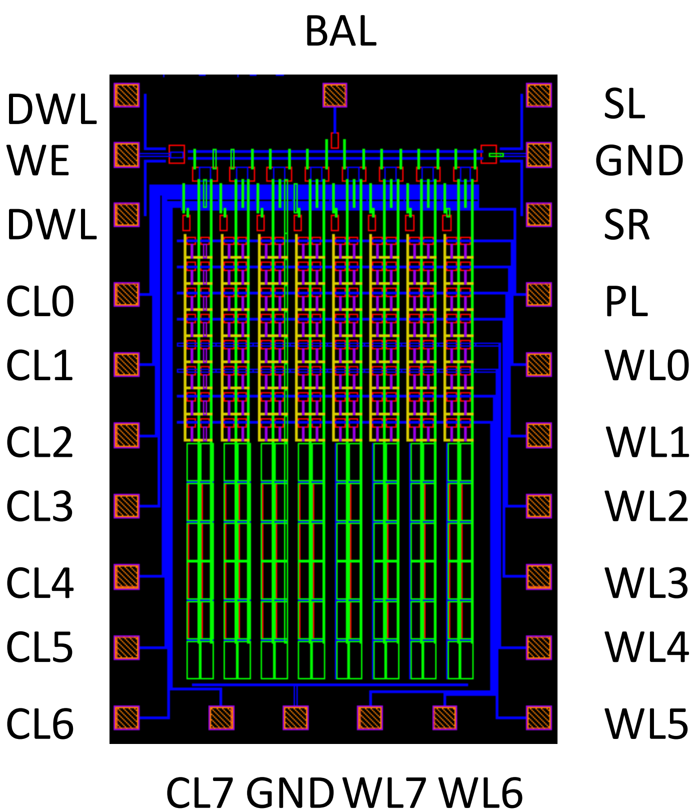


1. **CBD CdS as the semiconductor**
2. **ALD HfO_2 as the gate dielectric**
3. **Parylene as ILD**
4. **Low temperature process, maximum temperature is 100 °C**

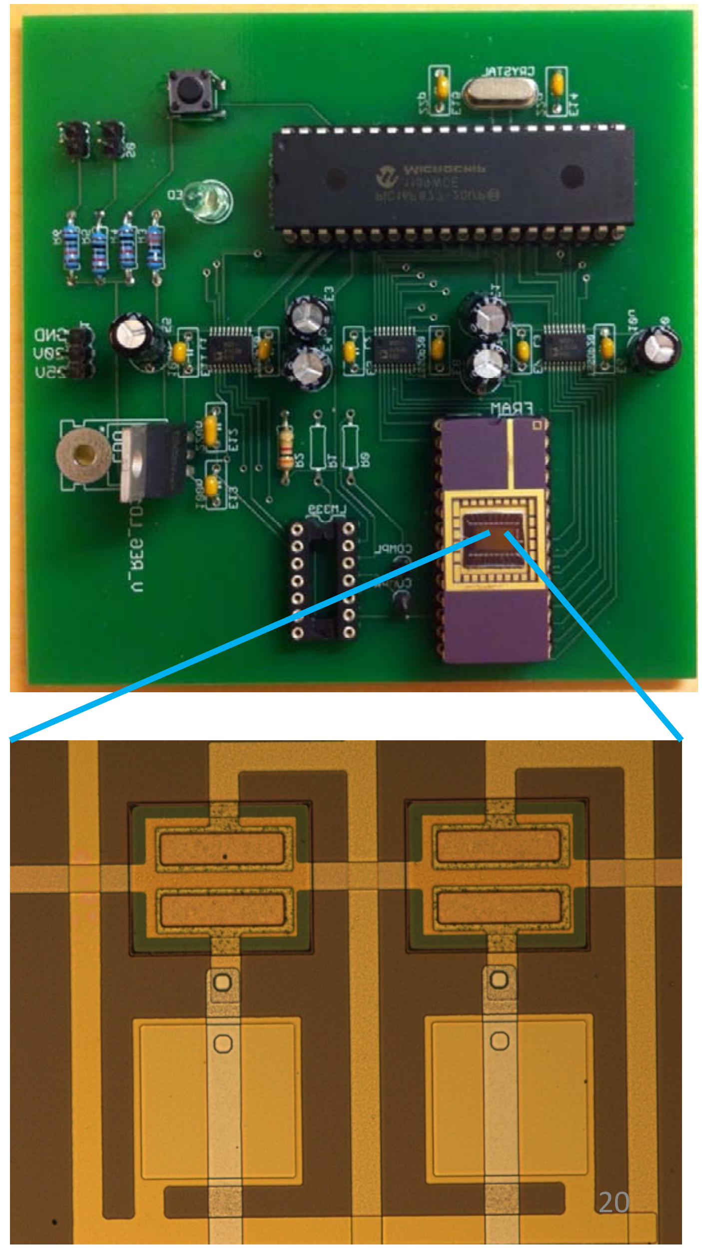




2T2C FRAM Characterization

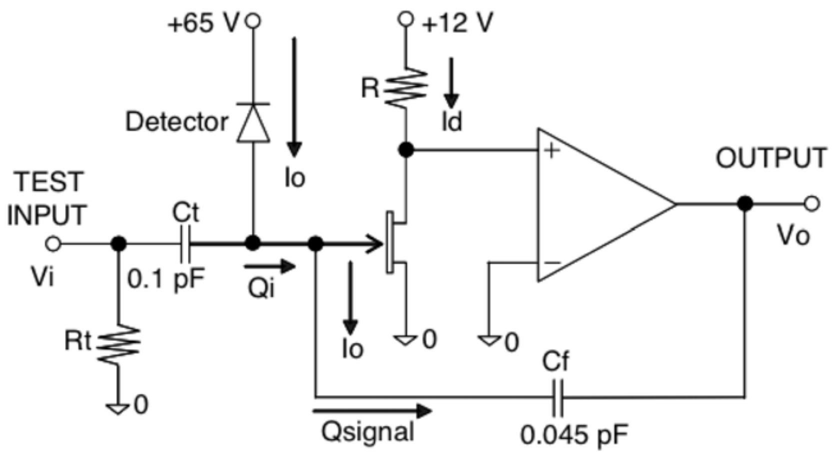


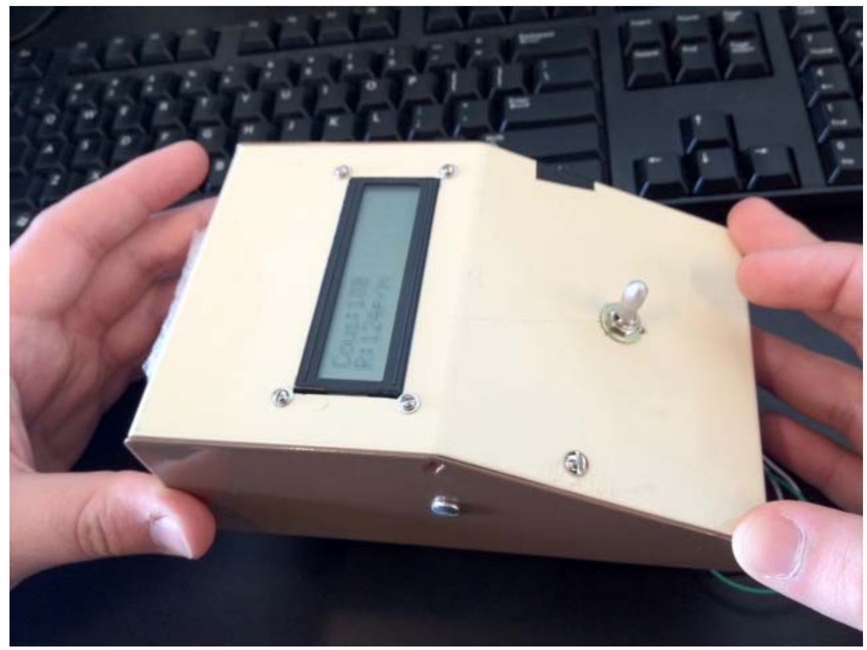
64-bit FRAM layout



In-pixel charge amplifier – Ramirez design
Prototype neutron detector

- The output signal from the sensor element is a low voltage pulse with 10’s ns width, with very high impedance due to the capacitive nature of the device.
- Charge amplifiers provide very high input impedance - they integrate weak charge pulses to convert them into voltage pulses with low impedance.

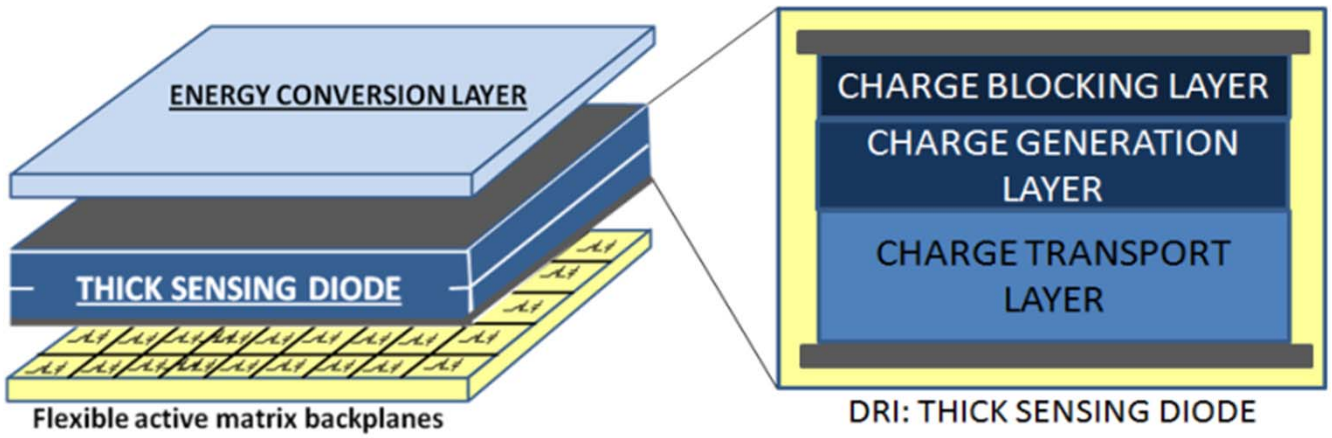




[1] F. J. Ramirez-Jimenez et al., Nuclear Instruments and Methods in Physics Research A, 497, (2003), 577-583.
[2] Bernd J. Pichler et al., IEEE Transactions on Nuclear Science, 48(6), (2001), 2370-2374.
[3] HAMAMATSU, model H4083.

Potential Advantages

- Very large aperture at moderate cost based on AMLCD
- In-pixel electronics provide low capacitance for pixelated array
- Potential for high γ-ray rejection rate due to TFT array electronics
- Potential for fission neutron multiplicity measurements
- Potential for determination of directionality of the neutron source



Thank You!