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A low-profile monolithic multi-element Ge detector for X-ray fluorescence applications

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A highly compact and rapid-count-rate multi-element solid-state detector has been designed, built and recently commissioned on the oldest XAFS station of the SRS, station 7.1, which has undergone major refurbishment. The low profile of the detector has been achieved by using the monolithic solution where nine elements with a combined active area of 370 mm^2 have been fabricated on Ge of diameter 21.8 mm. A typical energy resolution of 170 eV with a semi-Gaussian shaping time of 0.5 µs has been achieved with X-rays of energy 5.9 keV. The low profile of the detector makes it ideal for several synchrotron radiation applications as it can be easily incorporated into complicated experimental set-ups. These include XAFS of single crystals and samples generated in a stopped flow system, protein crystallography (fluorescence XAFS for MAD or for on-line monitoring), microprobe fluorescence imaging and trace-element analysis.

Keywords: XAFS; MAD; fluorescence detectors; high count rates; X-ray detectors.

1. Introduction

Substantial progress has been made in the field of X-ray fluorescence detectors since the original scintillation-counter-based system of station 7.1 in the early 1980s (Hasnain *et al.*, 1984). This improvement is primarily a result of the progress made in the solid-state-detector-based systems (Jacklevic *et al.*, 1977) and the ability of putting together a large number of elements on a single cryogenically cooled detector head (Cramer *et al.*, 1988). In order to cope with the high count rate, the number of elements have increased from 13 to 30 in recent years (Derbyshire, 1991). However, this has tended to result in bulkier systems which are cumbersome to manipulate and difficult to position close to the samples. Their sheer size often prohibits the use of complex sample stages and auxiliary equipment, *e.g.* stopped flow, diffractometers or cryostats.

A new approach in detector design is thus appropriate. A 'low-profile' multi-element detector has been designed and built through a collaboration established as a result of the EPSRC Chemistry Equipment Initiative. The motivation for this development arose from two basic scientific requirements, namely that the detector should be non-obtrusive to the rest of the equipment around the sample (*e.g.* diffractometer, cryostat, stopped flow) and that it should be capable of a very high count rate so that at a minimum it is capable of coping with the photon flux expected from the station when sagittal focusing is fully operational.

A nine-element monolithic design has been built and recently commissioned. To our knowledge, this is the first monolithic multi-element Ge detector for X-ray fluorescence applications. The details of the detector, its performance and potential synchrotron radiation applications are discussed.

2. Detector design

As reported earlier (Derbyshire, 1991), the packing of several diodes together leaves a large dead space and current technology provides the 13-element multi-element solid-state detectors (MESSDs) with an active area of 36% of the solid angle that the detector subtends to the sample. The first step towards achieving maximum count rate and throughput is to devise a very compact detector system so that the detector can be positioned as close to

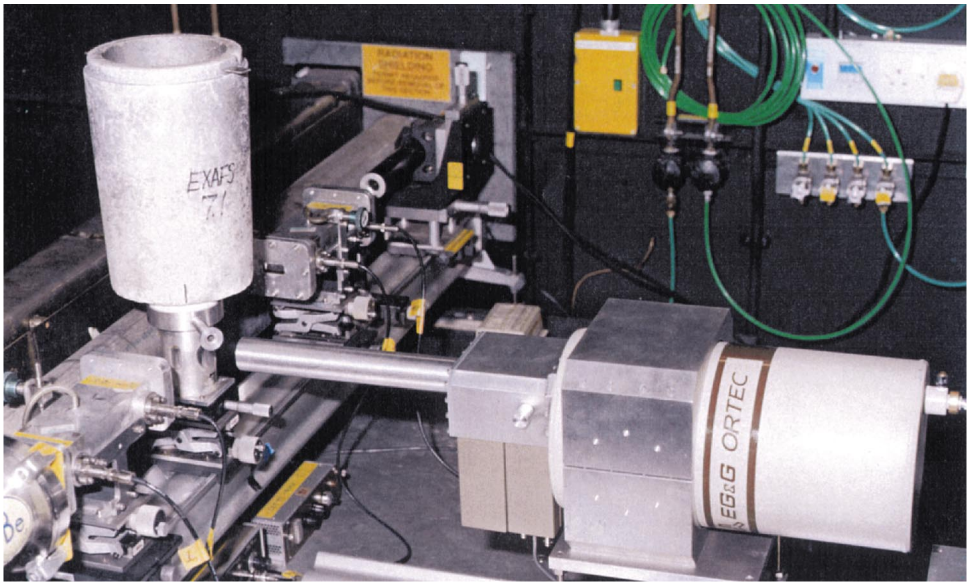

Figure 1
The C-TRAIN detector assembly on XAFS station 7.1 of the SRS.

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the sample to be analysed as possible without obstructing the rest of the equipment around the sample. The second step is to maximize the effective active area of such a detector by reducing the amount of dead space between elements. A monolithic detector structure is one of the highly effective approaches to the solution. However, in the past this type of structure has always been plagued with, among others, the problems of crosstalk due to electronic interference and/or charge sharing between elements.

In a collaborative project between CCLRC Daresbury Laboratory and EG&G ORTEC, a compact detector for time-resolved and anomalous diffraction inline (C-TRAIN) has been designed and manufactured (Fig. 1). It consists of a monolithic structure nine-channel array on a 21.8 mm active diameter with an active area of greater than 90%. The Ge wafer has an active depth of 6 mm. The monolithic array resides inside a cryostat snout of length 305 mm and diameter 45 mm (Fig. 2), with the front active surfaces within 7 mm behind the front Be window. The 250 µm-thick front Be window allows a usable energy range of above 3 keV. The dewar is compact and the multi-attitude design provides a holding time in operation of over four days before refilling is required.

3. Detector performance

Fig. 1 shows this detector assembly with the present pre-amplifier on the recently refurbished XAFS station 7.1. A typical energy resolution of 170 eV at a count rate per channel of well over 1×10^5 c.p.s. using standard analog shaping amplifiers with a semi-Gaussian shaping time constant of 0.5 µs has been achieved with X-rays of energy 5.9 keV (Fig. 3), as measured with the system integrated on the beamline. Crosstalk between channels under laboratory conditions appears to be negligible. The 250 µm-thick front Be window allows for a usable energy range of above 3 keV. With a Ge crystal of active depth 6 mm, this system has a good efficiency response and performance using X-rays of energy well above 50 keV. The improvement of almost 100 eV in energy resolution, compared with the existing 30-element system currently in use on station 16.5 (Farrow *et al.*, 1998), has been necessary for use of the new detector at a lower energy range whilst maintaining the high throughput rate. The combination of all the improvements mentioned, *i.e.* compact detector snout, maximum ratio of active-to-total subtended solid angle, high throughput and high energy resolution *etc.*, is extremely valuable for obtaining high-quality XAFS spectra. This detector, together with the XSPRESS (X-ray signal processing electronics for solid-state detectors) digital electronics developed at Daresbury Laboratory, is expected to provide a high photon-count-rate capability in the region of several MHz. It is possible that this C-TRAIN–XSPRESS combination will offer a performance and throughput rate approaching that of the 30-element SSD (Farrow *et al.*, 1998).

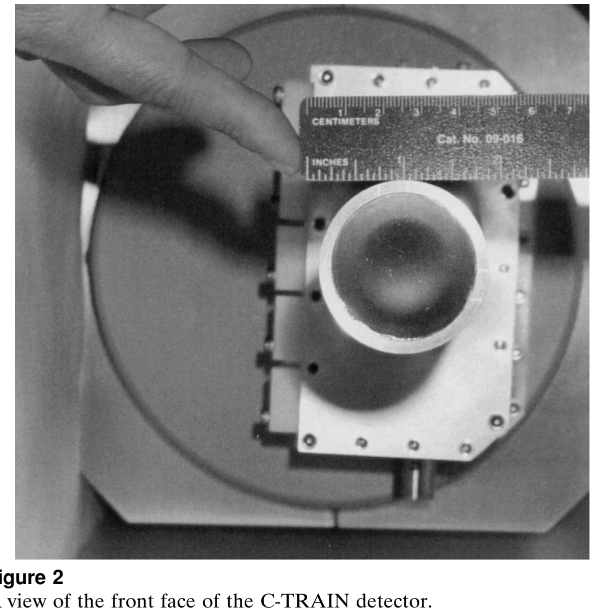

Figure 2
A view of the front face of the C-TRAIN detector.

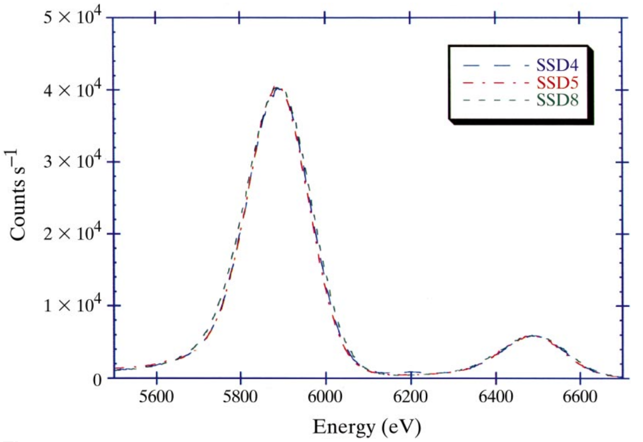

Figure 3
Energy spectrum of three of the representative elements.

Currently, a miniaturization of the bulky pre-amplifier for each detector element is taking place which would result in an extremely low profile for the whole assembly enabling us to position the detector close to a stopped flow system as well as integration with a diffractometer.

4. Conclusions

A low-profile high-energy-resolution multi-element solid-state detector has been built using the monolithic solution. This has enabled an increase in the percentage of total active area of the detector to greater than 90% compared with 36% usually obtained with traditional multi-element assemblies (Cramer *et al.*, 1988; Farrow *et al.*, 1998). In addition, a long-neck dewar assembly became possible making it feasible for it to be incorporated into complex sample stages such as diffractometers. The high energy resolution at short shaping time makes the detector suitable for high-count-rate applications. The low profile of the detector assembly also makes it suitable for incorporation into MAD beamlines.

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