Edge-On Sensor with Active Edge Fabricated by 3D-Technology

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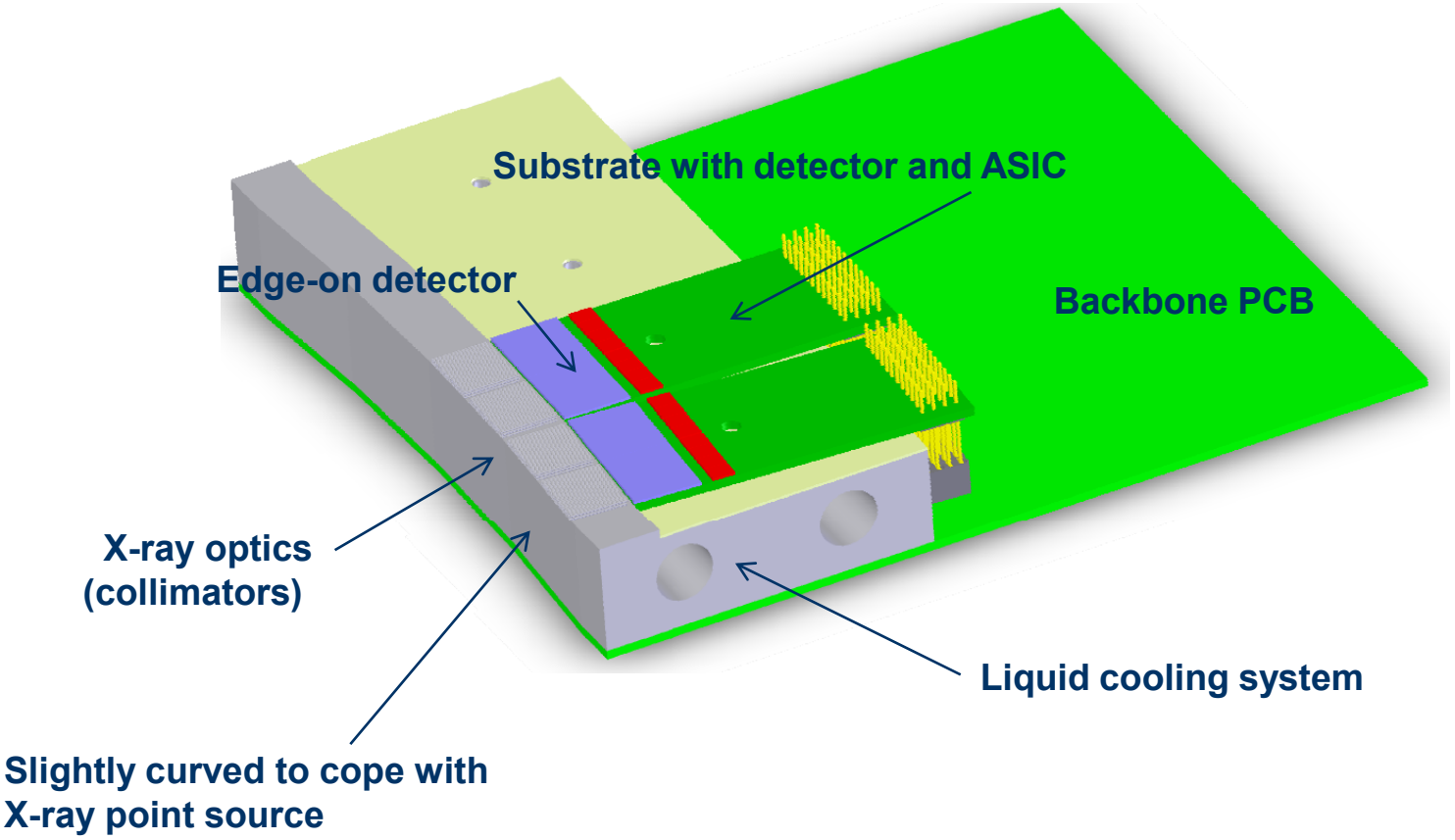
Background for this work is a SINTEF internal project: X-RAY IMAGING SYSTEM WITH PHOTON COUNTING AND BINNING

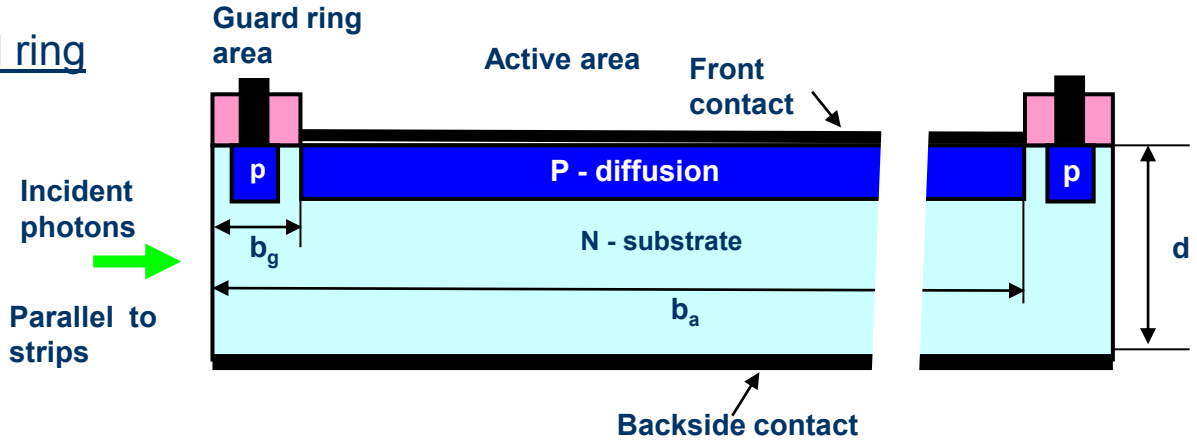
Physical demonstration system to be realized before end of 2011



The edge-on silicon strip sensor configuration

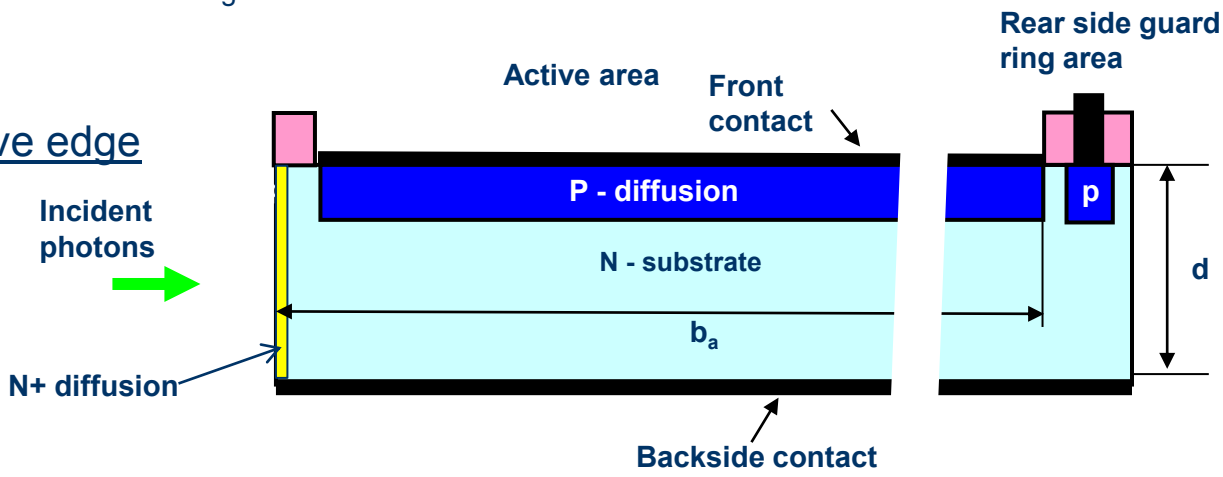
Incident radiation parallel to strips with total strip length serving as absorption length b_a.

With guard ring



Guard ring width b_g represents a dead region

With active edge

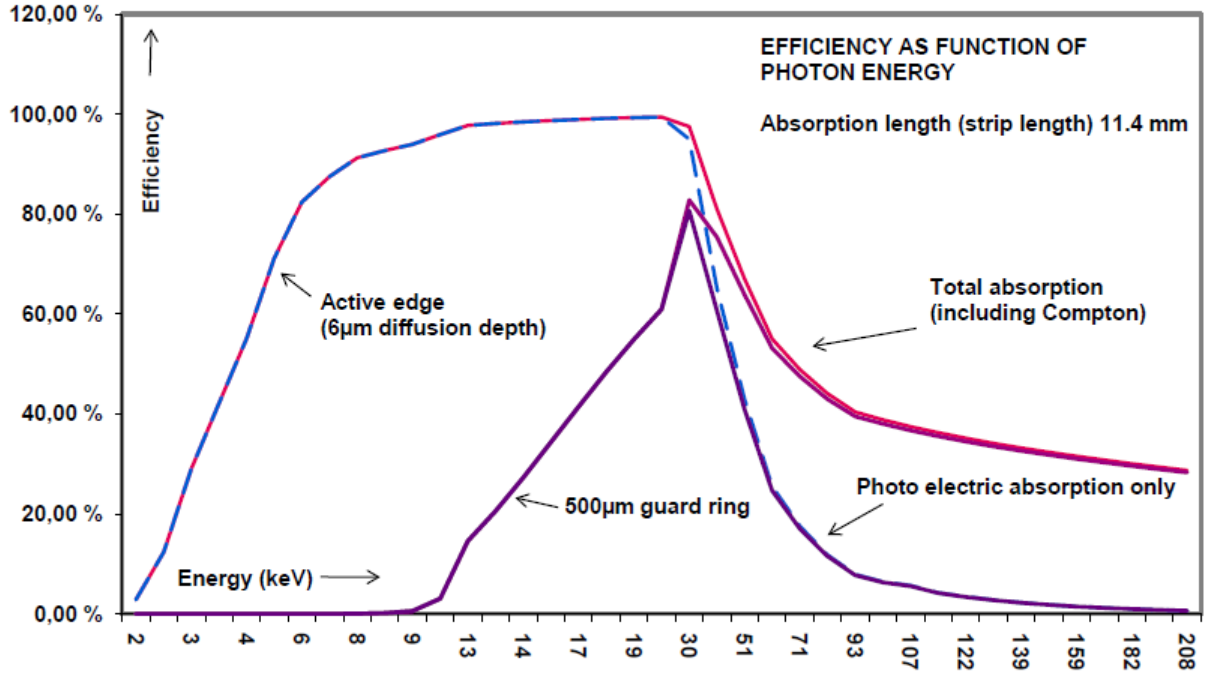


Guard ring on side facing incident photon replaced by N+ diffusion to stop depletion layer

Edge-on X-ray sensor chip efficiency

- Approximated efficiency: $Q_e = [1-\exp(-\alpha b_a)] \cdot \exp(-\alpha b_g)$
  Assumes total photon energy deposited in the sensor volume

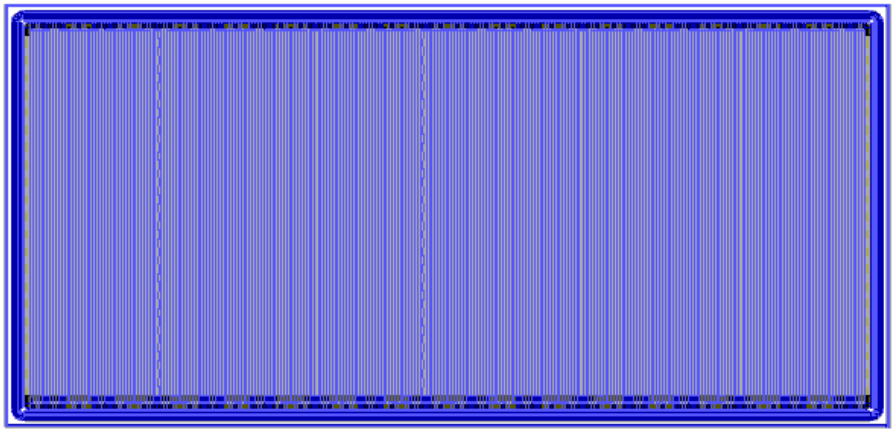
- Average number of generated electron/hole pairs N_e per incident photon with energy E_p (eV): $N_e = Q_e \cdot E_p / 3.6$



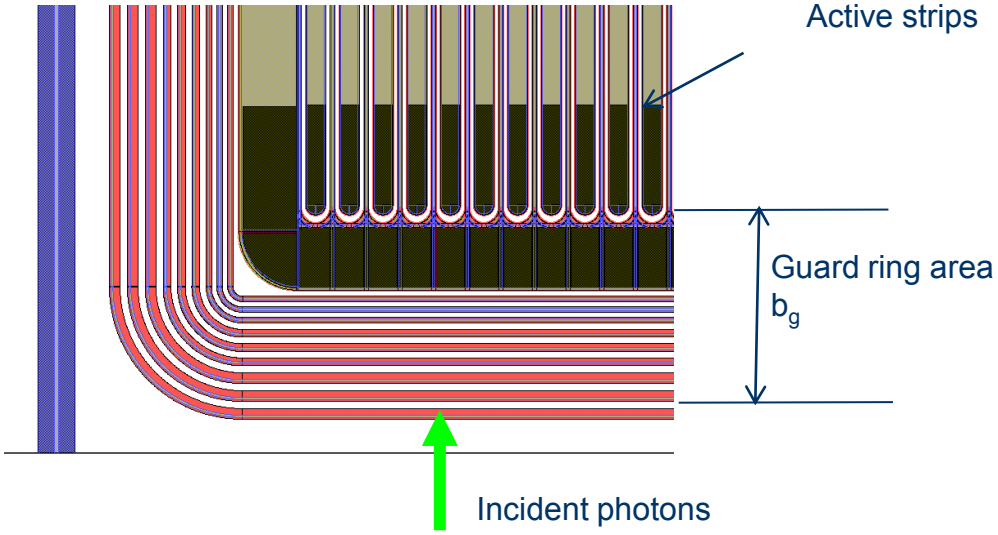
Advantages:

1. Higher efficiency than front illuminated sensors ≥ 20 keV
2. Potential use at ≥ 100 keV
3. Fast with response times in the10 to 20 ns region

Example of edge-on silicon x-ray strip sensor with guard ring for material analysis application



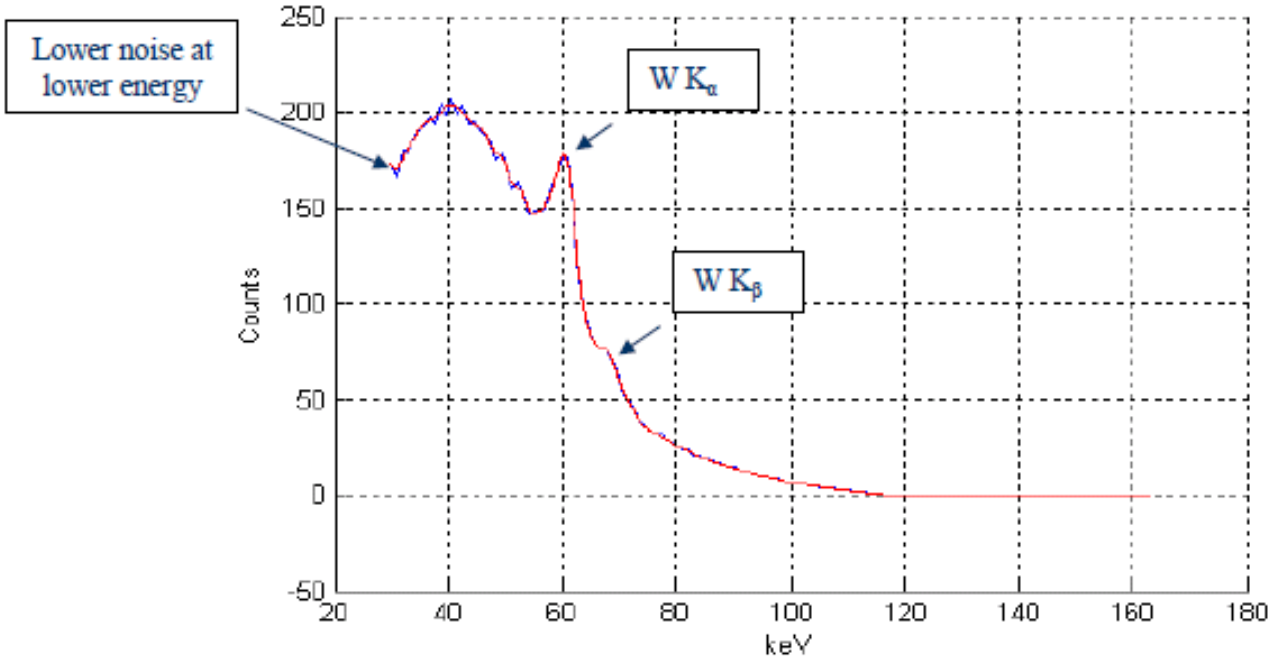
Edge-on chip made at SINTEF MiNaLab
Dimensions 25.7 x 12.9 x 0.5 mm^3



Layout details:
256 strips,
50 µm width,
90 µm pitch
11.8 mm strip length

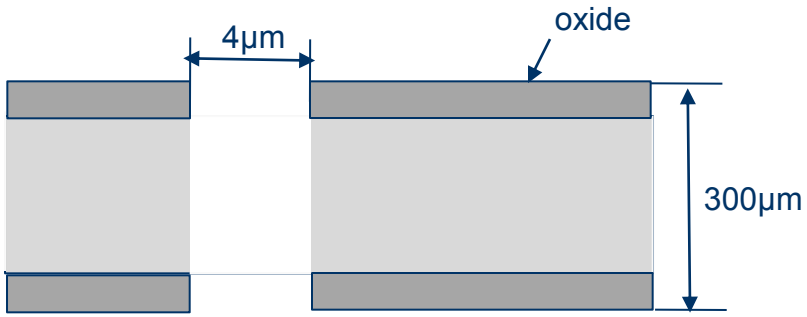
X-ray test on edge-on sensor chip with guard ring

Test restricted by sub-optimal front-end readout ASIC originally made to detect negative charge, not positive holes, and with insufficient dynamics)

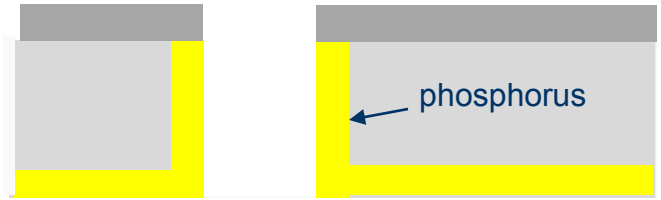


Scan from 31 to 164keV. Source 160keV tungsten tube

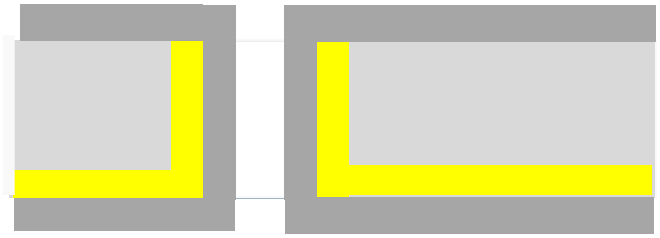
Fabrication of edge-on sensor with active edge



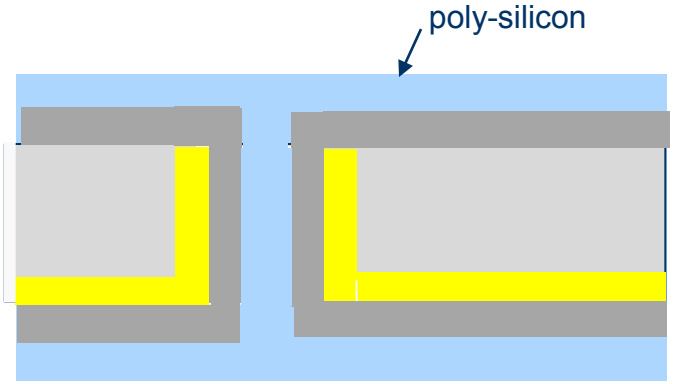
1. DRIE etch 4µm trench



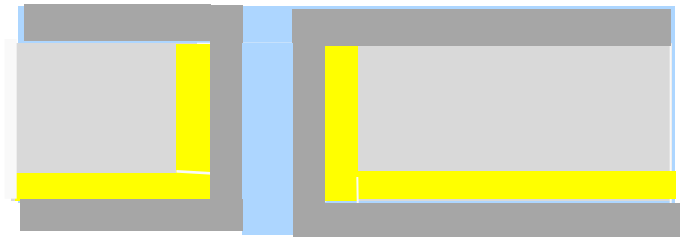
2. Phosphorus diffusion (POCL)



3. Oxidize edge 1µm



4. Deposit 1µm of poly-silicon

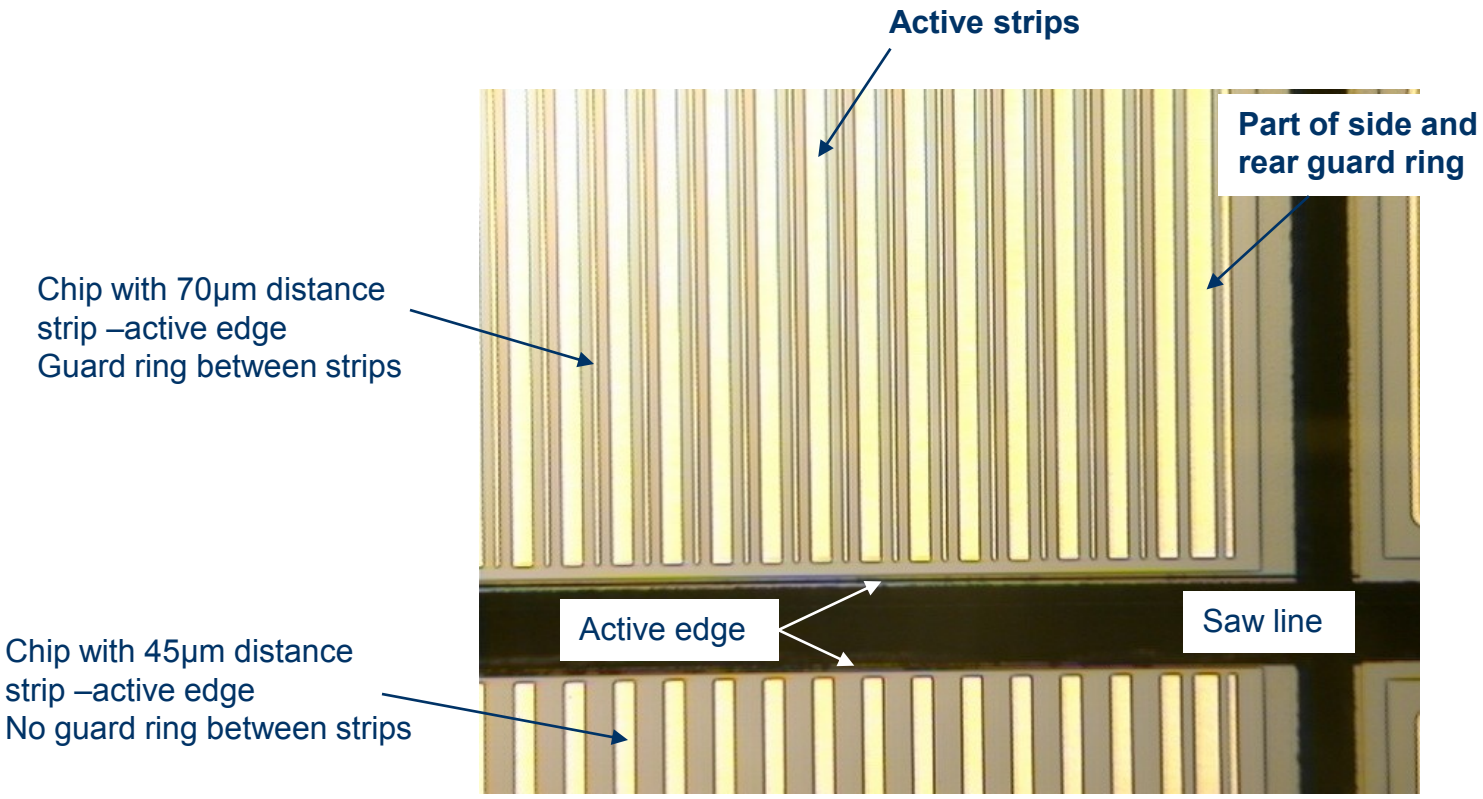


5. Back-etch polysilicon and planarize

6. Go on to planar processing

Edge-on x-ray sensor with active edge

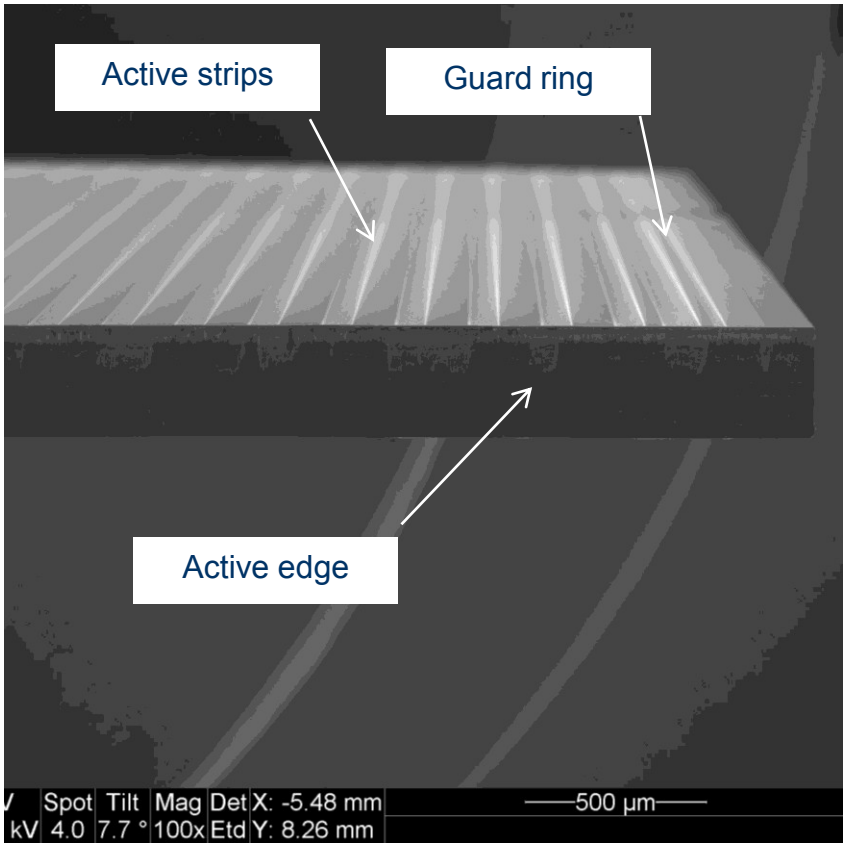
64 sensor chips on 6-inch wafer



Edge-on sensor chips with active edge fabricated at SINTEF MiNaLab
64 strips, width 80µm, length11.3mm, pitch 200µm
Picture taken with chips on blue tape after sawing and expansion

Edge-on x-ray sensor with active edge

64 sensor chips on 6-inch wafer



SEM picture of active edge chip after dicing.
Dicing not trivial, requires combination of DRIE etch and diamond saw

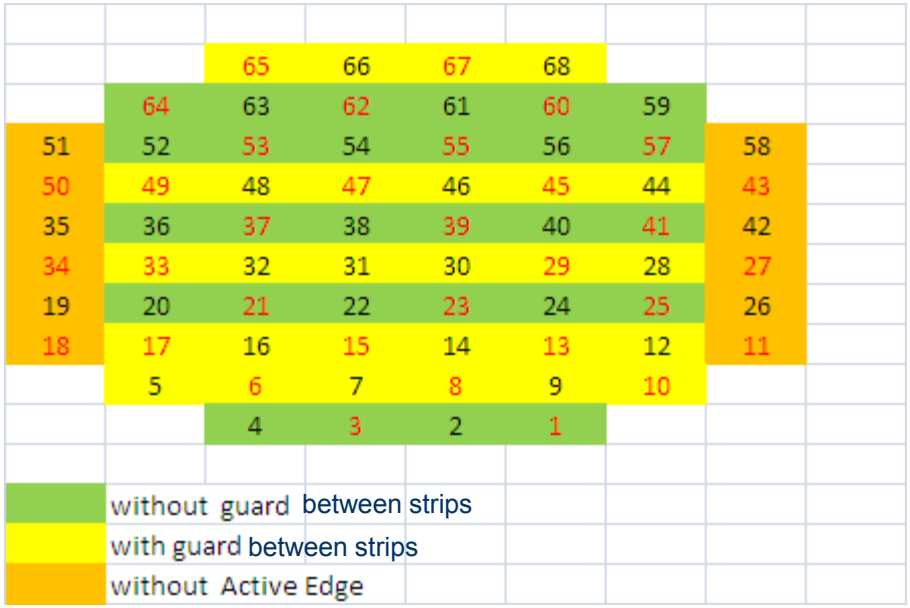
64 chips per wafer:

50% of all chips with guard ring between strips
50% of all chips without guard ring between strips

8 reference chips with all guard ring

56 chips with active edge:

50% with 45µm distance strip to active edge
50% with 70µm distance strip to active edge



Edge-on x-ray sensor with active edge
Measurements at wafer stage (6-inch wafer)

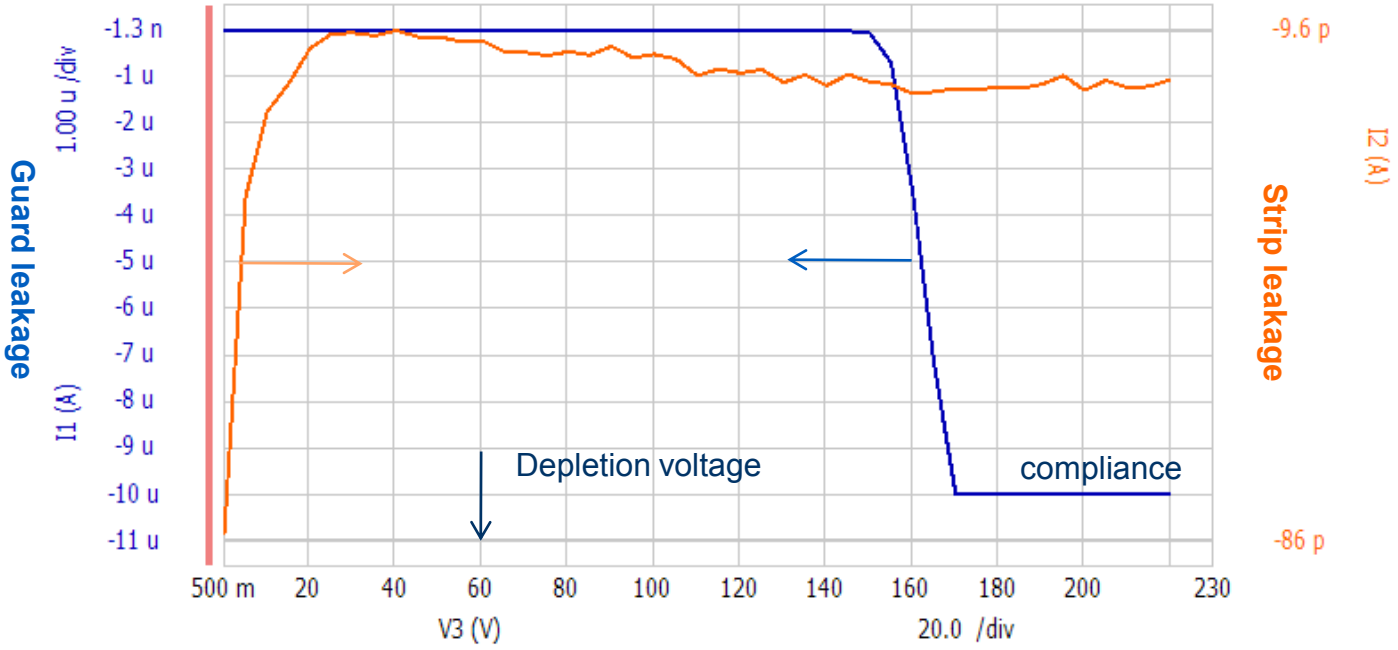
Average breakdown voltage (BV) first tested wafer
(56 chips on wafer with active edge)

Distance strip to active edge	45µm	70µm
Average BV	190V	215V
Depletion voltage (300µm)	60V	
Total yield (BV > 120 V)	85%	

Reference chip with guard ring on all sides

Average BV: 340V

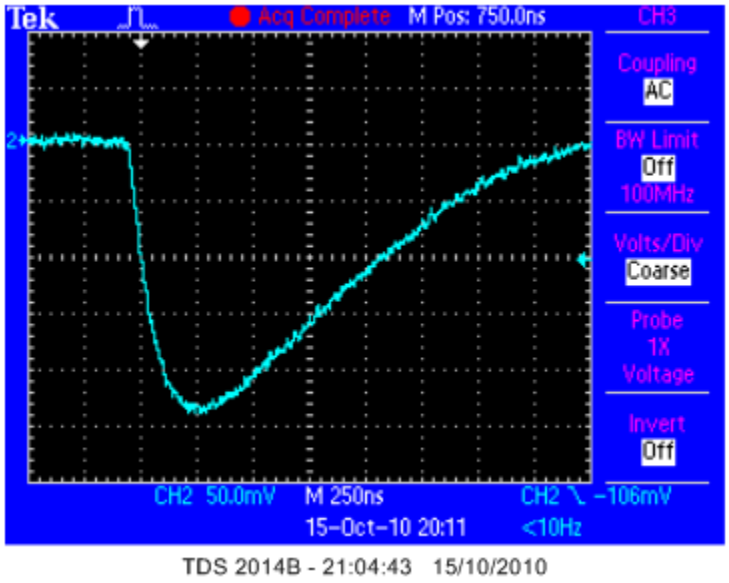
Edge-on x-ray sensor with active edge
Measurements at wafer stage (6-inch wafer)

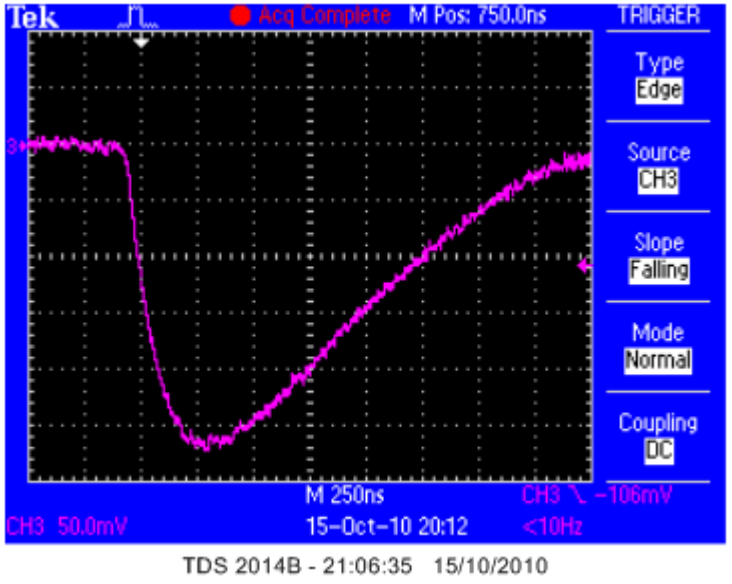


IV-characteristics chip with 45 µm distance to active edge

Edge - On Silicon Sensor
Mounted with much improved front-end readout ASIC

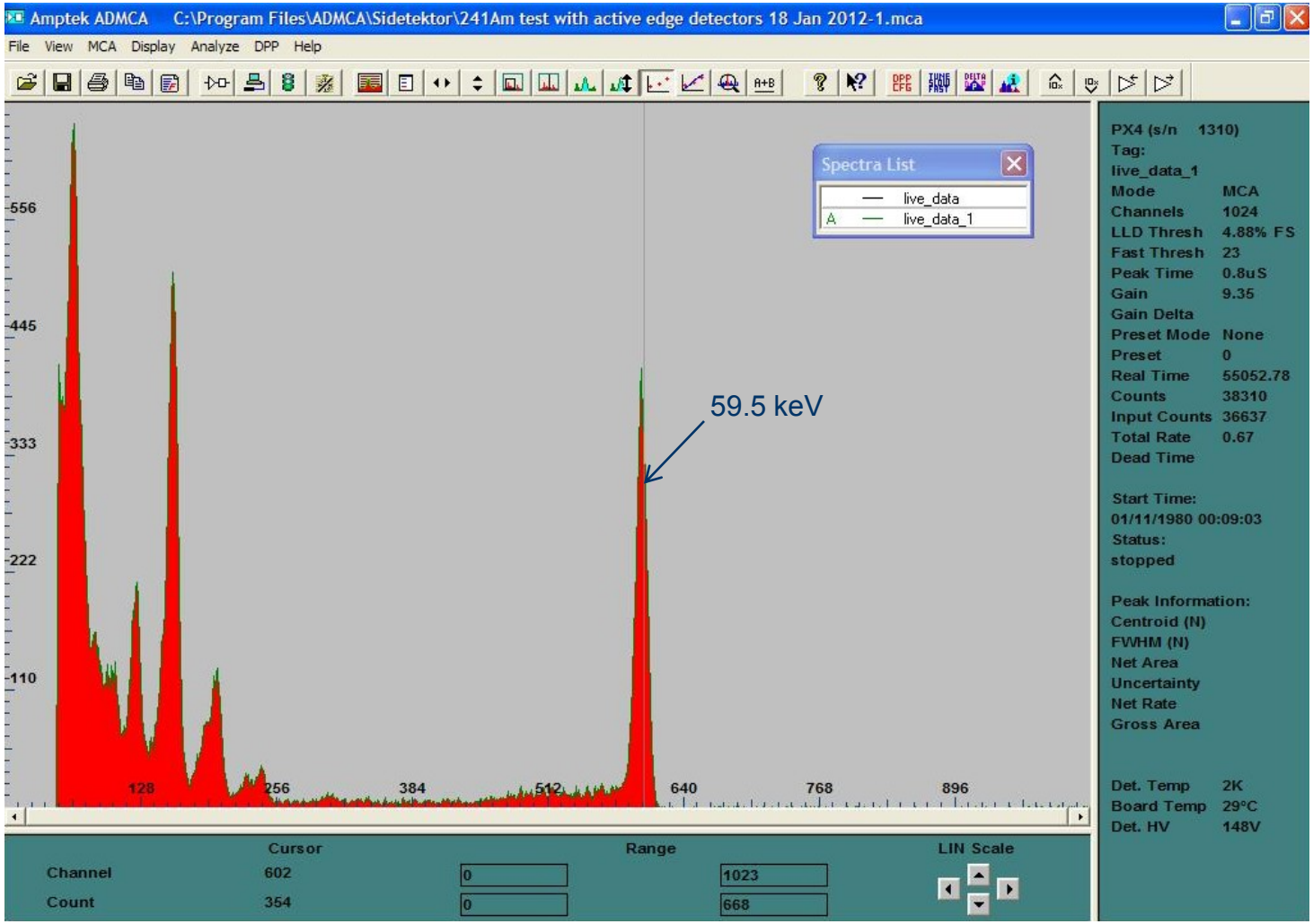
- Test with ^{241}Am: 59.5 keV photons



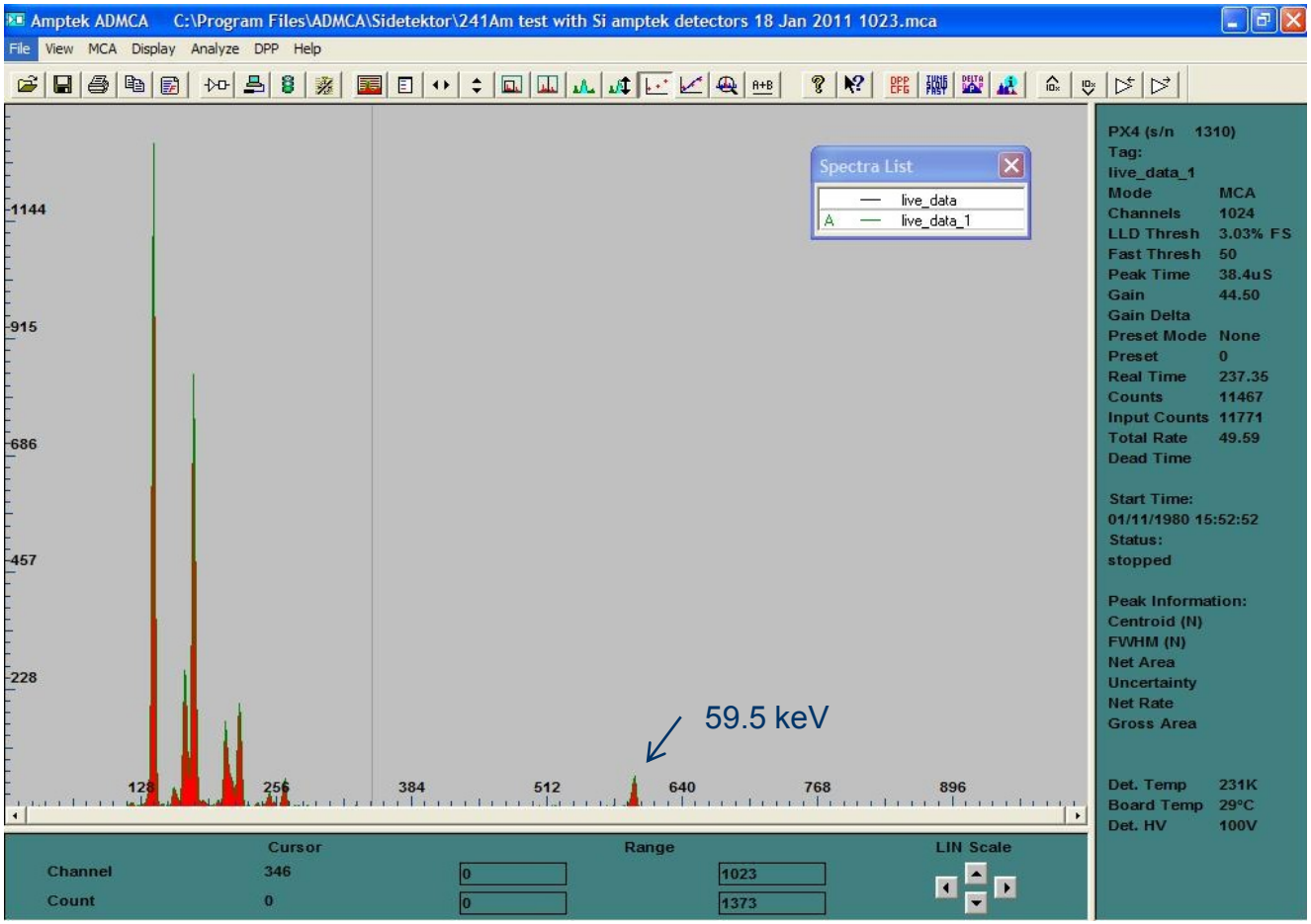


Observed pulses

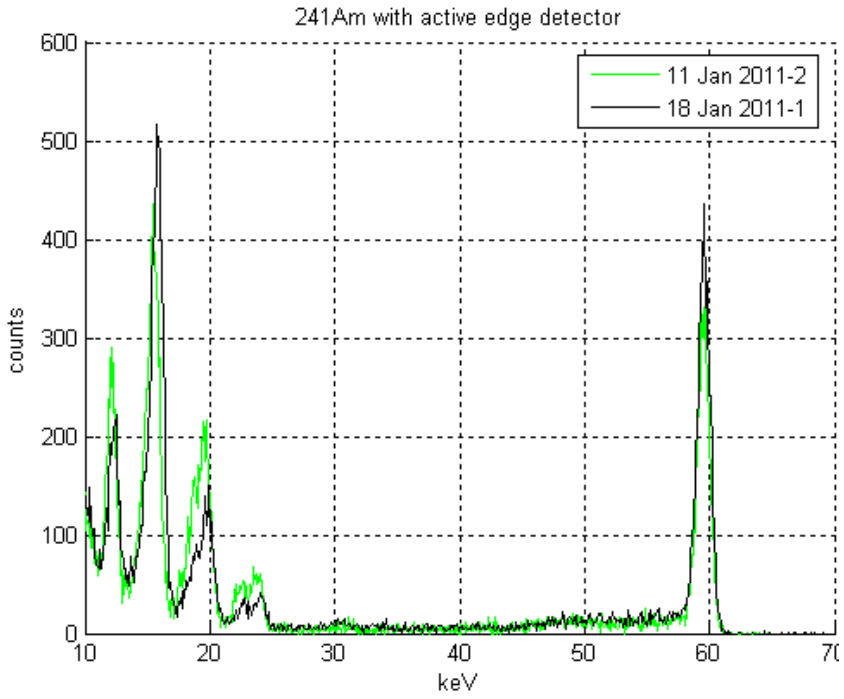
^{241}Am spectrum taken with edge-on, active-edge sensor non - cooled



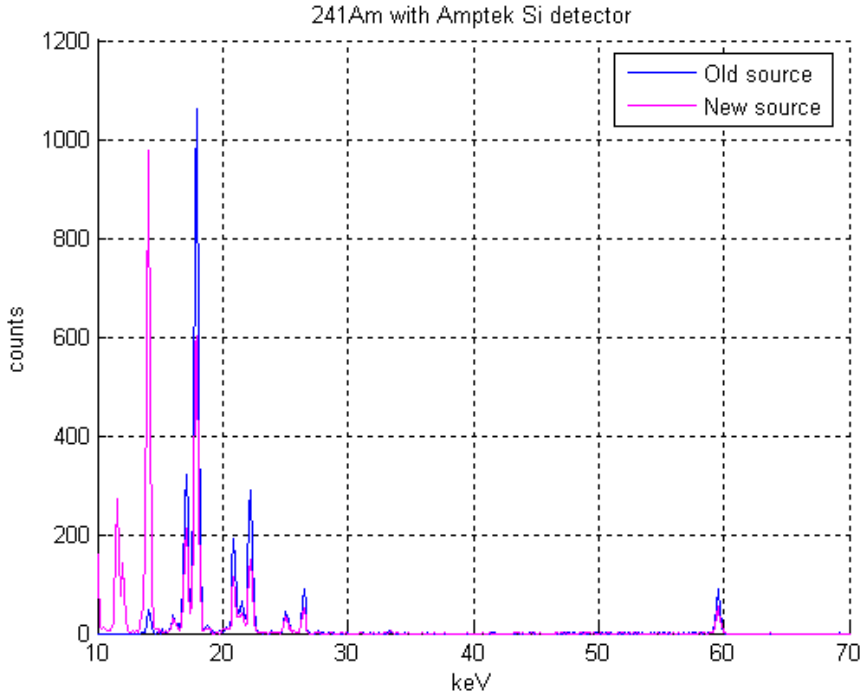
^{241}Am spectrum taken with TE-cooled front illuminated Amptek Si PIN detector (6mm^2)



Comparison with TE-cooled front illuminated Si PIN detector (6mm^2)

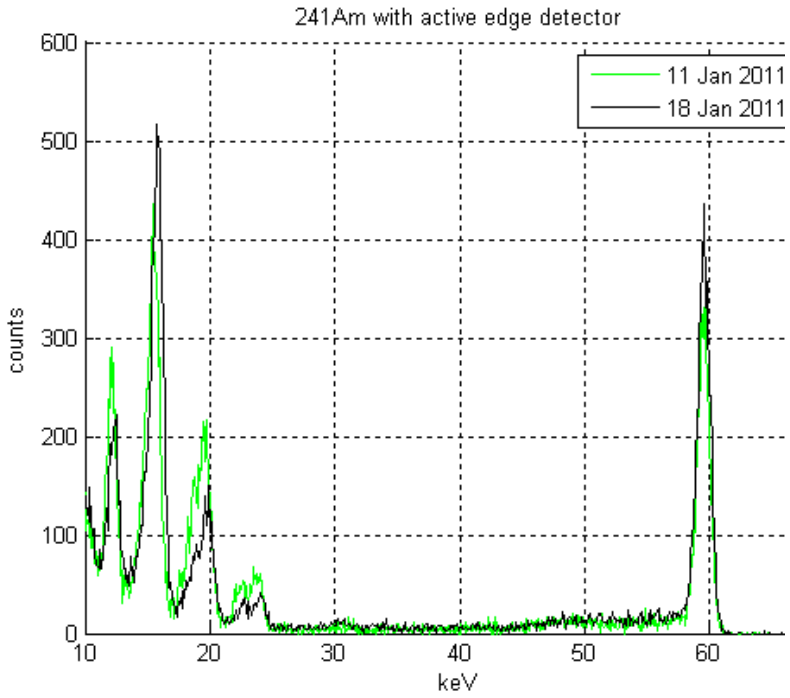


Active edge illuminated detector

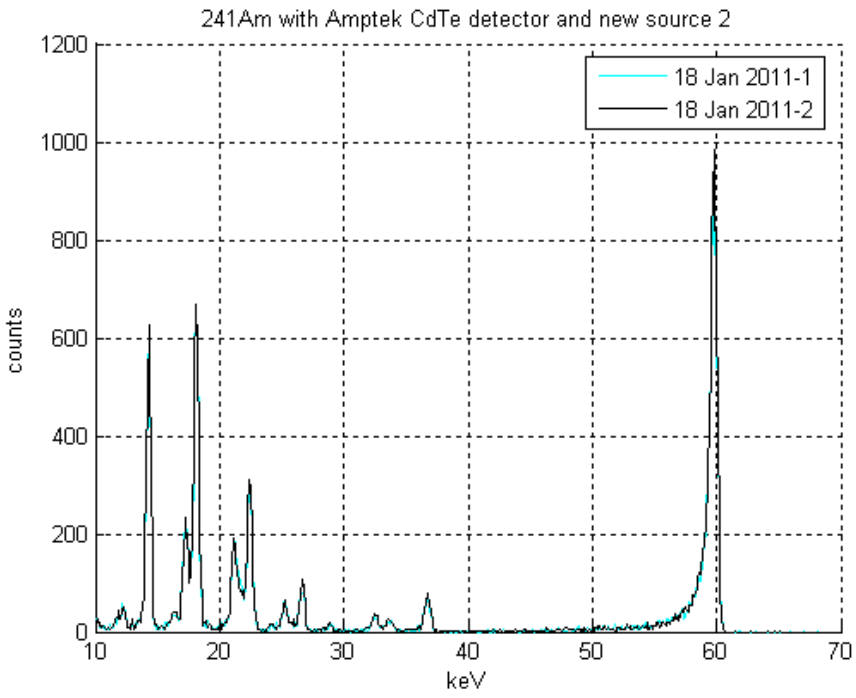


TE-cooled Si PIN-detector from Amptek

Comparison with TE-cooled front illuminated CdTe detector



Active edge illuminated detector



TE-cooled CdTe detector from Amptek

Conclusions and further work

- Edge-on sensor chips with active edge has been successfully fabricated.
  Good breakdown, IV characteristics and yield

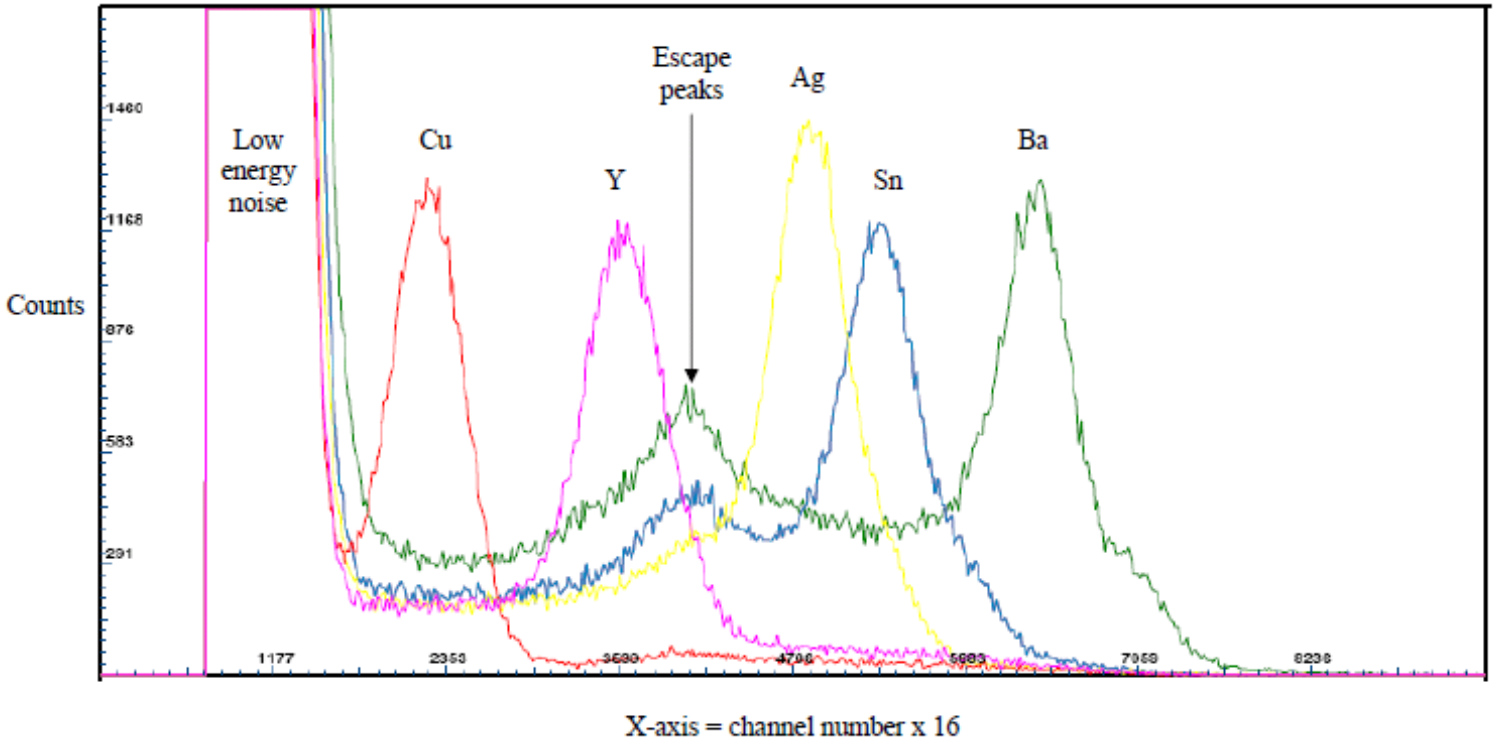
- Edge-on sensor chips should cover the photon energy range ≤ 5keV to ≥ 100keV
  So far proved to 70keV

- Almost comparable energy resolution with cooled CdTe detector at 59.5keV

- We are in the process of procuring ^{57}Co sources for testing at 125 and 136keV. Expect results hopefully end of March. Will also use low energy sources to test efficiency of active edge

Thank you for your attention!

Measurements with low energy sources incident angle > 90^0



- Angle of incident relative to edge > 90^0 to evade guard ring region.

Isotope spectra ranging from Cu at 8.2 KeV to Ba at 32.2 KeV