Characterisation of a CMOS MAPS Sensor with Alpha Particles

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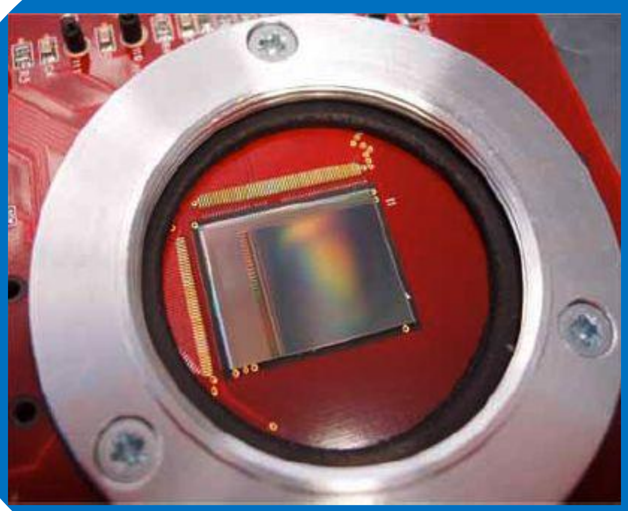
Introduction

Alpha particles as a test stimulus offer several advantages for probing materials of nano- and micrometer thicknesses where photons, electrons etc. are not suitable. Alpha particle detection plays an important role in many applications such as radiography, radon monitoring, plasma physics and environmental measurements. The traditional way of recording alpha particle images is solid-state nuclear track detectors (SSNTD), which have been in use for four decades. Their advantages include low cost, long exposure duration and permanent track record. However, their analogue nature significantly complicates data analysis. SSNTDs have poor sensitivity, limited linearity and spatial resolution. Whereas CMOS MAPSs can overcome these limiting factors. The devices are fabricated in a standard CMOS process and can be tailored for particular applications in terms of the desired performance and built-in functionality at low cost.

Vanilla CMOS MAPS



Vanilla is a general multi-purpose CMOS MAPS developed by the MI3 collaboration for technology evaluation in various applications. It can be read out in analogue and digital mode. It features hard, soft and flushed reset in addition to region of interest (ROI) readout. The sensor was also back-thinned (BT) to the epi-layer. The sensor parameters are summarised below:

Vanilla performance	
Gain (e^-/ADC)	8.5
Read noise (e^-)	15
Dark current(pA/cm^2)	50, 90 (BT)
Non-linearity (%)	< 6
Dynamic range (dB)	60
Full well capacity (e^-)	65000

Vanilla design parameters	
Pixels	520 x 520 @ 25 μm
Epi-layer	14, 20 μm, 20 μm BT
ADC	12 bit on/off chip
ROI	Up to 6x6 pixels
Reset type	Soft, hard, flushed

Detection efficiencies

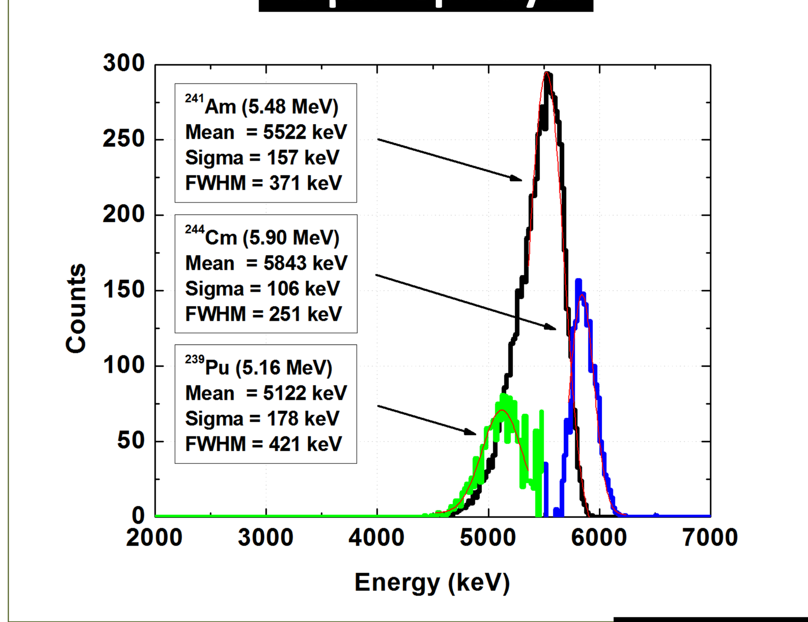
The alpha detection efficiency was estimated using the assumption that the surface emission rate of particles from the source in 2π is uniform. Taking into account the geometry of the setup as well as the round shape of the emitting surface and square shape of the detector, the expected number of alpha particles on the surface of the sensor was calculated.

Detection efficiencies			
Epi-layer thickness	Particles expected on the detector surface	Particles recorded	Detection efficiency
14 μm	171000 ± 3500	124398	72 ± 2 %
20 μm	171000 ± 3500	119927	70 ± 2 %
BT	171000 ± 3500	166824	97 ± 3 %

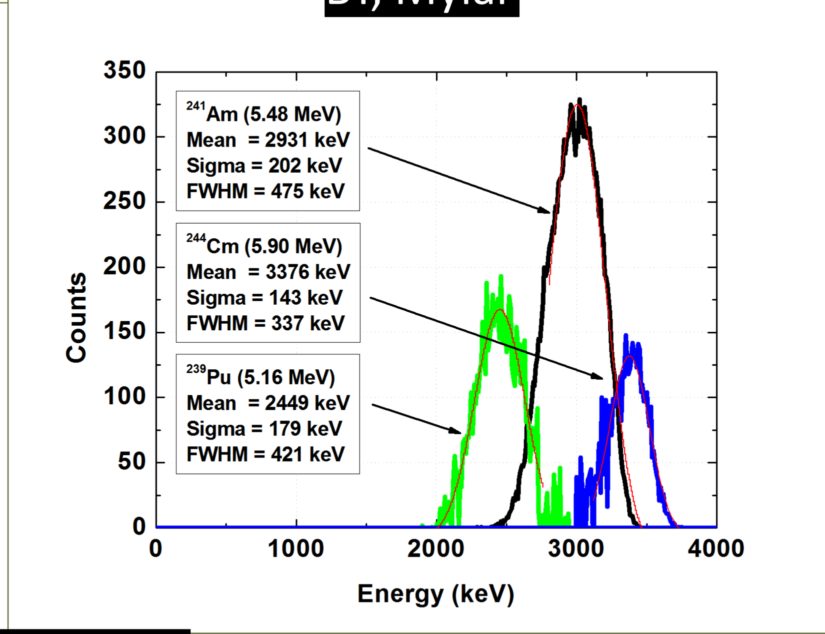
Energy calibration

Energy calibration was performed using Am and mixed PuAmCm sources. For the 20 μm epi sensor the normalised Am spectrum was subtracted from the mixed source spectrum resulting in the figure to the left. The BT sensor was covered with a 21.6 μm layer of Mylar which produced sufficient attenuation for the alpha particles to deposit all of their remaining energy in the epi-layer. The ADC-energy calibration for the 20 μm epi sensor was used to the estimate energy deposition for the BT sensor (figure to the right). This agrees within standard deviation with SRIM simulations.

20 μm epi layer



BT, Mylar



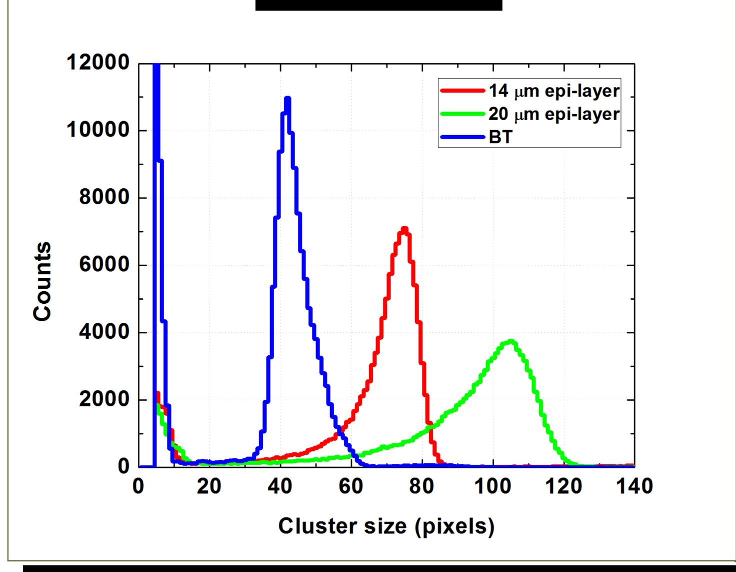
Conclusions

It has been demonstrated that CMOS MAPSs are suitable for alpha-particle detection. The BT sensor has nearly 100% detection efficiency. The energy resolution can be improved by tailoring alpha particle energy or epi-layer thickness. Cluster centroiding improves image quality by a factor of 2 and corrects for fixed pattern noise.

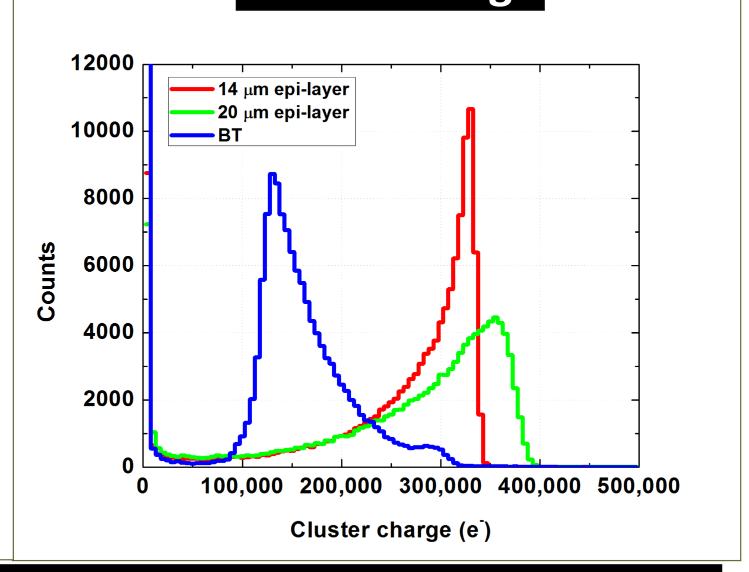
Alpha response cluster analysis

An alpha particle of energy 5.5 MeV travels ~25 μm in silicon. In MAPS a fraction of the energy is deposited outside the sensitive epitaxial layer. The energy loss also occurs in the passivation, oxide and metal layers of the sensor. This degrades the spectrum and reduces the detection efficiency. Both 14 μm and 20 μm sensors show a typical straggled Bragg distribution while the BT sensor charge distribution is Landau-like. The small bump is associated with a thin Si_3N_4 passivation layer on the surface.

Cluster size



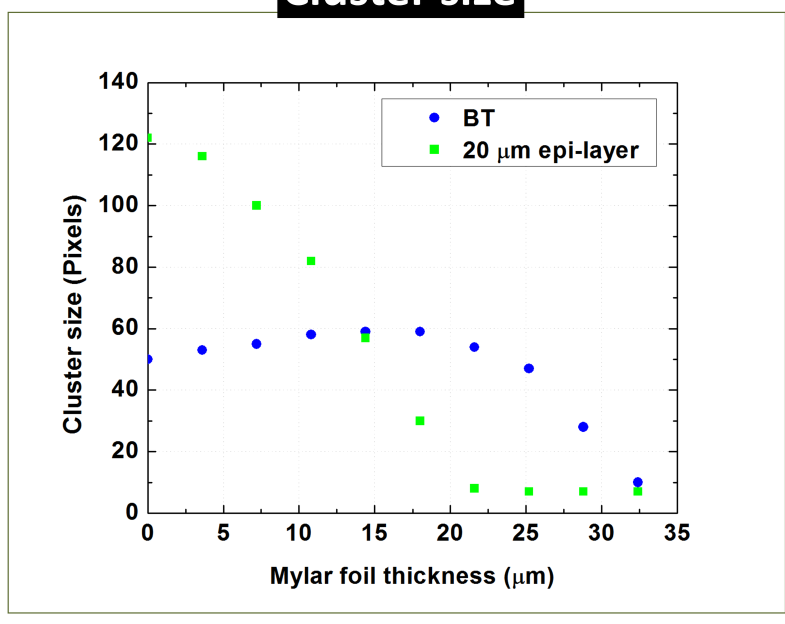
Cluster charge



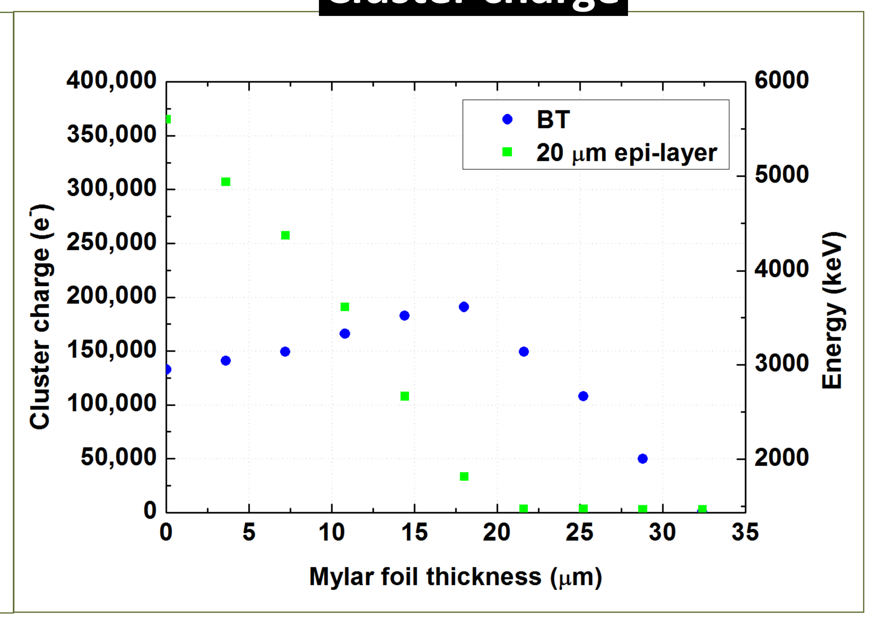
Mylar foil thickness calibration (5.48 MeV α)

The energy deposited by an alpha particle in the sensor is proportional to the thickness of a specimen. This in turn is related to both the cluster size and cluster charge detected. Performing a thickness calibration of a known material allows the determination of the thickness of the specimen. Nine 3.6 μm thick Mylar foils consecutively stuck to each other were used to establish a relationship between the amount of deposited energy (in terms of cluster size and charge) and the thickness of the foil.

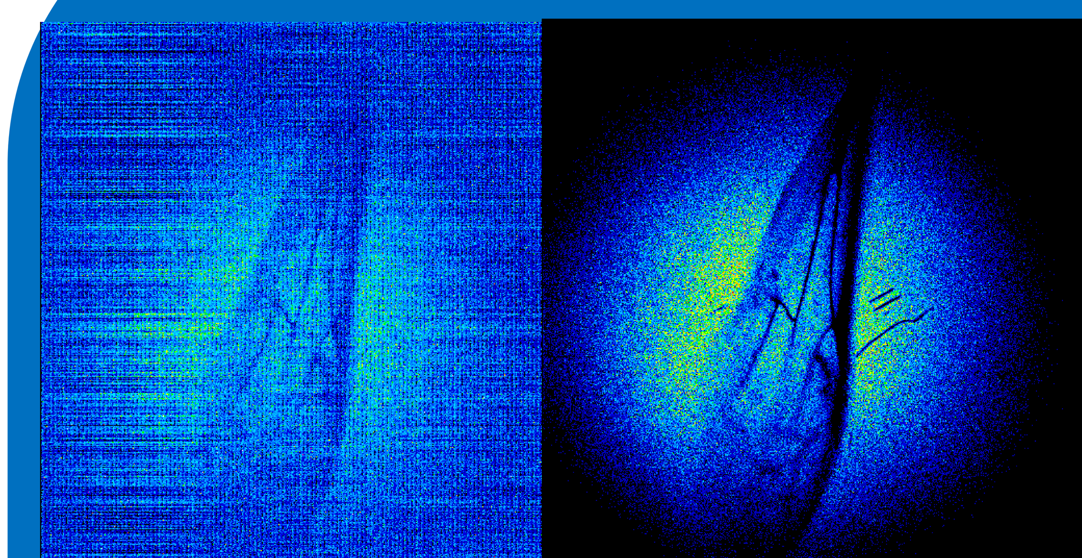
Cluster size



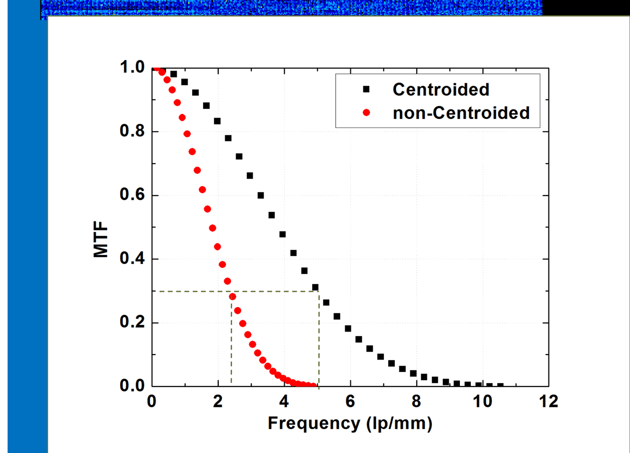
Cluster charge



Imaging and centroiding



These figures show a wasp wing imaged with clusters of up to 3 MeV alphas interacting in the BT sensor. Individual alpha clusters were fitted to Gaussians and the centres were found.



The total cluster energy was then placed in the pixel corresponding to that centre. This resulted in improved image quality as shown. Sub pixel resolution can be achieved by acquiring multiple alpha interactions per pixel.

The modulation transfer function above was measured with 50 μm Mylar foil. Cluster centroiding shows an improvement in the spatial resolution by a factor of 2 at 30% contrast level.