Journal of
Synchrotron
Radiation

ISSN 0909-0495

Introduction to the Special Issue on Detectors

Heinz Graafsma

European Synchrotron Radiation Facility, 6 rue Jules Horowitz, BP 220, 38043, Grenoble CEDEX 9, France

The idea of producing a special issue of the *Journal of Synchrotron Radiation* on X-ray detectors was born during a workshop on detectors associated with the ESRF users' meeting in 2003. During this meeting it became clear that the user community needed to be provided with an overview of the current state of the art in detectors as well as of the various ongoing developments. This overview should be provided in a format and language accessible for the beamline scientists at synchrotron sources, without the specific jargon used by detector scientists and engineers, and pointing out the potential applications and advantages for the users at the synchrotron beamlines. This is what the authors of the ten review papers had in mind when writing their manuscripts.

The mismatch between the synchrotron source performance on one side and the detector capabilities on the other has been pointed out repeatedly in publications (see, for example, Lewis, 2003, and references therein), as well as at numerous workshops and meetings on detectors. These workshops also pointed out the impact that new and better detectors could have on the science performed at synchrotron beamlines (for example, the 'European Workshop on X-ray Detectors for Synchrotron Radiation Sources', Aussois, France, 1991). It is generally known, and unfortunately accepted, that the detector is often the limiting factor in the experiment. This persistent 'production–detection' gap is mainly due to the phenomenal increase of spectral brightness of the storage-ring sources, and not so much due to a lack of detector developments. The number of recorded photons per second, or more precisely the number of ADUs (*i.e.* analogue to digital units, or arbitrary detector units) per second has increased exponentially over time as we have moved from X-ray film to gas-filled detectors, to imaging plates, to CCD-based systems, and now to the so-called pixel detectors. A plot of the number of recorded photons per second as a function of time shows a remarkable similarity with the well known plot of the progress of source spectral brightness. Nevertheless, today, detectors still fall behind the sources in their performance. One of the reasons that this situation is tolerated is the fact that, even with non-optimal detectors, innovative and cutting-edge science has been possible; therefore, the push by the users for new detectors was never sufficient to put detector developments to the forefront – a situation that might change in the future.

Storage rings are approaching their performance limits and the exponential increase in the spectral brightness of storage-ring-based synchrotron sources will level off in the years to come, whereas the detection capabilities will continue to improve dramatically, as indicated in the review papers of this issue. Of course, new sources, not based on storage rings, like the energy-recovering linacs and the X-ray free-electron lasers, will become operational in the future, continuing the exponential increase in spectral brightness. However, these new sources, by their very nature, will not replace the storage rings but rather be complementary to them. This means that not only detectors and detector technologies being developed directly for the storage rings, but also that the new technology developed for these short-pulse sources will increase the detection capabilities at the storage rings. This changes the perspective for detector developments for storage rings.

Possibly the highest 'return-on-investment' can be obtained by putting resources into detectors and detector development. This insight is reflected in the various long-term strategies currently under development at various established and emerging storage rings, which all contain a major part on instrumentation development in general and detectors in particular. It is also reflected in the fact that there is an increasing number of international collaborations between synchrotron radiation facilities in the field of detector developments. This increases the critical mass and allows for the development of fully custom-made systems, adapted to the needs of the beamlines. Current developments are, on the contrary, of smaller scale and often restricted to adapting existing systems or components to beamline applications.

It is no surprise that the semiconductor technology, and in particular silicon, will play an ever increasing role in X-ray detectors, both for the sensors themselves and for the front-end electronics. With microelectronics technology becoming widely available, it is economically feasible to design and fabricate application-specific integrated circuits, allowing for massively parallel signal processing. The first four manuscripts of this special issue, therefore, deal with silicon technology.

The first contribution, by G. Lutz, shows how silicon engineering and processing can be used to design detectors with special and outstanding capabilities: silicon drift and silicon pixelated detectors are widely used in space research, but so far only scarcely at synchrotrons. This is despite the fact that some of the systems could be directly used and would present a major advance in detection capabilities. The second and third manuscripts, by Ercan *et al.* and Broennimann *et al.*, respectively, present current development in hybrid pixel detectors. Ercan *et al.* describe analogue or integrating pixel detectors, for fast time-resolved applications, whereas Broennimann *et al.* describe the digital or counting pixel detector. Both pixel detectors have their own fields of application and should be seen as complimentary. The fourth paper in silicon detectors is by Baron *et al.* and describes avalanche photodiodes for very fast timing and high-count-rate experiments.

Since the application of silicon as X-ray detector is limited to approximately 25 keV owing to its modest X-ray absorption, it is of importance to investigate and develop other semiconductor materials. The developments in this area are mainly pushed by the medical imaging industry and space research science. An overview is given by A. Owens. Another material of special interest to the synchrotron detector community is diamond. Diamond can almost be considered as a new material; with the recent progress in chemical vapour deposition technology it is now possible to synthesize large-size diamonds of detector grade quality and with controlled and reproducible characteristics. The field of diamond X-ray detectors is reviewed by Bergonzo *et al.* Another detector technology whose development has been driven by space science is based on the superconduction tunneling junction (STJ). These detectors operate at sub-Kelvin temperatures and provide excellent energy resolution of a few meV. The STJ detectors and their application in synchrotron science are presented by S. Friedrich.

Gas-filled detectors are likely the first and best example of fully custom-made detector systems at synchrotrons. Whereas other systems, for example the CCD-based systems, were mainly adapted from other applications, gas-filled detectors have been fully constructed at synchrotron (and neutron) sources. G. Smith gives an overview of the field, including new and promising developments. The penultimate manuscript, by Martin & Koch, deals with detectors for imaging with very high spatial resolution, a field of increasing importance at storage-ring sources. These detector systems use in most cases commercially available CCD detectors and visible-light optics, combined with custom-made scintillators. The final manuscript, by C. Ponchut, gives a clear overview of the methods and definitions to characterize and test the various performances of imaging detectors.

Unfortunately, this overview of detectors is by no means complete, and the absence in this special issue of certain systems, like MOS CCD-based systems, active pixel sensors, and many others, is by no means meant to imply a lack of their importance or (future) impact. But it is hoped that this special issue will help to give detector development at storage-ring sources the importance it deserves, so that it will be recognized as a scientific activity in its own right, and not merely as an engineering exercise. Only by that can we reach the point where we 'develop what we need' instead of 'take what we can'.

References

Lewis, R. (2003). *Nucl. Instrum. Methods*, A**513**, 172–177.