FLAT PANEL X-RAY DETECTOR

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Part 1
Flat Panel X-Ray Detector
State of the art and limitations
• The replacement of the medical radiographic film has been the main driver, during the last decade for large area X-ray detectors development
• Several Flat Panel X-Ray detectors (FXD) are now available, all of them using Amorphous Silicon Technology, for digital radiography system
• FXD for dynamic imaging (30 fps) of the heart have been recently introduced
## Requirements for film replacement

<table>
<thead>
<tr>
<th></th>
<th>General radiography</th>
<th>Mammography</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size</strong></td>
<td>&gt; 40 x 40 cm</td>
<td>&gt;18 x 24 cm</td>
</tr>
<tr>
<td><strong>Pixel size</strong></td>
<td>~ 150 µm</td>
<td>60-100 µm</td>
</tr>
<tr>
<td><strong>Typical nb of incid. X/pel</strong></td>
<td>~1000</td>
<td>~5000</td>
</tr>
<tr>
<td><strong>Corresponding dose</strong></td>
<td>2.5 µGy</td>
<td>100µGy</td>
</tr>
<tr>
<td><strong>Energy range</strong></td>
<td>30-120 keV</td>
<td>~20 keV</td>
</tr>
<tr>
<td><strong>Input equiv. noise</strong></td>
<td>&lt; 5 X quanta</td>
<td>&lt; 5 X quanta</td>
</tr>
<tr>
<td><strong>Dynamic range</strong></td>
<td>12 bit</td>
<td>12 bit</td>
</tr>
<tr>
<td><strong>Exposure / Readout time</strong></td>
<td>.5 s / 1 s</td>
<td>1s / 5 s</td>
</tr>
</tbody>
</table>
FXD general architecture

- X-Ray converter: scintillator or photoconductor
- Active aSi:H readout matrix
- External readout Amplifiers/multiplexers and lines drivers

![Diagram of FXD general architecture]

- X-Ray Converter
- C Mos Amplifiers
- Address Lines
- A/D-Converter
- Glass Plate with aSi:H active matrix
Two designs are currently used:

**Indirect Conversion**
- (scintillator - photodetector)
- γ converts to light
- light generates charges
- 1000 charges at 60 keV

**Direct Conversion**
- (semi-conductor)
- γ generates charges
- 10 000 charges at 60 keV
Indirect Conversion

State of the art: Thallium doped Cesium Iodine (CsI) screen

- Vapour grown
- Tl doped for green emission
- Columnar structure
- Large area 43cm x 43 cm
- Thickness ~ 500 - 600µm
- X-ray Absorption: 80% at 60keV
Indirect Conversion: CsI(Tl) + aSi:Photodiode

Advantages:

- High absorption of X-ray: 80% at 60keV (500µm)
- Resolution due to CsI needle-like structure:
  MTF~ 40% at 2lp/mm (pixel 200µm)

Limitations:

- Light scattering effect
- Fill factor limiting the minimum pixel size
  - 64% for 150 µm pixel size
  - 50% for 100µm pixel size
- Sensitivity:
  - 1100 electrons per X-Ray (DN 5)
- Memory effect following stronger exposure:
  - 0.1% after few seconds
Direct Conversion

**State of the art**: amorphous Selenium photoconductor

- Large area 43cm x 43 cm
- Thickness ~ 500 - 1000µm
- Electric field ~10 V/µm
- X-ray Absorption: 52% at 60keV
Direct Conversion: Amorphous Sélénium

Advantages:

- High resolution:
  MTF~ 75% at 2lp/mm (pixel 150 µm)

- Fill factor:
  Almost 100% for 150 µm pixel

- Simpler readout matrix
  No photodiode

Limitations:

- Absorption of X-ray:
  52% at 60keV (500µm)

- Sensitivity:
  1000 charges per X-Ray (DN 5)

- Lag effect:
  2% after 33 ms
FXD READOUT ARCHITECTURES
FXD READOUT ARCHITECTURES

- 2D array of aSi-TFT switches addressed by line pulse
- Signal readout by column data bus and by external amplifier

LIMITATIONS:
- No pixel amplification
- Readout noise (~1000 electrons) equivalent to signal at Fluoroscopic dose
- Scintillator detectors require specific process for photodiode

150 µm
• The characteristics of commercial XFD are now approaching the maximum values provided by the present concept:
  
  • Performances for General Radiography are better than film
  
  • At very low dose used in fluoroscopy and interventional techniques the signal to noise ratio is still the limiting factor for both direct (Se) and indirect design (CsI:Tl)
  
  • Cost of these detectors remains high

New architectures and new photoconductors materials are required to overcome the present limitations.
Part 2
Flat Panel X-Ray Detector

Future Developments
To get a larger number of electrons per quantum X-Ray X-ray photoconduction is an attractive way:
- Larger number of created charges
- Spatial resolution is almost independent of thickness and MTF is very close to the theoretical pixel response

What we need:
- High absorption (Heavy materials)
- Low charge pair energy
- Good transport properties
- Low dark current (blocking contacts; high resistivity)
- Good lag characteristics
- Large area manufacturing process (40cm x 40 cm)
- Low manufacturing cost: ~ 1000 € for a 40 cm x 40 cm layer
## DIRECT CONVERSION MATERIALS

<table>
<thead>
<tr>
<th></th>
<th>Poly CdTe</th>
<th>Poly HgI₂</th>
<th>Poly PbI₂</th>
<th>Amorphous Selenium</th>
<th>Poly PbO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic Number</td>
<td>48-52</td>
<td>80-53</td>
<td>82-53</td>
<td>34</td>
<td>82-8</td>
</tr>
<tr>
<td>Density</td>
<td>5.9</td>
<td>6.4</td>
<td>5.5</td>
<td>4.3</td>
<td>?</td>
</tr>
<tr>
<td>Energy band gap (eV)</td>
<td>1.5</td>
<td>2.1</td>
<td>2.3</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>Charge Pair Energy (eV)</td>
<td>4.5</td>
<td>5.5</td>
<td>6.6</td>
<td>50 (effective)</td>
<td>15</td>
</tr>
<tr>
<td>Processing temperature (°C)</td>
<td>500</td>
<td>100</td>
<td>200</td>
<td>80 (Substrate)</td>
<td></td>
</tr>
</tbody>
</table>
DIRECT CONVERSION MATERIALS

- Cadmium Telluride, Mercuric Iodide and lead Iodine are considered as the best candidates for large area X-rays detectors for Medical applications.

<table>
<thead>
<tr>
<th></th>
<th>HgI2</th>
<th>PbI2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CdTe &amp; CdZnTe</td>
<td>• VARIAN/ RTRR</td>
<td>• XEROX/ RTRR</td>
</tr>
<tr>
<td>• CEA LETI</td>
<td>• XEROX/ RMD</td>
<td></td>
</tr>
<tr>
<td>• SHIMADZU</td>
<td></td>
<td></td>
</tr>
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</table>

- Further investigations and improvements are required to obtain materials with the required characteristics in very large area.
Matrix size: 512 * 512

Pixel pitch: 150 µm
SIGNAL INCREASE : PIXEL DESIGN

• In present aSi:H Matrix design a single TFT is used as a switch to read out the pixel signal resulting in a signal equivalent to the noise generated by the matrix readout process.

• The incorporation of an amplification at pixel level will overcome this limitation.

• The low charge mobility of aSi:H materials is not suitable for such a design:

  a new technology is required
**Technologies for future readout matrix**

<table>
<thead>
<tr>
<th>Poly SI</th>
<th>C MOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Relatively high mobility</td>
<td>• High mobility (crystal silicon)</td>
</tr>
<tr>
<td>• Low integration</td>
<td>• High integration</td>
</tr>
<tr>
<td>– single pixel amplification</td>
<td>– Pixel functionalities</td>
</tr>
<tr>
<td>• Very large area</td>
<td>– Matrix drivers</td>
</tr>
<tr>
<td></td>
<td>– Pixel counting</td>
</tr>
<tr>
<td></td>
<td>• Relatively large area</td>
</tr>
</tbody>
</table>
CMOS 12 inches wafer: the future

- CCMC Crolles 2 operating en 2003
- ST / MOTOROLA / PHILIPS

Numbers of operations 300mm

Area demand/year (10E6 in^2)

Year 1960 65 70 75 80 85 90 95 00 05 10 15 20 25

Source: VLSI research.
FXD Direct conversion and CMOS readout
PHOTON COUNTING FXD

- CMOS allows the design of Digital Counters in individual pixel.

- The counting mode will provide:
  - Better **stability**: temperature, gain
  - Digital information at pixel level: *insensitive to matrix readout noise*
  - Elimination of **memory effect and lag effect**
  - Spectral information: *multi-energy radiography*

- The two main limitations are:
  - Limitation of the **counting rate** at high dose exposure
  - **power consumption**
CONCLUSION: THE FOUR KEYS FOR FUTURE FXD

- Direct Conversion Materials
- CMOS Integrated readout Matrix
- Coupling Technology
  - Hybrid
  - Direct deposit?
- Digital counting?