The mechanism of PSL is illustrated in Fig. 7.1.8.1. When the IP absorbs incoming X-rays, some of the electrons in the valence band are pumped up to the conduction band of the phosphor crystals. (This corresponds to ionization of Eu^{2+} to Eu^{3+}.) The electrons, in turn, are trapped in Br^- and F^- vacancies, which were intentionally introduced in the phosphor crystals during the manufacturing process, forming temporary colour centres, termed *F*-centres. Exposure to visible light again pumps up the trapped electrons so that they generate energy for luminescence, while returning to the valence band of the crystal. (This process corresponds to a recombination of electrons with Eu^{3+} ions, resulting in Eu^{2+} luminescence.) Because the response time of the PSL is as short as 0.8 µs, it is possible to read an X-ray image with a speed of 5–10 µs per pixel with high efficiency. The PSL is based on the allowable transition from $5d$ to $4f$ of Eu^{2+}. The wavelength of the PSL ($\lambda \simeq 390$ nm) is reasonably separated from that of the stimulating light ($\lambda = 632.8$ nm), allowing it to be collected by a conventional high-quantum-efficiency photomultiplier tube (PMT). The output of the PMT is amplified and converted to a digital image, which can be processed by a computer. The residual image on the IP can be completely erased by irradiation with visible light, to allow repeated use. The IP is easy to handle, because it is flexible, like a film, and can be kept in light before its exposure to X-rays.

The measured DQE of the IP is shown as a function of the X-ray exposure level together with that of a high-sensitivity X-ray film (Kodak DEF-5) in Fig. 7.1.8.2. The advantage of the IP over X-ray film in DQE is clearly enhanced at lower exposure levels. This arises from the fact that the background noise level of the IP is much smaller than that of X-ray film. The background noise level of the IP corresponds to the signal level of less than 3 X-ray photons/100 $\mu\mathrm{m}^2$. This value compares favourably with the chemical 'fog' level of X-ray film, which amounts to 1000 X-ray photons per equivalent area. The background noise level of the IP depends largely on the performance of the IP read-out system, and it can be smaller than that of a single X-ray photon with a well designed IP read-out system (Amemiya, Matsushita, Nakagawa, Satow, Miyahara & Chikawa, 1988). The DQE of the IP decreases at higher exposure levels owing to 'system fluctuation noise'. Fig. 7.1.8.3 shows the fluctuation noise of the IP and X-ray film as a function of the X-ray exposure level. It is shown that the noise fluctuation at high exposure levels is governed by system fluctuation noise, which amounts to about 1%. Fig. 7.1.8.4 shows the propagation of signal and noise in the IP system. The origins of the system fluctuation noise are non-uniformity of absorption, non-uniformity of the colour-centre density, fluctuation of the laser intensity, non-uniformity of PSL collection, and fluctuation of the high-voltage supply to the PMT. Although it might be possible to reduce the total system fluctuation noise from ~1% to ~0.5%, it is very difficult to reduce it down to <0.1%. This means that the ultimate precision in intensity measurements with the IP is limited to the order of ~0.5%.

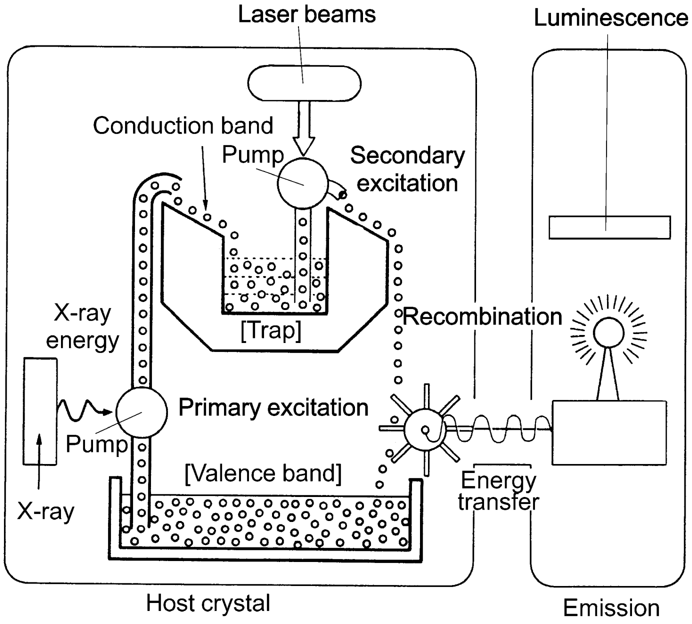

Fig. 7.1.8.1. Mechanism of photo-stimulated luminescence.

Compared to X-ray film, the dynamic range of the IP is much wider, of the order of $1{:}10^5$ (Fig. 7.1.8.5). The response of the PSL is linear over the range from 8 to 40 000 photons/(100 $\mu\mathrm{m}^2$), with an error rate of less than 5%. It is shown that the dynamic range of an IP is extended towards the lower exposure levels of X-ray film, but not to the higher exposure levels. The dynamic range of the IP is practically limited to four orders of magnitude by that of the PMT during the read-out. Two sets of PMT's are used in some read-out systems in order to cover the entire dynamic range of the IP.

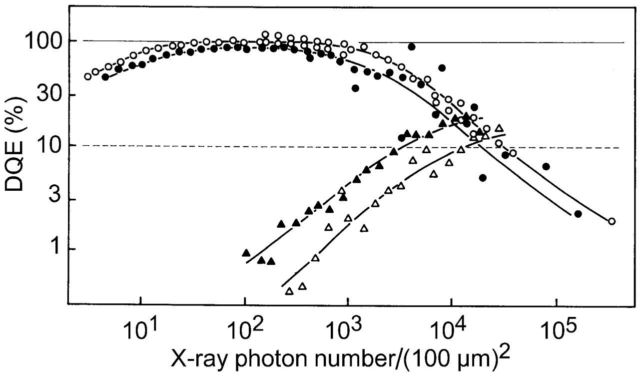

Fig. 7.1.8.2. Measured detective quantum efficiency (DQE) of the imaging plate and high-sensitivity X-ray film as a function of the exposure level. The circles correspond to the imaging plate (with the FCR 101 read-out system, Fuji Film Co. Ltd), triangles to the X-ray film (Kodak DEF-5). The filled symbols are for 8.9 keV and open symbols for 17.4 keV. The solid line indicates a noiseless counter of 100% absorption efficiency (ideal detector). The dashed line indicates a noiseless counter of 10% absorption efficiency (Amemiya & Miyahara, 1988).

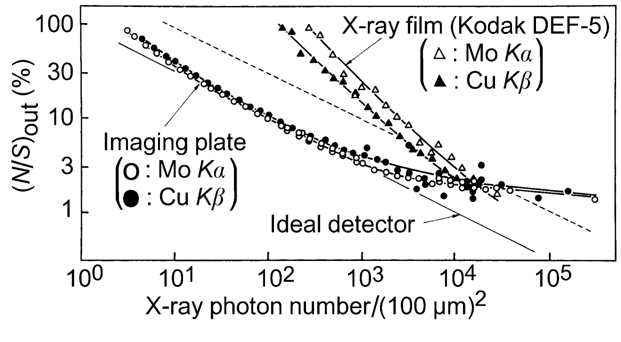

Fig. 7.1.8.3. Fluctuation noise in the signal as a function of the exposure level. The circles correspond to the imaging plate and the triangles to the X-ray film (Kodak DEF-5). The filled symbols are for 8.9 keV and the open symbols for 17.4 keV. The dashed line indicates a noiseless counter of 10% absorption efficiency (Miyahara, Takahashi, Amemiya, Kamiya & Satow, 1986).

references