International Tables for Crystallography (2006). Vol. C, Figure 7.1.7.4, p. 635.

4×10^{11} Mo $K\alpha_1$ photons s^{-1} m^{-2}, $C = 0.5$ and $\delta = 30$ µm (Chikawa, 1974) in (7.1.7.3). In order to improve the resolution further, q must be as high as possible even when ν_p is increased by 10–100 by use of synchrotron radiation, because R_I decreases with improving resolution (decreasing δ). (Note that C is not expected to increase much with improving resolution.) For example, to keep R_I at the same level as the previous case, q should be 0.7, say, for $\nu_p = 10^{13}$ photons s^{-1} m^{-2} and $\delta = 6$ µm. However, resolution and detection efficiency are, in general, mutually exclusive; the resolution of X-ray sensing photoconductive or phosphor materials is determined by the sizes of their grains and their sensitivities decrease with decreasing grain sizes. High resolution, without sacrificing detection efficiency, has been obtained with an amorphous Se–As alloy photoconductive layer, which has the advantage that no degradation of resolution occurs on increasing the layer thickness (Chikawa, Sato, Kawamura, Kuriyama, Yamashita & Goto, 1986). A layer with a thickness of 20 µm has an absorption efficiency of $q = 0.52$ for Mo $K\alpha$. The resolution of these tubes is shown with their modulation transfer functions in Fig. 7.1.7.2. The limiting resolution of 6 µm was obtained by making the scanning electron beam narrower with a diode-type electron gun have a barium-impregnated tungsten cathode (DIS type) (Chikawa, 1999). The Se–As layer shows very low lag characteristics (less than 1% after one frame).

This type of camera tube was developed primarily for TV broadcasting use and named 'Saticon' as the acronym for the components of the photoconductor, Se, As and Te. (Te enhances the sensitivity to red light.)

Such camera tubes have excellent linearity. The output signal current is proportional to the incident X-ray intensity up to 4 µA. The amplifier is always improving in signal-to-noise ratio, and, at present, the noise level of video amplifiers is ~0.2 nA; it is equivalent to an input intensity of $\sim 10^{11}$ Mo $K\alpha$ photons m^{-2} s^{-1} in the US/Japan standard scanning system (30 frames s^{-1}).

Therefore, it is important to increase conversion efficiency ($\eta_1, \eta_2, \ldots, \eta_s$). With increasing voltage applied on the photoconductive layer, the signal current is saturated (in Fig. 7.1.7.1, all the holes produced by an incident photon are collected), and then increases again further by avalanche amplification, as shown in Fig. 7.1.7.3; holes accelerated by a strong electric field cause their multiplication (Sato, Maruyama, Goto, Fujimoto, Shidara, Kawamura, Hirai, Sakai & Chikawa, 1993). It was referred to as 'HARP' (high-gain avalanche-rushing amorphous photoconductor). Together with the signal current, the dark current also increases as shown in Fig. 7.1.7.3. By allowing it to increase to the noise level of the video amplifier, an order of magnitude higher SNR can be achieved. Consequently, individual X-ray photons can be imaged as spots with a size resulting from the point-spread function, unless they are absorbed near the back surface of the photoconductive layer. For X-ray detection, a thick HARP layer should be employed with a very high applied voltage, and stable operation with avalanche amplification was confirmed for a 25 µm thick HARP layer. These pilot tubes were fabricated with a conventional electron gun and had a resolution of about 25 µm.

In general, avalanche amplification results in degradation of spatial resolution and has been used for zero-dimensional detection such as solid-state detectors. To make two-dimensional detection, isolation of each picture element is required. For the HARP, however, no appreciable degradation of resolution due to avalanche amplification was confirmed with a DIS-type tube having an 8 µm thick HARP layer by using visible light through a glass window. X-ray sensitive DIS-type tubes are now commercially available.

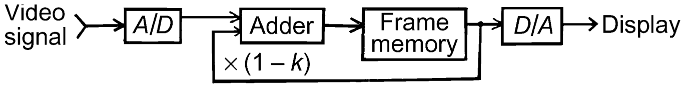

Fig. 7.1.7.4. Principles of a noise reducer.

7.1.7.3. *Image processing*

The resolution δ and integration time t should be selected appropriately according to experimental requirements (Chikawa, 1980). For example, when topographic images of a single dislocation in silicon were observed with $t = 1/30$ s by synchrotron radiation, their contrast and SNR were found to be $C = 0.5$ and $R_I = 20$ for $\delta = 30$ µm, and $C = 1$ and $R_I = 8$ for $\delta = 6$ µm. Since the SNR is desired to be 100, the integration time should be as large as possible unless images of moving objects are degraded. Digital image processing (Heynes, 1977) enables one to adjust the integration time easily. As an example, a noise reducer (McMann, Kreinik, Moore, Kaiser & Rossi, 1978; Rossi, 1978) is shown in Fig. 7.1.7.4. The video signal is sampled and digitized by the A/D converter and the digital video is sent to the adder and thence to the memory. Image information in the memory is continually sent both to the adder through the multiplier for combination with incoming data and to the display through the D/A converter. The weighting of new to old data is made by changing the factor k of the multiplier in the range $0 \leq k \leq 1$. For $k = 0$, the original input image is displayed. In the range $0 < k < 1$, a sliding summation of successive frames is displayed, and the SNR is improved by a factor of $[(1+k)/(1-k)]^{1/2}$. The factor k can be adjusted automatically by detecting the difference between successive frames.

Using a HARP tube, the SNR can be improved without integration of the amplifier noise by image processing, and topographs were displayed with an intensity of $\nu_p \simeq 10^9$ photons s^{-1} m^{-2} by a conventional X-ray generator.

Acquisition of extremely low intensity images, dramatic improvements in SNR *via* frame integration, and isolation and enhancement of selected-contrast ranges are possible by digital image processing (Chikawa & Kuriyama, 1991).

7.1.8. Storage phosphors (By Y. Amemiya and J. Chikawa)

A storage phosphor, called an 'imaging plate', is a two-dimensional detector having a high detective quantum efficiency (DQE) and a large dynamic range. It was developed in the early 1980's for diagnostic radiography (Sonoda, Takano, Miyahara & Kato, 1983; Kato, Miyahara & Takano, 1985). The performance characteristics of the imaging plate was quantitatively evaluated in the mid 1980's (Miyahara, Takahashi, Amemiya, Kamiya & Satow, 1986) and it was proved to be very useful also for X-ray diffraction experiments (Amemiya, Wakabayashi, Tanaka, Ueno & Miyahara, 1987; Amemiya & Miyahara, 1988). The imaging plate has replaced conventional X-ray film in many X-ray diffraction experiments.

The imaging plate (IP) is a flexible plastic plate that is coated with bunches of very small crystals (grain size about 5 µm) of photo-stimulable phosphor [previously BaFBr:Eu^{2+}, recently BaF(Br,I):Eu^{2+}] by using an organic binder. The photo-stimulable phosphor is capable of storing a fraction of the absorbed X-ray energy. When later stimulated by visible light, it emits photo-stimulated luminescence (PSL), the intensity of which is proportional to the absorbed X-ray intensity.

references