Technical Note 52342

Silicon Drift Detectors

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Key Words

Silicon Drift Detectors (SDD), Energy resolution, High count rate, SEM/EDS

Silicon Drift Detectors (SDDs) are the current state-of-the-art for high resolution, high count rate X-ray spectroscopy. Modern SDDs benefit from a unique design that enables them to achieve a much higher performance than lithium drifted silicon – or Si(Li) – detectors. Specifically, they experience far less electronic noise, which is particularly observed at short peaking times (i.e. high count rates), larger detector areas and low X-ray energies. As a result, they have largely displaced Si(Li) detectors and are now used in large quantities for industrial scale applications like electron microscopy (SEM/EDS) and X-ray fluorescence analysis (EDXRF).

Figure 1 shows a typical SDD device. The chip is mounted on a thermoelectric cooler which provides device cooling. SDD devices come in a variety of shapes. The droplet-like shape shown in this figure is commonly used for smaller active areas such as 10 mm² and 20 mm². The radiation entrance window which is shown in the picture consists of a flat p-implanted region covered by a thin conductive layer to keep the entrance window radiation hard.

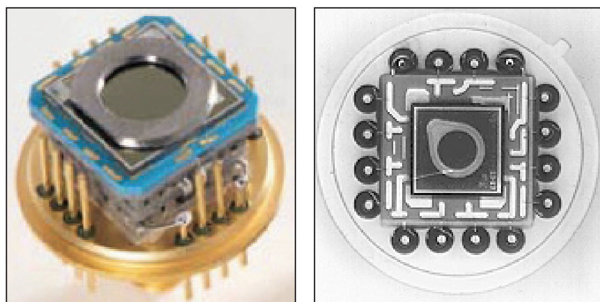
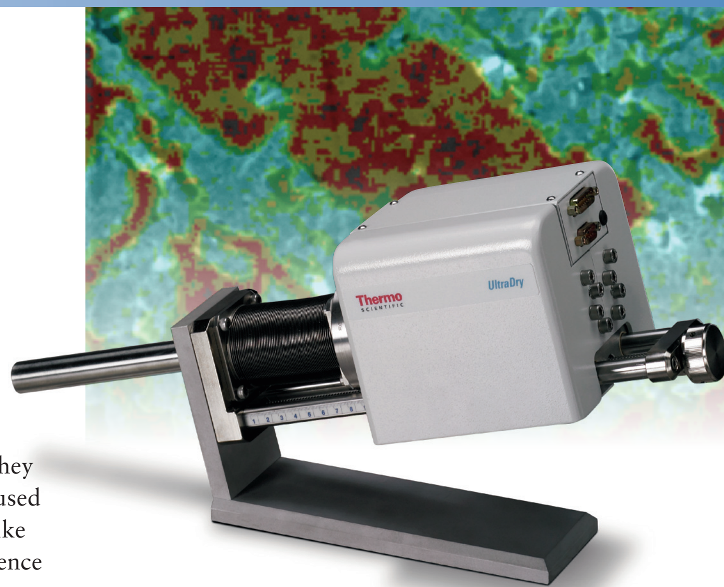


Figure 1: Typical mounted and bonded SDD devices



X-ray Detector Fundamentals

Typical X-ray detection devices consist of an active region composed of fully depleted, high-resistivity silicon, a front contact area and a collection anode. X-rays incident upon the front contact area are absorbed in the bulk Si region and generate electron-hole pairs. The quantity of charged carriers generated depends on the energy of the incident X-ray. A pre-established electric field between the front contact and the anode causes these electrons and holes to drift along the field lines; i.e. toward the anode. The charge accumulated at the anode is then converted to a voltage by a pre-amplifier.

The incident X-ray energy can be determined by monitoring the magnitude of the voltage step after each pulse; i.e. after each incident X-ray is absorbed. Figure 2 is an example schematic of the electronics associated with an X-ray detector. When the output waveform exhibits fluctuations due to noise, there is a limit to how precisely this voltage step is measured. The measurement

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imprecision creates a Gaussian spread for a given energy. Thus, noise effectively widens the measured X-ray peaks. Figure 3 illustrates the voltage steps and associated noise. Noise is influenced by factors such as the FET gain, input capacitance and pre-amplifier leakage current. Over longer shaping times, the noise is averaged out and the resolution improves. Over shorter shaping times (i.e. those used to drive higher count rates), there is less averaging of the noise and subsequently more uncertainty in the voltage step, worsening resolution. Additionally, the signal to noise ratio is necessarily lower for low energy X-rays; indicating that noise plays a larger role in the resolution of low energy X-rays.

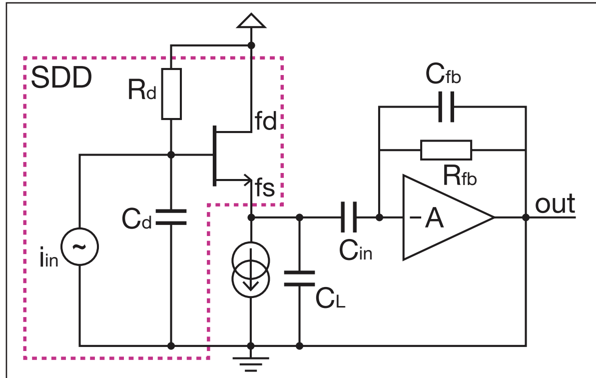

Figure 2: Schematic of the electronics in an X-ray detector. The SDD dashed line illustrates the electrical impact of the integrated FET.

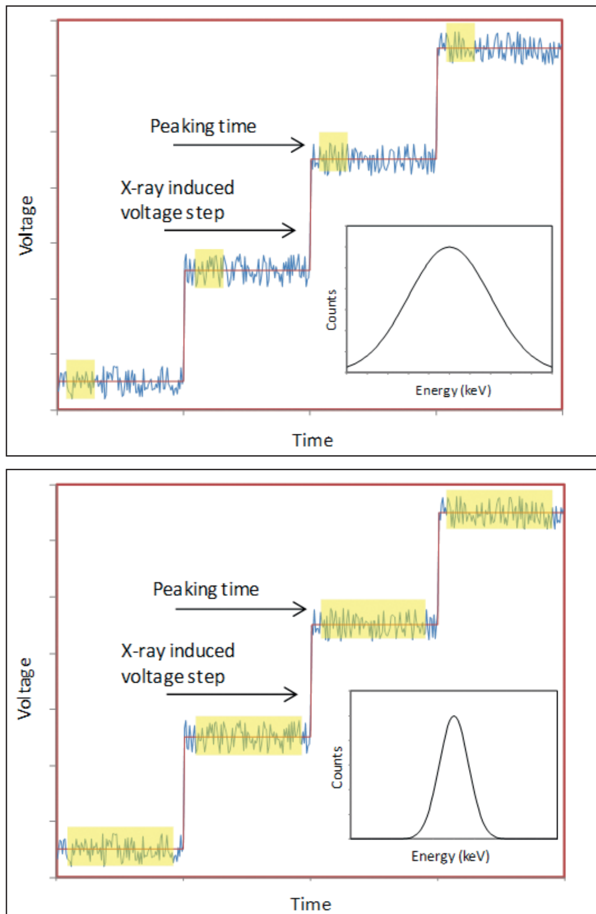

Figure 3: Illustration of voltage steps as a function of an absorbed X-ray. The noise fluctuations demonstrate the impact of noise and shaping time (top vs. bottom) on resolution.

Sources of Noise

There are several sources of electronic noise, characterized by the equations below.

$$\textit{Electronic noise} \propto \textit{shot noise} + 1/f\ \textit{noise} + \textit{thermal noise}$$

$$\textit{shot noise} \propto I_{leak}$$

$$1/f\ \textit{noise} \propto C_{in}^2$$

$$\textit{thermal noise} \propto \frac{kT}{g_m}\frac{C_{in}^2}{\tau_{peak}}$$

The first factor is shot noise, generated by leakage current in the pre-amplifier. The next factor is "1/f" noise, which is directly related to the capacitance squared. The third factor is thermal noise, which is related to the capacitance squared, to the temperature and to the inverse peaking time. As the capacitance gets small enough – for example as the anode size is reduced – the total resolution for an X-ray becomes predominantly dependent on the shot noise. Because the shot noise is independent of temperature, cooling the detector is much less important to achieving good resolution. It is also now far less dependent on a long shaping time. Eventually the noise becomes small enough that resolution becomes almost entirely limited by Fano broadening. Fano broadening is based on statistical fluctuations in the radiation interaction with the Si crystal lattice and the charge production process. When this limit is reached, the theoretical best resolution is roughly 120 eV.

Figure 4 demonstrates the resolution – as measured at the Mn Kα peak – as a function of shaping time for a typical SDD and a typical diode detector. Because the SDD has lower capacitance – and therefore lower noise – this translates into superior resolution with shorter shaping times and larger active areas; i.e. superior resolution at superior count rates.

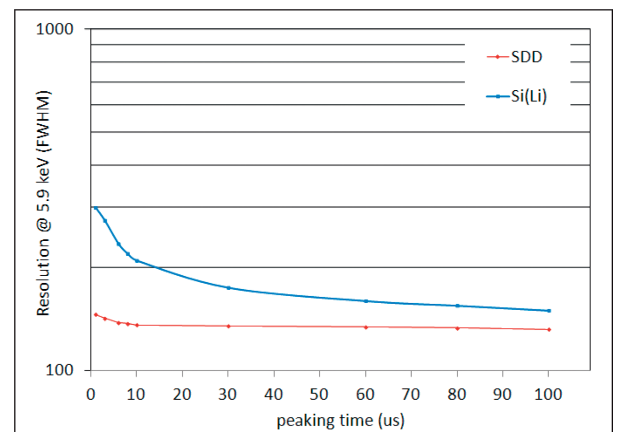

Figure 4: Energy resolution at Mn Kα as a function of peaking time for typical SDD and Si(Li) detectors

Modern X-ray Detectors – the Silicon Drift Detector (SDD)

The basic form of the Silicon Drift Detector (SDD) was proposed in 1983 by Gatti & Rehak.[1] It consists of a radial electric field which is intentionally established and controlled by a number of increasingly reverse-biased, circular field strips covering one surface of the device.[2] This field terminates in a very small collecting anode on one face of the device. The design of an example SDD, Figure 5, demonstrates this ring electrode structure, which creates the radial electric field. The radiation entrance window on the opposite side is composed of a thin, shallow implanted p^+ doped region, which provides a homogeneous sensitivity over the whole detector area. A thin conductive layer is applied on top of this p^+ doped region in order to improve radiation hardness.

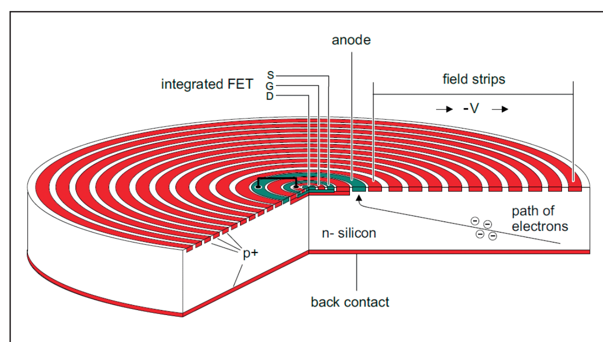

Figure 5: Example SDD detector design

The unique value of this type of detector is the extremely small size of the anode, relative to the overall active area of the detector. The X-ray generated charged carriers (i.e. electrons and holes) are guided along these electric field lines to the very small anode at the center of the detector. Because the device capacitance is directly related to the size of the anode, a dramatically smaller anode results in a dramatically lower device capacitance. Typically observed anode capacitances are 25 – 150 fF. Because the electronic noise at short shaping times is proportional to capacitance squared (see below for more discussion on noise), the benefit of a smaller anode is better resolution at shorter shaping times (higher count rates); in particular at low energies where the signal to noise is lower.[3] The noise is small enough that the device can be operated at temperatures (~ -20 °C) that are readily achieved with a peltier device; thereby eliminating the need for LN_2 cooling.

To take full advantage of the small output capacitance, the front-end transistor of the amplifying electronics is integrated directly onto the detector chip and connected to the collecting anode by a short metal strip. This eliminates parasitic capacitance at bonding pads; minimizing capacitance between the detector anode and the amplifier FET. Additionally, noise caused by electric pickup, cross-talk and micro-phony effects are rendered insignificant. This impact is illustrated schematically in Figure 2.

A more modern SDD design, Figure 6, involves an offset anode and FET. This is often referred to as a "tear-drop" or "droplet" SDD. When the integrated FET is at the center of the device, as in Figure 5, it is susceptible to irradiation by incident X-rays. Additionally, the electrostatic fields surrounding the FET result in performance losses at low X-ray energies. When the FET is offset, as in Figure 6, it is outside the active area and therefore not subject to incoming radiation. This design is still relatively unique and is most common on smaller area (10 mm²) detectors.

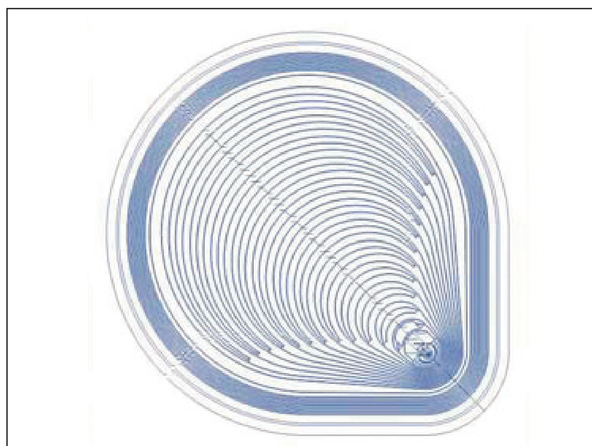

Figure 6: Modern detector with offset anode and pre-amplifier FET

References

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