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7.1.6.5.2. *Light coupling*

Each incident X-ray photon should give rise to several photoelectrons from the first photocathode in order to achieve a high DQE (Arndt & Gilmore, 1979). The best photocathodes have a yield of about 0.2 electrons per light photon; only fibre-optics coupling between the phosphor and the photo-cathode can give an adequate light-collection efficiency (in excess of 80% for 1:1 imaging). With demagnifying fibre optics, the light loss is considerable for purely geometrical reasons. Fibre-optic cones, in which each individual glass fibre is conical, are available for magnification or demagnification up to about 5:1. It should be noted that image intensifiers and TV tubes with electrostatic focusing are normally made with fibre-optics face-plates and that some CCD's are also available with fibre-optics windows.

Where lens optics must be employed, it is best to use two infinity-corrected objectives of the same diameter, but not necessarily of the same focal length, back to back. In practice, the best light-collection efficiency that can be achieved at a demagnification of M is about $(2M)^{-2}$. It is for this reason that there are limitations on the maximum size of image that can be projected onto a CCD without the use of an image intensifier (but see Naday, Westbrook, Westbrook, Travis, Stanton, Phillips, O'Mara & Xie, 1994; Koch, 1994; Allinson, 1994). The function of this intensifier is to match a relatively large diameter X-ray phosphor to a small-size read-out device. As a result of the high sensitivity of CCD's, especially of slow-scan CCD's, a low photon gain in the intensifier and a low light-coupling efficiency in the coupling between intensifier and read-out device are quite adequate. It is, however, essential to couple the X-ray phosphor as efficiently as possible to the photocathode.

Roehrig *et al.* (1989) have described a design in which an image intensifier with 150 mm diameter input and output face plates is coupled by means of six demagnifying fibre-optic cones to six CCD's. Allinson (1994) has examined the need for image intensification and has shown that it is possible to construct a 150 mm square detector that has a performance approaching that of an ideal detector without using an image intensifier. Different methods of light coupling and format alteration have been discussed by Deckman & Gruner (1986).

7.1.6.5.3. *Image intensifiers*

In an image intensifier, the photoelectrons from a photocathode are made to produce a visible intensified image on an output phosphor. In so-called first-generation tubes, the intensification is produced by subjecting the electrons to accelerating voltages of up to about 15 keV: the number of visible-light photons at the output per keV of electron energy is about 80. The photon gain of the devices is typically about 100; there may be a brightness gain factor of M^2 if the electrostatic electron-optical system produces a demagnification of M. Standard first-generation image intensifiers of this type are made with input field diameters up to 80 mm, they always have fibre-optics input face plates on which X-ray phosphor may be deposited, they are stable and robust, and have a good resolution of better than 100 µm at the input. Their low gain requires the use of a low-light-level TV camera tube in the next stage (Arndt & Gilmore, 1979) or of two or more intensifiers of this type in tandem (Kalata, 1982) or of an intrinsically more sensitive slow-scan read out (Eikenberry, Gruner & Lowrance, 1986).

For military and civilian night-vision applications, first-generation image intensifiers have largely been replaced by devices embodying one or two microchannel plates (MCP's) that produce an electron gain of up to 1000 per stage (see, for example, Emberson & Holmshaw, 1972; Garfield, Wilson, Goodson & Butler, 1976). Commercial second- and third-generation intensifiers (Pollehn, 1985) are less suitable for quantitative scientific purposes than the first-generation devices: their GaAs photocathodes are less well matched to most X-ray phosphors, the gain of MCP's decreases with time, and the tubes have a slightly lower resolution than diode types of comparable diameter. Most third-generation intensifiers have plain rather than fibre-optics face plates and none appear to be available with a diameter greater than 50 mm (Airey & Morgan, 1985). Nevertheless, these high-gain intensifiers do make it possible to construct relatively cheap moderate-performance X-ray detectors using standard-sensitivity TV pick-up devices, including CCD's (Dalglish, James & Tubbenhauer, 1984), instead of the low-light-level camera tubes necessary with a lower pre-amplification.

An intensifier can, in principle, employ a variety of read-out methods, *e.g.* by substituting a resistive disc anode, a coded anode or a CCD for the output phosphor. However, the only way of employing standard modules is to couple them to a TV pick-up device.

7.1.6.5.4. *TV camera tubes*

Vacuum-tube television cameras have been largely replaced by semiconductor devices but of the former the preferred tube for use in an X-ray detector is still the silicon-intensifier-target (SIT) tube (Santilli & Conger, 1972). It has an adequate resolution for images up to 512×512 pixels and a linear transfer function (unity gamma) and its sensitivity is well matched for use with a single-stage image intensifier with a gain of 100. When cooled, this tube can be used for long exposures in an integrated slow read-out mode (Milch, Gruner & Reynolds, 1982).

When better high-gain image intensifiers become available, the preferred choice may be tubes like the Saticon (Goto, Isozaki, Shidara, Maruyama, Hirai & Fujita, 1974) whose diode gun gives them a superior resolution (Isozaki, Kumada, Okude, Oguso & Goto, 1981) and which have superior 'lag' or 'sticking' performance, that is a short 'memory' for previous high-intensity patterns to which they have been exposed (Shidara, Tanioka, Hirai & Nonaka, 1985).

7.1.6.6. *Some applications*

The use of linear and area detectors has increased markedly in recent years (Arndt, 1988). No new principles for the construction of linear devices have emerged, but more examples of each type have become commercially available.

Many more structures have been determined with area-detector diffractometers. The most commonly used gas-filled detectors at present are the delay-line read out MWPC first described by Xuong *et al*. (1978), as developed by Hamlin (1985), and a detector using a modification of the coded-anode read out due to Burns (Durbin, Burns, Moulai, Metcalf, Freymann, Blum, Anderson, Harrison & Wiley, 1986; Howard, Gilliland, Finzel, Poulos, Ohlendorf & Salemne, 1987; Derewenda & Helliwell, 1989). Corresponding instruments in the USSR and their use have been described by Anisimov, Zanevskii, Ivanov, Morchan, Peshekhonov, Chan Dyk Tkhan, Chan Khyo Dao, Cheremukhina & Chernenko (1986) and by Andrianova, Popov, Kheiker, Zanevskii, Ivanov, Peshekhonov & Chernenko (1986).

A two-dimensional photon-counting X-ray detector has been described by Collett & Podolsky (1988).

The widespread use of area-detector methods in single-crystal studies, especially for macromolecular material, has been greatly

references