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FLAT PANEL X-RAY DETECTOR

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Part 1
Flat Panel X-Ray Detector

State of the art and limitations

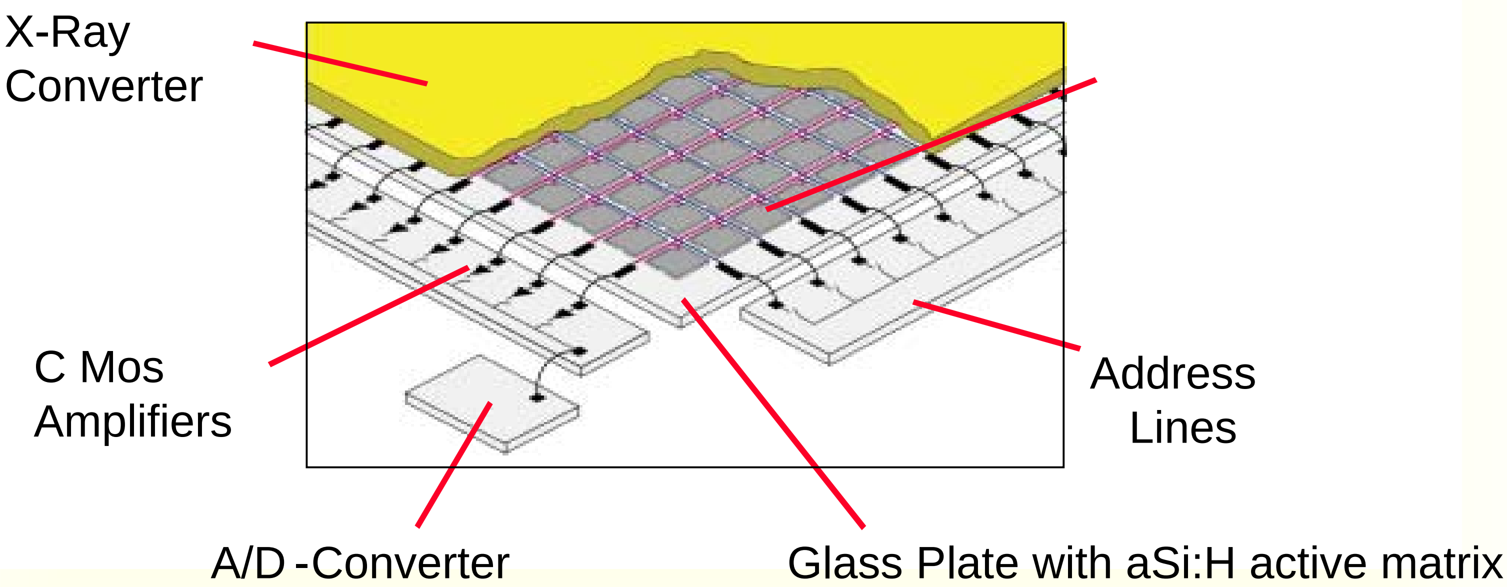
- The replacement of the medical radiographic film has been the main driver, during the last decade for large area X-ray detectors development
- Several Flat Panel X-Ray detectors (FXD) are now available, all of them using Amorphous Silicon Technology, for digital radiography system
- FXD for dynamic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

Requirements for film replacement

	General radiography	Mammography
Size	> 40 x 40 cm	>18 x 24 cm
Pixel size	~ 150 µm	60-100 µm
Typical nb of incid.X/pel	~1000	~5000
Corresponding dose	2.5 µGy	100µGy
Energy range	30-120 keV	~20 keV
Input equiv. noise	< 5 X quanta	< 5 X quanta
Dynamic range	12 bit	12 bit
Exposure / Readout time	.5 s / 1 s	1s / 5 s

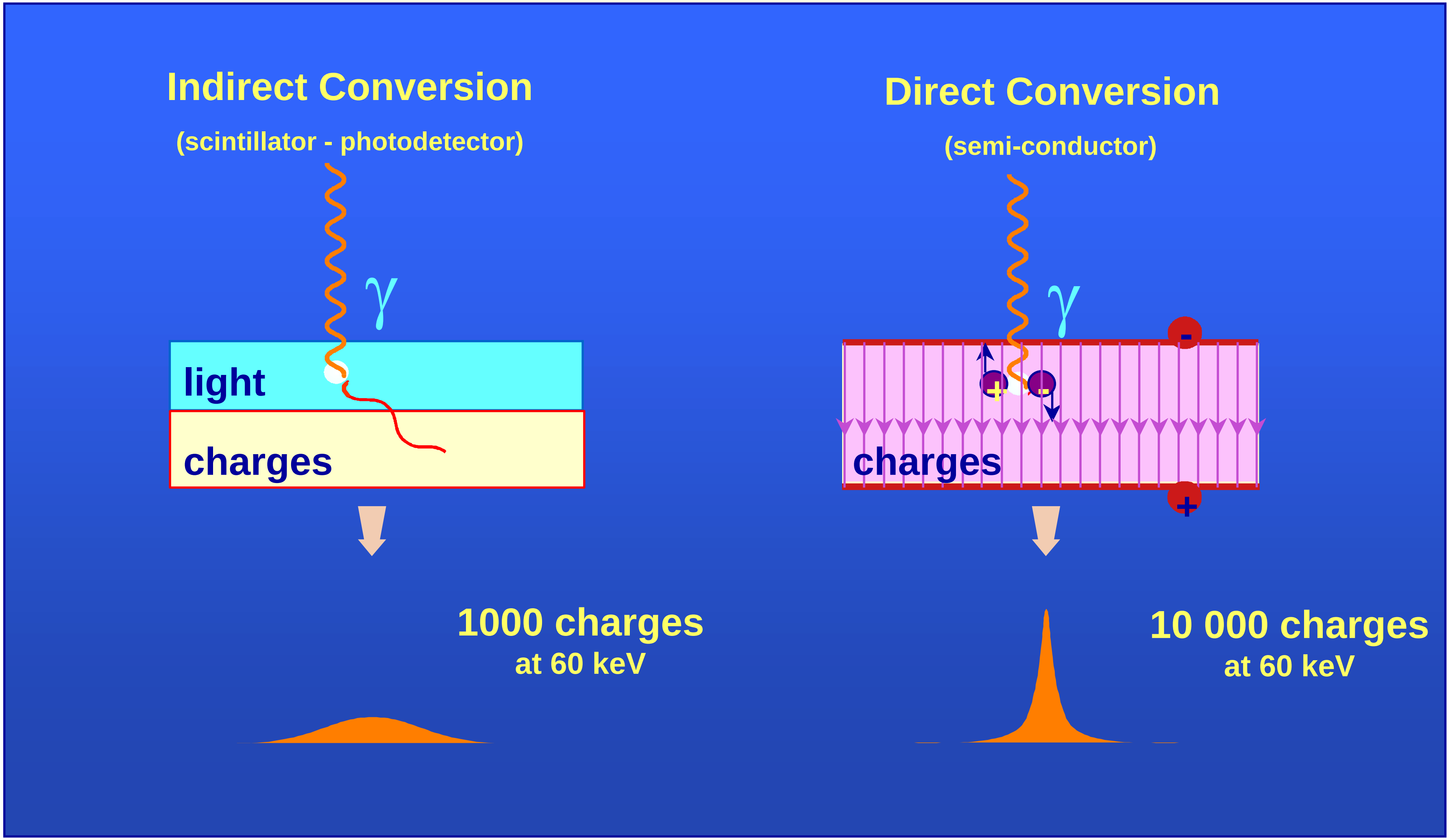
FXD general architecture

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



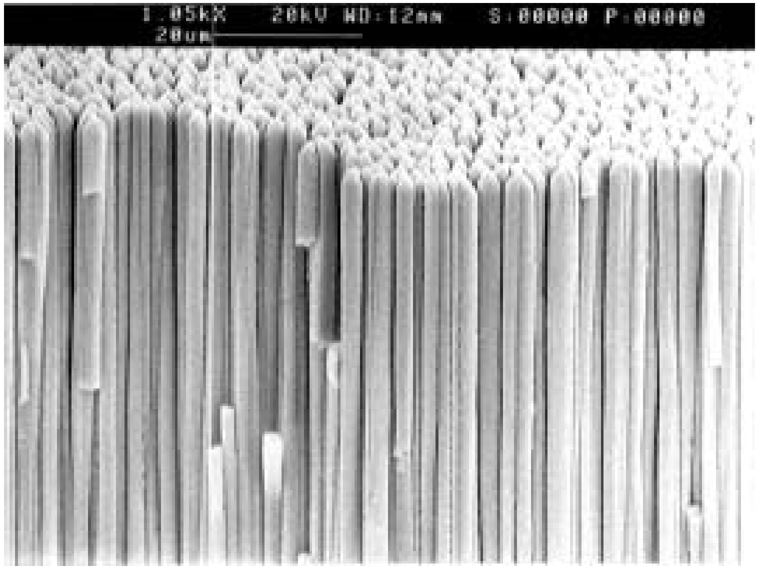
X-Ray Conversion Direct / Indirect

Two designs are currently used



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 :

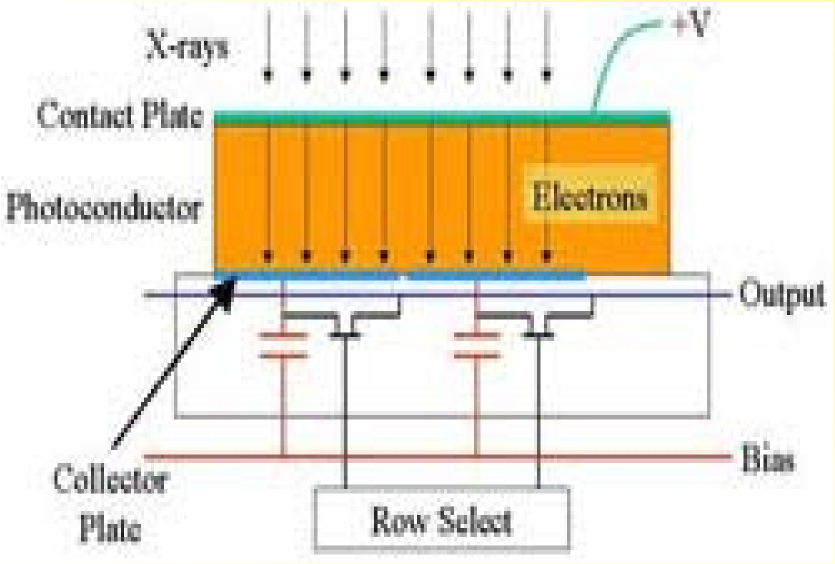
1100 electrons per X-Ray (DN 5)

• Memory effect following stronger exposure :

.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)

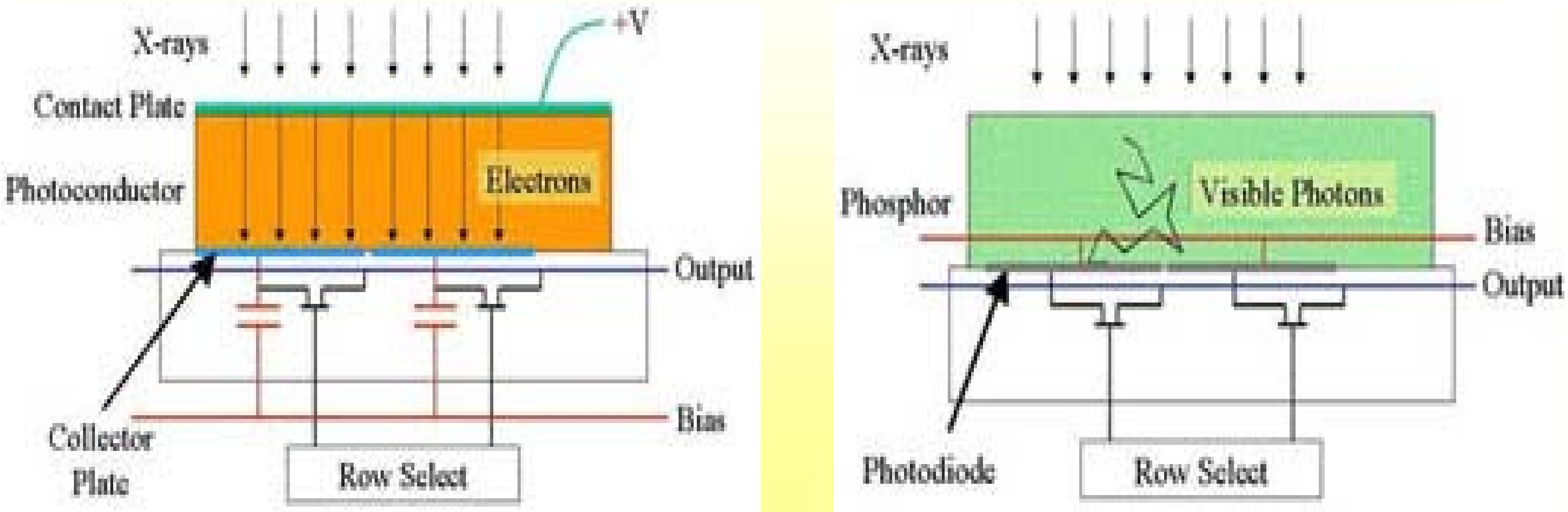
- Sensitivity :

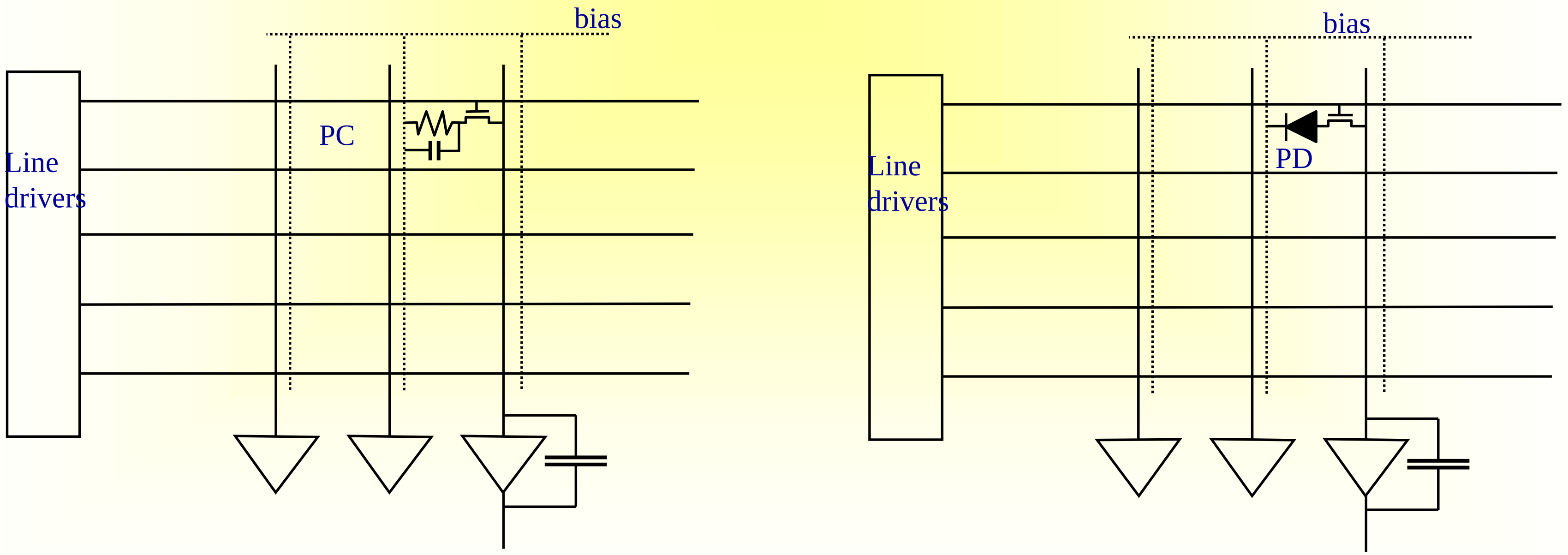
  1000 charges per X-Ray (DN 5)

- Lag effect :

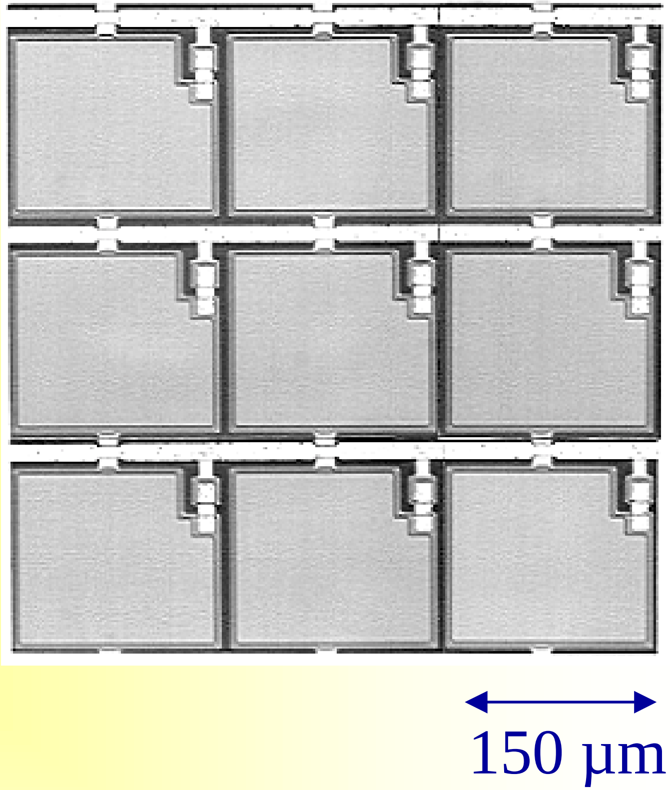
  2% after 33 ms

FXD READOUT ARCHITECTURES





FXD READOUT ARCHITECTURES



- 2D array of aSi-TFT switchs adressed 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

- 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

SIGNAL IMPROVEMENT : DETECTION

- 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 theoritical 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

	Poly CdTe	Poly HgI_2	Poly PbI_2	Amorphous Selenium	Poly PbO
Atomic Number	48-52	80-53	82-53	34	82-8
Density	5.9	6.4	5.5	4.3	?
Energy band gap ev	1.5	2.1	2.3	2.2	
Charge Pair Energy eV	4.5	5.5	6.6	50 (effective)	15
Processing temperature °C	500	100	200	80 (Substrate)	

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

CdTe & CdZnTe	HgI_2	PbI_2
• CEA LETI • SHIMADZU	• VARIAN/ RTRR • XEROX/ RMD	• XEROX/ RTRR

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

CZT poly + TFT Shimadzu-Sharp (2001)

Matrix size : 512 * 512

Pixel pitch : 150 µm

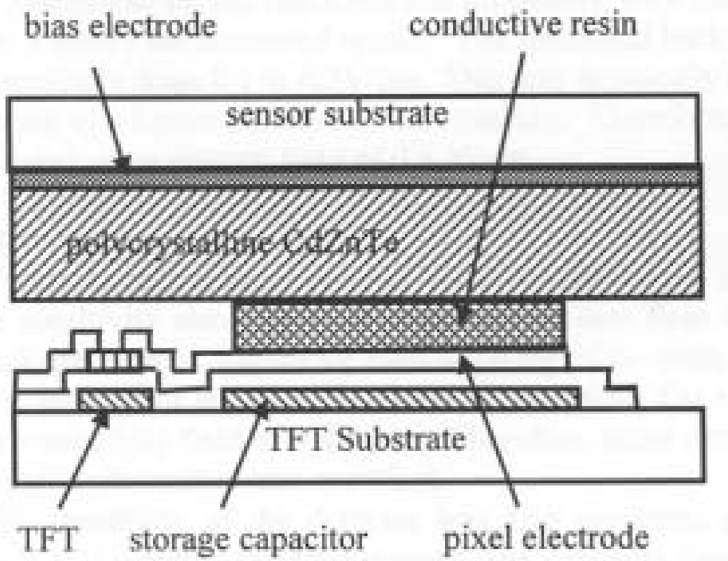
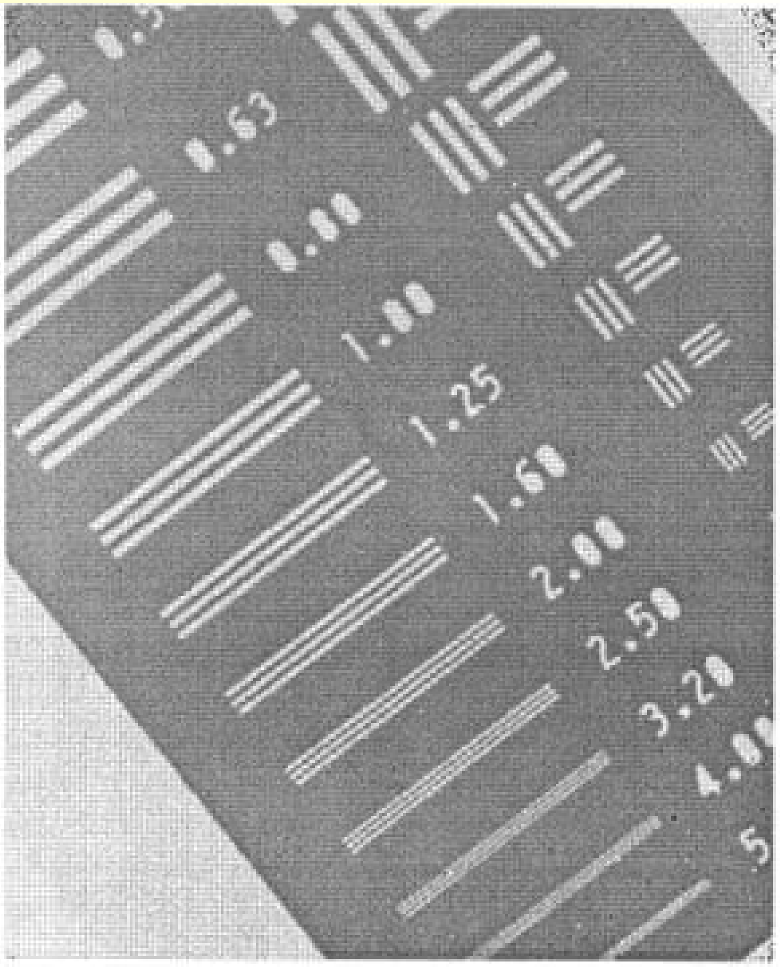


Figure 1 Schematic cross-section of the flat-panel detector with CdZnTe film



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.

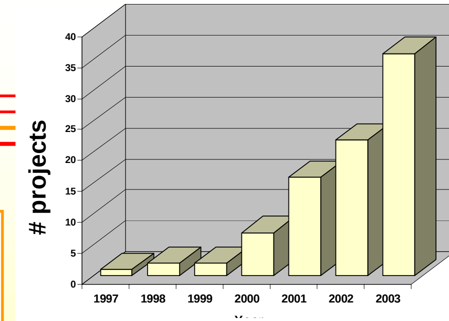
• The low charge mobility of aSi:H materials is not suitable for such a design :

a new technology is required

Technologies for future readout matrix

Poly SI	C MOS
• Relatively high mobility • Low integration – single pixel amplification •Very large area	• High mobility (crystal silicon) • High integration – Pixel functionalities – Matrix drivers – Pixel counting • Relatively large area

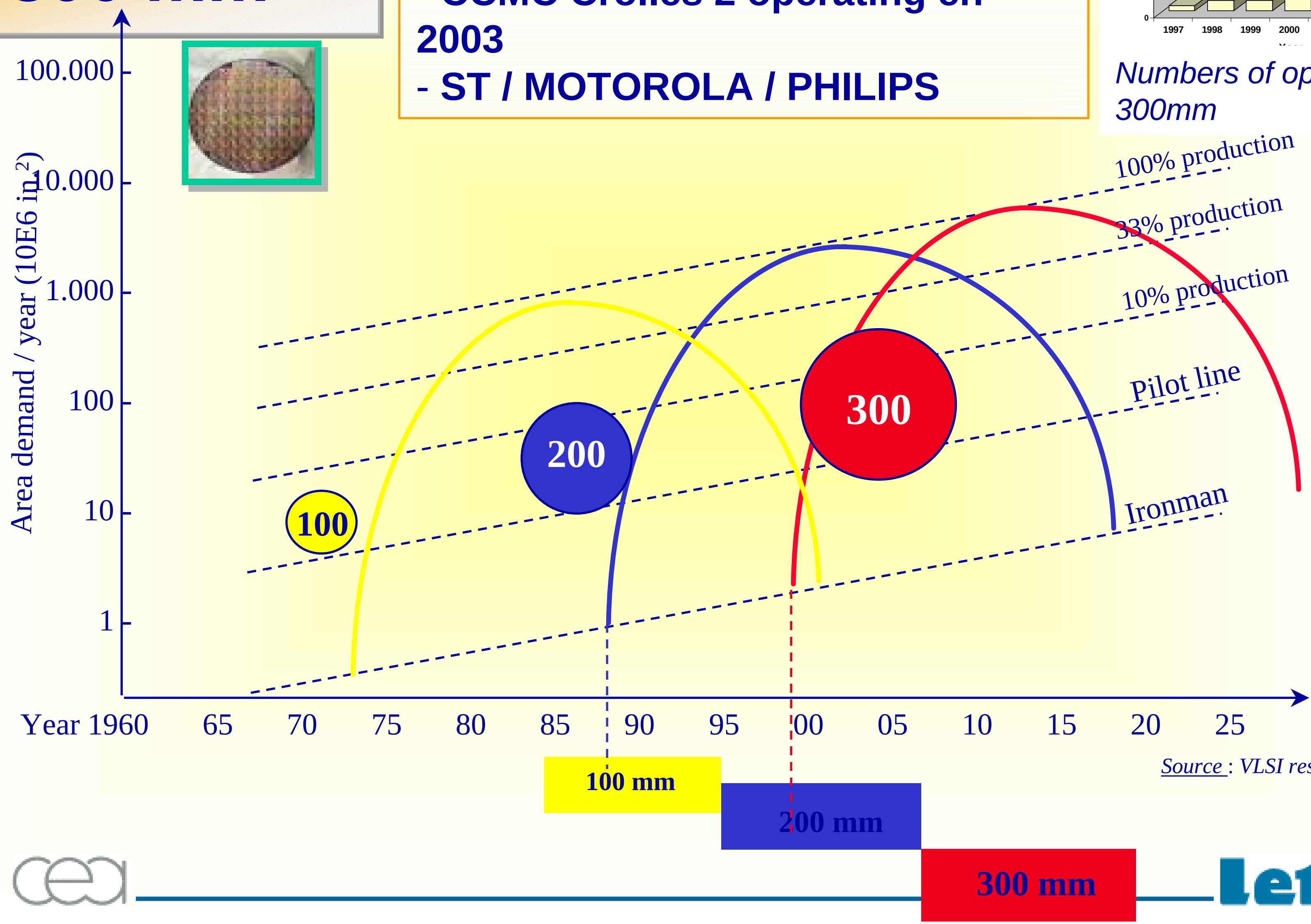
CMOS 12 inches wafer : the future



Numbers of operations 300mm

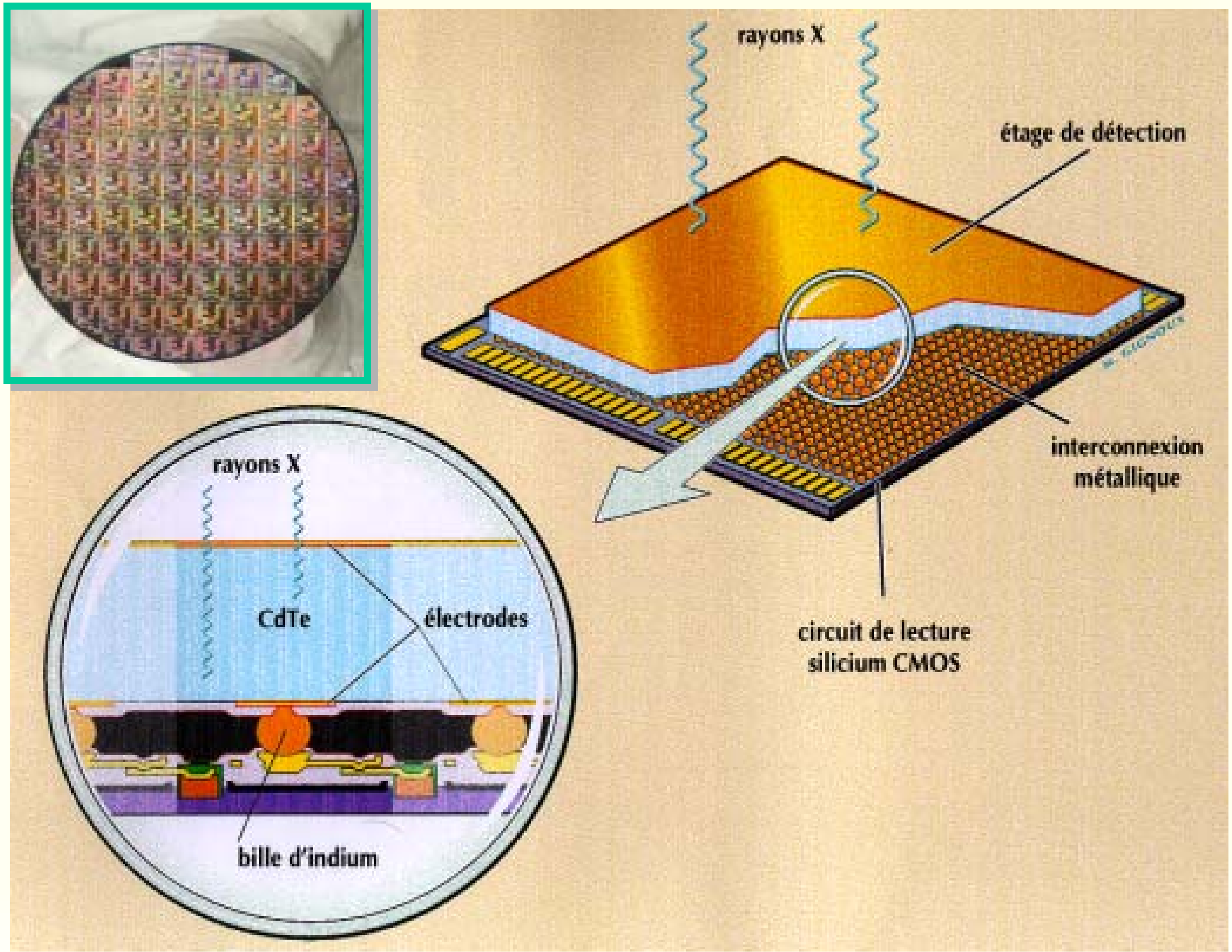
300 mm

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



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 ?