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Mythen detector system

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Abstract

Time-resolved experiments in powder diffraction are limited by the long time required to record spectra with current detectors. A major improvement can be made by using a massively parallel X-ray detection system together with a fast read out. The Mythen detector (Microstrip system for time-resolved experiments) has been built for the Powder Diffraction Station of the Material Science beamline at the Swiss Light Source to meet these requirements. The specifically developed read out chip (Mythen chip), the detector system and first measurements are shown.

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1. Introduction

The SLS is a third generation synchroton radiation facility with a very high brilliance [1]. Among the first beamlines which are operational are those for material science and protein crystallography. For both beamlines there is an ongoing effort in the field of detector development: a large area pixel detector for protein crystallography is covered in Ref. [3] and a microstrip detector system for the powder diffraction station of the material science beamline, which is covered in this article.

The X-ray intensity of the material science beamline is up to 10^{13} photons/s on the sample. The main beamline properties are listed in Table 1.

X-ray powder diffraction is based on Bragg's law, $2d\sin(\theta) = n\lambda$, which states that diffraction of X-rays with wavelength λ from a lattice with spacing d only occurs at angle θ. The order of the reflection is given by n.

In a powder diffraction experiment, the intensity of diffracted X-rays is recorded as a function of angle [2]. Conventionally, this is done by scanning a scintillator with a photomultiplier over the angle of interest.

The information which can be extracted from a spectrum includes the angles, intensities and widths of the diffraction peaks. The angle determines the lattice spacing d. The intensity of the peak is directly related to the arrangement of the atoms in the unit cell and the amount of material.

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The width of the peak comes from imperfections in the periodic arrangement such as stacking faults and atomic disorder. Powder diffraction is therefore one of the most important tools for material scientists.

2. Detector system

The powder diffraction station is schematically shown in Fig. 1. It has two detector systems: a conventional analyzer setup and the microstrip detector system.

Table 1
Principle properties of the material science beamline

Energy range	5–40 keV
Energy resolution	1.4×10^{-4} at 5 keV
Vertical divergence	0.2 mrad
Intensity	10^{13} photons/s on sample

The conventional analyzer system has five channels each equipped with an Si 111 crystal to improve the angular resolution, an NaI scintillator and a photomultiplier. The photomultipliers are each connected to a discriminator and a counter.

The microstrip detector system consists of 12 modules each having 1280 channels, making 15360 channels in total. A module is based on a small printed circuit board, the MCB (module control board) which is shown in Fig. 2. It carries 10 readout chips, with 128 channels each, and a silicon sensor. The sensor has 1280 strips with a length of 8 mm on a pitch of 50 μm. The thickness of the sensor is 300 μm. The properties of the microstrip detector are summarized in Table 2.

The principle advantages of the microstrip detector are the parallel detection of X-rays and the fast readout time of 250 μs. This dramatically reduces the time needed to record a full spectrum from hours required with the analyzer to seconds with the microstrip detector. This allows one to

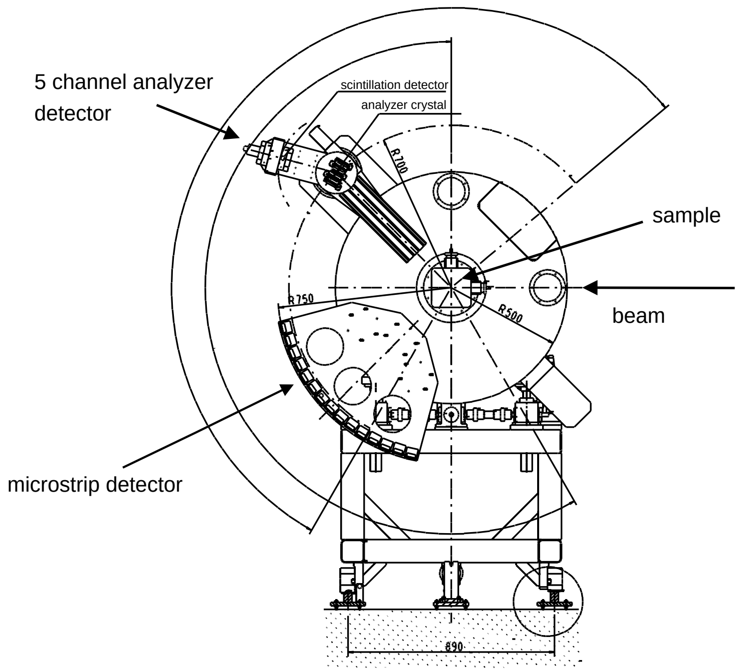

Fig. 1. Powder diffraction station at the material science beamline of the SLS. The sample is mounted in a capillary at the center. The five channel analyzer detector is used in the upper half of the diagram and the microstrip detector in the lower. Both systems can be used in parallel. The strip detector is mounted at a distance of 76 cm from the sample position.

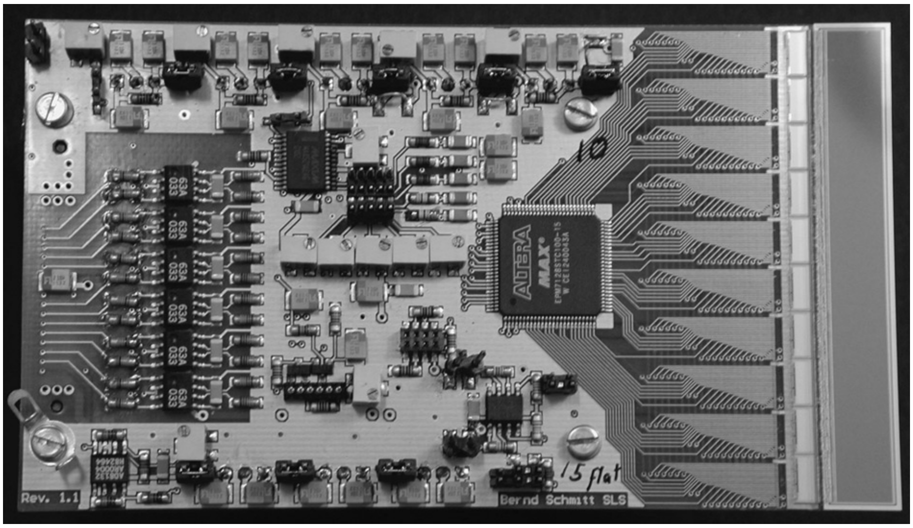

Fig. 2. The module control board. On the right side is the silicon sensor connected to the 10 readout chips by wire bonds. The module also carries voltage regulators, a DAC to supply the required voltages and additional electronics for chip selection. The size of the module is about 11 cm × 6.5 cm.

Table 2
Properties of the microstrip detector system

Angular coverage	60°
Intrinsic angular resolution	0.004°
Strip pitch	50 μm
Strip length	8 mm
Number of channels	15360
Readout time	250 μs

make time-resolved measurements which, before, were nearly impossible to do.

3. Readout chip

The charge generated by X-rays in a silicon sensor is very low. On average, 3.62 eV are needed to create one electron–hole pair. In the most useful range for powder diffraction (5–25 keV) a charge of about 1400–7000 electrons is generated.

The detector is operated in single photon counting mode. This means that each X-ray generating a charge above a certain threshold is counted. The threshold is preferably set at half the X-ray energy to avoid dead regions between strips. The noise σ of the chip should also be several times lower than the threshold in order to avoid noise counts. Therefore, the main requirements of the readout chip are low noise and low threshold variations. The maximum count rate per channel (measured with test pulses) should be larger than 1 MHz to avoid dead time corrections due to the high flux of the beamline. The counter should have 18 bits to avoid overflows.

The chip is designed in the radiation hard DMILL process. It consists of a chip control block and 128 identical channels. The schematic of a channel is shown in Fig. 3.

The analog part of a channel consists of a charge sensitive pre-amplifier, two shapers and a comparator. Each shaper is AC coupled to the preceeding stage. A source follower drives the coupling capacitor. The comparator threshold voltage is identical for all channels. Each channel, however, can be individually fine tuned by a 4 bit DAC. In the digital part, the level shifter converts the output of the comparator from the comparator supply voltage to the -5 V logic level used in the digital block. The counter is realized as an 18 bit pseudorandom counter [4], i.e. an 18 bit shift register with a XOR feedback. The clock generator generates the steering signals for the shift register. Each channel has six programmable bits. One bit disables the channel. One bit puts the analog signal

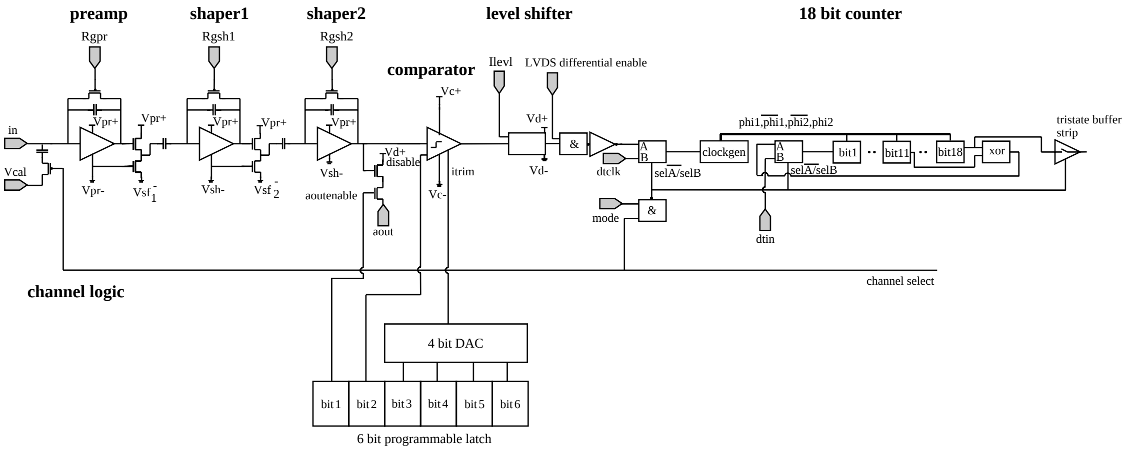

Fig. 3. Readout chip schematic. The chip consists of a global chip control logic (bottom part) and the channel electronics (upper part) which is identical for each of the 128 channels.

to the analog output of the chip. The other four bits are for the programming of the DAC. The analog output is, together with the possibility to pulse a selectable channel, a very important tool for debugging.

The chip control block consists of a 136 bit long shift register which serves to select a channel for readout and pulsing. The lower 6 bits also serve to program the programmable bits of the selected channel. The data from the counters is serially put on one digital output pin during readout.

The chip was designed in two steps. For the first submission the full chip with 10 different preamps was designed. The noise of the preamps was measured and the optimal combinations were chosen for the final production run in the second submission.

The equivalent noise charge (ENC) of the final chip with sensor has been measured to be 240e^{-}. With a threshold at 5σ and half the X-ray energy this corresponds to a lower detectable energy of 8.7 keV. With a threshold at 4σ this reduces to 7.0 keV. The maximum achievable count rate for standard settings has been measured with test pulses to be 1.4 MHz per channel.

4. Readout system

The complete detector system is shown in Fig. 4. Its main feature is the direct data flow, without intermediate data storage. This keeps it both simple and fast.

The 12 detector modules are connected to a detector control board (DCB). The detector control board distributes the control signals coming from a VME pattern generator to the individual modules and also sends the data from the modules to an input board. Currently, the input board is a VME fifo module with an input width of 32 channels and a depth of 64k. The VME module will later be replaced by a 64 bit wide PCI card in a PC. All chips on all modules can be read out in parallel with a speed of 10 MHz. Therefore, there is a 120 bit wide serial data stream from the modules coming to the DCB. The DCB then multiplexes this onto the 32 bit VME fifo or the 64 bit PCI card. The VME fifo has a 10 MHz input rate. The DCB reads out three modules at a time in four groups. The readout time with the VME fifo module therefore is 1 ms. The PCI card accepts an input rate upto 80 Mhz. For this configuration the DCB will multiplex the 120 bits at 10 MHz coming from the modules to 60 bit at 20 MHz to the PCI card. The readout time then will be 250 μs.

The serial data coming from the shift registers after readout is converted to parallel data and the pseudorandom counter values are converted to real counter values using a look-up table. This is done by software.

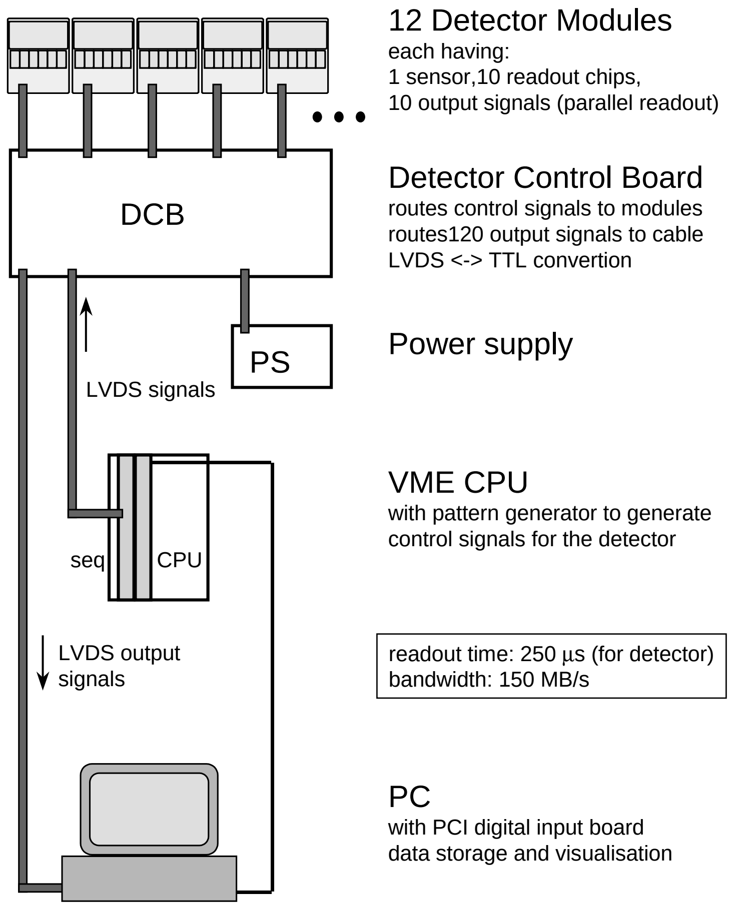

Fig. 4. Readout system. The complete detector system has been optimized for fast readout.

5. First measurements

Since August 2001 one module covering an angular range of 5° in 2θ is permanently installed at the beamline and routinely used for measurements.

The first time-resolved measurement was a study of the hardening process of cement (done with I. Müller, University Münster). The module was positioned at a certain angle and, without moving it, data was iteratively accumulated for 1 min during the first hour of the hardening process and then written to disk. Fig. 5 shows the result. The development of the different phases with time is clearly visible.

A flat field correction was used to equalize the different channel efficiencies since the software for an automatic fine adjustment of the threshold was not yet ready. For this correction the module was exposed to a flat illumination with X-rays. For each channel a correction factor was determined such that the counts of all channels are the same after applying these factors. These correction factors were then used to correct the data.

6. Conclusions

A new detector system for X-ray applications, the Mythen Detector, has been developed. Its principle applications are time-resolved measurements. The specifically developed readout chip works well and allows measurement of X-rays down to 8.7 keV with a 5σ separation from the

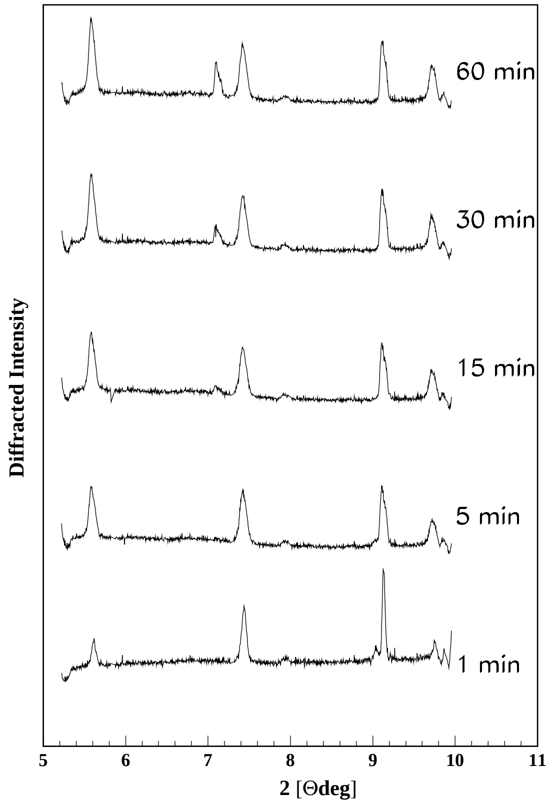

Fig. 5. Time development of the cement hardening process as recorded by the single module strip detector. The 1280 channels cover an angular range of about 5°.

noise and a threshold at half the X-ray energy. The full detector will be installed in April 2002. First measurements are promising and show the potential of the detector. More measurements, especially a detailed comparison of the Mythen detector with the crystal-analyzer setup remains to be made.

Acknowledgements

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