

7. MEASUREMENT OF INTENSITIES

appropriate to a semiconductor imager, even though a 2000×2000 CCD with $27 \times 27 \mu\text{m}$ pixels is available.

Semiconductor point counters cooled to 80 K are characterized by their very high energy resolution (better than 2% in the 8 keV region). Some counting PSD's potentially have a similar energy resolution. Two-dimensional X-ray-sensitive CCD's for X-ray astronomy research have been used as photon counters (Walton, Stern, Catura & Culhane, 1985; Lumb, Chowanietz & Wells, 1985) but they can only be used at very low counting rates. In integrating devices, the energy discrimination is lost. Silicon detectors for visible-light applications are made with depletion depths of the order of $10 \mu\text{m}$. For the detection of 8 keV photons with more than 90% efficiency, depletion depths of $165 \mu\text{m}$ are necessary and these can be produced only from very high resistivity material (Howes & Morgan, 1979). Moreover, in commercial visible-light imagers, the depletion region is covered by circuitry or by an inactive layer that constitutes an absorbing window for X-ray detection. For the detection of X-rays or electrons, it is, therefore, customary to thin the device and to illuminate it from the back (see, for example, Meyer-Ilse, Wilhelm & Guttman, 1993).

One-dimensional X-ray detectors utilizing PDA's, such as those made by the Reticon Corporation, have found a number of applications, especially in dispersive X-ray absorption spectroscopy (EXAFS) (Jucha, Bonin, Dartyge, Flank, Fontaine & Raoux, 1984).

A particular problem with silicon detectors is the damage caused by the incidence of X-rays or of energetic electrons. The effects can be minimized by masking all but the active part of their device and by operating it at low temperatures (Jucha *et al.*, 1984).

The use of the room-temperature semiconductor mercuric iodide in place of silicon seems promising (Patt, Deluca, Dolin & Ortale, 1986).

The X-ray diffraction applications of directly sensitive semiconductor PSD's are likely to remain limited. A previous conversion to visible light or to electrons offers the possibility of an optical or electron-optical demagnification onto the imager, as well as of avoiding some of the other problems discussed above (Deckman & Gruner, 1986).

7.1.6.3.2. Light-sensitive semiconductor PSD's

Standard light-sensitive semiconductor imaging devices can be used for X-ray detection if the X-rays are first converted to light by means of a phosphor. One 8 keV X-ray photon produces several hundred light photons in a good phosphor (see Table 7.1.6.2). Because of the low noise levels possible with cooled CCD's (~ 10 electrons r.m.s.), only 1 to 3% of these photons need to reach the device to produce a perfect X-ray detector. Unfortunately, even this is possible only with optics that do not demagnify to any considerable extent (see Subsection 7.1.6.5) and one is thus restricted to a small detector. However, CCDs are now available that can be butted along two or three edges and these make possible the construction of 'tiled' detectors that contain four or six of such CCD chips (Burke, Mountain, Harrison, Bautz, Doty, Ricker & Daniels, 1991; Fordham, Bellis, Bone & Norton, 1991; Allinson, 1994). Individual channels can be read simultaneously (Hopf & Rodricks, 1994), thus making possible a relatively rapid read out of a large number of pixels.

7.1.6.3.3. Electron-sensitive PSD's

In image intensifiers, an output image is produced on a phosphor screen by electrons with an energy of a few keV. A

promising device with direct positional read out consists of a demagnifying intensifier in which the phosphor is replaced by a CCD. Various intensifiers have been described in which the electrons reaching the CCD have an energy of several keV so that the electron-hole generation is amplified (EBS process) (Lowrance, Zucchini, Renda & Long, 1979; Lemonnier, Richard, Piaget, Petit & Vittot, 1985). High-energy electrons are liable to cause radiation damage and similar precautions as for X-rays, such as thinning and back-illumination, are necessary. Experiments have been reported with less-damaging low-energy (200 eV) electrons produced in a microchannel plate (MCP) image intensifier (Dereniak, Roehrig, Salcido, Pommerrenig, Simms & Abrahams, 1985). Both approaches look promising but it is questionable whether a device with an X-ray phosphor input and of adequate size and resolution at an affordable price will emerge in the near future.

7.1.6.4. Devices with an X-ray-sensitive photocathode

Image converters and television cameras with X-ray-sensitive photocathodes have been reported. These cathodes must be thin, or they must have a low bulk density to allow the photoelectrons to escape (Bateman & Apsimon, 1979; Haubold, 1984).

Television tubes with a beryllium window and a 25 mm diameter lead oxide target are available and experimental 125 mm tubes have been described (Suzuki, Uchiyama & Ito, 1976).

X-ray-sensitive Saticon television camera tubes with an amorphous selenium-arsenic target (Chikawa, Sato & Fujimoto, 1984) have an active diameter of only 10 mm but a limiting resolution (MTF = 5%) of $6 \mu\text{m}$. They have an absorption efficiency of 52% for Mo $K\alpha$ radiation and are used mainly for X-ray topography. Other X-ray-sensitive television camera tubes have been described by Matsushima, Koyama, Tanimoto & Tano (1987), Suzuki, Hayakawa, Usami, Hirano, Endoh & Okamura (1989) and Sato, Maruyama, Goto, Fujimoto, Shidara, Kawamura, Hirai, Sakai & Chikawa (1993). Such tubes are discussed further in Section 7.1.7.

7.1.6.5. Television area detectors with external phosphor

Much development has gone into quantitative measurements with area detectors in which the diffraction pattern is formed on an external phosphor fibre-optically coupled to a low-light-level television camera. Mostly the television camera embodies a demagnifying image intensifier coupled *via* demagnifying optics to a sensitive television camera tube (Arndt & Gilmore, 1979; Arndt, 1982; 1985; Arndt & In't Veld, 1988; Kalata, 1982, 1985; Gruner, Milch & Reynolds, 1982) or to a CCD or an array of CCD's (Strauss, Naday, Sherman, Kraimer & Westbrook, 1987; Strauss, Westbrook, Naday, Coleman, Westbrook, Travis, Sweet, Pflugrath & Stanton, 1990; Templer, Gruner & Eikenberry, 1988; Widom & Feng, 1989; Fuchs, Wu & Chu, 1990; Karellas, Liu, Harris & D'Orsi, 1992). Camera tubes were frequently read at commercial television rates (625 lines with a field repetition rate of 25 Hz or 525 lines with a field repetition rate of 30 Hz in Europe and in North America and Japan, respectively), leading to pixel rates of about 10 MHz. Successive images were then digitized and their sums stored in memory (see Fig. 7.1.6.7). Milch, Gruner & Reynolds (1982) developed a slow-scan method for a silicon-intensifier-target (SIT) tube. This latter method has been facilitated by the development of very large scale integration memory circuits, which have made it possible to construct economical image stores into which the camera can write at a slow rate and which can then be read at normal television rates for display purposes.