X-Ray Detectors: A Changing World

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Introduction

*The first in a series of articles looking at developments in **X-ray detectors and Field effect transistors**. In recent years we have seen both **Si(Li) and Intrinsic Silicon Detectors** with resolutions below 130 eV. These same detectors are capable of measuring the soft X-rays like Be K, B K, C K etc. with good resolution and with peak positions reasonably close to the exact position for these lines. The Carbon peak is the one most affected by the L absorption edges in Silicon and in some circumstances can be shifted as much as 30 eV down in energy. Shifts can also result from the settings of amplifier threshold discriminators and ADC designs. At higher energies (e.g. Mo K) the Si(Li) detector, if not properly drifted can also have a down shift by as much as 200 eV.*

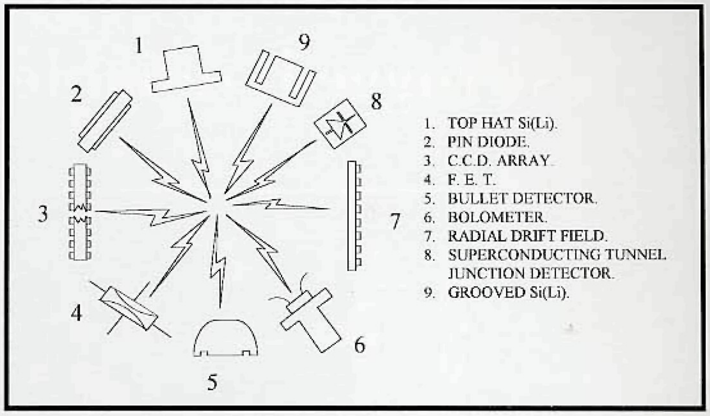
The more recently introduced Intrinsic Germanium Detector suffers from slightly different problems. The Ge L edges affect the Al K more than any other line but in a good detector the Al K is in the correct position with the right width. To date no one has reported high energy non linearities and except for the problems with escape peaks and being able to cool on demand, Germanium does look like the better long term candidate when these particular problems have been overcome.

Simultaneous detection of a wide range of characteristic x-rays with good resolution is now a routine feature of the science of microanalysis, x-ray fluorescence and x-ray diffraction. This has been achieved using detectors made from semiconductors. Excitation can be accomplished in a variety of ways. Electrons are used in the electron microscope and the electron microprobe(1) whereas x-rays from a small compact x-ray tube(2) are used in x-ray fluorescence and diffraction equipment. Samples can also be excited by particles from a particle accelerator (Pixe)(3) or x-rays from an electron synchrotron.(4)

Silicon technology has dominated these application areas for over 30 years. The silicon detectors are typically 3 mm deep with cross-sectional areas in the range 5 mm^2 to 80 mm.^{2} In recent years Germanium(5) has been introduced as an alternative to Silicon. We are just now beginning to see the early commercial exploitation of several new silicon detectors. These include PIN diodes(6), Drift Chambers,(7) CCD arrays,(8) novel pixellated structures(9) and a group of devices that are operated at temperatures close to that of liquid helium.(10) As scientists and engineers strive to push the technology barriers further towards the theoretical limits and as new materials become available we will hopefully see some further very exciting new detectors.

With these advances it is worth taking a moment to review some of the desirable properties that we require from x-ray detectors. For many applications in microanalysis scientists are interested in detecting all x-rays down to and including the very soft X-rays from Oxygen, Carbon and even sometimes Boron and Beryllium. This performance demands good resolving power and a good peak to background ratio. For a "without compromise" performance a Premium Silicon detector should have a resolution measured at 5.9 keV (^{55}Fe Mn Kalpha) of better than 130 eV and a resolution at 273 eV (Carbon K) of better than 70 eV. To achieve this the detector should have an intrinsic peak to background ratio as measured between 5.9 keV and 1.0 keV of better than 3000:1 and preferably better than 20,000:1. Both the modern Si(Li) and Germanium detector is capable of this peak to background performance. Also Germanium detectors are capable of yielding a resolution of better than 110 eV at 5.9 keV.

The results seen with PIN diodes and CCD arrays are significantly worse in terms of peak to background and the appearance of unwanted satellite peaks. Both these detection technologies have not, as yet, benefited from the front and rear contact technology perfected for the Si(Li) and Germanium detectors. Also, the depletion layer thickness of these diode structures is relatively thin (between 50 and 500 microns) and spectra often contain fluorescent lines from the contact structure and from materials behind the detector. These detectors will transmit x-rays at energies above 10 keV. However, the resolution at warmer temperatures is encouraging and these structures will find use in areas where dedicated instruments are required to detect well separated lines in the 1.0 keV to 10.0 keV region. Improvements will be made over the next few years and eventually these new devices will compete favourably with that of the Si(Li) detector with the advantage of operating at warmer temperatures.



To summarize what is available today the following table has been drawn-up from results reported either in the scientific literature or manufacturers' data sheets.

Detector Type	Resolution at 5.9 Kev	Cooling method	Peak to background
Si(Li)	better than 135eV	Cooled using LN	>10,000:1
HPG	better than 110eV	Cooled using LN	>10,000:1
PIN	better than 250eV	Peltier Cooled	>200:1
Drift Chamber	better than 200eV	Peltier Cooled	>100:1
CCD	better than 200eV	Room temperature	>100:1
Pixellated Arrays	better than 200eV	Room temperature	>100:1
Bolometers	better than 15eV	Liquid helium cooled	>1000:1
Super Conducting Tunnel Junction detectors	better than 20eV	Liquid Helium cooled	>1000:1

There are further compromises that have to be taken into account when selecting the correct detector. For example all Silicon x-ray detectors have the well known escape peaks resulting from the loss of Silicon K x-rays at 1.74 keV and the L lines at energies of between 70 and 150 eV. Spectra recorded with a Germanium detector will have more escape peaks (one from the Kalpha and one from the well resolved Kbeta) for energies above the Germanium K-absorption edge (11.1keV). Ironically, Germanium, even though it has the higher stopping power which is more useful for the higher energy photons also has a better resolving power which is more useful at the medium and low energies. Here the spectra are free from escape peaks (at least in the region up to 11.4 keV) except for those from the Germanium L lines (1.1 keV). At higher energies the spectra do become cluttered with escape peaks and these have proved to be difficult to remove by software except under certain conditions. Consequently Silicon, even with its ower stopping power is more appropriate for events above 10 keV. The new developments (PIN Diodes, Drift Field Detectors, CCDs etc.) are thin structures for use in the 1-10 keV region. **It is a pity they could not be made from Germanium!!**

One other major advantage of the high purity Germanium detector is that the manufacturing process does not include the "Lithium Compensation" step required in Silicon. Germanium can be grown and refined to a level where it can be depleted to depths of up to several mm's with reasonable voltages (500 - 1000 volts). It has been known for many years that the Lithium compensation process in Silicon can produce traps. These can give rise to satellite peaks and non-linearity particularly at the higher energies. At these energies (above 20 keV) the charge released during ionisation will be distributed throughout the bulk of the detector with a fraction appearing near the side walls and the rear contact. Some of the holes produced will now have the maximum distance to travel in the applied field and, if hole trapping is present, will lead to both a downshift and a broadening of the high energy events. **If only Intrinsic Silicon were available in regular supply quantities then this problem could also be avoided!!**

In summary the important technical features to look for in a detector are:

(a). Will it efficiently cover the energy range you are interested in?

(b). Does it have the resolving power capability for the work you intend to do? This is a very important requirement for low energies.

(c). Does it have the peak to background performance for your application? This is important at low energies for electron excited spectra where the bremstrahlung is reducing and at all energies for XRF and Pixie applications. Here, the form of excitation produces much lower backgrounds making the detectors' intrinsic peak to background more useful.

(d). Does it contribute satellite or stray peaks to the spectrum. This is particularly noticeable in thin PIN diodes and CCDs and may well apply to the detectors that are cooled close to liquid helium temperature.

(e). Does it have the solid angle requirement commensurate with the yield of x-rays from the specimens under examination. This is for example a major requirement if you are looking at biological specimens in a Transmission Electron Microscope where the x-ray yield is low. There is a clear case here for new detection geometry with much higher solid angles.

The final choice may also have to take into account the convenience and cost of any consumable employed as for example the mechanism for cooling the detector. Arguably, for some applications, a Peltier cooled detector is extremely beneficial. Similarly a Liquid Helium cooled detector even though it has low efficiency and a low data throughput rate (Bolometer or Superconducting tunnel junction detector) may find applications in a few areas where the resolving power is paramount and overrides the cost of a sealed low temperature cooler or a recirculating liquid helium cooler

It does seem from the above that the vast majority of applications will be best served with the reliable and well proven Si(Li) detector and the more expensive Germanium detector for some time yet. These of course can also be cooled by Peltier coolers or sterling engines removing the need for liquid nitrogen. ■

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