Performance of imaging plates for electron recording

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Abstract

The characteristics of newly developed 25 μm pixel size imaging plates with a detection area of 3000 × 3760 pixels are measured using the same methods applied for the slow-scan CCD (SSC) camera at various electron accelerating voltages. These are compared directly with the SSC camera. Examples of electron images recorded with the imaging plate and the SSC camera are given and analysed based on the measured camera characteristics. Advantages of each system are illustrated.

1. Introduction

As an alternative to the CCD camera, a second digital imaging device has recently become available for transmission electron microscope (TEM). Imaging plates (IPs) are reusable flexible sheets, which are used in the standard cassettes. They are read out digitally and have a linear electron response, large dynamic range and 3000 × 3760 pixels. They are easily handled and rather insensitive to room lights. The image plate records electron image by storing electron energy in the potential well of the defect states in a photostimulable phosphor, which remain for the lifetime of the defect state (a day or so at room temperature). This is in contrast to the CCD, where the potential well is created by an external voltage, which requires complicated circuitry. The imaging plate is simple and can be made at a relatively low cost. Unlike the film for which the development is non-linear and a one-shot process, storage and extraction of electron energy in imaging plates are both linear and can be repeated many times. The imaging plate was first developed in the 1980s as an area detector for X-ray diagnostic imaging [1]. Characteristics of the IP for X-ray detection have been reported [2, 3], and its use in X-ray crystallography has been widely accepted. The same characteristics of linearity, large dynamic range and high sensitivity responsible for its success with X-ray work were also found for electron detection [4]. The IP originally developed for X-rays has a pixel size of 100 μm, which is not suitable for the high-resolution electron image recording. For electron microscopy, a 50 μm IP was initially developed [4]. More
recently, an even higher-resolution version of the IP with 25 µm pixel size and an usable area of 3000 × 3760 pixels was developed by Fuji, Japan [5], which is used for this study. Some applications of the imaging plate for electron diffraction and high-resolution imaging have been reported; for example, see Refs. [6, 7].

The image read-out system of the image plate is very similar to the serial digitizer for the film. Bürmester et al. [7] reported an optical spot scanning system using an elliptical mirror. Properties of the 50 µm imaging plate using this read-out system for electron image recording were measured [7]. In this paper, we describe our evaluation of the new 25 µm image plate using the commercial reader (Fuji FDL5000), which uses the conventional mirror and lens system. In the previous paper [8], characteristics of the slow-scan CCD camera have been reported together with the measurement methods. Here we apply the same procedure to the imaging plate. In addition, we report results of a comparison of electron image recording using imaging plates and the SSC camera, together with an analysis based on the measured detector characteristics.

2. Imaging plates and reader

The imaging plate consists of a layer of photostimulable phosphors of BaFX (X = Cl, Br) doped with Eu2+ and a plastic protective layer above and with supporting material below (see Fig. 1). In the new 25 µm IP, the phosphor layer is 110 µm thick [9]. The new IP also has an additional light-shielding layer on the backside. The mechanism of the photostimulable phosphors is described by Takahashi et al. [10] for X-ray and UV excitation. The process is similar for electrons. Briefly, by electron excitation, Eu2+ is ionized to Eu3+. Some of the electrons excited to the conduction band are trapped at F−-centers of the crystal, which are about 2 eV below the conduction band. Thus, part of the incoming electron energy is stored. The trapped electrons return to Eu3+ ions and convert them into Eu2+ upon illumination by visible light, or photostimulation. Luminescence is emitted when the excited Eu2+ returns to its ground state, with a wavelength of luminescence 390 nm. The IP is sized so that it fits into the regular film cassette of the electron microscope, and has an usable area of 75 × 94 mm².

The recorded electron image is read out by scanning a laser beam (typically He–Ne, 630 nm wavelength) whose probe size is equal or smaller than the step size of 25 µm, and the luminescence emitted from the IP is detected. The luminescence is distinguished from the backscattered laser probe using filters. Fig. 2 shows the schematic diagram [9] of the commercial FDL5000 reader [11], which was used here. A He–Ne laser spot of size 19 µm is formed on the surface of the IP through a lens. The same lens is used together with a mirror to guide the light emission of the IP to a photomultiplier tube (PMT). The scanning is performed by stepping the device horizontally and sweeping the laser probe vertically (see Fig. 2). In the FDL5000, the

![Fig. 1. Schematic diagram of the Fuji 25 µm imaging plate cross section.](image)
output signal of the PMT is logarithmically amplified and digitized into 14 bits or a maximum of 16,384. The electron beam intensity may be recovered by the transformation

\[ I = C \times 10^{D-8192}/8192 \text{ (counts)} \]  

(1)

Here \( C \) is a calibration constant and \( D \) is the digitized 14-bit signal. This gives the count \( I \) with a range of \( 10^4 \). Additionally, six different sensitivity levels can be set in the FDL5000 reader to read IPs irradiated with electron doses from \( 10^{-14} \) to \( 10^{-10} \) C/cm\(^2\) and electron doses from \( 4 \times 10^{-13} \) to \( 4 \times 10^{-9} \) C/cm\(^2\) with the highest and lowest sensitivity, respectively. This is achieved by varying the gain of the PMT and by the insertion of a filter.

The process of electron detection using an IP can also be separated into three stages: (1) the storage of electron energy in the IP, (2) transportation of the photons generated to the PMT via optical coupling, and (3) detection of photons in the PMT. The overall gain of the IP, \( g \), is a combination of factors

\[ g = \eta_L \eta_e \frac{\Delta E}{E_{ph}} \]  

(2)

where \( \Delta E \) is the average energy of an electron absorbed in the phosphor, \( E_{ph} \) the electron energy needed to generate a single photon, and \( \epsilon \) the energy conversion efficiency, so that

\[ G \equiv \eta_{ph} - \epsilon \frac{\Delta E}{E_{ph}} \]  

(3)

gives the number of photons generated per electron. Here \( \eta_L \) is the efficiency of the optical coupling system, and \( \eta_e \) the quantum efficiency of the PMT. The head-on type PMT with bialkali photocathode material has a peak wavelength of 420 nm and a quantum efficiency of about 25%, which matches well with the luminescence of the IP.

3. Experimental measurements

The experiment was carried out in the same way as described in Ref. [8], and most measurements were done simultaneously with the slow-scan-CCD camera under identical conditions.

4. Gain

The gain of the IP was measured at 120 kV over a range of electron doses. Fig. 3a shows counts \( I \) (Eq. (1)) versus electron dose. The calibration constant \( C \) is set at 39.009 or \( 10^{-12}/\text{e um}^2 \) at the highest reading sensitivity. The averaged gain obtained from Fig. 3a is about 0.845 counts/beam-electron for IP at 120 kV. A slight decrease of gain was found when the lowest sensitivity is used in the FDL5000 reader. The quantum efficiency of the IP is discussed in Section 7 together with the noise characterization.

The dependence of gain on the electron accelerating voltage in the 50 um pixel IP was investigated by Mori et al. [4], who showed the highest sensitivity of the IP at about 150 kV. Fig. 4 shows the measured gain as a function of high voltage for the 25 um IP. The dependence of IP's gain on high voltage is similar to the CCD camera. The reduction in gain at lower voltage is due to a combination of reduced electron energy and the presence of the protective layer in both the IP and SSC.

After an exposure, the imaging plate can be read a number of times, since a single readout does not clear all of the stored energy. The signal decreases after each readout. Fig. 3b shows one example of the dependence of signal on the number of readouts; the solid curve is fitted to the function \( (1 + n)^{-1.92} \). The noise also increases with each readout. This will also be discussed in Section 7.
not possible to discuss the properties of the imaging plate alone. The linearity of the imaging plate system was measured by Miyahara et al. [2], who found no significant deviation from linearity except near the saturation level for X-rays. The energy storing and retrieval processes involved in the imaging plate are linear. The photomultiplier tube itself is also an excellent linear detector. The dynamic range of the imaging plate system is limited by the saturation and sensitivity of imaging plates (about $10^5$) and the dynamic range of the PMT (about $10^4$). The uniformity of the IP is checked in the factory by placing the IP 5 m away from an X-ray source. In an analysis by Ito and Amemiya [3], they put an upper limit of 0.5% on the non-uniformity for the 100 μm pixel IP. There are no large-scale variations or patterned structure in the IP as seen in the SSC (see Fig. 4 of Ref. [8]). Thus, the IP can be used without gain normalization. The effects of grain to grain variation will be discussed in Section 7.

The excellent uniformity of the IP makes it possible to study the uniformity of illumination in an electron microscope. Fig. 5a and b show the measured contour maps of the same illumination condition (Zeiss 912, $M = 20$ K) using two different imaging plates. The similarity of the two patterns also confirms the uniformity of the IPs. As discussed in Ref. [8], the uniformity of the SSC depends on the uniformity of illumination. For this purpose, the IP can provide an independent verification.

6. Resolution

The point-spread function of the IP is determined by the spreading of electrons inside the IP and by the laser spot and light scattering of luminescence inside the media. The spreading of high-voltage electrons in solids has been extensively studied in many fields, for example, see Ref. [12]. Mori et al. have measured the electron transmittance in phosphors as used in IP. They found transmittances of 0.56, 0.18 and 0.07 for thicknesses of 15, 30 and 35 μm, respectively. From the long ellipsoidal shape of the penetrating high-energy electrons with the long axis in the incident direction, it
is expected that the spreading of electrons is less than 35 μm. The spot size of the laser used in the FDL5000 reader is 19 μm, which is sufficiently small. The experimentally measured MTF of the IP using the Wiener spectrum method as described in Ref. [8] is shown in Fig. 6. It is difficult to use the edge method here because the measured edge profile is often asymmetric, possibly due to the X-rays generated in and near the edge which is also detected by the IP. In measuring the modulated transfer function (MTF) using the Wiener spectrum of noise, a highpass filter was applied to remove the low-frequency variations mainly in the electron illumination. The highpass filter works by subtracting off averaged intensities (over $n \times n$ pixels with $n = 64$ typically) from each pixel. Unlike the SSC, in which gain normalization removes this artifact as long as the same illumination is used, it is rather difficult to apply normalization due to the lack of pixel registry in successive imaging plates.

Fig. 6 shows the MTF and its dependence on electron dosage at 120 kV. The change of MTF with decreasing electron dosage is due to the finite sampling of the point-spread function in the IP media with limited numbers of photons per beam electron (about 650 photons per 120 kV beam electron (Section 7) as opposed to several thousands in the SSC). The effects of finite sampling on the Fourier spectrum are well known, for example, see Ref. [13]. The dependence of the IP MTF on electron dosage was first pointed out by Isoda et al. [14] for 50 μm IP. In their measurements, a simple form of point-spread function was used without justification and somewhat different results were obtained.

Fig. 7 shows the dependence of the MTF on electron incident voltage; a minimal difference in
MTF was observed between 225 and 400 kV. The dependence of the MTF on high voltage is entirely due to the scattering of electrons inside the IP. The dependence of MTF on high voltage has also been observed by Isoda et al. [14].

No simple functional form was found for the MTF of the IP. Since it is not possible to obtain the PSF directly from the measured MTF, we approximate the MTF and the PSF with a combination of simple functions

$$M(\omega) = \frac{a_0}{1 + k\omega^2} + \sum_{i=1}^{2} a_i \exp(-b_i\omega^2) + c.$$  (4)

Although the first function has a sound physical basis in the description of light scattering, the Gaussian functions are used purely for convenience. This introduces some arbitrariness into the interpretation of the results. The parameters for the IP MTF at high dose are listed for 120, 225 and 400 kV electrons in Table 1. Fig. 8 plots the integrated point-spread function $2\pi r$ PSF(r) for 120 kV electrons as a function of radius. Compared to the same plot for the SSC [8], the long tail structure of PSF in the SSC is absent in the IP. The contributions from 3 to 6 pixels distance away are negative. This effect is called the adjacency effect in photographic films. One manifestation of the adjacency effect is the Eberhard effect, that the intensity of a bright line depends on the size of an image with the same exposure [13]. The adjacency effect also makes the edge somewhat sharper. This adjacency effect is introduced during the readout, which is further discussed in Section 9. The ratio of the signal from the nearest pixels and the next nearest pixel is about 43%, which is slightly larger than the 25–30% (with and without antireflection YAG) for the SSC. This indicates a less spread between nearby pixels in the SSC.

### 7. Noise and detector quantum efficiency

The detector quantum efficiency (DQE) of the IP was measured by analyzing the mean and variance
Fig. 9. DQE of imaging plates and its dependence on output signal.

of a uniformly illuminated IP. Fig. 9 shows the measured DQE of camera I as a function of electron dose and electron accelerating voltage.

The noise performance of the IP for both X-rays [2] and electrons [7] has been studied. Additional noise in the IP is introduced by the deposition of electron energy, by luminescence and by the detection of photons in the PMT. Applying the same error analysis as used for the SSC, we have

$$\text{var}[I] = g^2 m \bar{N}_e + g^2$$

$$\times \left( m F \bar{N}_e + \frac{\bar{N}_e}{G} + \frac{N_e}{\eta_\text{PMT} G} + A \cdot \bar{N}_e^2 + \text{var}[B] \right).$$

(5)

Here $m$ is the mixing factor as defined in Ref. [8]. The first term arises from noise in the illumination, i.e. the shot noise of the electron beam. The terms inside the bracket represent noise introduced in each step of the detection process. The constant $F$ describes the fundamental noise of the electron ionization process (Fano noise), which also exists in the SSC. The second term in the bracket is the shot noise of photon emission and $G$ is the number of photons generated per electron. The next term gives the statistical noise of photon detection by PMT. Here $\eta_\text{L}$ is the optical efficiency of the reading system (limited by the numerical apertures) and $\eta_\text{PMT}$ is the quantum efficiency of the PMT (about 25%). $A$ describes the linear noise in the IP, which comes from several sources: (1) fluctuations of laser intensity, (2) fluctuations of PMT gain due to voltage instabilities, (3) non-uniformity of scanning speed and (4) granular variations of IP. The first three can be improved through the reader design. The granular variation of luminescence is more prominent in powder phosphors scintillators, which are bonded together through organic binders. Direct observations of luminescence variations can be made by detecting cathode luminescence in an SEM. Variations in the luminescence can be removed in the SSC through gain normalization. The last term $\text{var}[B]$ is the background noise in the system, which also has several sources: (1) dark current of PMT (leakage, thermoionic emission, and ionization of residual gas), (2) light leakage in IP reader, (3) residual luminescence of IP and (4) X-ray background in the electron microscope. From the above equation, we obtain a theoretical expression for the IP DQE:

$$\text{DQE} = \frac{mgI}{\text{var}[I]}$$

(6)

An approximation to Eq. (6) is given by Burmester et al. [7]. By fitting the measured DQE as a function of electron dose (in Fig. 9) we obtain

$$F + \frac{1}{m G} \left( 1 + \frac{1}{\eta_\text{L} \eta_\text{PMT}} \right) = 0.22 \pm 0.04,$$

(7)

$\sqrt{A} = 2.8\%$ and $\text{var}[B] = 0.08$. The Fano noise $F$ approaches the backscattering limit for 120 kV electrons, which is about 0.075 [15]. The mixing factor $n = 1/m$ of imaging plates at 120 kV ranges from 3.5 to 4 depending on electron dose (Figs. 6 and 8). The efficiency of the PMT is about 25%, and optical coupling efficiency is about $0.5 \times 29\%$ with numerical aperture $\text{NA} = 0.7$. The factor of 0.5 arises because only photons from one side of the IP are collected. Using these numbers and expression (5), we estimate that about 650 photons are generated per incoming 120 kV electron for the first readout. Considering the fraction of electron energy extracted in the first readout, we estimate that
Table 2
Measured characteristics of imaging plates (for details, see Section 7)

<table>
<thead>
<tr>
<th>HV (kV)</th>
<th>120</th>
<th>225</th>
<th>400</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F$</td>
<td>0.075*</td>
<td>~ 0.2</td>
<td>~ 0.4</td>
</tr>
<tr>
<td>$G_1$ (photons/beam-electron)</td>
<td>~ 650</td>
<td>~ 570</td>
<td>~ 340</td>
</tr>
<tr>
<td>$G_2$ (photons/counts)</td>
<td>~ 26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>var{$[B]$} (counts)</td>
<td>0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixing factors $1/\tau$ (high dose)</td>
<td>3.95</td>
<td>5.02</td>
<td>4.99</td>
</tr>
</tbody>
</table>

*Note: Gr: number of photons generated per beam electron.
$G_2$: number of detected photons for each digital count for the first readout.
$\sim$: the numbers marked by this sign are qualitative estimates based on NA = 0.7 and quantum efficiency of 25% for PMT.
*a From Ref. [15].

...a total of about 2000 charged F-centers are generated per 120 kV electron. The energy required to excite an electron to the conduction band is about 6 eV in the IP. This gives the energy conversion efficiency of the imaging plate as about 10%. The characteristics of the IP are summarized in Table 2 for 120, 225 and 400 kV electrons using the same analysis. The Fano noise $F$ is significantly larger for the IP compared to single-crystal YAG-based SSC; this is due to the granular structure of the IP which introduces larger fluctuations of ionization along different electron paths.

8. Applications of imaging plate and CCD camera

The high-sensitivity, large dynamic range and high-resolution, large area recording of the image plate make it ideal for diffraction studies. Fig. 10 shows a recorded energy-filtered diffraction pattern of magnetite just above the Verwey transition temperature of 123 K. In this figure both strong Bragg and weak thermal diffusion intensities are recorded. The diffuse scattering streaks are clearly visible. In this material the diffuse scattering intensity increases as the temperature is lowered toward the Verwey transition, which is related to electron hopping in the Fe$^{3+}$ sublattice and its coupling with phonons [16]. The combination of imaging plates and the energy filter are highly promising for the new field of quantitative analysis of diffuse scattering from thermal motion or static disorder using electron diffraction.

The on-line accessibility of images from the slow-scan CCD camera, low noise-to-signal ratio in the medium- to high-dose region make it ideal for the recording of high-resolution images. Fig. 11a shows a high-resolution image of [1 1 0] GaAs on amorphous carbon recorded at a magnification of about 400k with the SSC on JEOL 4000EX electron microscope. Fig. 11b shows the FFT spectrum of Fig. 11a after the removal of the point-spread function as measured in part I. The (4 0 0) information or 1.4 Å resolution is visible after the deconvolution. At 400k magnification, the Nyquist frequency $1/\lambda_{max} = 1.2$ Å. High-resolution images of very thin crystals can often be approximated as $I(x, y) = I_0[1 - \delta(x, y)]$

with $\delta(x, y)$ small. Detection of high-resolution images requires that the noise-to-signal ratio of the detector is smaller than the ratio of $\varepsilon$. The noise is associated with the large uniform background. Fig. 11a has an average count of about 300; the noise-to-signal ratio at this level is about 1.4% according to Fig. 9 and Eq. (12) of Ref. [8]. This is less than the contrast of the lattice fringes which is about 7%. The long tail in the PSF of the SSC is advantageous in this case, by averaging out the noise in the uniform background. For the SSC, the noise-to-signal ratio can be improved by increasing the electron dose, which is not the case in the IP, where the noise-to-signal ratio tends to a constant value in the high-dose region. This noise can be reduced through binning at higher magnifications. Fig. 12a shows a high resolution of InP obtained at...
the magnification of 800k and a binning of $2 \times 2$ pixels. Fig. 12b shows the FFT spectrum of Fig. 12a without deconvolution. The (4 2 0) information of 1.3 Å is clearly visible, which is very close to the Nyquist limit of 1.2 Å in this case.

The difference in the MTF of IP and SSC is more obvious in images with large contrast. Fig. 13a and b show the energy-filtered zero loss $[0 0 1]$ zone axis CBED of magnetite as recorded at 120 kV and $-165^\circ$C temperature on Zeiss 912 microscope with an Ω energy filter with the IP and SSC, respectively. Fig. 13c and d show the intensity profile of Fig. 13a and b along the marked lines, respectively. The full lines are as-recorded intensities, and the dashed lines are the corresponding profiles after the removal of the PSF by deconvolution. For the imaging plate, the difference between the as-recorded and deconvoluted patterns is very small, while for the SSC the improvement with deconvolution is clearly visible. Fig. 13b was recorded using the SSC with antireflection YAG [8], which has a better resolution than SSC with regular YAG.

9. Discussions and conclusions

The measurements of this paper show that the quantum detector efficiency of the imaging plate in the low-dose region is limited by the fundamental
Fig. 11. (a) HREM image of GaAs with amorphous carbon using the SSC at magnification of 400k; (b) MTF corrected FFT spectrum of (a). The circular mask is applied to avoid streaks.

Fig. 12. (a) A 1024 x 1024 pixels subsection of HREM image of InP using the imaging plate at magnification of 800k and pixel size of 50 μm through binning of four 25 μm pixels; (b) FFT spectrum of (a).

noise in the scintillation process, the resolution of the camera and the efficiency in terms of the number of photons detected per beam electron. In the dose region from a few to about 100 beam electrons per pixel, the DQE is about 0.8 at 120 kV. The DQE drops off slightly at very low dose. The good low-dose performance of the IP is primarily due to the low dark current of the photomultiplier, which
is the best light detector available. The DQE in the high-dose region is limited by the constant linear noise in the IP, which is about 2.8% at 120 kV. The linear noise comes from a number of sources, including the granular variation of the phosphor which is difficult to correct, unlike the SSC, for a number of reasons. Each IP is a separate detector, so any gain characterization must be recalibrated for each IP. The illuminated area on each IP also varies depending on the positioning inside the electron microscope. This makes the preparation of a gain image difficult. It is possible to overcome this by placing a mark such as a cross on the IP. Images taken using the same plates can be correlated with the help of the mark. This would involve some computational effort.

The MTF of the IP is relatively flat at low frequencies, which differs from the sharp drop in the SSC due to the long tail of the PSF as a result of light channeling in the YAG scintillator. The difference is that the collection of photons from the IP is serial; any sideway propagating photons can be excluded with a limiting aperture, while in the SSC the luminescence is imaged onto the CCD via parallel optical coupling. The IP’s MTF drops to between 0.35 and 0.4 at the Nyquist limit \( f = 0.5 \) per
The relative flatness at the low frequencies and the drop at medium- and high-frequencies suggest some sort of adjacency effect, which is confirmed by modeling of the measured MTF with a combination of functions (see Section 6). The adjacency effect, or negative contribution from nearby pixels, can be attributed to the excitation of photons in nearby pixels by the spreading laser beam and exclusion of these photons with resolution enhancing apertures. The IP's pixel-to-pixel resolution, as measured by the contribution from the nearest pixels, is slightly worse than the SSC as indicated by the drop of the MTF at medium and high frequencies (see Fig. 8).

The number of detected photons per beam electron is about the same for the imaging plate and the SSC without antireflection YAG. The difference in the gain of these two cameras is the gain of the detector or number of quanta per count. In case of the IP, it is 26 detected photons per count, while for the SSC the number is 46. The gain of the detector is limited by the background level or dark current and its noise. The background signal of the IP is very small, about 0.1–0.3 counts, with the read-out time fixed by the reader. The background of the SSC is about 50 counts with exposure of 1 s or less. The background noise of the IP is about 0.09. This is more than ten times better than the SSC, which is the main difference between the DQE of these two detectors in the low-dose region. Overall, the imaging plate is a better low-dose detector.

The amount of data for each IP image of 3000 × 3760 pixels is 22.5 Mb with data stored as short integers (2 bytes). The FDL5000 reader uses digital audio tape (DAT) for the data storage, which holds about 40 images for one 60 min DAT. The DAT is currently an excellent inexpensive and widely adopted backup medium. The only drawback is that the access of tape file is sequential and consequently time consuming. The organization of the tape file is in the Fuji format, which differs from the more commonly used 'tar' format. A program is provided together with the IP reader for the handling of tape. The image format of the IP is raw data stored sequentially row by row. Additional information such as number of rows and columns and data type are stored in separate files. This makes the export of the IP data to other applications relatively straightforward. There are two image processing programs supplied with the IP reader, which have the basic image processing functions, such as FFT. The Fuji image reader uses Macintosh computers, which are adequate for the functions provided.

The amount of data for each SSC image of 1024 × 1024 pixels is about 2 Mb with data stored as short integers (2 bytes). The Gatan SSC uses Macintosh computers and the data storage media of the computer for image storage. Common choice includes a magneto-optical disk of 128 Mb with a capacity for 60 1k × 1k images or similar removable bulk storage media. The Gatan SSC is controlled by DigitalMicrograph software, which stores images in its own proprietary format. Some of the more common image formats are also supported, such as TIFF. Additionally, the image can be stored in a small header of 8 bytes length, with the number of rows and columns in the first 4 bytes, which, together with other common standards, can be used to export the images to other applications.

As more images are recorded digitally, both the storage and image format become increasingly important to allow continuous access in the future. Unlike film, which is an excellent storage medium too, digital images need to be maintained and access to the stored images in the future can only be assured if they are continuously adapted to future storage media and formats. A common open format for the benefit of exchange and future adaptability is badly needed. Two particular formats designed for scientific data are (1) the Flexible Image Transport System (FITS), which is used by astronomers to exchange image data among different computers, and (2) hierarchical data format (HDF) developed by the National Center for Supercomputing. A decision by the microscopy community for the type of standard to be adopted is urgently required.

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