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Development of high-throughput flexible multichannel electron detectors at Daresbury Laboratory

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Continuing demands from Synchrotron Radiation Source (SRS) end-users for higher throughput and improved reliability in photoelectron spectroscopy experiments have driven an intensive development programme for new multichannel electron detectors. The development philosophy focuses on high throughput to match present and future source intensity, flexible structures to allow increased mobility of designs and modular design for easy maintenance and repair. Developments include parallel readout electronics and innovative detector heads for the hemispherical deflection analysers currently in use on the SRS. Novel anode arrays have been implemented in the detector heads and extensive microchannel plate (MCP) characterization has been undertaken to source the MCPs most suited to this application. The present multichannel detection systems provide a significant enhancement to single-channel detection systems. They have also surpassed previous multichannel detection systems due to their high throughput, flexible structure and modular design. Information on these developments and experimental results obtained at Daresbury Laboratory are presented.

Keywords: microchannel plates; electron detectors; high throughput; multichannels.

1. Introduction

The development of efficient electron-detection systems is of critical importance if existing and future synchrotron radiation sources are to be fully exploited. Extensive work has been carried out at the Synchotron Radiation Source (SRS) on the development of new multichannel electron detectors with parallel readout for use in surface science. This development programme has been driven by end-user requirements for higher throughput and improved reliability in photoelectron spectroscopy experiments. Modularity has been designed into the system from the start to ease maintenance and repair of the system and to provide users at the SRS with the maximum flexibility in their choice of detection system, *i.e.* electron energy analyser with input lens, detector and readout electronics.

Signal rates on surface-science stations at the SRS can be in the MHz region. On a third-generation source with a high-performance analyser, projected signal rates are in the GHz region. However, existing multichannel detectors (MCDs) are limited to $\sim$50 kHz mm^{-2} by the microchannel plates (MCPs) used for electron multiplication. Multichannel detection systems capable of reliably handling signal rates in the GHz region are the ultimate goal of the present work.

2. The multichannel detection system

A comprehensive description of the multichannel detection system has been given by Manning *et al.* (1997). The system basically consists of a hemispherical deflection analyser (HDA), MCD head and parallel readout electronics. To preserve the surfaces being studied it is necessary to place the experiment in an ultrahigh-vacuum (UHV) environment; this places very stringent requirements on the detection system, in particular on reliability.

Two types of HDA with multichannel detection are currently available at the SRS: a 100 mm-mean-radius HDA (VSW HA100) on a fixed mounting and a 50 mm-mean-radius HDA (VSW HA50) on a single-axis goniometer. An MCD head has been designed for both analysers utilizing a novel anode array and UHV-compatible connector. A novel feature of the anode array is the guard-rail focusing bias which increases the collection efficiency of the anode array while retaining the main purpose of the guard rail, to reduce cross-talk on the anode array. Low-resistance MCPs are used to improve the count-rate linearity of the detection system. External to the UHV environment are the discrete-component parallel-readout electronics; each channel consists of a current amplifier, leading-edge discriminator and CAMAC-based LeCroy 4434 24-bit scaler. Cross-talk between channels is effectively controlled by the use of a current amplifier and correct shielding. Maintenance and repair of the system is made easier by the use of plug-in amplifier and discriminator cards in the front-end signal-processing unit.

3. Comparison of multichannel detection with single-channel detection

To verify the improved sensitivity provided by a multichannel detection system, a carefully controlled experiment was conducted to compare directly the performance of a multichannel and a single-channel detection system. The experimental set-up is shown in Fig. 1. Both HA100s were fitted with a 14D input lens and controlled by identical VSW HAC5000 electron-analyser power supplies. A single-channel detector (SCD) was fitted to one of the HDAs and an MCD to the other. The SCD comprised a 4 × 10 mm aperture, a Philips X919BL channel electron multiplier (CEM) and NIM/CAMAC-based data-acquisition system (EG&G 9301 preamplifier, EG&G 474 timing filter amplifier, EG&G 436

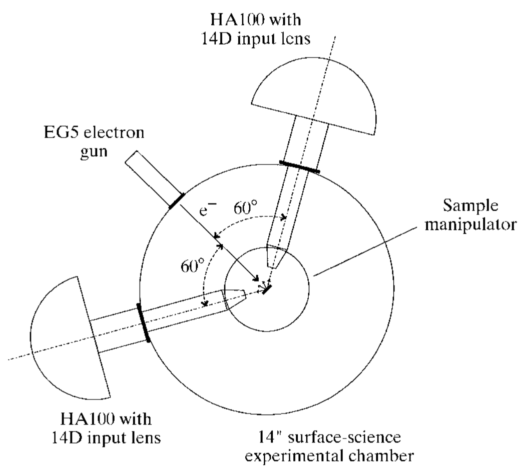

Figure 1
Experimental set-up used to compare directly the sensitivities of a multichannel and single-channel detection system.

Table 1
Electron multiplier characteristics.

	A	*B*	*C*	*D*
Manufacturer	Philips	Philips	Galileo	Galileo
Type	CEM	G12-46DT/13 MCP	EDR MCP	EDR MCP
Configuration	N/A	Chevron	Chevron	Chevron
Aspect ratio	~50:1	80:1	40:1	60:1
Channel diameter	2.3 mm (10 mm front cone)	12.5 μm	25 μm	10 μm
Open area ratio	N/A	64%	64%	64%
Resistance	~1 GΩ	~60 MΩ	~8 MΩ	~6 MΩ
Interplate gap	N/A	1 mm	200 μm	1 mm

discriminator and EG&G 449-2 ratemeter or CAMAC-based scaler). The multichannel detector comprised a 22 × 10 mm aperture, a chevron pair of Philips G12-46DT/13 MCPs (42 mm active diameter, 12.5 μm pore, aspect ratio 80:1, nominal plate resistance 60 MΩ), a 16–channel anode array (pitch 1.44 mm, single electrode area 11.2 mm^2, collection efficiency 78%) and the parallel readout electronics described in §2. The data-acquisition system for the SCD was found to be linear to >500 KHz for random events and the MCD data-acquisition system was linear to >10 MHz per channel for random events.

It was necessary to characterize both detection systems before undertaking the comparison to establish suitable operating points. In both cases, the discriminator level was set to just above the noise level and the count-rate linearity was determined after discrimination; the count-rate linearity limit is defined as the point where a 10% fall in count rate is observed. The results are detailed in §4.

The pulse height distributions (PHDs) collected from the CEM and MCPs are shown in Fig. 2. The CEM gave a saturated PHD at a bias voltage of 2225 V, whereas the MCPs remained unsaturated at a bias voltage of 1000 V per plate; the unsaturated PHD and the high resistance of the plates accounts for the poor count-rate linearity of this MCP. The PHDs were collected using a VSW charge-sensitive preamplifier, connected to either the CEM anode or one of the MCD anodes, and a PC-based Aptec multichannel analyser (MCA) with built-in shaping amplifier and 12-bit ADC. The gain of the amplification system was calibrated, allowing the MCA channel number to be translated into electron gain, by feeding a charge pulse of known amplitude into the acquisition system.

The sensitivities of the single-channel and multichannel detection systems were compared by studying the count rate from the electrons elastically scattered from an amorphous Cu target. The FWHM of this primary peak is ~2 eV, hence the peak count rate can be compared directly since it is unaffected by the different resolutions of the two detection systems. The electron gun and sample were carefully aligned to maximize the count rate in each detection system. At a gun energy of ~840 eV, a pass energy of 22 eV and a sample drain current of 0.17 nA, the peak count rates from the MCD and SCD were ~212 kHz and ~24 kHz, respectively, as shown in Fig. 3. The MCD throughput is 8.8 times that of the SCD; this result was found to be repeatable to within 7%. The SCD utilizes 40 mm^2 of the CEM collection area and the MCD utilizes 168 mm^2 of the MCP active area; note that one channel of the MCD is connected to the MCA for collection of PHDs, hence only 15 channels are active. From the active area alone, the throughput of the MCD should be only 4.2 times that of the SCD. However, this calculation does not take into account the fact that the CEM is not 100% efficient over its entire area; the detection efficiency can vary significantly over the front cone, as shown by Seah & Smith (1991). The apparent improvement in throughput could indicate that, over this area, the MCPs have more than twice the detection efficiency of the CEM at an electron energy of ~80 eV.

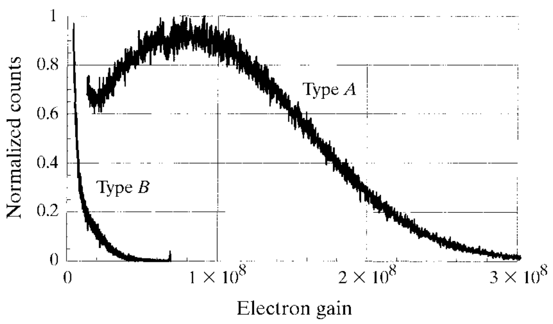

Figure 2
Pulse height distributions collected from a Philips X919BL CEM (type *A*) with a bias of 2225 V and Philips G12-46DT/13 MCPs (type *B*) with a bias of 1000 V per plate.

4. MCP and CEM characterization

The count-rate linearities of the MCD and SCD are limited by the electron multiplier; MCPs in the MCD and CEM in the SCD. This linearity limit can severely restrict data-aquisition rates even on second-generation sources. To maintain the count rate within the linear region of the detection system, photoelectron spectra are often taken with reduced photon flux. Hence optimizing this parameter will have a dramatic effect on acquisition rates. The count-rate linearity of four types of electron multiplier, as described in Table 1, have now been

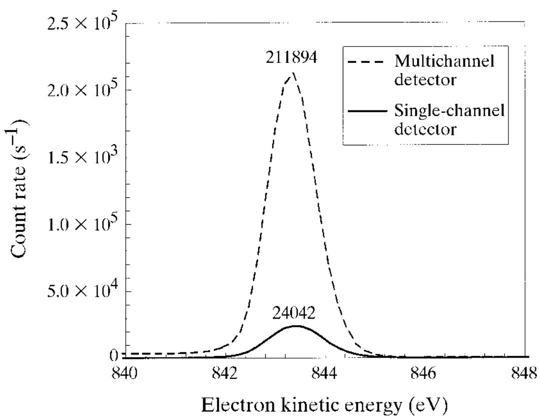

Figure 3
Elastically scattered electron peak from an EG5 electron gun collected with a multichannel and a single-channel detection system.

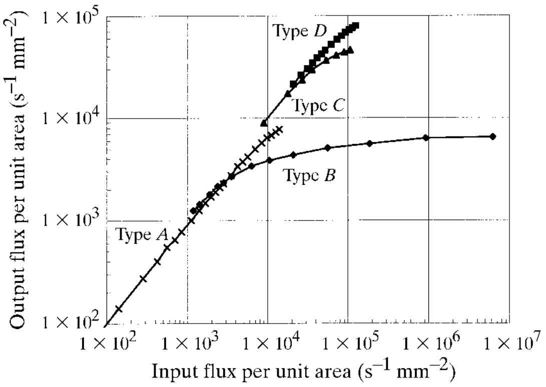

Figure 4
Count-rate linearity of four types of electron multiplier.

studied and the results are shown in Fig. 4; note that the results for electron multipliers B and C have already been presented by Manning *et al.* (1997).

The roll-off in linearity of the CEM (A) is far less dramatic than that of the MCP electron multipliers (B, C and D), particularly that of the high-resistance MCP (B); this is because the CEM has a saturated (or quasi-Gaussian) PHD which is desirable for pulse counting, whereas the MCPs have an unsaturated (or quasi-exponential) PHD. However, the count-rate linearity of the low-resistance MCPs (C and D) is still more than an order of magnitude better than that of the CEM (A). The improvement in count-rate linearity from C to D was achieved by selecting a low-resistance MCP with lower gain (smaller channel diameter); this produced a factor of two increase in count-rate linearity to 50 KHz mm^{-2} for a bias voltage of 1000 V per plate. It is thought that with suitable preconditioning, the MCPs will produce a saturated PHD; this has been demonstrated by Siegmund (1991). However, the practical difficulties of implementing MCP preconditioning on a user station have slowed such an investigation.

5. Conclusions

A high-throughput reliable multichannel detection system has been developed at Daresbury Laboratory and is available to SRS users in a variety of configurations. Nearly an order of magnitude improvement in the throughput from an MCD utilizing MCPs, compared with that from an SCD utilizing a CEM, has been demonstrated. MCPs offer improved count-rate linearity and a larger active area compared with a CEM, thus allowing efficient electron detectors to be designed.

A limitation of the type of multichannel detection system discussed here is the number of channels which can be implemented. Due to this, the collection of high-resolution snapshot spectra is not currently possible. Current developments are focused on producing a high-throughput MCD with many more channels which is capable of time-resolved snapshot analysis. The key to this development is a modular signal-processing integrated circuit which will allow all the readout electronics to be placed inside the UHV environment, directly on the detector head.

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