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Characterisation of a detector based on microchannel plates for electrons in the energy range 10–20 keV

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ABSTRACT

As part of a feasibility study into the use of novel electron detectors for an X-ray photoelectron emission microscope (XPEEM), we have characterised a detector based on microchannel plates (MCPs), a phosphor screen and a CCD camera. For XPEEM, an imaging detector is required for electrons in the energy range 10–20 keV. This type of detector is a standard fitment on commercial instruments and we have studied its performance in some detail in order to provide a baseline against which to evaluate future detector technologies. We present detective quantum efficiency (DQE), noise power spectrum (NPS) and modulation transfer function (MTF) measurements of a commercial detector, in the energy range of interest, as a function of the detector bias voltage.

1. Introduction

Development of novel imaging cameras for the detection of low-energy electrons is being pursued at the Rutherford Appleton Laboratory (RAL) and the University of Oxford. RAL has in-house expertise in the design of monolithic active pixel sensors (MAPS), which provide a candidate technology for a wide range of applications. MAPS offer a number of potential advantages over existing detectors, such as improved sensitivity and faster frame rate. However, detailed characterisation of existing detectors is required before an accurate comparison can be made. Hence, this paper presents extensive characterisation of a detector based on microchannel plates (MCPs) typical for X-ray photoelectron emission microscopes (XPEEM).

XPEEM is used in a wide variety of applications [1], such as the study of adsorption on metal films, microtopography of metal and semiconductor surfaces, surface reactions in catalysis, surface diffusion of metals, growth of films on metals and semiconductors, and biological samples. In an XPEEM instrument, the sample is excited by X-rays from a synchrotron light source and photoelectrons are emitted. A typical XPEEM uses an electrostatic immersion lens to collect these electrons and accelerate them through a series of magnetic lenses, projecting a highly magnified image onto the detector. By sweeping the energy of the incident photons through the electron binding energies of the different chemical elements in the sample under study, maps of their distribution may be built up. The electrons impinging upon the detector are monoenergetic, with an energy determined by the accelerating voltage used. For the commercial system supplied by Elmitec [2] to the Diamond Light Source in the UK (DLS), the electron energy is 20 keV, while the PEEM2 instrument at the Advanced Light Source at Lawrence Berkeley National Laboratory in the USA (ALS) uses an accelerating voltage which is variable and in the region of 10–20 kV [3]. We have therefore examined the performance of imaging electron detectors in the energy range 10–20 keV.

An imaging camera manufactured by Burle Electro-Optics [4] was made available to us by DLS and has been selected as the baseline against which other potential technologies will be compared. We were not able to find suitable specifications in the existing literature; the most closely related work being an electron detection efficiency measurement of Mullard MCPs read out by a pickup electrode [5]. In addition, work has been carried out by other authors to characterise detectors for the ALS XPEEM, which uses, at present, a detector based on a scintillator, fibre-optic taper and CCD chip [6].

2. Experimental

The detector was supplied with an Elmitec XPEEM and is based on two MCPs in a chevron configuration. Incident electrons cause avalanche multiplication in the MCP pores; the resulting clouds of electrons are accelerated from the rear face of the chevron onto a P20 phosphor. Using a fibre-optic feedthrough allows light to be

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carried from the phosphor, which is in vacuo, to the air side of the detector. The fibre optic is viewed by a Sensicam EM camera [7], equipped with a 25 mm f-1.4 lens and a cooled CCD (Fig. 1).

In the experiments reported here, a cylindrical vacuum vessel was used, evacuated by a turbomolecular pump, backed by a scroll pump. The pressure during data acquisition was set between 5×10^{-8} and 5×10^{-7} Torr. A Kimball Physics EMG4212 gun [8] was used (Fig. 2), which produces electrons with energy between 0.5 and 20 keV. The gun was mounted diametrically opposite to the detector on an extension tube, so that the distance between the gun and the detector was 800 mm. The controllable parameters of the gun were the accelerating voltage, focusing voltage, filament current, grid voltage and deflection in the horizontal and vertical directions. The gun was equipped with a tantalum disc cathode; this makes use of thermionic emission of electrons, together with some light, due to the high temperature. The method employed at each measurement point was to set the accelerating voltage and then set the focusing voltage to give the largest achievable spot size and hence obtain a uniform illumination of the detector. The grid voltage was set to a value giving the maximum beam current for each accelerating voltage and the filament voltage ramped slowly to the desired value, while monitoring the detector with the CCD camera.

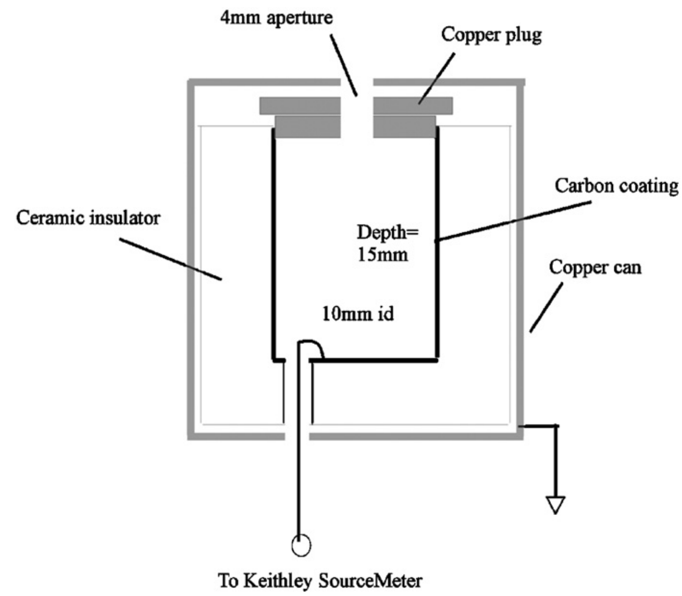

Fig. 3. Schematic diagram of the Faraday cup.

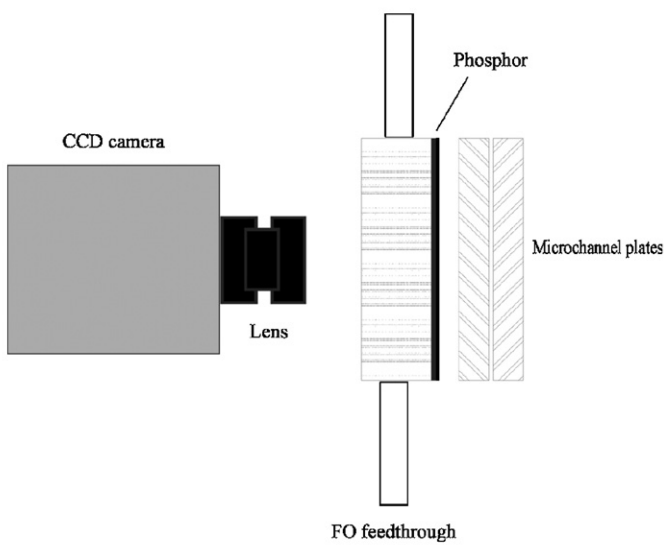

Fig. 1. Schematic diagram illustrating the overall layout of the electron detector.

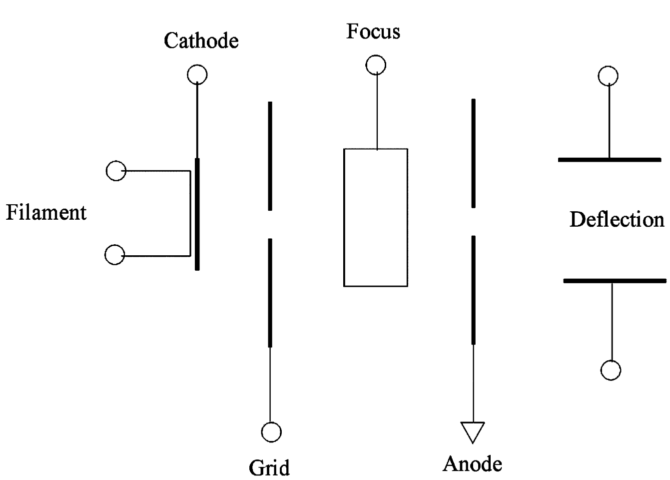

Fig. 2. Schematic diagram of the electron gun.

A grounded aluminium opaque shadow mask was placed in front of the detector, with a fine-finish milled side acting as a knife edge for the determination of the detector modulation transfer function (MTF). The shadow mask was fixed ~2 mm above the input MCP at a small angle to the CCD pixel rows. Two circular apertures of known area in the mask were used in the measurement of the absolute counting efficiency. Aluminium was chosen for the mask to reduce the yield of Bremsstrahlung. An AXUV-100 diode coated with 100 nm of aluminium from International Radiation Detectors [9] was mounted on the mask to allow beam current measurement. Aluminium coating was used to minimise sensitivity to the light emitted by the electron gun. Electron flux measurements were performed using the silicon diode in photovoltaic mode connected to a Keithley 6517A electrometer. Since the energy required to create an electron–hole pair in silicon is 3.61 eV [10], the use of a diode gives a gain of 2770 signal-electrons per incident electron completely stopped in the silicon at 10 keV. This confers a distinct advantage in measuring small beam currents, as compared to a Faraday cup. The Al coating minimised the sensitivity to light, but did not eliminate it, and therefore a procedure to extract light contribution was developed as follows: (i) the current in the diode was measured under the same conditions for which the images were recorded, (ii) the electron beam was cut off by increasing the grid voltage in the gun and (iii) a second measurement of the current was recorded. Each current determination therefore consisted of six or more separate measurements, to allow averaging and estimation of the achievable reproducibility.

The diode itself is however not an absolute standard as there may be a dead layer at the surface and hence incident electrons may not deposit all their energy in the material of the device. It was therefore necessary to calibrate the efficiency of the diode against an absolute standard, such as a Faraday cup operating at higher beam intensities. Accordingly, a Faraday cup was built based on the design in Ref. [11], as shown in Fig. 3. This was constructed around an insulating ceramic cylindrical pot, coated internally with carbon dag, which has a smaller backscatter coefficient than any other practical electrode material [12]. During