

BREAKTHROUGH IN EDS TECHNOLOGY

Silicon drift detectors provide better sensitivity, higher resolution, and faster operation than traditional Si(Li) detectors for energy dispersive X-ray spectrometry.

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Silicon drift detectors (SDDs) have been known since the concept was invented by Gatti and Rehak in 1984, and they have been available commercially for energy-dispersive X-ray spectrometry (EDS) since 1996. However, as of the 2007 Microscopy and Microanalysis meeting, it has become clear that SDDs are now the future of X-ray microanalysis. Every major EDS manufacturer offers one, and sales of traditional Si(Li) detectors have declined dramatically.

The reasons for the switch to SDDs are many. The table shows some of the advantages of the technology, while the only significant drawback is loss of sensitivity to X-rays above about 12 keV.

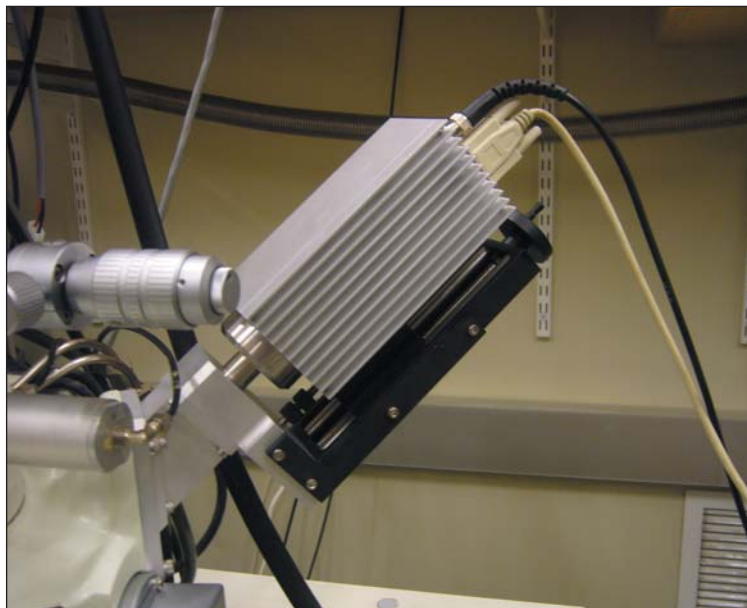
The high count-rate operation cited in the table needs some explanation. Although the nature of SDD technology with its associated pulse-processing electronics permits count rates well in excess of 100 kcps, this presupposes that such count rates can be generated by the beam without destroying the sample. Metals, ceramics, and minerals can generally withstand such bombardment, but modern high-resolution SEMs may not be able to generate enough current, and certainly not under high-resolution imaging conditions. Moreover, the X rays have to be on a path within the solid angle subtended by a 5 or 10 mm² detector.

SDDs are based on silicon chips about 400 μm thick. Accordingly, high energy X-rays can penetrate the chip without being detected. Even though nearly all elements have an X-ray line of interest between 100 eV and 10 keV, there may be reasons, such as peak overlaps, for choosing a K line instead of L lines.

How the technology works

Semiconductor processing is used to create a pattern on the silicon chip. A schematic diagram is shown in Fig. 1. The purpose of the concentric pattern is to provide a field gradient for the electrons produced by incoming X-rays. Under the influence of this field, the electrons drift towards a small contact that serves as the anode. Because the contact is small, the capacitance of the device

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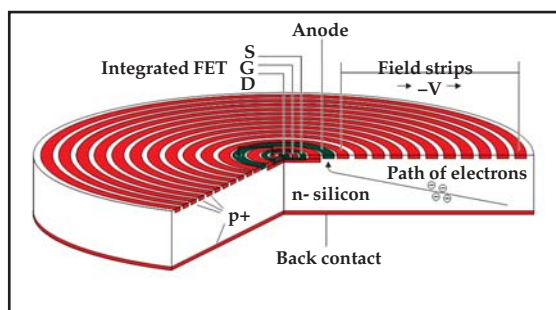


Fig. 1 — Diagram of SDD showing rings to shape the field, small central anode, and on-chip FET (diagram courtesy of PNSensor).

is reduced, thus reducing the noise. The result is better spectral resolution. A typical anode size is 400 μm², and is independent of the device area, which could be 5 to 60 mm². The solid angle available to collect X-rays depends on the device area and its distance from the point where the beam hits the sample.

A significant advance in the technology came when the preamplifier field-effect transistor (FET) was patterned onto the chip itself. By so doing, higher count rates can be achieved, and electronic noise is reduced. Furthermore, since bond pads and wires are not needed, microphonics are eliminated. A further significant design improvement involves moving the FET out of the line of sight of the X-rays in a teardrop or “droplet” configuration. A collimator is placed over parts of the device, including the FET. Accordingly, incoming X-rays do not generate noise in the charge-sensitive preamplifier, yet the FET remains onboard

Benefits of silicon drift detectors

High count rate operation (>100,000 cps)
Near room-temperature operation (~ -20 °C)
No LN ₂
Rapid cool down
Near theoretical spectral resolution
No peak shift or broadening with count rate
Light element detection to Be
Carbon resolution better than 50 eV
No microphonics
Radiation hardness

Why is it so fast?

Electron-hole pairs are produced in the silicon by the incoming X-ray photons, but only the electrons are collected. They drift toward the anode under the influence of the field, where they are collected, and the charge is transferred to the on-chip FET.

SDDs have much lower capacitance than traditional devices with planar electrodes, thus allowing for short shaping times, and high count rates. Multi-element array detectors have also been developed for count rates in excess of 10^6 cps, if such count rates are needed and if the chamber has space for the array.

the chip for fast response. This configuration is shown in Fig. 2.

Operational considerations

The reason Si(Li) detectors are no longer preferred seems to be that SDDs have so few drawbacks. The count-rate capability leads to greater precision in an analysis, because precision depends on the number of counts in a peak. Minimum detectability limits are also lowered when many counts are collected and the peak/background ratio is high.

The practical consequence of a lower detectability limit is the analysis of materials with elements present in $<0.1\text{wt}\%$ concentration. Because EDS is a micro-analytical technique, alloys and their constituent phases can be distinguished confidently, even based on their low-concentration components.

Not only can SDDs operate at very high count rate, but also they can respond to changes in

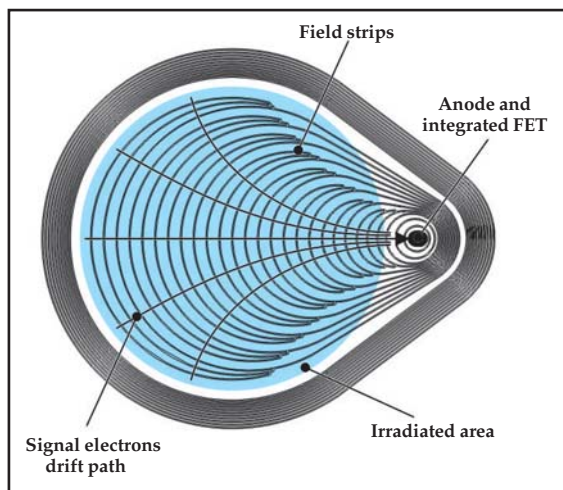


Fig. 2 — Diagram of an SDD configuration with an on-chip FET displaced from the irradiated area FET (diagram courtesy of PNSensor).

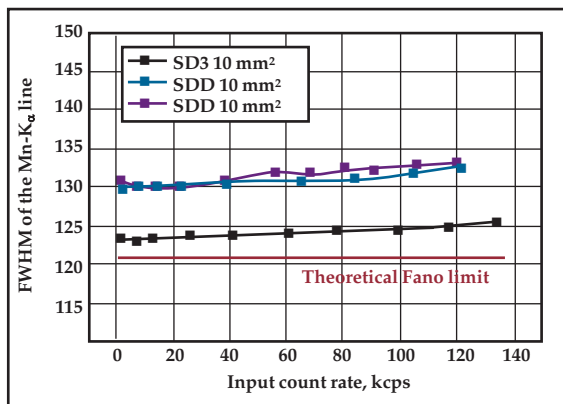


Fig. 3 — Plot of detector resolution vs. count rate for various SDDs. Plots labeled SDD refer to devices with the FET mounted in the center. Plot labeled SD3 refers to a droplet device (diagram courtesy of PNSensor).

count rate without peak shifts or significant loss of resolution, as shown in Fig. 3. Detectors from different manufacturers do not all have the same properties, but some are truly impressive.

High-quality X-ray maps can be collected in a short period of time, and they look almost like electron images. Operators often collect maps at a higher spatial resolution than warranted by the X-ray/specimen interaction volume, to avoid maps that look pixelated. At a few thousand times magnification, 128 pixels in one direction approximately matches the X-ray range in metals. In other words, the size of one pixel is approximately the same as the area from which X-rays are emitted.

Even though it makes sense to avoid oversampling, and collect to the required precision, many operators persist in selecting high digital resolution and not extending the counting time. With the high count-rate capability of drift detectors, little time is wasted by using 512 or even 1024 pixels to produce an aesthetically pleasing map.

The near-room-temperature operating environment eliminates the need for filling a liquid-nitrogen Dewar several times per week. Thermoelectric (Peltier) cooling brings the device to operating temperature in the range of -10 to -70°C , often in the time it takes to put the sample in the microscope and pump it down. Likewise, some of the devices warm up in about the time it takes to vent the chamber, and the detector can be left warm when not in use. Atmospheric thin windows (ATWs) or windowless configurations are available.

Light element detection down to beryllium has only recently been demonstrated and is probably one reason that SDD technology has overtaken lithium-drifted silicon. Early SDDs with ATWs could detect carbon, but nothing lighter. Pulse pile-up varies with count rate and is most significant at maximum count rates and with soft X-rays, such as from light elements. Two recent papers have demonstrated different approaches to minimize the effects of pile-up: Mott has demonstrated the effect of pulse-processor hardware specifically designed for the SDD, and Statham has shown a method to minimize pile-up in software.

Converting from Si(Li)

Upgrading from a Si(Li) detector system could involve replacing only the detector to achieve most of the benefits cited above. However, pulse processors designed for traditional detectors usually cannot process pulses from an SDD fast enough. Therefore, to achieve the highest count rates, a new pulse-processor will probably be necessary. Digital beam control hardware and software are unaffected. Modern computer analyzers commonly control the detector electronics in software, so that becomes a consideration when replacing the detector and electronics.

Future improvements

It is always dangerous to make predictions, but I expect few significant improvements in the highest-performing detectors from this point on. Spectral resolution of some is near theoretical for a silicon-based device. Some SDDs claim a full-width-half-max (FWHM) at the Mn K α peak of 123 eV, compared with a theoretical FWHM of about 120 eV. The count rate capability inherent in the device and its pulse-processing electronics are beyond what many electron beam instruments can generate easily.

The design of the pulse processor, whether digital or analog, has an effect on the resolution and count rate, but in the case of hardware optimized for the SDD, there is little room for improvement. The cooling technology is firmly established and operating the device colder does not improve performance. Light-element performance depends on silicon crystal processing and on the matching electronics, and can always be an area for improvement.

Since sophisticated semiconductor processing is necessary to produce the device, EDS manufacturers buy at least the silicon chip from a semiconductor producer. Some EDS companies also buy the cooling circuitry and the associated pulse-processing electronics, while others design downstream components themselves. Consequently the properties vary somewhat between detectors of different manufacturers, but all have the ability to operate near room temperature and process high count rates.

FWHM and light element capability may vary somewhat from one manufacturer to another, but SDDs are no worse than Si(Li) detectors, except at higher energy lines. In the best cases, SDDs significantly exceed the performance of modern Si(Li) detectors. Inasmuch as materials such as metals and ceramics can generally withstand high beam current, they are excellent specimens for high-count-rate operation. All things considered, this seems like an excellent time to upgrade to a silicon drift detector. ◆

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In the best cases, SDDs significantly exceed the performance of modern Si(Li) detectors.

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