Slide 1

Active Pixel Sensors for X-ray Imaging

Jose Barcenas

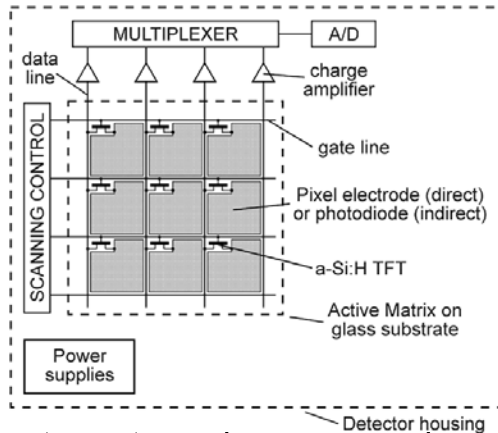
Outline

- Introduction to X-Ray Imaging
  - X-Ray Detection
  - Passive Pixel Sensor
  - Active Pixel Sensor
- Active pixel Sensors(APS)
  - TFT C-APS
- TFT APS design
- APS Operation
- APS Properties
- APS Fabrication
- APS Noise and Quantum Efficiency
- Examples of TFT APS Architectures
  - 2TFT APS
  - IGZO TFT APS
- Today’s X-Ray imagers using APS

Slide 3

Introduction to X-Ray Imaging

- Traditional X-Ray technique captures images with X-ray film
  - consisted of a large sheet of photographic emulsion between two phosphor screens. The photographic film is then chemically developed.
- Digital imaging
  - CCD or CMOS cameras typically used for pixel sensors
    - Complex lens and mechanical systems leads to cost and size issues
  - Thin Film Transistors(TFT) are alternative to produce large-area digital X-ray imagers
    - Improved image quality
    - Compact flat panel structure
    - Low X-ray exposure dosage to patient



Schematic diagram of main components of an active matrix array

R. Fahrig, A. Ganguly, P. Lillaney, *et al*, Proc IEEE, 96 (2008)

Obtaining high spatial resolution and contrast is the goal of radiographic imaging. An absolute requirement of new medical imaging technology is to weigh the risk of exposure versus the benefit to the patient. By using amorphous silicon arrays, the same quality of diagnosis can be achieved with an equivalent or low dose exposure to the patient. Traditional X-Ray techniques involved a photographic film that captured X-Ray images transmitted through the patient after brief X-Ray exposure. Digital imaging traditionally incorporates a CCD or CMOS sensor. For X-ray imaging, a larger area is needed to resolve crucial features. Sensors based on thin film transistors are able to be manufactured over a large area. This leads to improved image quality, compact flat panel structure, and minimizes X-ray exposure dosage to patients

Detector Contrast, Film vs Digital imager

- Screen-Film Contrast
  - Sensitivity loss at low exposures
  - Certain level of light exposure has to be reached before the density of the film increases linearly with exposure.
- Digital imagers contrast
  - Linear response over a wide range of radiation exposure
    - Linearity of imager response produces the same contrast in the x-ray signal , when an object has a large range x-ray attenuation

Figure 1 and Figure 2 are optical density measurements of Screen-film contrast and digital imager contrast, respectively. The Sigmoid shape of Screen-Film imaging signifies smaller increase in optical density at low and high exposure levels.

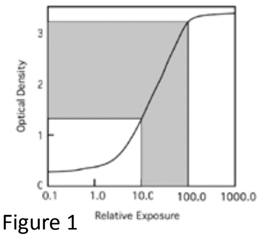


Figure 1

GOOD IMAGE CONTRAST

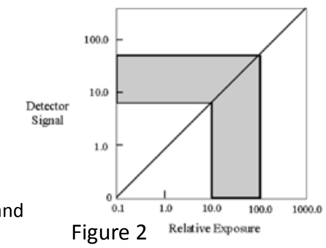


Figure 2

J. T. Bushberg, J. A. Seibert, E. M. Leidholt and J. M. Boone, 2002

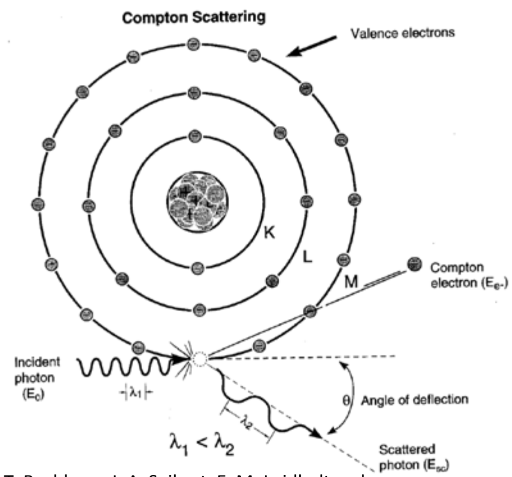
Digital imagers have a linear response over a wide range of light exposure. Image processing can also selectively enhance the contrast of different regions. Film loses sensitivity at low exposures compared to the a-Si arrays, therefore digital imaging produces good images at lower x-ray doses. When compared to Screen-film X-ray imaging, film does not have a linear response. High and low radiation exposure levels experience smaller optical density increase and thus are unable to resolve features in final x-ray image.

X-Ray Interaction and Detection

- Two major types of interactions for X-ray imaging
  - Compton scattering > 50keV
  - Photoionization < 50keV
- Digital imagers capture incident X-ray photons by either phosphor/photodiode or X-ray photoconductor
  - Produces electron hole pairs in the intrinsic layer of the a-Si:H photodiode
  - Numbers of pairs created is given by the following equation

$$N_p = E_x / W$$

  - W is the average energy needed to create an electron-hole pair, usually 2-3 times the band gap energy. Ex is the incident X-ray energy



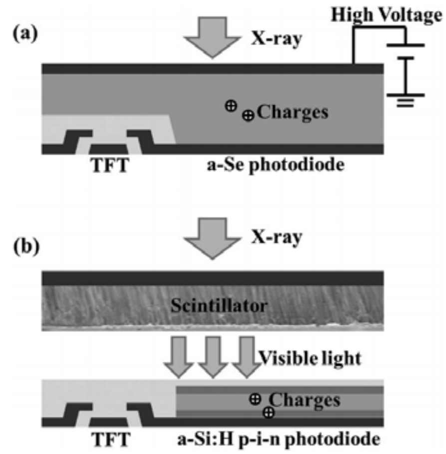
J. T. Bushberg, J. A. Seibert, E. M. Leidholt and J. M. Boone, 2002

There are two major types of x-ray photon interactions, Compton Scattering and photoionization. These interactions begin when an energetic X-ray photon excites a high energy electron. Compton scattering predominates in the diagnostic energy range above 26 keV in soft tissue. Incident x-ray electrons are absorbed by a sensor, usually of a phosphor/photodiode or X-ray photoconductor. Phosphor acts as a scintillator material that allows the X-ray to be re-emitted as light. The energetic electron then transfers its energy by creating successive electron-hole pairs; average energy is usually 2-3 times the band gap energy.

Direct and Indirect X-ray Conversion Detectors

- Figure (a)
  - Direct conversion
  - Thick photoconductor sensitive to X-ray photon is used
  - Amorphous selenium photoconductor favorable for X-ray sensors
- Figure (b)
  - Indirect conversion
  - Scintillator
    - X-ray phosphors remit X-ray photons into visible light, coated onto array
    - Thallium-doped cesium iodide (CsI:Tl) scintillator favorable for X-ray imaging. CsI:Tl has a columnar structure that efficiently distributes light, minimizing light spreading issues
  - Favorable for low dose conditions and short scan time

Readout of the pixel is handled by the thin film transistor(TFT) in an active or passive pixel sensor configuration



J. Kanicki and C. Zhao, Medical Physics 41, 091902 , 2014;

As mentioned in the previous slide, scintillator /photodiode or photoconductors are used to detect incident X-ray. Figure (a) illustrates a direct conversion of X-ray photon to electric charges that are collected by the pixel storage capacitance to represent the signal that is sent to the thin film transistor. Figure (b) illustrates an indirect conversion process that utilizes a scintillator material to re-emit X-ray photons as visible light for the a-Si: H p-i-n photodiode. The scintillators have strong x-ray absorption properties that allow for low dose conditions when compared to direct conversion detectors. Direct conversion detectors are capable of high spatial resolution when compared to indirect conversion detectors. The detectors in both cases are attached to the drain/source of the thin film transistor that is then configured in either a passive or active pixel sensor architecture.

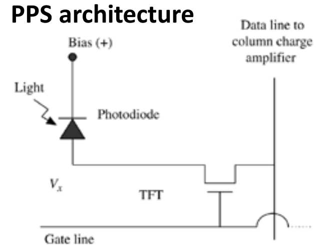
Active and Passive Pixel Sensors

Readout is done by transferring one row at a time to the column storage capacitors, Column decoder and multiplexer then read out the row(similar to random access memory).

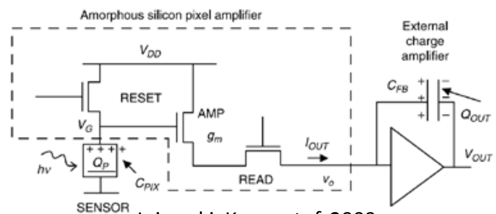
- Passive Pixel Sensors(PPS)
  - One TFT in PPS pixel architecture
  - Small pixel -> large fill factor(fraction of pixel area occupied by a photodetector)
  - Low Signal-to-Noise Ratio
  - need column charge amplifiers to read small output PPS signal.

- Active Pixel Sensors(APS)
  - At least three TFT in APS pixel architecture
  - High Signal-to-Noise Ratio
  - Larger pixel -> lower fill factor
    - Lower fill factor is no longer a problem due to technology scaling. TFT/ Sensor placement can also be optimized to increase fill factor.

PPS architecture



APS architecture

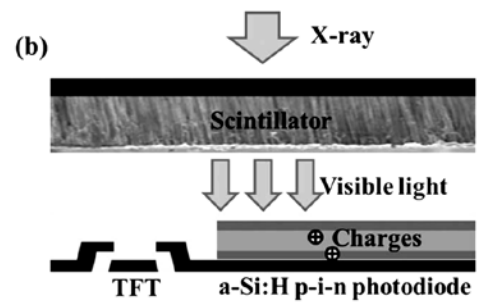


Iniewski, Kryzysztof. 2009

The underlying architecture of digital imagers rely on either passive or active pixel sensors. The pixel sensors operate as a large matrix that are connected to a word and bit line that are read out to column decoders and multiplexers. Passive pixel sensors (PPS) are most widely used due to one thin film transistor (TFT) architecture. This leads to an advantage of being compact, and thus capable of achieving high-resolution imaging. Active Pixel sensors (APS) utilize at least three TFT and have a high signal-to-noise ratio (SNR). Passive pixel sensor architecture for large-area applications, such as X-ray imaging, proves to be extremely challenging. Extra column charge amplifiers are needed to read the small PPS output signal. While the fill factor is large for PPS, APS can be configured to optimize the fill factor by TFT and Sensor placement. X-ray imaging benefits from high spatial resolution, making APS the main topic of conversation.

TFT APS Design(Indirect x-ray conversion design)

- C-APS
  - Based on a-Si:H TFT, current mode APS produces a current output to drive an external charge amplifier, or current transfer operation
    - CMOS APS produces a voltage output
  - Low carrier mobilities associated with a-Si:H TFT(< 1cm^2/V*s) produce speed constraints using a voltage transfer operation
  - Therefore, for TFT APS, a current mode design is necessary. Charge amplifier, current integrator is needed to produce voltage output
- Photodiode Structures- Indirect X-ray conversion design
  - Requirement of photodiodes are Low dark current, Low capacitance, and fast photoresponse
    - Low capacitance improves speed and lowers noise
  - Photodiodes parasitic capacitance serves as a storage capacitor that charges/discharges based on APS operation mode

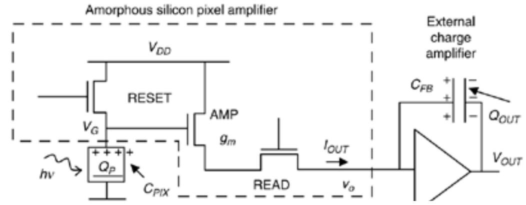


J. Kanicki and C. Zhao, Medical Physics 41, 091902 , 2014;

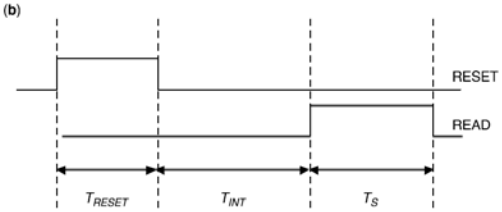
When utilizing a APS based on TFT rather than CMOS, the difference in operation is the transfer operation for output. CMOS APS produces a voltage transfer and therefore a voltage is output of the APS circuit. TFT APS however, has speed constraints due to a-Si:H mobilities, which are roughly less than 1 cm^2/V*s. Photodiodes incorporated into APS, for indirect X-ray conversion design, require low dark current, low capacitance and fast photoresponse. Low capacitance improves speed and lowers noise of the photodiode. This parasitic capacitance serves as a storage capacitor that charges/discharges based on operation mode of the APS

APS Operation

APS architecture



(b)



Readout Timing Diagram

Iniewski, Kryzysztof. 2009

- APS operates in three modes
  - Reset mode- Reset is on and charges Cpix through the on-resistance of the TFT
  - Integration mode- after reset, reset and read TFT's are switched off. hv input signal generates photocarriers, discharging Cpix and decreasing the potential on Cpix by a small signal voltage
  - Readout mode- carried out after integration mode, Read is switched on and connects to a charge amplifier for a sampling time of Ts.
- The APS circuit is connected to an external charge amplifier, Readout mode charges the feedback capacitor, C_{FB}
  - External charge amplifier is a current integrator.
    - Voltage output is proportional to integrated input current

The APS operates in 3 modes: reset, integration and readout modes. Reset mode is activated when Treset is switch on, causing the photodiode to accumulate a charge through the on-resistance of the TFT. Integration mode follows reset mode by switching off Treset and Tread. The absorbed light discharges the charged photodiode, decreasing the potential on the photodiode by a small signal voltage. Finally, readout mode consists of Tread switched on, connecting the pixel with an external charge amplifier, applying an output voltage to the amplifier.

TFT Current-Mode APS Properties-Linearity

- Determined by change in output current with respect to photodiode or photodetector illumination. Linear sensor constant is given by

$$\gamma = \frac{dI_{out}}{dh\nu} = \frac{dQ_p}{dh\nu}\frac{dV_G}{dQ_p}\frac{dI_{out}}{dV_G}$$

- Vg is the bias voltage at the AMP TFT gate
  - By using a standard MOS I_{dsat} equation for I_{out}, we can determine conditions for linear APS operation
    - the change in gate voltage must be small, when photodiode absorbs incident photons
- Change in output current, I_{out} comes from small signal change at the AMP gate, Vg
  - Small signal change at the gate also affects change in charge at the photodiode. The capacitance is linearly dependent with respect to gate voltage

$$\Delta Q_p = \Delta V_{gate} \cdot C_{photodiode}$$

K. S. Karim, A. Nathan, and J. A. Rowlands. *IEEE Trans. Electron Devices*, Jan. 2003

Linear circuit operation is determined by a change in output current with respect to photodiode or photodetector illumination. The linear sensor constant can be determined by several factors, the rate of change of: stored charge at photodiode with respect to incident photons, gate voltage with respect to stored charge at photodiode, and output current with respect to gate voltage. By using the standard Idsat equation for a MOS, one can determine the conditions for linear circuit operation. The change in gate voltage must be minimized to avoid nonlinearity. Change in output current also comes from small signal change at the AMP gate, Vg.

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TFT Current-Mode APS Properties-Gain

- Integration node has change in potential due to photon absorption by photodiode
- Leads to change in output current at amplifier TFT, with respect to gate voltage. The relationship is given by the following equation, in which gm is the transconductance of the Amp and Read TFT

$$\Delta I_{out} = g_m \cdot \Delta V_{gate}$$

- By using change in output current, the output voltage can be determined using the charge amplifier circuit, otherwise known as a current integrator. The charge integration is done over a sampling time or read pulse widths, Ts

$$\Delta V_{out} = -\frac{1}{C_{FB}} \int_0^{Ts} \Delta I_{out} dt = \frac{g_m \Delta V_g Ts}{C_{FB}}$$

- Voltage gain can then be given by

$$A_V = \frac{\Delta V_{out}}{\Delta V_{gate}} = \frac{g_m Ts}{C_{FB}}$$

- Therefore, for a high voltage and charge gain, it is necessary to maximize gmTs and minimize the feedback capacitance on the charge amplifier.

K. S. Karim, A. Nathan, and J. A. Rowlands. *IEEE Trans. Electron Devices*, Jan. 2003

Gain can be calculated by finding the change in output current. The integration node experiences a change in potential due to change in photodiode charge. The change in the amplifiers output current is therefore given by the product of the transconductance of both the amplifier and read TFT and the change in gate voltage of the amplifier TFT. The change in output voltage can then be derived by integrating the change in output current, per the charge amplifier over a read time pulse width, or Ts. Voltage gain can now be calculated and simplified to determine the maximizing and minimizing factors for increasing voltage and charge gain. The

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TFT Current-Mode APS Properties-Experimental Results vs Theoretical Results

Should I mention the a-si model that was used to find theoretical values?

- Experimental values are compared to theoretical values
  - Experimental gain closely matches theoretical voltage gain(ΔVout/ΔVgate)
  - Small signal linearity also closely matches change in photodiode charge($\Delta Q_{photodiode} = \Delta V_{gate} C_{photodiode}$)
    - This implies a relationship between charge gain and voltage gain
  - Charge gain can thus be determined from equations discussed in previous slides.
    - Charge gain can be determined by the ratio of the feedback capacitor, sensor capacitance and the voltage gain

$$G_i = \frac{\Delta Q_{out}}{\Delta Q_p} = \frac{\Delta I_{out} Ts}{\Delta Q_p} = \frac{g_m Ts}{C_{photodiode}} \Rightarrow G_i = A_V \frac{C_{FB}}{C_{photodiode}}$$

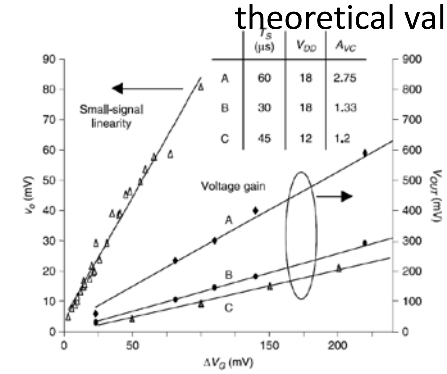


Fig. 2.14. Small-signal linearity and voltage gain for an in-house fabricated C-APS.

K. S. Karim, A. Nathan, and J. A. Rowlands. *IEEE Trans. Electron Devices*, Jan. 2003

Experimental values where found using an a-Si:H model published by the university of waterloo[name]. The experimental values where compared to theoretical values based on the formula derived for voltage gain. The small signal linearity condition implies a relationship between charge gain and voltage gain. Both voltage gain and charge gain rely on the potential difference at the amplifying TFT. Further derivation leads to charge gain being a product of the voltage gain, and the ratio between the feedback capacitance and the sensor capacitance.

TFT APS Properties-Summary

Voltage and Charge gain characteristics of the C-APS architecture benefit X-ray imaging by:

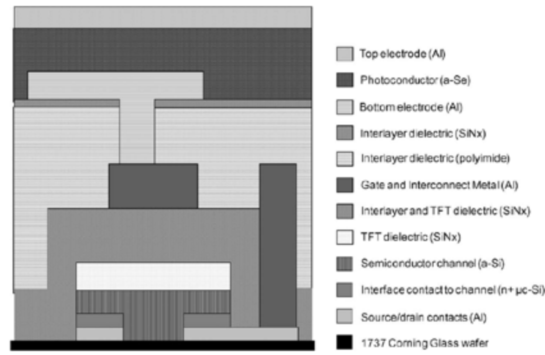
- Increasing charge gain can be done by minimizing sensor capacitance, which affects the following
  - minimizes the effect of external noise on the APS
  - Reset time constant is also reduced, leading to faster pixel operation.
  - Lower X-ray dosage to patient.

Therefore, the charge gain characteristic of the C-APS architecture, is the advantage over using PPS architecture for X-ray imaging.

The use of C-APS in digital imaging provides several benefits that make the circuit ideal for X-ray imaging. The charge and voltage gain dependency on low sensor capacitance, leads to minimal external noise affecting APS operation. Reset time constant is also reduced with a low sensor capacitance. Quicker reset times allow for faster pixel operation. Low X-ray dosage to patient can also be achieved by amplifying the signal at the circuit level, without negatively affecting operation. Therefore, the charge gain characteristics is the main advantage of using a C-APS architecture over a PPS architecture.

TFT APS(Direct X-ray conversion) Fabrication Process

- TFT fabrication requires less photolithography steps, compared to MOS fabrication
  - The a-Si:H TFTs in this design are fabricated using 6 masks
- The TFT's are deposited on a glass substrate.
  - Non-metals usually deposited by a CVD process
  - Metals deposited by sputtering process
- Polymide layer deposited on top of TFT architecture to minimize parasitic effects between photodiode and underlying architecture(TFT, data lines)
  - Can also be used as a light shield for the TFT
- a-Se or other photodetector deposited on top of polymide layer followed by electrode(aluminum in this case)



M. H. Izadi, O. Tousignant, M. F. Mokam, and K.S. Karim, *IEEE Trans. Electron Devices*, Nov. 2010

One of the reasons a-Si arrays are low cost, is due to the simplified fabrication process. In this example, only 6 masks are needed to develop a TFT. CMOS fabrication processes may take twice or three times that many masks to develop the device. Metal and non-metal metals are deposited on a glass substrate. Metal devices are typically deposited using a sputtering technique. Non metal films are deposited using a chemical vapor deposition. After TFT device is created, a polymide layer acts as a passivation layer between the TFT device and the photodetector. The polymide layer also serves as a light shield to block any unwanted incoming light to the TFT. The photodetector is then deposited on the polymide layer, followed by an electrode. Indirect X ray conversion APS follow the same principle, however, more masks may be needed to create a photodiode during fabrication process. A scintillator

Noise Issues with TFT APS(work in progress, needs more explanation and equations)

– Total output noise contributions
  - Charge amplifier noise
  - Reset noise
  - Thermal and flicker noise

Having a bit of trouble with this slide. Suggestions on how to present it? Derive noise equations or simply talk about noise issues associated with APS?

Quantum Efficiency(work in progress, needs more explanation and equations)

- Detective Quantum Efficiency(DQE)
  - Measure of noise propagation through imaging system
  - Describes overall signal-to-noise ratio (SNR) performance
    - Depends on spatial frequency
  - DQE and SNR related by:

$$DQE(f) = \frac{SNR_{out}^2}{SNR_{in}^2}$$

  - APS DQE determined by Modulation Transfer Function (MTF) and Noise Power Spectrum(NPS)

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Examples of TFT APS

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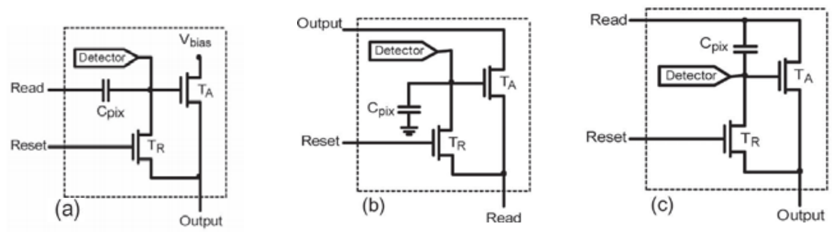
High Resolution APS- 2TFT APS Architecture

- One way to increase the high resolution capability of APS is to increase fill factor. One such solution is to use two-TFT APS architecture, Direct X-ray detection process using a-Se as photoconductor
- 3 2TFT architectures can be realized, C-APS structure still used
  - Gate-Switched Amplifier-figure (a)
  - Source Switching-figure (b)
  - Drain Switching-figure (c)
- PPS operation is possible by connecting the reset TFT directly to the detector node. This allows for immediate readout from the detector to the external charge amplifier.
- PPS operation is beneficial when input signal is high, while APS operation improves noise performance during low input.

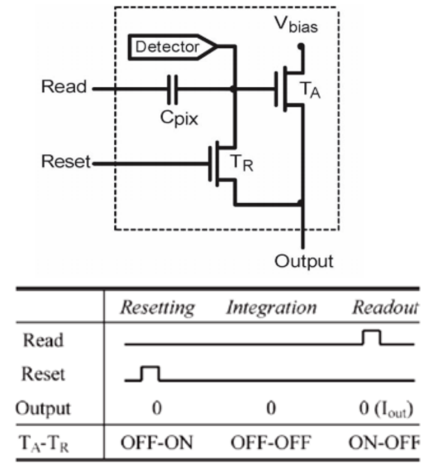


F. Taghibakhsh and K. S. Karim, *IEEE Trans. Electron Devices*, Aug. 2008

Several approaches in increasing resolution and large-area imaging capabilities have included a two transistor approach. Reducing area by removing a TFT results in an increasing fill factor. This approach can allow for high resolution X-ray imaging. Coupled with an amorphous selenium photoconductor, this APS circuit removes the read TFT and enables the amplifying TFT, T_A, to act as both a switch amplifier and the readout transistor. 3 different architectures are presented, each with different read and output conditions. In this configuration, the sensor acts as a PPS, readout is done directly from the detector to the external charge amplifier. PPS operation is favorable when the input signal is high, while APS operation improves noise performance during low input

2TFT APS Operation – Gate Switch Amplifier

- In the gate-switch configuration, T_A acts as both a switch amplifier and the readout transistor. The same 3 operation modes of an APS still apply to a 2TFT architecture
  - Reset mode
    - Reset TFT is turned on, the detector node voltage is then connected to the grounded output, discharging the node
  - Integration mode
    - Both TFT's are turned off and the detector node is susceptible to a potential difference by radiation absorption of the detector
  - Readout mode
    - Voltage is applied to the pixel capacitor. T_A is turned on, while preserving charge
- Same driving scheme is used as traditional APS, addressing signal is applied to a capacitive gate. While the source and drain switching architectures require current drivers, which are not ideal to use in large imaging arrays due to parasitic noise.

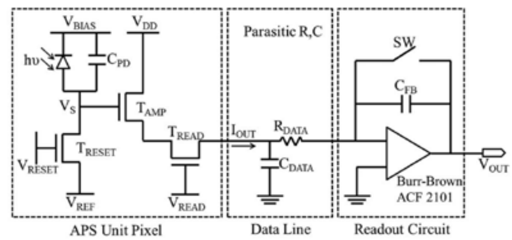


F. Taghibakhsh and K. S. Karim, *IEEE Trans. Electron Devices*, Aug. 2008

The operation modes do not change between a 3 TFT APS and 2 TFT APS. Reset, Integration, and Readout mode still operate in a similar way. The main difference being read and amplify TFT's are tied together for simultaneous operation. For readout mode, voltage is applied to the pixel capacitor, which simultaneously turns on the amplify TFT, allowing for direct readout to an external charge amplifier. Gate switch amplifier is preferred over the 2 other architectures, source and drain switching, due to same driving scheme used as a traditional APS. Addressing signal is applied to a capacitive gate, while the other configurations require current drivers, which are not ideal to use in large imaging arrays due to noise.

a-IGZO TFT APS Architecture

- APS architecture utilizing Amorphous Indium Gallium Zinc Oxide(IGZO) TFTs use the same operation principles that were previously discussed
  - 3 TFTs are used Read, Amplify, and Reset.
  - 3 Operation Modes Reset, Integration, and Readout
- Main difference comes from the use of new material, IGZO to enhance mobility thereby, increasing pixel density possible.
- Indirect X-ray conversion
  - Scintillator- Thallium-doped cesium iodide(CsI:Tl)
  - (Organic) Photodiode - poly(3-hexylthiophene):phenyl-C_{61}-butyric acid methyl ester (P3HT:PCBM)



J. Kanicki and C. Zhao, Medical Physics 41, 091902 , 2014;

Another improvement over a-Si:H TFT APS, is to replace the TFT all together with a better material. Amorphous Indium Gallium Zinc Oxide(IGZO) TFTs have promising characteristics for next generation medical imaging applications. IGZO has a higher field-effect mobility than a-Si:H. The values range from 5-20 cm^2/V*s for IGZO, compared to a-SI:H values which are < 1 cm^2/V*s. A low temperature fabrication process is utilized to deposit IGZO, RF magnetron sputtering or pulsed laser deposition with KrF excimer laser at room temperature. This APS architecture uses indirect X-ray conversion, the scintillator is a Thallium-doped cesium iodide(CsI:Tl)

IGZO TFT APS Performance vs. a-Si TFT APS

- Work in progress
- Compare DQE and leakage current for both?

Today's X-Ray imagers using APS

- Should I find an X-ray imager from GE or related company, then talk about the architecture they employ?

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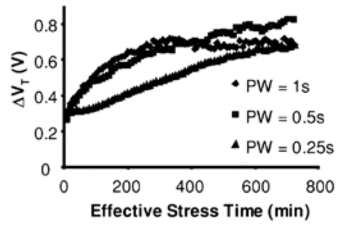
Slide 24

Appendix(place holder slides)

a-Si:H APS Metastability

- TFT threshold voltage fluctuates with prolong bias at the gate, caused by:
  - Charge trapping
  - Defect state creation- increased density of Si dangling bond states in a-Si:H layer

APS circuits circumvent this issue by introducing bipolar clocking pulses to provide a small switch resistance and a small leakage current to give a constant threshold voltage.



(a)

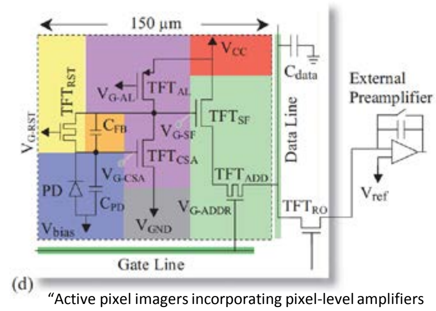
"Amorphous silicon active pixel sensor readout circuit for digital imaging," *IEEE Trans. Electron Devices*

One major consideration to account for in a-Si:H TFTs, is a varying threshold voltage. This effect is present when the gate has been biased for a prolonged period of time. These fluctuations are due to charge trapping and defect state creation. APS circuits circumvent this issue by introducing bipolar clocking pulses to provide a small switch resistance and a small leakage current to give a constant threshold voltage. The plot shows a linear relationship when bipolar clock pulses at a faster rate.

Poly-Si TFT APS

Poly-Si TFT APS offers improved performance over a-Si:H TFT APS

- Higher carrier mobility
  - up to 100 cm^2/V*s, a-Si:H has a mobility < 1 cm^2/V*s
- APS designs utilizing n and p channel TFTs, additional circuitry can be integrated to reduce amount of external devices. Higher TFT current is possible allowing for greater in-pixel amplification
  - 3 to 5 TFT architectures, additional in-pixel amplification circuitry.
  - Figure (d) is a 5 TFT APS architecture with fast readout rates and low noise level, when compared to a 3 TFT APS architecture

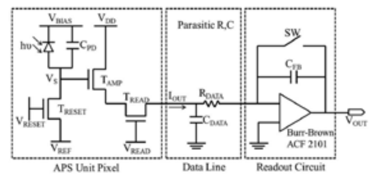


"Active pixel imagers incorporating pixel-level amplifiers based on polycrystalline-silicon thin-film transistors," Med. Phys. 36 (7) July 2009

Polycrystalline silicon TFTs offer improved performance over traditional a-Si:H TFTs. Poly-Si TFT are capable of achieving some of the highest carrier mobility values in amorphous thin film transistors at 100 cm^2/V*s . While a-Si:H is only capable of achieving a mobility less than 1 cm^2/V*s. This difference in mobility allows poly-Si to tolerate a higher current through TFT, higher in-pixel amplification is possible. APS designed based on n and p channel TFT are possible with poly-Si. Architectures with as many as 5 TFTs are possible, allowing for complex circuitry than can reduce readout rates and suppress noise level, when compared to a 3 TFT architecture.

a-IGZO TFT APS Architecture

- Amorphous Indium Gallium Zinc Oxide TFTs are devices that have promising characteristics for next generation medical imaging applications.
  - High field-effect mobility (5-20 cm^2/V*s)
    - this allows for smaller TFTs, increasing pixel density, without suffering conductivity loses.
  - Low temperature fabrication process
    - RF magnetron sputtering or pulsed laser deposition with KrF excimer laser at room temperature



"Amorphous In–Ga–Zn–O thin-film transistor active pixel sensor x-ray imager for digital breast tomosynthesis," Medical Physics 41, 091902 (2014)

Another improvement over a-Si:H TFT APS, is to replace the TFT all together with a better material. Amorphous Indium Gallium Zinc Oxide(IGZO) TFTs have promising characteristics for next generation medical imaging applications. IGZO has a higher field-effect mobility than a-Si:H. The values range from 5-20 cm^2/V*s for IGZO, compared to a-SI:H values which are < 1 cm^2/V*s. A low temperature fabrication process is utilized to deposit IGZO, RF magnetron sputtering or pulsed laser deposition with KrF excimer laser at room temperature.

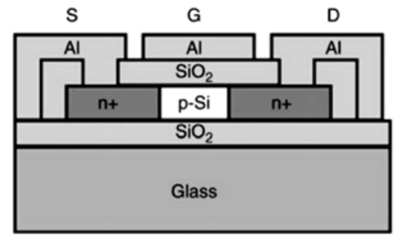
Poly-Si TFT APS

Replacing a-Si:H TFT with Poly-Si TFT in APS architectures yield beneficial characteristics such as:

- Higher carrier mobility
  - up to 100 cm^2/V*s, a-Si:H has a mobility < 1 cm^2/V*s
- Possibility of integrating additional circuitry, reducing density of connections and external electronics
- Poly-Si maintains large area processing capability
  - a-Si:H is used to create poly-si TFT, laser annealing process used for crystallization of a-Si:H to Poly-Si

Poly-Si TFTs replace only the a-Si:H TFT, the photodiode is still based on a-Si:H

Poly-Si TFT cross section



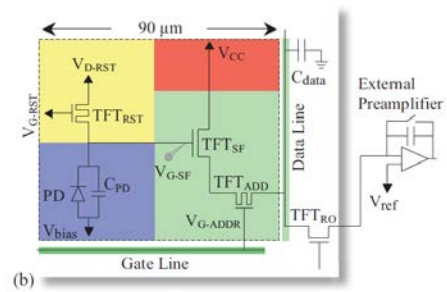
(a)

Thin Film Book

Polycrystalline silicon TFTs offer improved performance over traditional a-Si:H TFTs. Poly-Si TFT are capable of achieving some of the highest carrier mobility values in amorphous thin film transistors at 100 cm^2/V*s . While a-Si:H is only capable of achieving a mobility less than 1 cm^2/V*s. This difference in mobility allows poly-Si to tolerate a higher current through TFT, higher in-pixel amplification is possible. Integrating additional circuitry is possible through the use of Poly-Si. This would reduce connection density and external electronics, minimizing parasitic noise. Poly-Si can be processed in large areas while maintaining reliability, this is due to the crystallization process that takes place to produce thin films of Poly-Si. Amorphous silicon is initially deposited using a CVD process, a laser annealing process then crystalizes a-Si:H to Poly-Si. Amourphous material does remain for the photodiode, as the Poly-Si only replaces the TFT's in the architecture.

Poly-Si TFT APS Design and Operation

- Figure (b) - Poly-Si circuit that utilizes 4 TFTs, Similar layout to an a-Si:H 3TFT APS architecture, with the addition of an addressing TFT.
  - All other TFT's have similar functions
  - TFT_{ADD}
    - Dual-gate addressing uses both the data line and gate line for pixel addressing



"Active pixel imagers incorporating pixel-level amplifiers based on polycrystalline-silicon thin-film transistors," Med. Phys. 36 (7) July 2009