Thin Film Amorphous Silicon Technology

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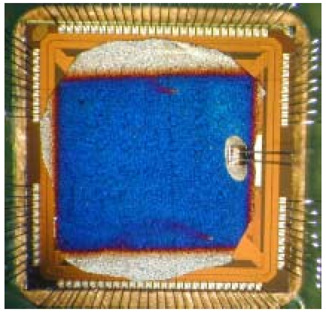
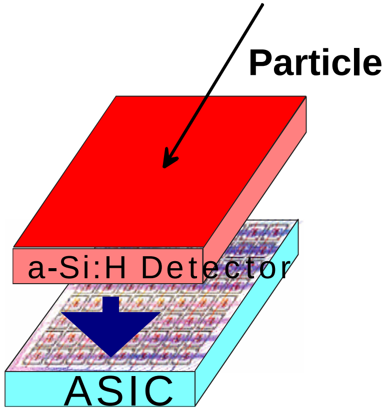
Applications for detectors

- Thin-film on ASIC particle sensors

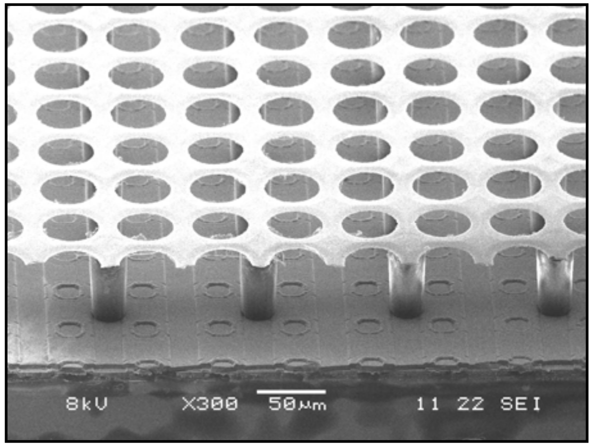
5-32 µm thick diode deposited on Macropad chip for β and X-ray detection





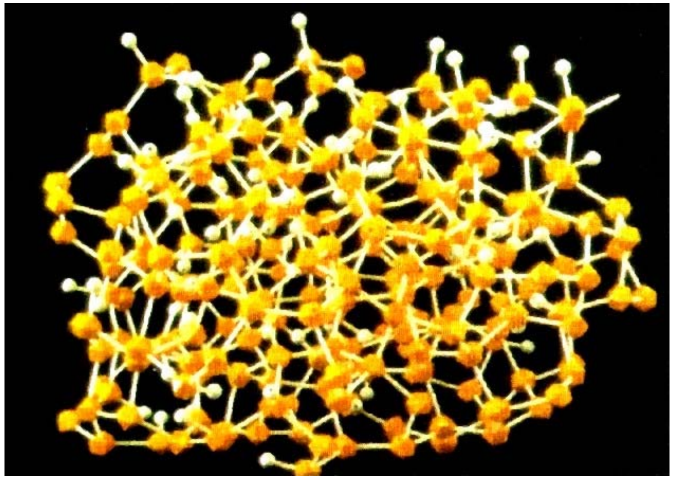
- SiProt: protection layer for pixel sensors

32 µm SiProt layer on Timepix chip with Ingrid



- Resistive layer

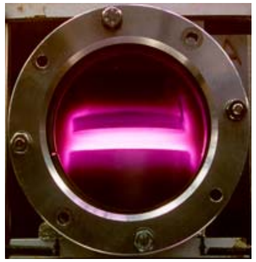
a-Si:H Main Characteristics

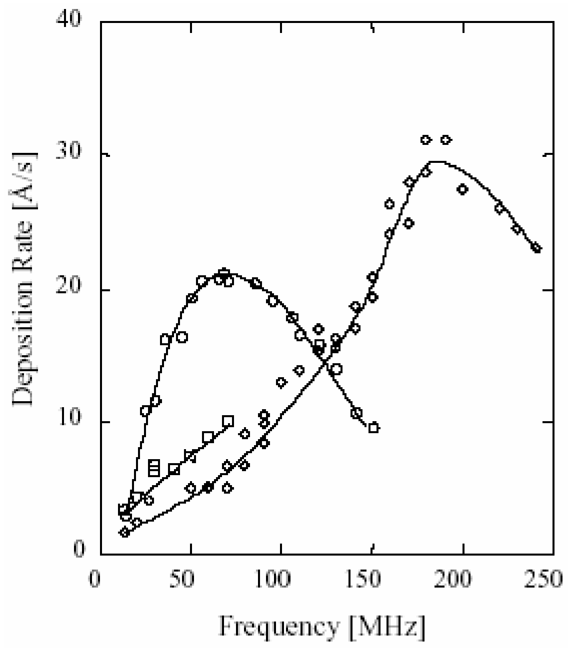


- Disordered semiconductor
  - High optical absorption
  - Low mobility
  - Radiation hardness
- Low defect density
  - Hydrogen used for defect passivation
  - Alloy of Si with hydrogen (around 10% atomic H)
- Relatively high gap semiconductor (≈1.75 eV)
  - High resistivity, low dark current
  - Band gap engineering (alloying with C, O, Ge, …)
- Low process temperature a-Si:H
  - Deposition on various substrate materials (including polymers)
  - 3D integration

Deposition of a-Si:H

- Low temperature (≈ 200°C)
- Source gases: SiH_4 (H_2, B_2H_6, PH_3)
- H dilution of SiH_4 for improved quality
- RF PE-CVD (13.56 MHz)
  - Typical deposition rates: ≈1 Å/s
- VHF PE-CVD (70-120 MHz)
  - Typical deposition rates: ≈5-15 Å/s
  - Lower mechanical stress (compared to RF deposition)
  - Patented by IMT (1986)
  - **Several advantages for thick layer deposition**

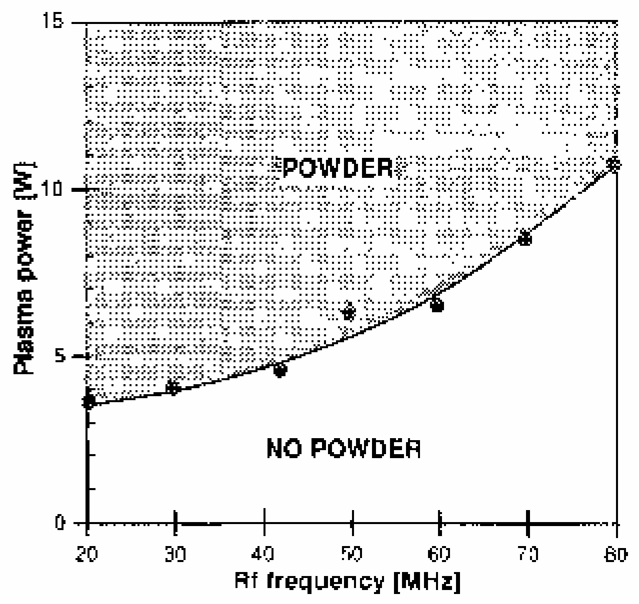




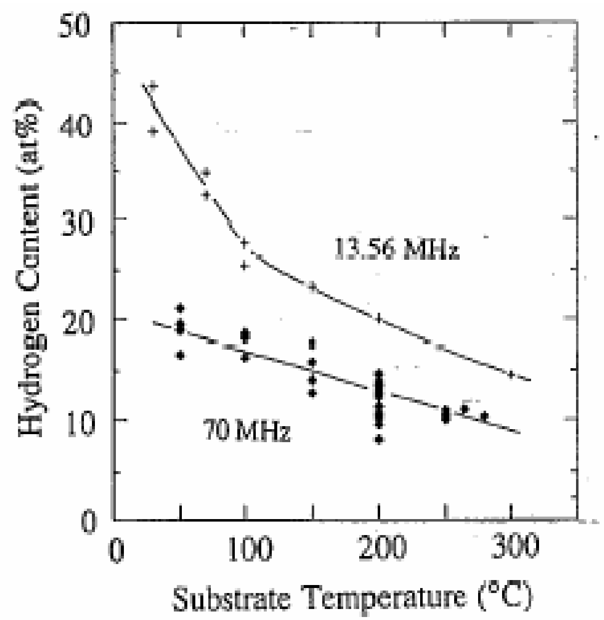
U. Kroll et al., Sol. Ener. Mat. & Sol. Cells 48 (1997) 343.

Advantages of VHF PE-CVD

- Higher deposition rates
- Less powder formation
- Lower void density
  at lower deposition temperature



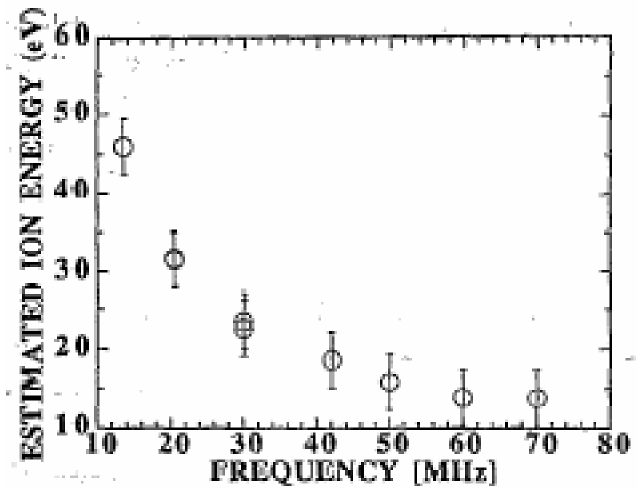
J.-L- Dorier et al.,
J. Vac. Sci. Technol. A 10 (1992) 1048.

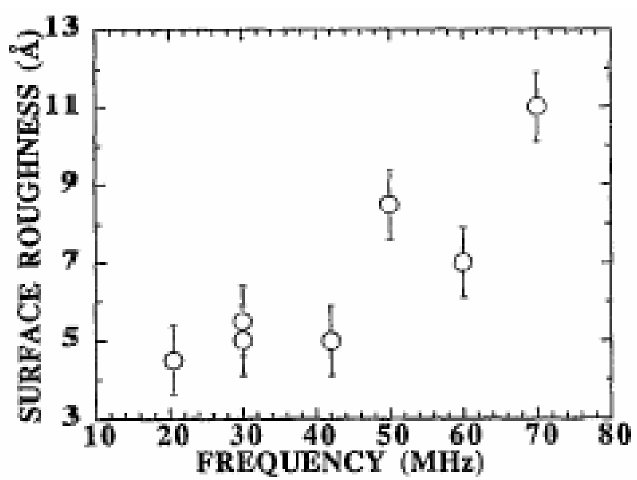


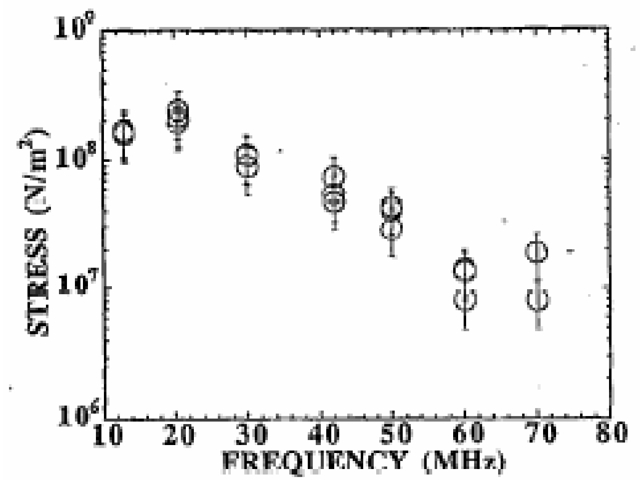
F. Finger et al., JAP 71 (1992) 5668.

Advantages of VHF PE-CVD (2)

- Lower ion energy
  - ⇒ Lower defect density (at same deposition rate)
  - ⇒ Lower internal stress
  - ⇒ Larger surface roughness
  - ⇒ Deposition of thicker films

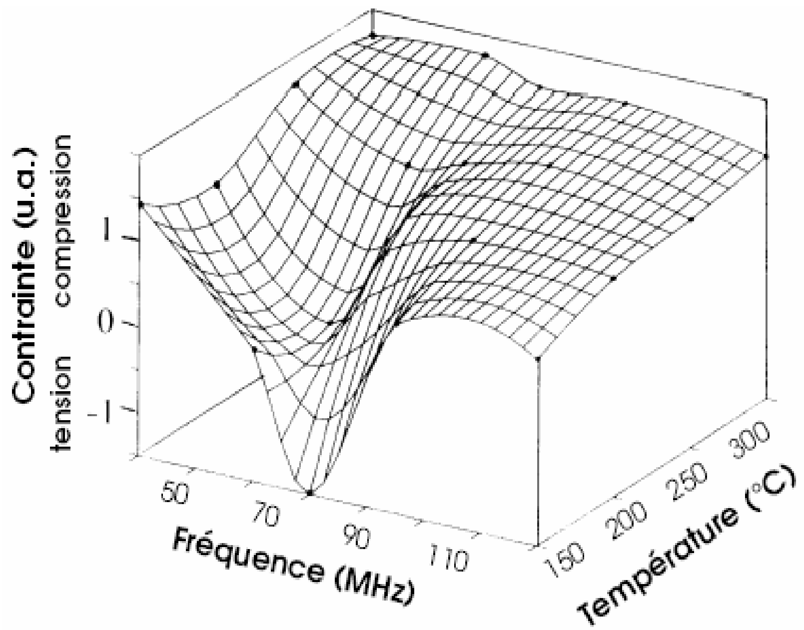


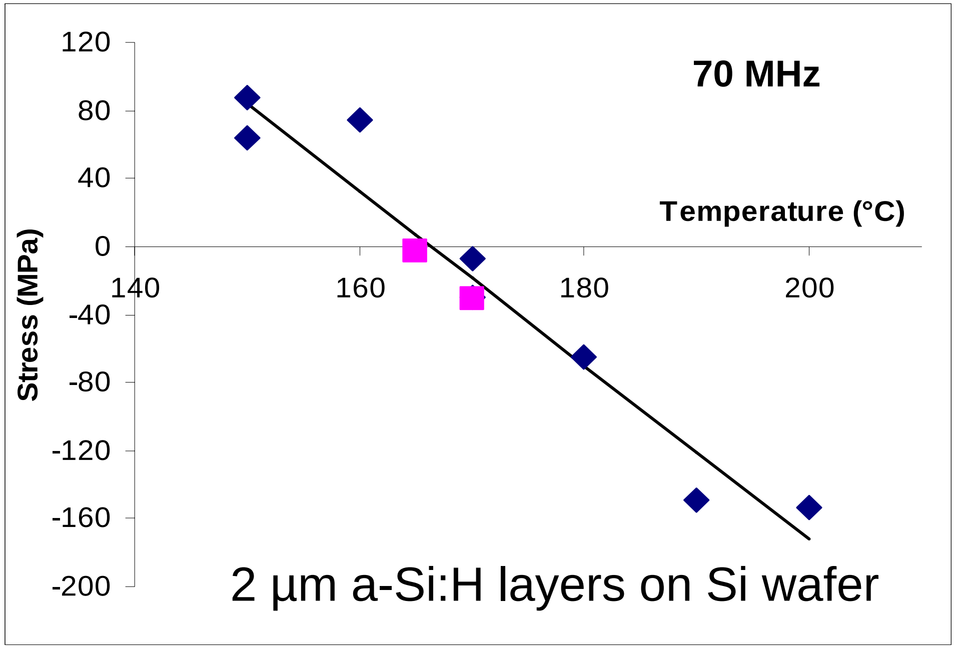




J. Dutta et al., JAP 72 (1992) 3220.

Stress control of a-Si:H





- Stress depends on ion energy (i.e. power, pressure, frequency) and temperature (difference in thermal expansion coefficients)
- Stress free a-Si:H layers by VHF PE CVD at 170°C
- Thick a-Si:H diodes possible without peeling off problem
- Lower temperatures leads to more defective materials

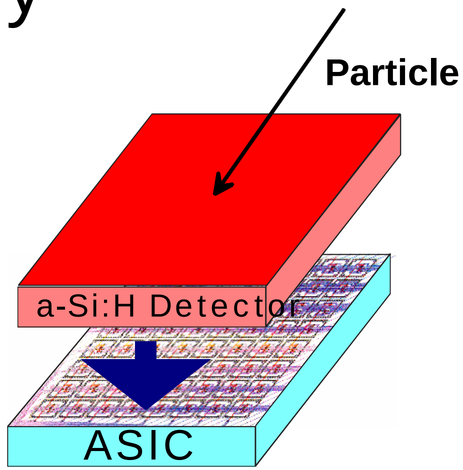
Deposition system

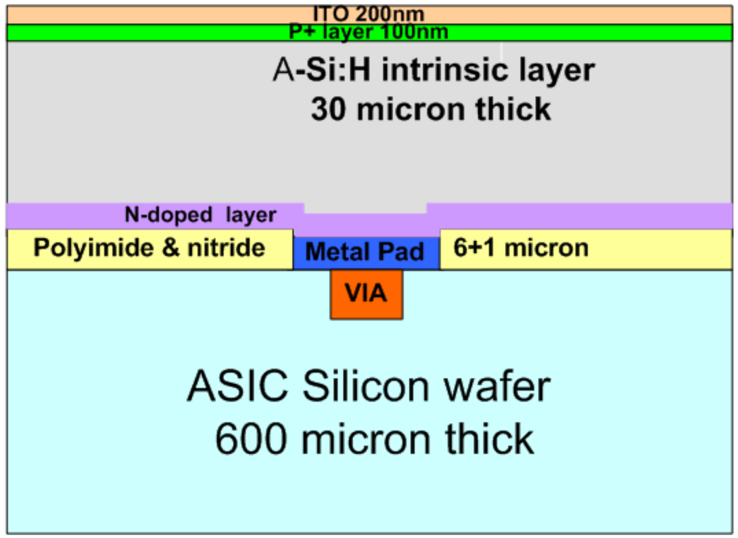
- IMT designed system
- Single chamber PE-CVD system
- load-lock
  - Higher throughput
  - Transfer of sample to load lock between layer deposition (chamber cleaning)
- Substrates:
  - size up to to 6''
  - or up to 9 4x4 cm^2 substrates
- Operated at VHF frequencies (50 – 150 MHz)

TFA technology

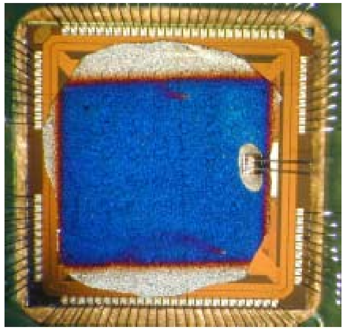
- Technology developed first for vision applications → thin diode
- Particle detection requires thick diodes
  - up to 30 µm
  - Full depetion difficult for thick devices

- Pixel segmentation of the n-i-p film given by high the resistivity of i- and n-layers



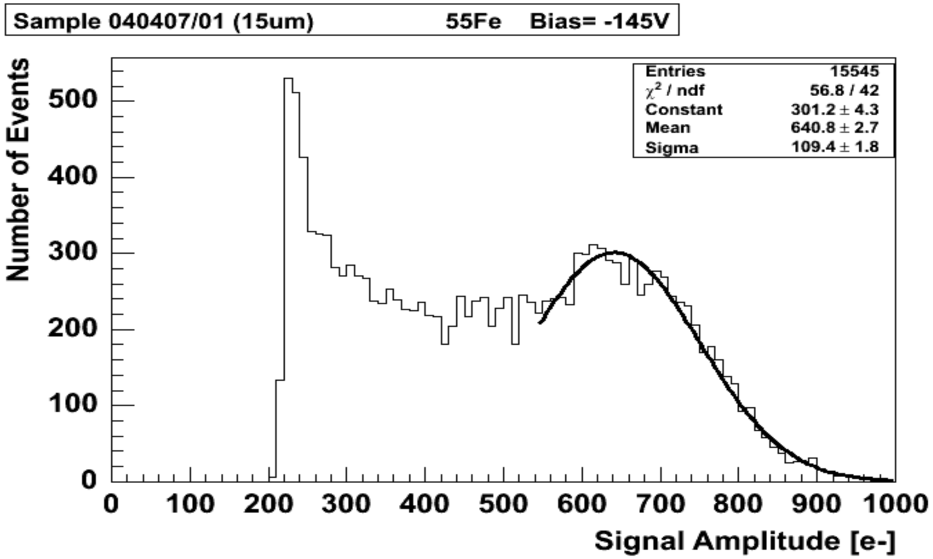


Thick diodes

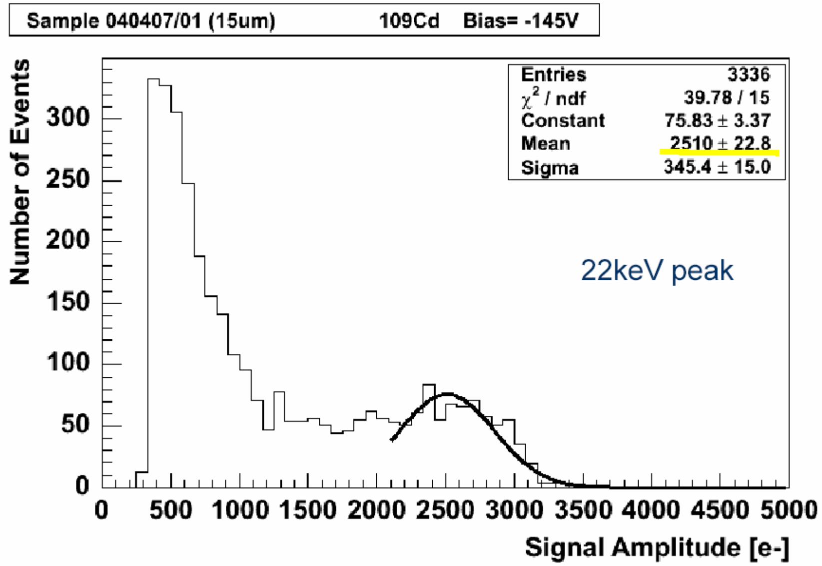


IBM 0.25 µm technology (MPW)

- 4x4 mm^2 ASIC
- 48 pixels with 150 µm size and 380 µm pitch connected to active feedback amplifiers
- 15 µm thick a-Si:H diode



^{55}Fe source: peak at 5.9 keV



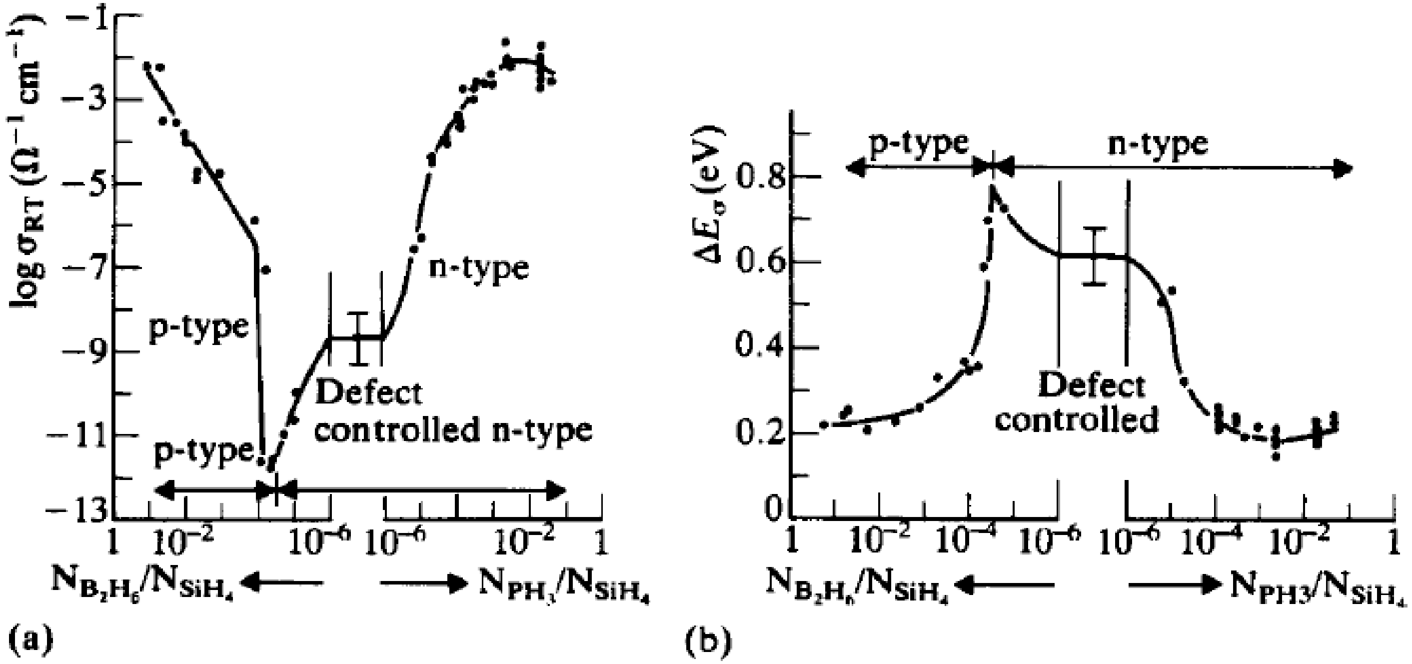
^{109}Cd source: peak at 22 keV

Protection and resistive layers

- Use similar i-layer (and similar deposition conditions) of TFA devices
- Deposition temperature T_{dep}: 150-250 °C (up to 350°C possible)
- H effusion for T_{anneal} > 350°C
- Resitivity of undoped material depends on E_{gap} which is a function of H content
- Typical resistivity values
  - σ_{dark} of state-of-the-art intrinsic a-Si:H at RT: 10^{-10} - 10^{-12} $(\Omega cm)^{-1}$
  - Resitivity of doped materials at RT: 10^{-5} - 10^{-2} $(\Omega cm)^{-1}$

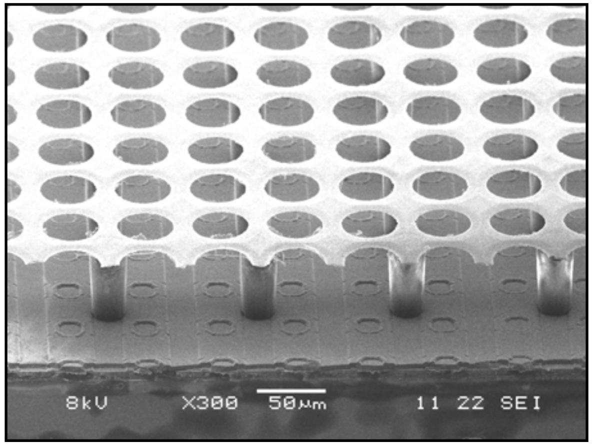
- Deposition of nano- or micro-crystalline Si possible with the same deposition chamber (using H dilution of silane)
  - σ_{dark} of state-of-the-art intrinsic nc-Si:H at RT: 10^{-7} - 10^{-6} $(\Omega cm)^{-1}$
  - Resitivity of doped materials at RT: 10^{-1} - 10^{2} $(\Omega cm)^{-1}$

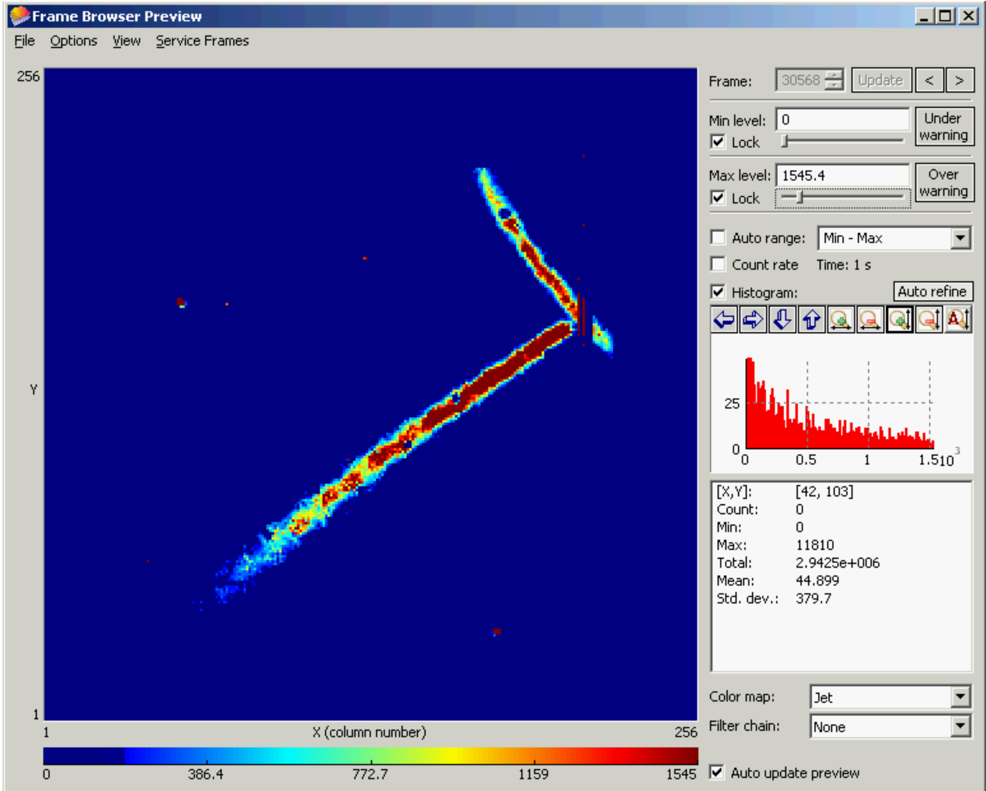
Dark conductivity vs. Doping for a-Si:H



Effect of diborane and phosphine in the plasma gas phase on (a) room temperature conductivity, (b) activation energy. [Spear, 1976].

Siprot layer

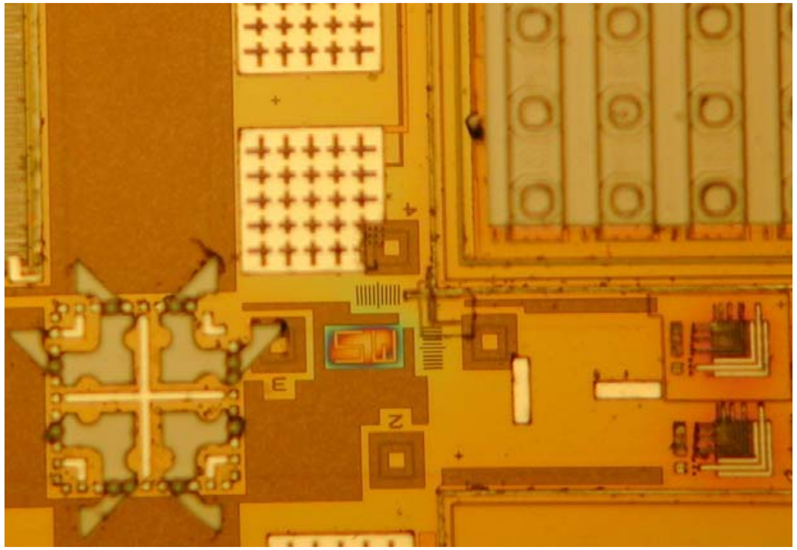




- Timpix +Siprot+Ingrid
- Thorium in Ar
- Discharge resistant device

SiProt patterning

- Dry etching in SF_6/O_2 plasma (wafer processing)



- Lift-off of SiProt from pads (Single chip processing)

Conclusions

- a-Si:H technology fully compatible for deposition on CMOS chips
  - Low temperature
  - Low stress
  - Wide range of material resistivity
- Successful development of TFA sensors for detection & imaging
- Successful application as protection layer for pixel sensors