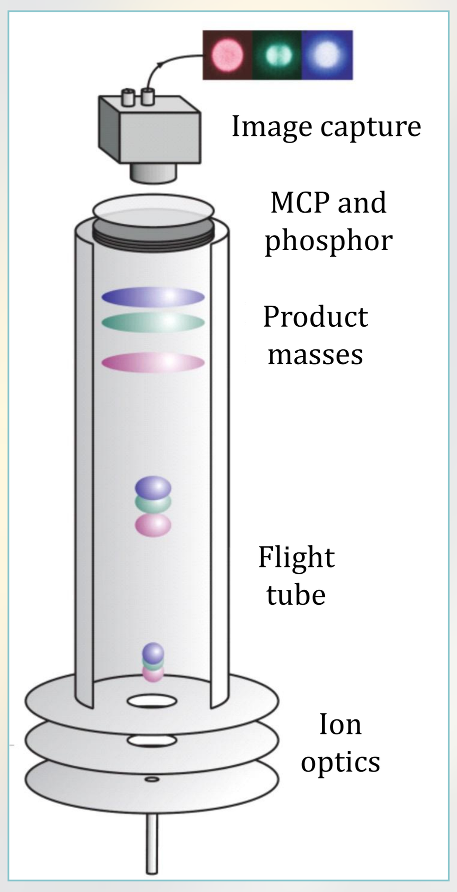
PImMS – Pixel Imaging Mass Spectrometry using Fast Pixel Detectors

Oxford Physics

PImMS Nº1

Pixel Imaging Mass Spectrometry



Velocity-map imaging time-of-flight mass spectrometer – *C. Vallance*

Pixel Imaging Mass Spectrometry (PImMS) is a combination of traditional Time of Flight (ToF) mass spectrometry and ion imaging.

- Molecular samples are dissociated into ions by laser, these are accelerated into and drift along a flight tube using a tunable electric field.
- The ions are incident on a microchannel plate (MCP) converting them to an electron signal, this is coupled to a phosphor screen converting the electrons to a photon signal, which is recorded by the PImMS camera.
- Compared to traditional ToF mass spectrometers, the PImMS pixel array provides timestamped arrival times with (x,y) co-ordinate information.
- Light ions drift faster than heavy ions and so arrive earlier. This mass dependence on drift time gives a 1-D mass spectrum, integrated across the whole sensor, of dissociated fragments dependent on their time-of-arrival.
- Velocity mapping preserves initial velocities of ions, for studies of reaction dynamics among others. Spatial mapping preserves the initial positions of ions, useful for surface imaging, among others.

M. Brouard et al *Rev. Sci Instrum.* **79** (2008) 123115.

Sensor Specifications

Specification	PImMS 1	PImMS 2
Array size	72 x 72 pixels	324 x 324 pixels
Active area	5mm x 5mm	22.7mm x 22.7mm
Sensor size	7mm x 7mm	25.4mm x 26.1mm
Pixel size	70µm x 70µm	
Pixel threshold trim	4 trim bits + 1 masking bit per pixel	
Timestamp storage	Four 12-bit registers per pixel	
Test pixel	1 test pixel to access inner analogue nodes	
Time resolution	Target: 25ns Verified: 12.5ns	Target: 25ns Verification in progress
Substrate	5µm epi	
Acquisition rate	555Hz	50Hz

- Extendable 51µs experimental cycle
- < 500 ns dead time within a pixel after a hit
- USB 2.0 digital and analogue readout
- External and internal TTL trigger enabled

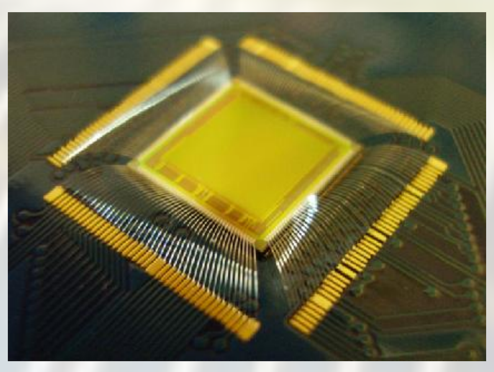
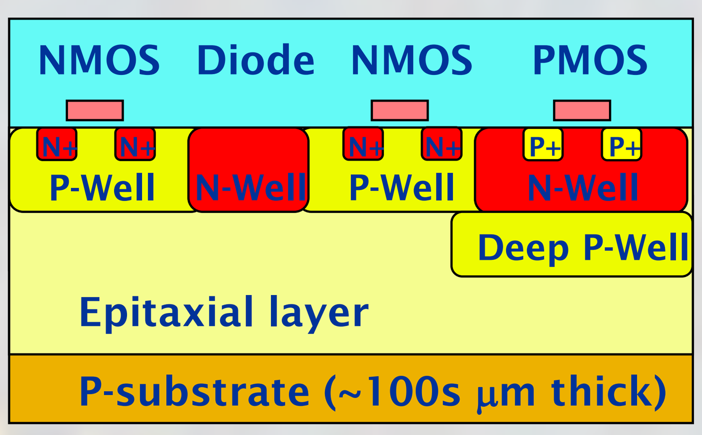


Photo of the PImMS 1 sensor

Sensor Technology

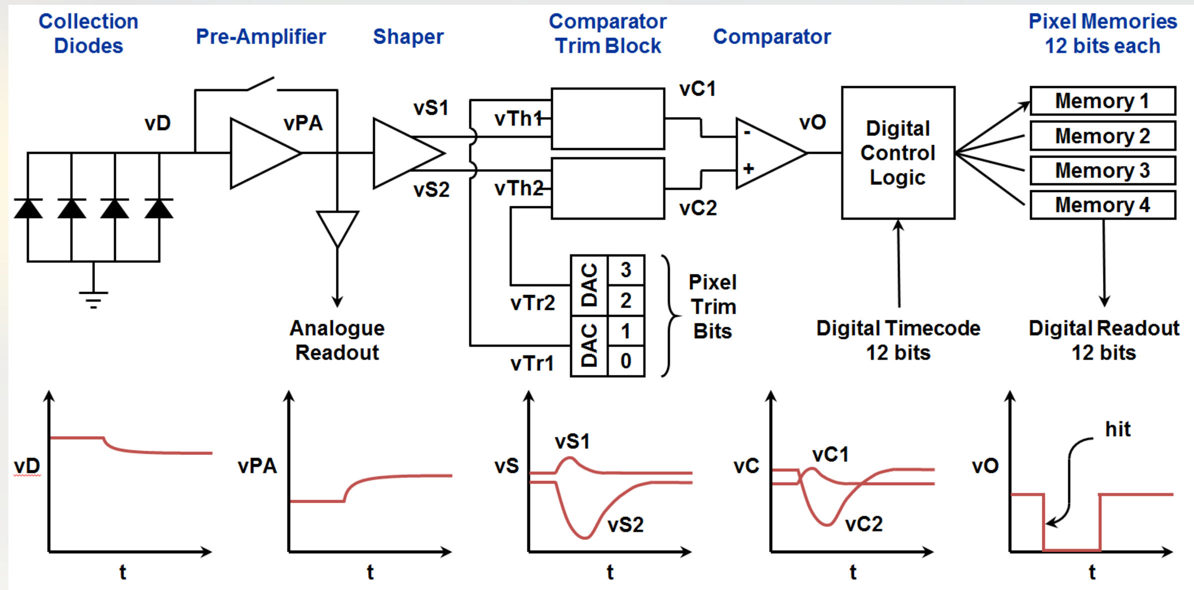
- PImMS is a Monolithic Active Pixel Sensor (MAPS) implemented using 0.18 micron CMOS technology.
- In-pixel circuitry implemented using the INMAPS process developed by STFC-RAL CMOS Sensors Group.



Silicon cross-section, INMAPS - *R. Turchetta*

- Key advantage: can implement full CMOS circuitry with 100% fill factor.
- This allows for complex in-pixel circuitry and processing. There are a total of 615 transistors in the PImMS1 pixel resulting in over 3 million in the whole chip.
- This is enabled by the deep p-well implant that shields PMOS transistors against the N-wells forming parasitic charge collecting diodes.

Pixel Design

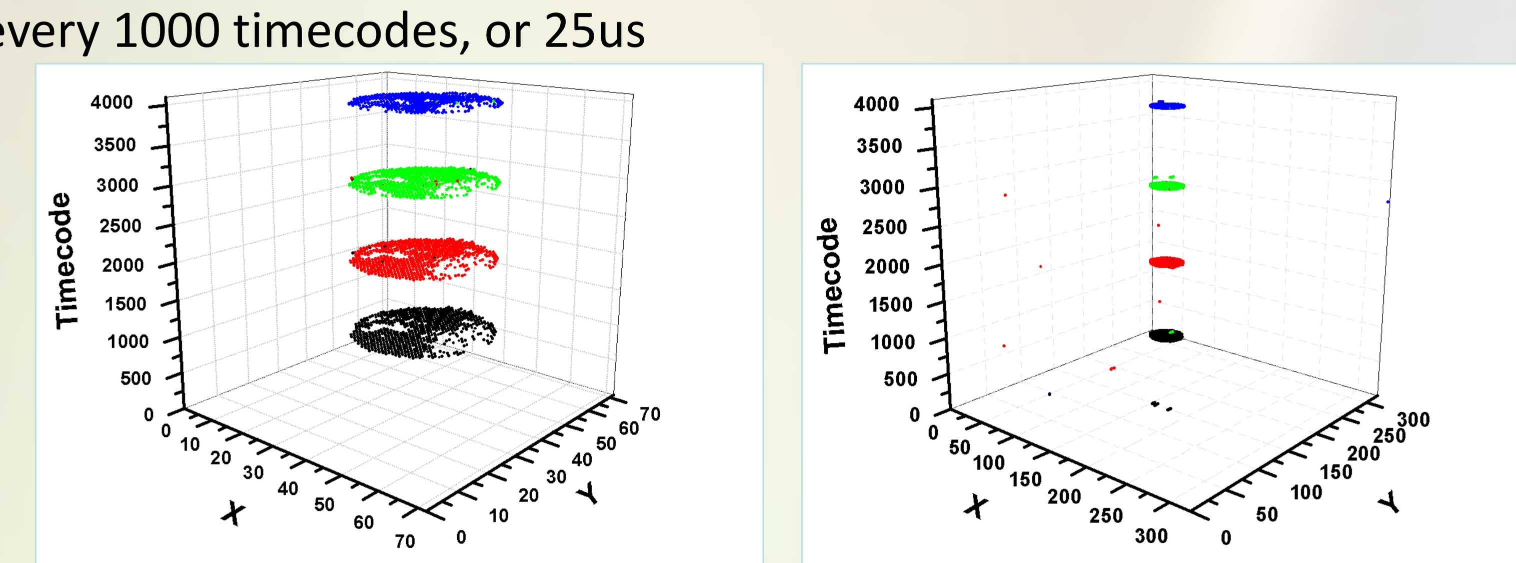


PImMS pixel and signal schematics – *JJ John*

- Signal charge is collected by 4 diodes in each pixel and amplified.
- A pre-shaper converts steps in charge to pulses.
- A comparator discerns events above a tunable threshold and registers a 'hit' by storing the timecode of the comparator input crossing points.
- Up to 4 time-stamps can be recorded in each pixel per acquisition cycle.
- The pre-amplifier analogue signal is output for intensity information.
- Per pixel capacitor trimming to the comparator inputs corrects for CMOS process variations that cause spread in the threshold levels of a pixel.

First Results

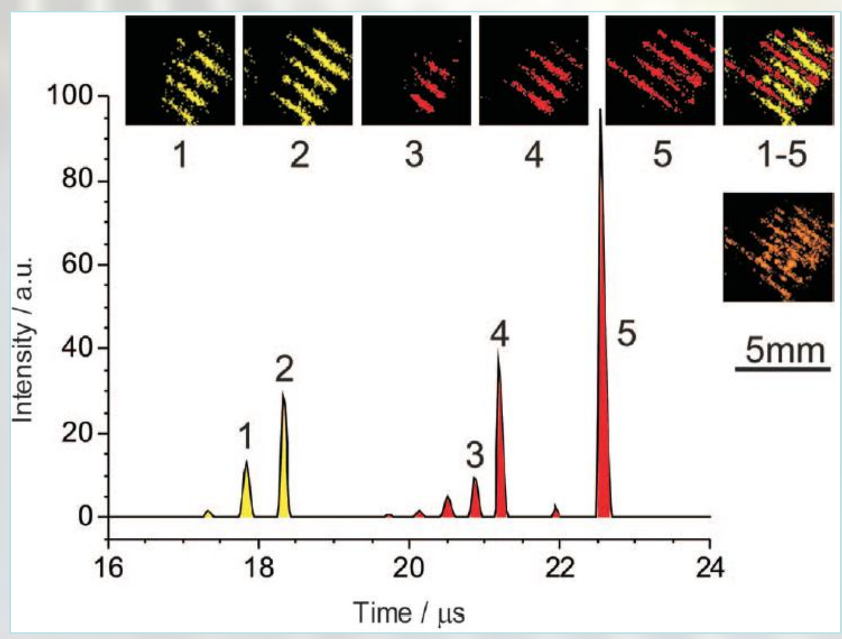
- Initial commissioning tests were performed using a 405nm laser emitting 5ns pulses at a repetition rate of 40 kHz. With the PImMS timecode clock set to increment every 25ns, laser pulses were detected by the sensor every 1000 timecodes, or 25us



4D Hit map of 4 laser pulses recorded into 4 separate memory registers. Left: PImMS 1, Right: PImMS 2 – *L Hill*

- PImMS 1 optical characterisation results are shown in the adjacent table – *A Clark, I Sedgwick*
- The sensitivity calibration using the trimming technique described above has yielded a 9.2mV improvement in threshold spread across the sensor. This will be improved further on PImMS 2 with additional handles on the trim – *J Lee*

Characteristic	Value
Full Well Capacity	24,000 e^-
Fill Factor	16.9 %
Gain	0.2015 DN/e^-
Quantum Efficiency	8-9 %
Threshold Dispersion	12.8 mV raw 3.6 mV trimmed



Mass spectrum and ion images obtained using PImMS; signals 1 and 2 are contributions from Auramine O dye (yellow) and signals 3–5 from Rhodamine 590 dye (red). An image of the total range is shown to the right of the spectrum, and compared with an overlay of the images 1–5. Note that all data shown in this figure were taken in one measurement.

Auramine O (yellow, 1,2) and Rhodamine 590 (red, 3-5) PImMS 1 Mass Spectrum and Ion Images – *M. Brouard et al. Rev. Sci Instrum. 83 (2012) 114101*

Status

- First PImMS1 sensors were received in November 2010
- Initial Characterisation and commissioning performed in Early 2011
- First experiments in a Mass Spectrometer in April 2011
- Sensor calibration was completed July 2011
- PImMS2 sensors received September 2012, characterisation is in progress.

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