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Imaging plate illuminates many fields

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The erasable phosphor imaging plate developed for medical radiography has found new uses in the laboratory. X-ray diffraction, protein crystallography and autoradiography have all benefited from this technology transfer from the clinic.

SEVERAL years ago, researchers at Fuji Film developed an erasable X-ray imaging plate for diagnostic radiography, based on the X-ray excitation of a phosphor layer[1]. Recently, the imaging plate has been used to obtain quantitative intensity measurements in X-ray diffraction experiments[2,3] and in autoradiography[4,5]. The results show that the imaging plate is much more useful than conventional X-ray film, establishing it as a rival to other X-ray image sensors such as X-ray television cameras, solid-state image devices and gas-type area detectors.

The imaging plate is approximately 0.5 mm in thickness, and is composed of a flexible plastic plate coated with fine photostimulable phosphor crystals ($BaFBr:Eu^{2+}$) combined with an organic binder. The photostimulable phosphor is capable of storing a fraction of the absorbed incident energy from irradiation with X-rays, ultraviolet light, electrons or protons. When later stimulated by visible or infrared radiation, it emits photostimulated luminescence (PSL), the intensity of which is proportional to the absorbed radiation energy.

An inside look

When the imaging plate absorbs incoming radiation, some of the Eu^{2+} ions are further ionized to Eu^{3+}, liberating electrons to the conduction band of the phosphor crystals. The electrons, in turn, are trapped in bromine vacancies which were introduced in the phosphor crystals during the manufacturing process, forming temporary colour centres termed F-centres. Exposure to visible light releases the trapped electrons from the bromine vacancies in the lattice back to the conduction band of the crystal, where they go on to convert Eu^{3+} ions to excited Eu^{2+} ions. Eu^{2+} luminescence is then emitted[6].

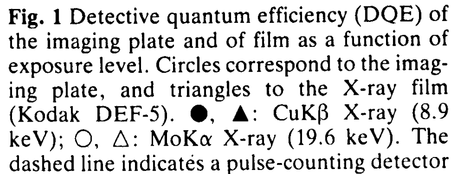

Fig. 1 Detective quantum efficiency (DQE) of the imaging plate and of film as a function of exposure level. Circles correspond to the imaging plate, and triangles to the X-ray film (Kodak DEF-5). ●, ▲: CuKβ X-ray (8.9 keV); ○, △: MoKα X-ray (19.6 keV). The dashed line indicates a pulse-counting detector of 10 per cent absorption efficiency[16]

Table 1 Comparison of exposure time between photographic film and imaging plate method.

Method	Isotope	Photographic film	Imaging plate	Reduction rate
Colony hybridization	^{32}P	2 days	20 minutes	1/150
Dot blot hybridization	^{32}P	Cannot detect	13 hours	?
Southern blot hybridization	^{32}P	2 days	14 minutes	1/200
Sequencing gel	^{32}P	20 hours	14 minutes	1/90
Thin-layer chromatography	^{14}C	10 days	4 hours	1/60
Whole-body autoradiography	^{14}C	4 weeks	4 hours	1/170
		.	4 hours	1/360
Pulsed field gel electrophoresis	^{14}C	2 months	~ 2 days	~ 1/30

Because the response time of the PSL is as short as 0.8 μs, it is possible to read between four and six megabytes of image data within several tens of seconds using a scanning laser beam. The wavelength of the PSL ($\lambda \sim 390$ nm) is reasonably separated from that of the stimulating light ($\lambda = 632.8$ nm), allowing it be collected by a conventional high-quantum efficiency photomultiplier tube (PMT). The output of the PMT is logarithmically amplified and converted to a 10-bit-depth digital image, which can be processed by computer and displayed on a computer screen or printed as a hard copy. The residual image on the imaging plate can be erased completely by irradiation with visible light, to allow repeated use.

Advantages

The imaging plate system has several characteristic performance advantages when compared to other image sensors[2].

First, the scanning pitch of the laser beam readout unit is 5–10 pixels per millimetre, and the full width at half maximum (FWHM) of the point spread function is 150 μm × 150 μm for 10 pixels per millimetre, giving the imaging plate higher resolution than many other devices.

Secondly, compared to other integrating-type detectors, such as film and X-ray television cameras, the dynamic range of the imaging plate system is much wider, on the order of 10^5. The response of the PSL is linear in the range from eight X-ray photons per pixel to 4×10^4 photons per pixel ($1{:}5 \times 10^3$), with an error rate of less than five per cent.

The detective quantum efficiency (DQE) of the imaging plate is also better than 80 per cent for CuKβ (8.9 keV) and MoKα (17.4 keV) X-rays (Fig. 1). Such a high DQE arises from both the high absorption efficiency of the phosphor for X-rays and the extremely low background noise level of the system. The noise level corresponds to less than three X-ray photons per pixel. This value compares favourably with the chemical "fog level" of film, which amounts to 1,000 X-ray photons per equivalent area.

The uniformity of response of the imaging plates varies less than 1.6 per cent over the active area. Unlike X-ray television cameras and gas-type area detectors such as multiwire proportional counters (MWPC), correction for non-uniformity of response is not required. Distortion of the image is also very small (one per cent), compared to television cameras and MWPC, and because the imaging plate is an integrating-type detector, it is free from the count-rate limitations which affect detectors operating in a pulse-counting mode.

Image data are obtained directly from the imaging plate using digital values which are easily processed by computer. With minimal precautions, the plate yields reproducible results over a long period of repeated use, unlike film, whose performance is affected by slight changes in development conditions. Fading of the stored image on the imaging plate is seldom a problem for most experiments. The fading observed after two months' exposure to radiation is 10 per cent at 0 °C, 46 per cent at 20 °C and 87 per cent at 40 °C.

The imaging plate is available not only for X-rays, but also for ultraviolet light, electrons and proton beams. Imaging plates applicable for neutron beams have been made by adding gadolinium oxide to

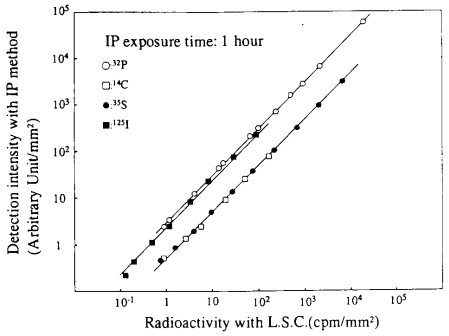

Fig. 2 Imaging plate (IP) and liquid scintillation counter (LSC) methods in the detection of various radioisotopes. The measured values for the four radioisotopes show very good correlation between the two methods, suggesting that the imaging plate has a dynamic range of five orders of magnitude.

the phosphor. The plates are easy to handle, because they are flexible, like film. Various sizes of the imaging plate are available, ranging from 250 mm × 200 mm to 430 mm × 350 mm.

Imaging plate uses

Recently, researchers in the field of X-ray diffraction have shown intense interest in the imaging plate, especially for molecular biology applications. In 1985, the usefulness of the imaging plate was demonstrated in a study of muscle contraction[3]. The high DQE and wide dynamic range of the imaging plate, together with its absence of count-rate limit, resulted in a sufficient reduction in exposure time to make possible the recording of a clear diffraction pattern from a contracting frog skeletal muscle in as little as ten seconds with synchrotron radiation. When compared with similar images of resting muscle, the technique allowed the molecular conformational changes during muscle contraction to be elucidated[7].

The imaging plate has helped protein crystallographers to obtain accurate data sets by shortening the time the protein must be exposed to the X-rays, limiting the instability of the protein crystals and their damage by radiation. Using the imaging plate, a full data set can be obtained from one crystal before it is damaged by radiation[2,8], and with a better signal-to-noise ratio than with film. The imaging plate is also well-suited to the Laue diffraction method applied to protein crystals using synchrotron radiation[9]. A system which is similar to the imaging plate is being used with this method at the Cornell High-Energy Synchrotron Source (CHESS) in the United States[10,11]. Data obtained by the imaging plate should have sufficient accuracy for use with the anomalous dispersion method for phase determination. The imaging plate has also been used with great success in small-angle X-ray scattering, X-ray Compton scattering, and X-ray diffraction under extremely high pressure and temperature because of its high sensitivity and wide dynamic range[9,12,13].

In medical computed radiography, the imaging plate system is taking the place of conventional Roentgenograms[14]. The imaging plate not only requires a much smaller radiation dose to the patient, but also has made digital X-ray image diagnosis possible. The imaging plate system will enable the creation of a Picture Archiving and Communication System (PACS), and will allow diagnoses to be compared between isolated hospitals by the transmission of digital images (teleradiology).

The imaging plate has also been attracting attention in the biotechnology industry — where autoradiography is commonly used to analyse gene and protein sequences — and in pharmaceutical metabolism research. The imaging plate is especially valuable because of its high sensitivity and accuracy, and because convenient, efficient measurements can be made through computer analysis. Figure 2 compares the imaging plate with liquid scintillation counter methods in the measurement of typical radioisotopes used in autoradiography. The radiation intensity in any portion of the image can be quantified with the same accuracy as the liquid scintillation method. The imaging plate has yielded quantitative data from 2-dimensional gels overnight, compared to the four weeks required in conventional autoradiography[4], and from whole-body autoradiography in 1.5 hours, compared to 3 days for the conventional method. Table 1 outlines exposure times for several widely used techniques.

In addition to the above-mentioned applications, the imaging plate is just beginning to be used in the fields of transmission electron microscopy[15], industrial non-destructive inspection and the detection of minute levels of cosmic rays or natural radiation. □

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1. Sonoda, M., Takano, M., Miyahara, J. & Kato, H. *Radiology* **148**, 833–838 (1983).
2. Miyahara, J., Takahashi, K., Amemiya, Y., Kamiya, N. & Satow, Y. *Nucl. Instrum. Meth.* **A246**, 572–578 (1986).
3. Amemiya, Y., Wakabayashi, K., Tanaka, H., Ueno, Y. & Miyahara, J. *Science* **237**, 164–168 (1987).
4. Nakatsuji, T. *et al.* in *Proc. Histocompatibility & Immunogenetics Conf.* (in the press).
5. Nakajima, E. *et al.* in *Proc. 2nd Int. ISSX Mtg* (in the press).
6. Takahashi, K., Miyahara, J. & Shibahara, Y. *J. electrochem. Soc.* **132**, 1492–1494 (1985).
7. Wakabayashi, K. *et al.* (in preparation).
8. Sakabe, N. *Acta crystallogr.* **A43** (supplement), C-8 (1987).
9. Amemiya, Y. *et al. Nucl. Instrum. Meth.* **A266**, 645 (1988).
10. Bilderback, D. *et al. Nucl. Instrum. Meth.* **A266** 636 (1988).
11. Whiting, B., Owen, J. & Rubin, B. *Nucl. Instrum. Meth.* **A266** 628–635 (1988).
12. Ito, F. *et al. Nucl. Instrum. Meth.* (in the press).
13. Shimomura, O. *et al. Nucl. Instrum. Meth.*, in the press.
14. Tateno, Y., Iinuma, T. & Takano, M. *Computed Radiography* 45–185 (Springer-Verlag, Tokyo, 1987).
15. Mori, N., Oikawa, T., Katoh, K., Miyahara, J. & Harada, Y. *Ultramicroscopy* **25**, 195–202 (1988).
16. Amemiya, Y. *et al. Biophysics and Synchrotron Radiation* 61–72 (Springer-Verlag, London, 1987).