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A fully integrated multi-channel detector for electron spectroscopy.

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Abstract

In electron spectroscopy, multi-channel detection combined with intense radiation sources provides the optimum experimental configuration. Building on the 5 mm, 192-channel ion detector developed at Aberystwyth, longer arrays have been fabricated for the detection of electrons in a commercial hemispherical analyser. The performance and reliability of a 10 mm, 384-detector array is discussed and the first array-detected photoelectron spectroscopy data for single-crystal diamond are presented. In scanning mode, the detector shows a large improvement compared to single channeltron detection and this improvement allows data to be collected in snapshot mode (1 s per spectrum) to enable real-time measurements.

1. **Introduction**

Often the main limitation in spectroscopic techniques is the efficient detection of radiation (both electromagnetic and particulate) and improvements in detection technology lead inevitably to significant advances in scientific knowledge. One example is the transformation of optical spectroscopy by the appearance of CCD detectors. The driving force for these wide-area devices is the enormous increase in collection efficiency. In electron spectroscopy, detection is still largely dominated by discrete channeltron systems, although there is a considerable effort worldwide to develop the electron equivalent of CCD detectors. The potential applications for such detectors are many – in photoelectron spectroscopy (PES) for example, such detection systems enable processes such as catalysis and thin film growth to be monitored in real time. Detector advances also offer considerable improvement in the speed of data collection for related techniques such as angle-resolved PES and X-ray standing wave spectroscopy. Few of the detector systems under development have however been able to demonstrate the required electrical stability needed in continuous operation in commercial systems. In 2001, a project was initiated to develop a new application in electron detection for the 5 mm, 192-channel ion detector originally developed at Aberystwyth over many years [1,2]. This has resulted in the design and fabrication of a 10 mm, 384-detector array electron detector and a more advanced 20 mm, 768-detector array.

Other designs of multi-channel detector have been fabricated using discrete devices for amplification/discrimination and counting pulses [3,4], but this design is unique in that all the front end electronics are integrated on a single chip, together with the collection anodes. This level of integration results in greatly simplified assembly onto the ceramic module, as only 25 bond wires need to be connected to the circuit for power, data and control signals to and from the external controller via the vacuum feedthrough.

2. **Device specifications and performance**

The UWA charge sensitive detector array comprises a custom silicon integrated circuit mounted on a ceramic substrate in proximity to the rear face of a multi-channel plate (MCP). The detector operation is illustrated schematically in Fig. 1. An electron incident on the MCP is amplified and the electron pulse is detected by the collector anodes of the array.

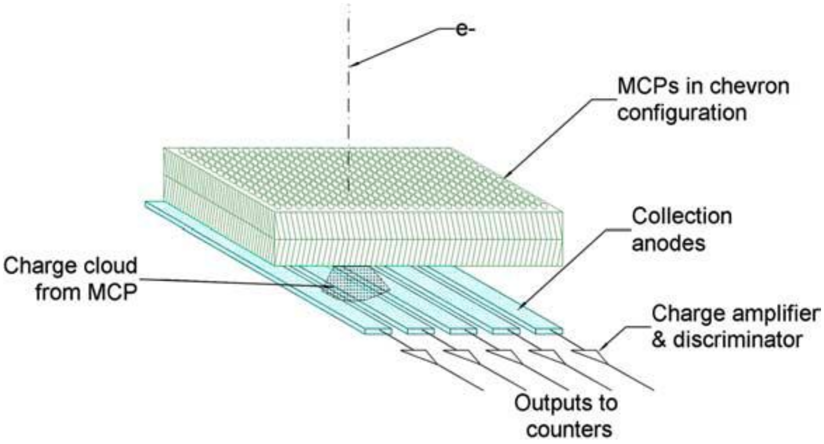

Fig.1.Theprincipleofoperationofthearraydetectorisbasedonthedirectdetectionofelectronsbyanarrayofcollection anodesplacedbeneathamulti-channelplateelectronmultiplier. Eachanodeisindirectcontactwithitspre-amplifieranddiscriminatorcircuitry.

The detector chip contains a number of channels, or pixels, on a pitch of 25 µm. The results presented here are taken from a device containing 384 channels with a total active area of 9.6 mm x 2 mm. A more advanced device containing 768 channels with a total active area of 19.2 mm x 3 mm is currently being characterised. 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, a 16-bit counter to accumulate the counts as they arrive and circuitry to read out the data sequentially from all channels in the array.

The detector chip is operated at around 2 kV relative to the analyser, and in order to provide this level of isolation, communication with the array is achieved via a floating controller. This controller, developed in collaboration with the CLRC Daresbury laboratory, provides timing, control and readout of data from the detector head as well as control of the MCP power supply. For application in electron spectroscopy, the detector device is bonded to a ceramic substrate that is mounted as a modular unit in a hemispherical electron analyser (VG CLAM4) such that the array detector lies at the focal plane. All materials used are ultrahigh vacuum (UHV) compatible such that, following incorporation of the detector module, the spectroscopy chamber achieved its routine base pressure of below 10^{-10} mbar.

Preliminary testing of the array detector included measurement of the point spread function for the detector (using a technique of speckle imaging [5,6]), the determination of the noise floor, measurement of the array uniformity and determination of readout speed and maximum count rate. To determine the point spread function, the array was uniformly illuminated with electrons and a short integration time chosen such that no counter received more than one event per integration period. The mean size of the point spread was found to be 5.5 channels, corresponding to a spatial resolution of 137 µm. This compares favourably with the figure of 150 µm obtained for the LBNL detector [7] and 470 µm for the Trieste device [4].

The noise floor of the detector was determined by operating the array for an extended period in the absence of any ionising radiation or charged particles. The noise value of 1.02×10^{-4} events s^{-1} pixel^{-1} is solely due to the MCP in the system, and is in good agreement with the figure quoted by the manufacturers [8]. This noise floor is well below the noise inherent in the XPS process.

The uniformity of response was determined by recording a large number of spectra at a series of electron energies such that every pixel on the array was exposed to the whole spectrum and thus all received equal numbers of electrons. The uniformity of the detector, given by the standard deviation of the response divided by the mean was found to be 7.9%. Although this is higher than the figure of 4% quoted for the LBNL detector [7] , most of this non-uniformity can be removed by correction techniques [9].

The readout speed of the detector is currently limited by the cabling between the vacuum feed-through and the control electronics. At present the readout speed is set to 2 µS/pixel, giving an overall readout period of 768 µS across the entire 384 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 1.8 m of multiway cable as at present. The LBNL detector uses double buffered counters, so the readout time is effectively zero [7], whereas the Trieste device has a quoted speed of 0.2 mS to read out 96 detectors [4].

At present it has not been possible to directly determine the maximum count rate as the laboratory X-ray source used does not generate a sufficient photo-current to saturate the device, even at the low-energy secondary electron tail. Earlier experiments with a similar MCP based device [10] yielded a maximum count rate in excess of 10_4 counts per second per pixel, leading to an overall count rate of approximately 4 MHz across the array. The exact figure for the 384-and 768-channel devices will be determined in a series of experiments planned for the synchrotron radiation source. It should be noted that the count rate limitation is due to the MCP characteristics and that higher figures could be obtained by using hot. MCPs, which may themselves bring other requirements such as the need for cooling to be built into the detector head [4].

Similarly, it has not been possible to directly determine the linearity of the present device using the laboratory X-ray source, however the previous device [10] exhibited good linearity over at least 6 orders of magnitude.

3. **Application in electron spectroscopy**

The UWA detector, incorporated in a VG CLAM4 electron analyser, has been used to detect photoelectrons excited by a range of radiation sources. Most of the initial experiments have been performed using a Mg Kα flood X-ray source, using several metal and semiconductor test samples. The 384-channel array has been continuously operational for over four months and this confirms that it is physically and electrically robust.

The detector can operate in two modes: energy scanning and energy fixed. The first mode takes advantage of the increased collection area across the focal plane and is used for acquiring high-resolution data over a wide energy range. In the second mode of operation, the analyser energy is fixed and the spectral information is obtained by the intensity image across the 384 pixels. The two modes are compared with a single channel detector under similar experimental conditions in

Fig. 2.A polished (111) diamond surface has been selected as the test sample since this provides a narrow C 1 s emission peak.

The data obtained with a single channeltron in scanning mode (Fig. 2(a)) were collected in 250 s by changing the retard potential of the electron analyser in increments of 0.1 V. The data obtained with the array in scanning mode (Fig. 2(b)) were obtained using the same analyser parameters (pass energy = 20 eV; entrance slit = 1 mm), and the spectrum shown is the result of weaving together 400 array images. The data acquired in this woven mode required a total collection time of 200 s, and so it is clear that the array provides a significant increase in total counts. It should be noted that the sample preparation was not identical in both cases, resulting in different intrinsic peak widths and so no comparison can be made regarding the energy resolution difference between the two modes. However, the value obtained for the full-width half maximum (FWHM) of the woven data is comparable to values reported for diamond surfaces under similar experimental conditions [11].

To enable real-time measurements, data must be recorded with a collection time smaller than the timescale of the process under investigation. This is possible with the UWA detector array in snapshot mode as shown for a diamond (111) surface in Fig. 2(c).

Fig. 2.
http://cadair.aber.ac.uk/dspace/bitstream/2160/1506/1/Langstaff%2c%20Bushell%2c%20Chase%2c%20Evans.pdf A comparison of the performance of a (a) channeltron detector with a 384-channel array detector in (b) weaving and (c) snapshot modes. The data were recorded with a Mg Kα X-ray source for a diamond (111) surface. Spectra (a) and (b) were recorded with the same analyser entrance slit (1 mm) and pass energy (20 eV) and the data collection time is similar. Spectrum (c) is corrected for array non-uniformity and data were collected in 1 s.

This spectrum was recorded with data collection time of 1 s. In order to image the C1 s peak across the 384-channel array, a pass energy of 100 eV was required. This increases the count rate compared to spectra (Fig. 2(a) and (b)), and also introduces an asymmetry in the peak that is due to analyser aberration at this pass energy (the detector response is unaffected).

One issue that must be addressed for array detectors is the non-uniformity that is always present due to manufacturing tolerances and can have contributions from the MCP, the integrated array, or the mounting of the MCP on the array. This has been a key problem since the advent of the MCP in the late 1960s, but this has been largely resolved using matrix deconvolution methods [12]. Where the spectral features are slow-varying, it is also possible to correct for the non-uniformity using a spectral region that is featureless. The data of Fig. 2(c) have been corrected in this way, and it is clear that the data quality of the 1 s snapshot is sufficient for this mode to be used in real-time experiments. These studies are currently underway and further improvements are planned using more intense synchrotron radiation sources and a larger 768-channel array.

4. **Conclusions**

A fully integrated 384-channel electron detector has been successfully constructed and incorporated into a hemispherical electron energy analyser for photoelectron spectroscopy. Test results confirm that the detector is reliable and robust and is able to out-perform existing single-channel detector systems. By operating in snapshot mode, it has been shown that data can be recorded at the 1 s time-scale, enabling real-time experiments to be performed. Further advances are likely by using high-flux synchrotron radiation sources where the UWA detector is particularly well suited since the small source size means that there is no redundant detector area. Using flood X-ray sources, the detector operates at less than 1% of its maximum count rate and this is limited by current MCP technology. The detector is therefore ideal for use with the latest high-brightness X-ray sources.

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