A multichannel detector array with 768 pixels developed for electron spectroscopy

D.P. Langstaff*, T. Chase

Institute of Mathematical and Physical Sciences, University of Wales, Aberystwyth, SY23 3BZ UK

Abstract

A one dimensional detector array using MCP technology in conjunction with a custom ASIC is presented. The ASIC features 768 pixels, each 3mm in length on a pitch of 25µm, giving a length in the dispersive direction of 19.2 mm. The chip and MCP are mounted on a ceramic and stainless steel assembly that replaces the conventional channeltron in an electron energy analyser. Results are presented showing key aspects of the detector, including the yield of the chip at wafer stage, the vacuum compatibility of the system, the speed of readout, uniformity of response and maximum count rate.

Keywords: Multianode detector; microchannel plate, count rate, dark noise
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1. Introduction

Multichannel detector arrays offer the potential for massive improvements in electron spectroscopy. Measurements can be made in a fraction of the time taken by conventional channeltron detectors, enabling real time studies of processes such as deposition, desorbtion and other surface processes, allowing fresh insights into the dynamics of these processes and opening up the development of new techniques.

The device presented here is a multi-anode readout device for a microchannel plate (MCP). Multi-anode detectors are conceptually the simplest imaging devices employed with MCPs. An array of anodes is placed within proximity focus of the rear face of an MCP stack in vacuum. Each anode is connected to an electronics channel comprising a charge sensitive amplifier, discriminator and counter.

Conventional multi-anode arrays utilise a multi-way feedthrough to connect the anodes to processing electronics located outside the vacuum system. The multi-way feedthrough and cabling results in large stray capacitances and cross talk between anodes [1]. In addition to the performance limits imposed by these capacitances, the multi-way feedthrough needed to connect the detector to the external electronics is a problematic and expensive component.

By integrating the charge amplifier and discriminator onto an ASIC together with the collection anodes, the problem of crosstalk can be greatly reduced. By further integrating the data acquisition electronics onto the same ASIC it is possible to greatly reduce the feedthrough requirements to a relatively small number of low-impedance logic level signals.

* Corresponding author. Tel.: +44-01970-621913; fax: +44-01970-622826; e-mail: Dave.Langstaff@aber.ac.uk.

2. The UWA Multichannel Detector Array

The UWA multichannel detector array comprises a custom silicon integrated circuit mounted on a ceramic substrate in proximity to the rear face of an MCP. The detector chip contains 768 channels, or pixels, each measuring 3mm × 18µm on a pitch of 25µm. Each channel has a metal anode to collect the electrons as they emerge from the MCP; a charge sensitive amplifier to produce a digital signal in response to the electron pulse and an 16-bit counter associated with it to accumulate the counts as they arrive and circuitry to read out the data sequentially from all channels in the array. The collection anodes are furnished with a secondary electrode allowing charge to be injected from an external source which allows the circuit to be tested at the die stage to select good devices for assembly into the detector modules. The test electrode also enables testing at the module stage and once the detector is in the vacuum system.

The silicon detector chip was fabricated on the AMI Semiconductor 0.5µm CMOS process accessed via the Europractice IC service. The previous generation of multi-anode devices designed at UWA [2] relied on a non-standard thick polyimide layer to achieve low capacitance on the anodes and increase sensitivity. The device presented here uses a completely standard CMOS process, resulting in high yield. A smaller device with 384 pixels was produced as a part of the project [3].

The calculated input capacitance (including stray capacitances) associated with each anode is approx 870fF with a cross coupling capacitance of approximately 3.8fF between adjacent anodes.

An important feature of any MCP readout device is its ability to withstand transients appearing on the input. The MCP is an avalanche device and it is possible for output pulses much larger than normal to be produced, particularly during initial run-up of the MCP. The input circuits on the UWA detector have been designed with protection devices such that excess charge on the collection anode is conducted away to ground before it can damage the sensitive circuitry of the charge sensitive amplifier. In addition a transient suppressor device is mounted on the detector module, between the rear face of the MCP and the ground of the detector circuit.

The circuit has been designed such that an arbitrary number of detector chips may be abutted together on a substrate behind the MCP, allowing for long focal plane detectors to be built, limited only by the size of MCPs available (currently approximately 100mm). The module presented here only uses a single chip, but the circuitry has been tested and will be able to support multiple chip modules.

The output from the 16-bit counters on the detectors is presented via an 8-bit port and is read into the control electronics sequentially from each counter in turn in low-byte, high-byte order. The control electronics system supplies a read clock signal and a start-of-cycle signal to initiate the readout process. Once the last counter on a chip has been read out, an end-of-cycle signal is asserted, the end-of-cycle signal from one chip on the module becomes the start-of-cycle on the next chip, the end-of-cycle from the last chip on the module is returned to the controller. In this way the controller can check that every reading cycle has occurred correctly.

The completed detector assembly, with MCPs in place, was fitted to a mounting fixture and introduced into the focal plane of a VG Thermo CLAM 4 analyser, replacing the existing channeltron detector.

The electron spectrometer system attained a base pressure of 10^{-10} mBarr after a bake at 100°C, indicating the vacuum compatibility and bakeability of the detector module.

2.1. Electrical Test and Yield

The devices were supplied from the fabrication house in the form of 24 loose, naked die. These were tested on a probe station with a test routine which first checked the readout circuit to ensure that the end-of-cycle signal was asserted after the appropriate number of clock cycles. The test routine then applied pulses via the secondary electrodes and a read cycle was carried out to check that all of the counters were being activated by the charge amplifiers. Following this test, it was determined that 79% (19) of the devices were fully functional.

A second level of testing was applied, whereby a number of pulses applied to the secondary electrodes and a read cycle carried out. The amplitude of the test pulses was then varied before repeating the read cycle in order to determine the trigger threshold of each pre-amplifier. Once the trigger threshold for each channel had been determined, the mean and standard deviation of trigger levels were calculated and the standard deviation expressed as a percentage of the mean. Over all channels on all 19 functional devices, it was determined that the average standard deviation was ~10% of the mean trigger level.

2.2. MCP Operating Conditions

The MCPs fitted to the detector were a pair of custom sized Hamamatsu plates with 12µm pores, arranged in a chevron configuration. They were connected to a variable 3kV power supply via a 10Mohm resistor. A resistive divider gave a potential of approx 30V between the between the rear face of the MCP stack and the detector chip ground.

A voltage of 1800V across the pair of MCPs was used in the experiments detailed here.

2.3. Determination of Noise Floor

The noise floor of the detector was determined by operating the detector array for an extended period with the X-ray source in the instrument turned OFF. Over a period of approximately 121hr, a total of approximately 1.23 x 10^5 counts were received on the detector, giving a rate of 3.7 x 10^{-4} counts s^{-1} $pixel^{-1}$. This noise is solely due to the MCP in the system, as may be determined by switching the MCP accelerating voltage to zero. By dividing the dark count rate by the area of a pixel (25µm x 3mm) it is possible to arrive at a figure of ~0.5 cps/cm^2 for the MCP, compared with the manufacturer's specification of <3 cps/cm^2 [4]. Figure 1 shows the dark noise per pixel across the array during this experiment.

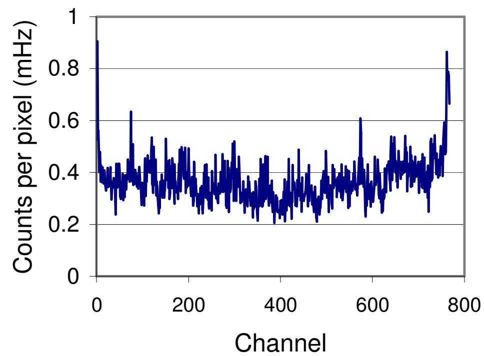

Fig. 1. Dark noise response of the UWA detector

2.4. Determination of Maximum Count Rate

The maximum count rate from the array has been determined by means of an XPS experiment at SRS beamline 4.1. A sample of silicon was illuminated with 130eV photons and the energy distribution of the photoelectrons measured by sweeping the energy analyzer potentials. Counts from the central pixel on the array (equivalent to a 25µm slit) were plotted to give the emission spectrum shown in figure 2.

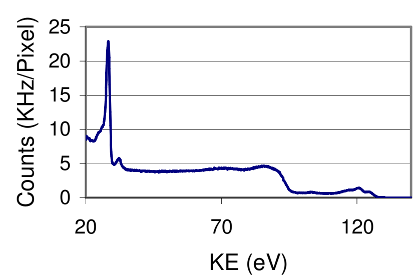

Fig. 2. Spectrum of Si taken at SRS4.1 showing maximum count rate of detector

The maximum count rate shown on the graph is from the Si2p core level and is in excess of 2x10^4 counts s^{-1} $pixel^{-1}$. In combination with the noise floor measurements, this gives an expected dynamic range of the device in the order of 10^8. It should be noted that the limitations in dynamic range at each end of the scale are due to MCP limitations.

2.5. Uniformity of Response

The uniformity of response was determined by choosing a relatively featureless region of a spectrum such as displayed in Fig 2. The selected region is swept across the array in small increments of retard potential and the spectra from each point added together on a channel by channel basis.. In this way it may be assumed that every pixel on the array has been exposed to equal numbers of electrons. The relative sensitivity across the array is shown in Fig 3.

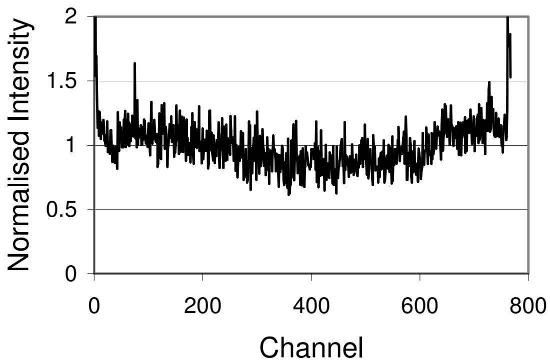

Fig 3. Uniform response of detector/analyser combination

2.6. Maximum Readout Speed

The readout speed of the detector is currently limited by the cabling between the vacuum feedthrough and the control electronics. At present the readout speed is set to 2µs/pixel, giving an overall readout period of 1.5ms across the entire 768 pixel array. It is hoped to improve upon this by mounting the control electronics directly on the vacuum flange rather than at the end of 1.8m of multiway cable as at present.

3. Conclusions

A fully integrated 768 channel multianode detector has been design, constructed and tested in a CLAM4 electron energy analyzer. The detector has demonstrated operation at high count rates and has low inherent noise, giving a large potential dynamic range.

4. Acknowledgements

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5. References

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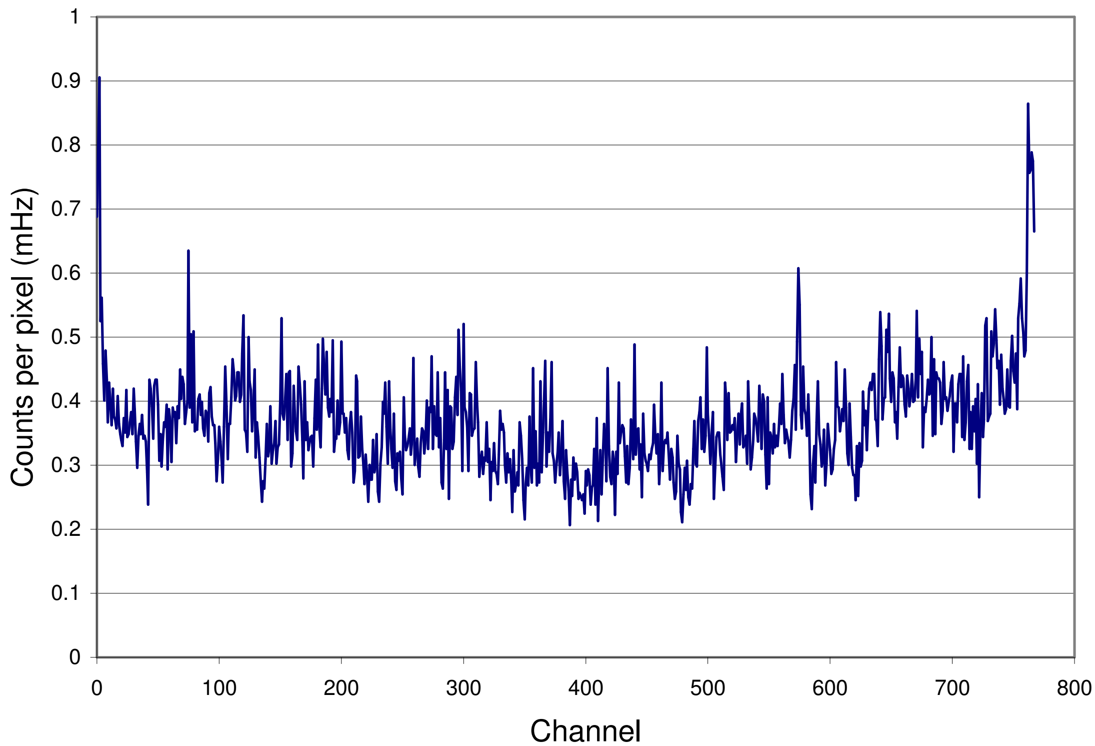

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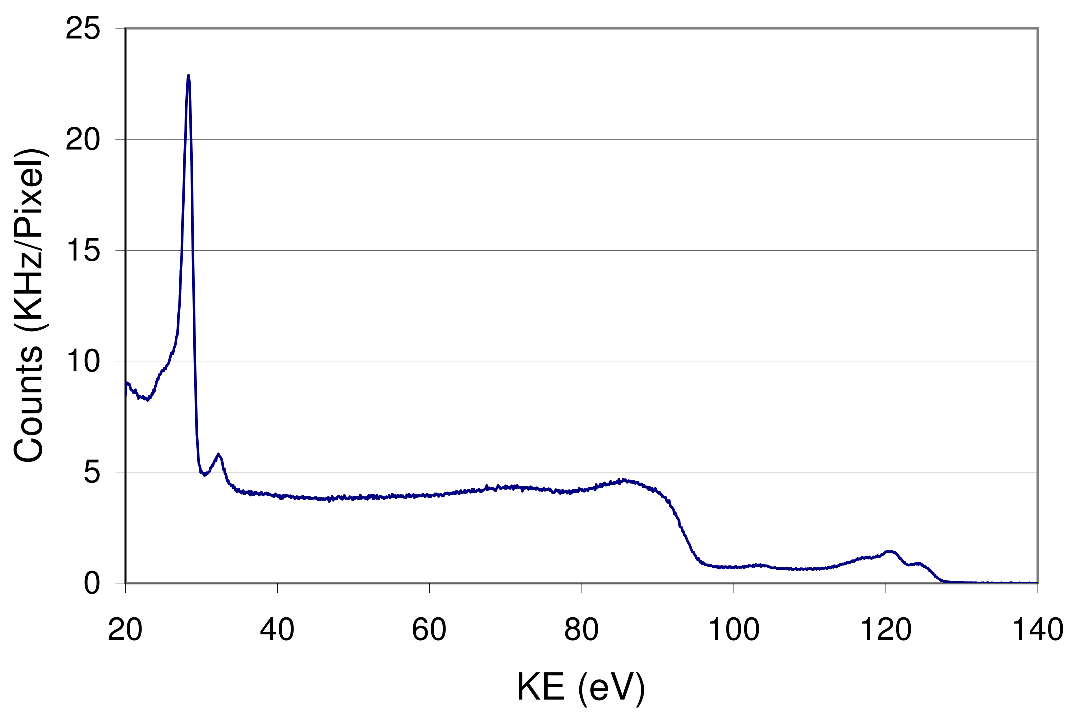
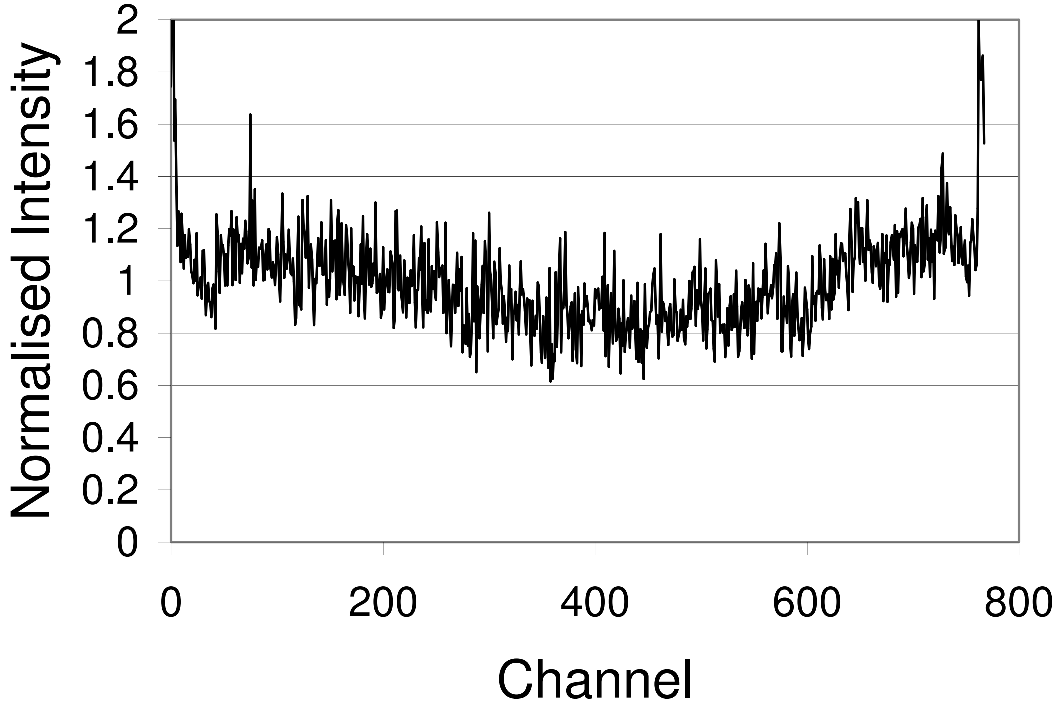


Fig. 2. Spectrum of Si taken at SRS4.1 showing maximum count rate of detector



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