X-Ray Spectroscopy with a CCD Detector

Application Note

In addition to providing X-ray imaging solutions, including CCD-based cameras that image X-rays using either direct detection (0.5-20 keV) or indirectly using a scintillation layer (5-500 keV), Xcam also offer a number of camera systems developed for X-ray spectroscopy applications. The CCD is an ideal detector for use in both dispersed and photon counting X-ray spectroscopy applications, and its ability to obtain both spectral and spatial information simultaneously allows it to be used for 'multi-spectral imaging'. Swept Charge Devices (SCDs) are also available for X-ray spectroscopy applications where spatial information is not required and can provide good spectral resolution using relatively large area devices (up to 400 mm^2). Combined imaging and spectroscopy is also a possibility, for example, combining XRD/XRF with the CCD monitoring the X-ray diffraction pattern whilst simultaneously recording a flourescence spectrum.

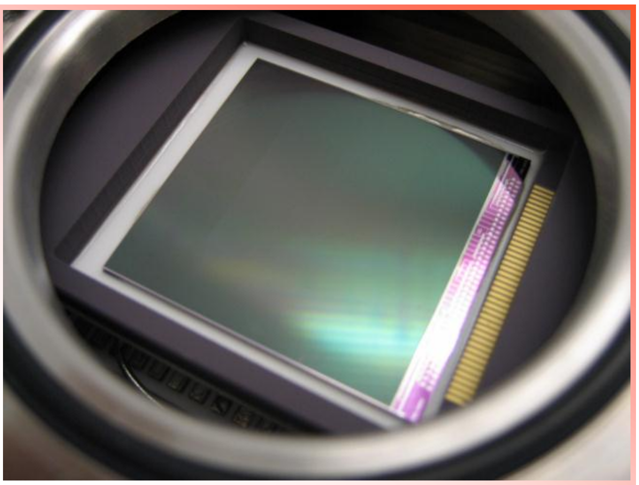

Fig. 1 An Xcam CCD camera head, suitable for X-ray spectroscopy applications

This application note provides an overview of the CCD and SCD camera systems available from Xcam for X-ray spectroscopy applications and also describes the use of CCDs for the technique of multi-spectral imaging.

Imaging X-ray Spectroscopy with a CCD

X-ray photons incident on the surface of a CCD detector may be read out from the device using low noise electronics in "sparse" or photon counting mode. The energy information about each X-ray event is then retained on read-out, allowing event recognition software to produce a spectrum of the incident X-ray photon energies from the recorded image. Cameras developed by Xcam can provide low noise systems of <5 electrons r.m.s., equivalent to ~140 eV at Mn-K (5898 eV), for spectroscopy applications.

Some of the benefits of the available Xcam CCD camera systems for X-ray spectroscopy are:

- High performance cryogen free system
- Large collecting area - for low photon yield applications
- Suitable for portable applications
- Energy resolution comparable to Si(Li) detectors
- High peak to background ratio in the spectrum
- Spatial information is retained (i.e. suitable for imaging applications)
- Full performance using thermoelectric cooling

Figure 1 above shows one of the available Xcam CCD camera systems suitable for X-ray spectroscopy applications featuring a 2k x 2k pixel (13.5 μm pixel) device. Figure 2 shows the same CCD camera system revealing the water cooling, vacuum pump and CCD headboard connectors on the side of the camera head.

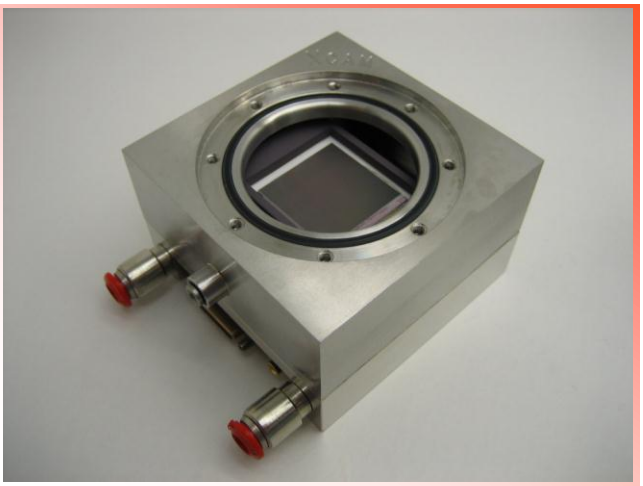

Fig. 2 An Xcam CCD camera head, suitable for X-ray spectroscopy applications

Non-imaging X-ray Spectroscopy with a CCD

Swept Charge Devices (SCDs), such as e2v technologies CCD54 and CIXS devices (see Figures 3 and 4 respectively), offer a low cost, large area, fast read-out alternative to the CCD, for situations where spatial information is not required. These devices are designed to operate at temperatures that can be achieved using Peltier cooling, so that liquid nitrogen is not required, making them a good replacement for the Si(Li), PIN and SDD devices.

Some of the features of SCDs include:

- Low cost
- Efficient detection over the 0.5-10 keV band
- Large area, up to 400 mm^2
- Typically ~5 electrons r.m.s. noise, giving 80 eV FWHM at 1 keV and 130 eV FWHM at 6 keV
- Peak to background ratio of 4000:1 with collimation
- Suitable replacement for Si(Li), PIN and SDD devices
- Can be operated warm requiring no liquid Nitrogen for cooling
- Fast read-out

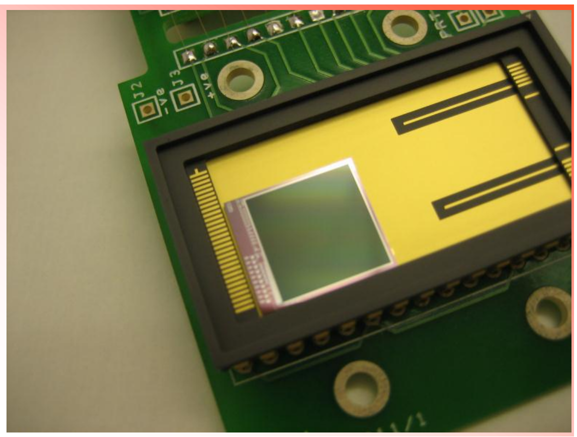

Fig. 3 An e2v technologies CCD54

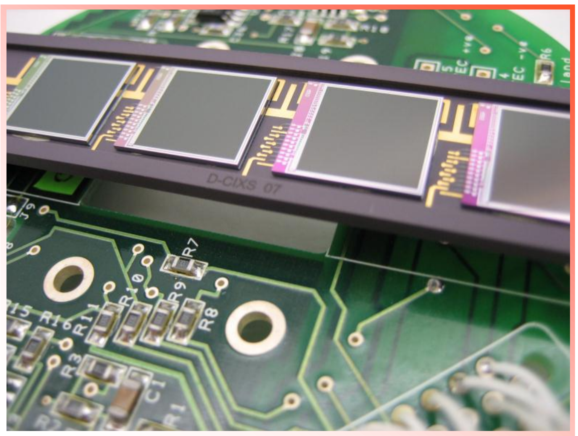

Fig. 4 A CIXS device featuring four CCD54 detectors in one ceramic package

Figure 5 shows a spectrum obtained from Vanadium using an SCD, showing the good peak to background of in excess of 3000:1 (without collimation) that can be achieved.

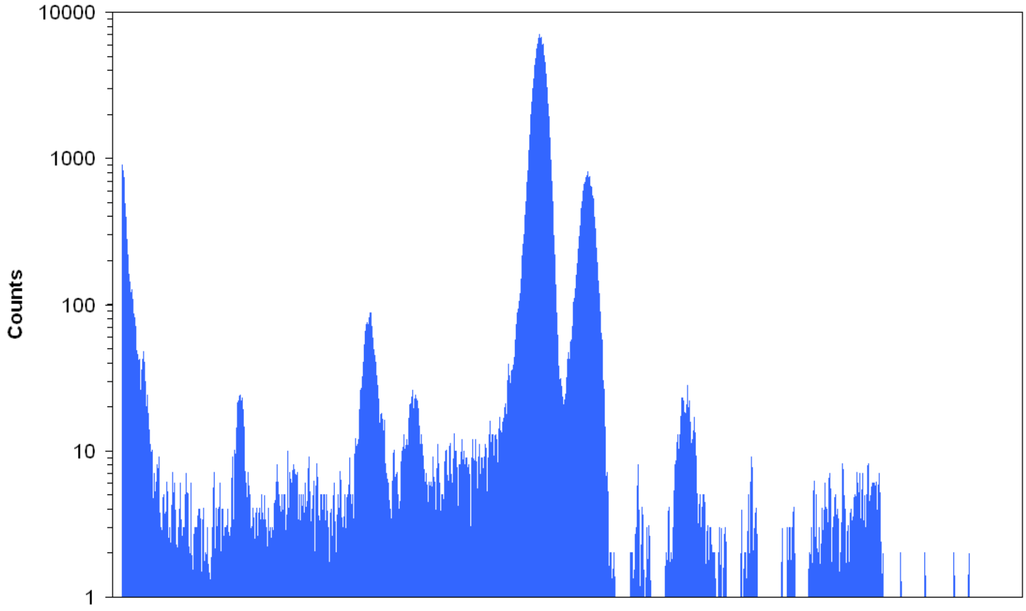

Fig. 5 Recorded X-ray spectrum of fluorescence from a Vanadium target

Dispersed X-ray Spectroscopy

In dispersed X-ray spectroscopy (using for example a grating or crystal), the CCD chip is used for detection of the dispersed spectrum, where the energy is determined from the positional information. Figure 6 shows a CCD recorded spectrum of V Kα produced by inserting a wire probe near the electron beam of an Electron Beam Ion Trap (EBIT) [1].

Some of the camera specifications offered by Xcam for spectroscopy systems are:

- Direct detection of X-rays for optimisation of the detection system
- Cryogen-free thermoelectric cooling, with supplementary air or water-cooling
- A selection of entrance windows are available for optimal transmission at the energy range of interest
- Possibility of direct coupling to the user's vacuum system or even installation of the sensor in the user's chamber
- 14 bit or 16 bit digitisation
- Typically <5 electrons r.m.s. noise, dependent on CCD type used
- Full software control of the system including, readout parameters, binning and windowing modes

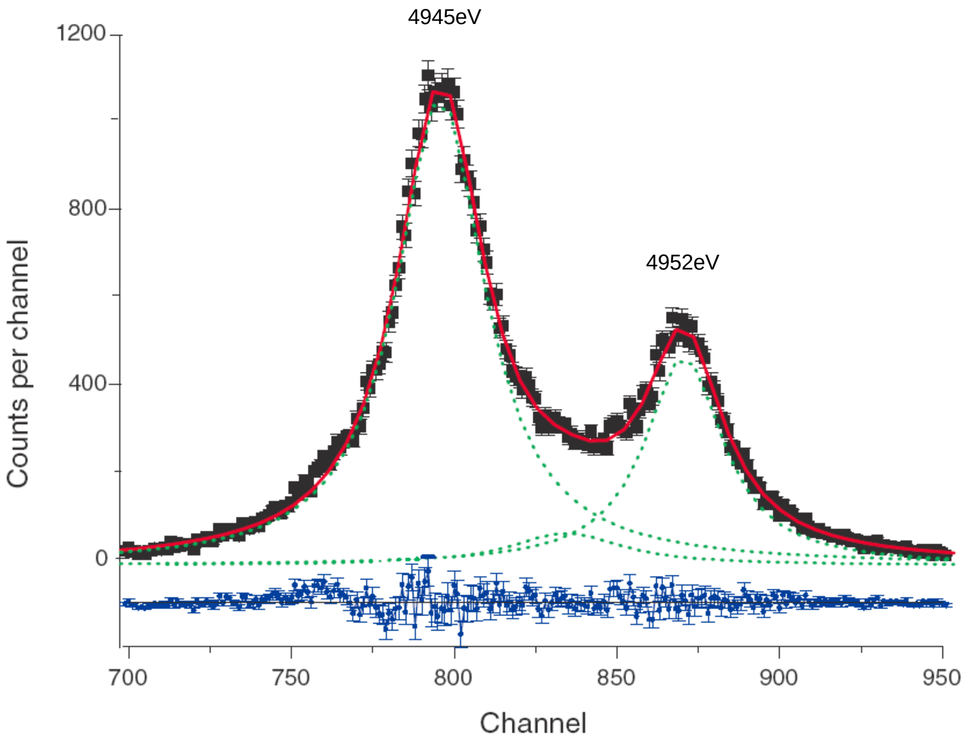

Fig. 6 A recorded V Kα spectrum obtained by inserting a wire probe near the electron beam of an EBIT. The spectrum is fitted by a sum of three Lorentzians with the residuals also shown (image used courtesy of Joshua Silver)

X-Ray Spectroscopy with a CCD Detector
Application Note

Photon Counting Spectroscopy

The low noise of CCDs (2-10 electrons r.m.s.), and high stopping power over the 0.5-10 keV range, makes the CCD the ideal photon counting detector for X-ray spectroscopy applications, for example in X-ray Fluorescence (XRF).

An example X-ray spectrum obtained using an Xcam spectroscopy system is shown in Figure 7 below. The spectrum shows the L and M line emission from Pb and Sn, together with trace elemental lines arising from the test system; Fe, Ni and Cr from the steel chamber, W from the X-ray source; and Si from the CCD.

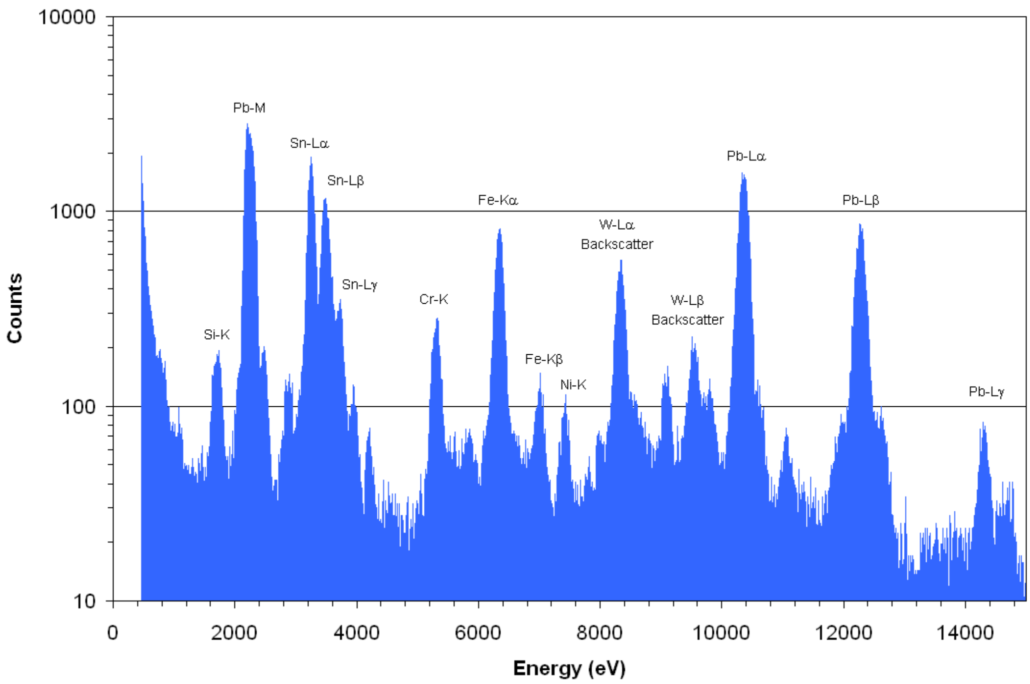

Fig. 7 An example of fluorescence from PbSn solder spectrum obtained using an SCD

Key features of photon-counting X-ray spectroscopy systems available from Xcam are:

- Cryogen-free operation using a thermoelectric cooler
- Typical Operating Temperature of -35°C, depending on user requirement
- Resolution of ~140 eV at Mn-K (5898 eV)
- Active area of 1-6 cm^2 dependant on CCD type (ideal for low photon flux applications)
- Count rate 20000/s
- High detection efficiency over 0.5-10 keV band
- Full software control of your system including, readout parameters, binning and windowing modes

Multi-spectral Imaging – Combining X-ray Spectroscopy with Imaging

At the same time as a spectrum is being recorded, the CCD can also record an image from the sample; examples below show this technique being used in both X-ray diffraction (XRD) and projection microscopy applications.

The CaF spectrum, shown in Figure 8, is of a powder sample having 3% CaF component, superimposed on an Fe-55 spectrum. When operating in photon-counting mode, a key result of CCD X-ray spectroscopy technology is that it is possible to obtain a spectrum of the incident photon energies, whilst also obtaining spatial information at the same time.

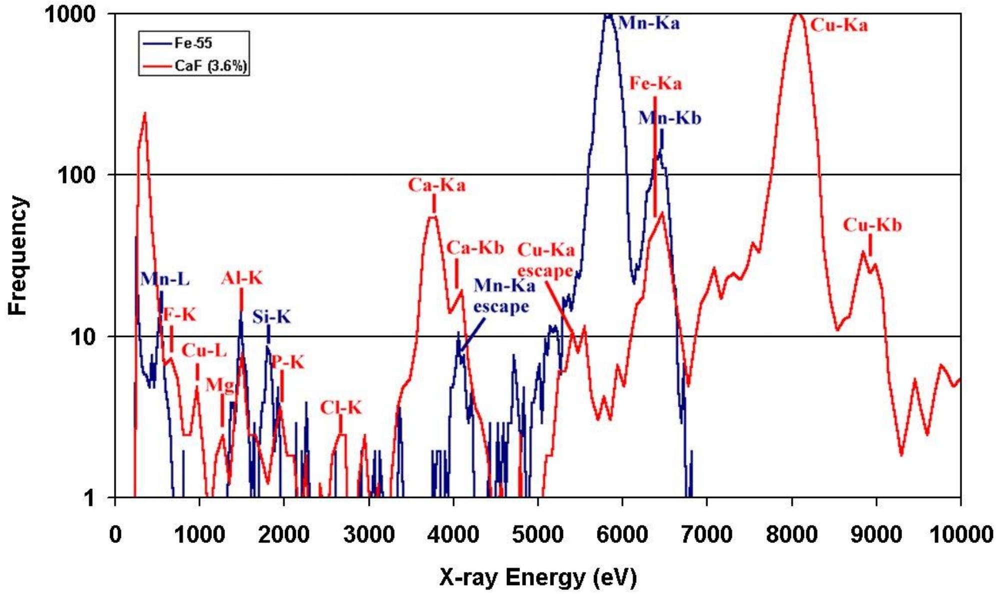

Fig. 8 A recorded CaF spectrum from a powder sample that has a 3% CaF component, superimposed on an Fe-55 spectrum

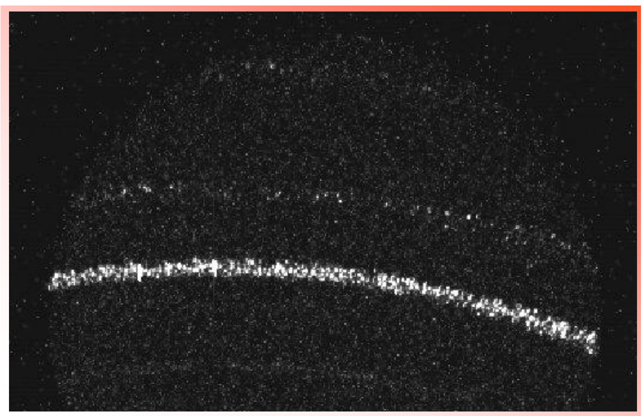

Fig. 9 Simultaneous XRD (rings) and XRF (background) image obtained from a Corundum sample

The technique of multi-spectral imaging (an X-ray Projection Microscopy technique) using an Xcam camera system has been investigated by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia. Figure 10 shows three images acquired simultaneously by use of multi-spectral imaging at 3.3, 1.7 and 5.0 keV from (upper left-to-right respectively) and (lower) a projected density distribution obtained by phase retrieval from these images. This image was published in the *Journal of Microscopy*, vol. 207, pt. 2, August 2002, page 93, and is shown here with Blackwell's permission [2].

Further information about this application, using Xcam hardware for X-ray projection microscopy, can be found in the Xcam application note: “X-Ray Projection Microscopy with a CCD Detector“, available from Xcam, or by download from the Xcam website.

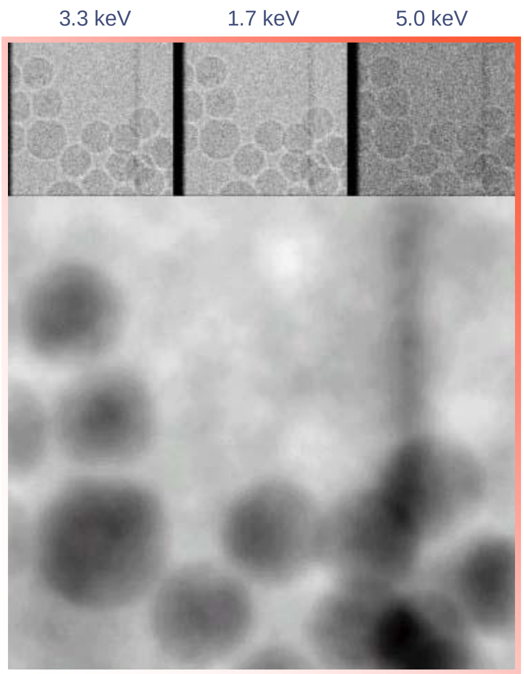

Fig. 10 Three images of 9 μm latex spheres acquired simultaneously using multi-spectral imaging at 3.3, 1.7 and 5.0 keV (upper left-to-right respectively) and (lower) a projected density distribution obtained by phase retrieval from the three images

References

[1] M. R. Tarbutt, J. D. Silver, "Measurements of the ground-state Lamb shift of hydrogen-like Ti^{21+}", *Journal of Physics B: Atomic, Molecular and Optical Physics*, vol. **35**, (2002), pp. 1467-1478.

[2] S. C.Mayo et al., "Quantitative X-ray projection microscopy: phase-contrast and multi-spectral imaging", *Journal of Microscopy*, vol. **207**, pt. 2, (2002), pp. 79-96.

XCAM Limited
2 Stone Circle Road
Round Spinney
Northampton
NN3 8RF, UK

Tel: 44 (0)1604 673700
Fax: 44 (0)1604 671584
Web: www.xcam.co.uk
Email: info@xcam.co.uk