Application of Slow-Scan CCD Cameras in Routine Biological TEM

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Slow-scan CCD (charge-coupled device) cameras (SSCs) are based on optical image detection technology introduced in the seventies[1] and first used in astronomy in the eighties[2]. When they are properly configured for the detection of medium energy electrons rather than photons[3,4], they are able to capture images that exceed the quality of images recorded on photographic film. Here we discuss aspects of their operation pertinent to routine biological TEM.

Compared to the TV-rate CCD sensors that have become ubiquitous in miniature camcorders, scientific (astronomy-grade) CCDs have several unique characteristics: 1) their pixels are typically 20-27 μm in size rather than the 6 μm typical of TV rate CCDs, 2) their read-out amplifiers are optimized for low noise at read out rates of 1/10 to 1/100 of TV rate, 3) they do not have a separate frame-transfer buffer for CCD read-out, and 4) they are available in large total sizes (up to 2048 x 2048 pixels). The absence of a separate read-out area means that all the CCD pixels are available for image detection, but also that the beam must be shut off during CCD read-out. The large pixel size permits up to about 400,000 CCD electrons to be accumulated per pixel before saturation. The low-noise amplifiers give a read-out noise of the order of 10 CCD electrons r.m.s. per pixel. Together these give an exceptional dynamic range (= sat. charge / r.m.s. noise) of around 40,000 : 1, which is some 2 orders of magnitude higher than photographic film. The CCD response is typically linear to within 1% over this whole range, whereas film gives non-linearities easily exceeding 50%. Further, an SSC camera optimized for low signals can detect single incident 100 kV electrons[5], has a DQE larger than 0.8 in images recorded with more than 10 incident electrons per pixel, and delivers images with a number of pixels exceeding that of most presently envisaged HDTV formats. The SCC performance thus considerably improves on photographic film and also on the recently introduced imaging plate.

Images recorded by the SSC cameras are available within seconds in the computer controlling the read-out and they can be processed, analyzed, sent over a network, printed electronically, and archived on optical discs or DAT cartridges. The introduction of the SSC technology coincides with personal computers becoming powerful enough to handle large images such as those generated by the SSCs, and also with the event of desktop printing of gray level images. As an example of these trends, 1k x 1k pixel images acquired by the Gatan SSC are typically displayed on a standard color or B&W 2-page Macintosh monitor, sent over Ethernet (which is built into all Macintosh Quadras by Apple) to another computer in about 4 seconds, and printed in about 2 minutes on a photographic-quality electronic printer. Figs 1 and 2 illustrate the obtainable image quality by 1024 x 640 pixel images electronically cut from 1k x 1k images captured by the Gatan SSC at 100 kV and pasted into one picture. Practical experience shows that individual pixels are not visible to the unaided human eye in a 1k x 1k SSC image printed by a dye-sublimation printer on a 8" x 10" sheet of paper, and that such an electronic print is indistinguishable from a photographic print. If larger prints are needed, images greater than the CCD size can be produced by shifting the specimen between exposures, and then splicing subsequent exposures together.

In summary, slow-scan CCD technology is making it possible to capture the rich information contained in biological TEM images electronically. These images have the potential to introduce the full power and convenience of digital imaging into the modern biological TEM laboratory. (Continued)

1. G.F. Amelio, Charge-coupled Devices, Scientific American, (Feb., 1974),22.
2. J. Kristian & M. Blouke, Charge-coupled Devices in Astronomy, Sci. Am., (Oct., 1982),66.
3. M.E. Mochel & J.M. Mochel, Proc. 44th EMSA Meeting (1986), 616.
4. P.E. Mooney, et al, Proc. XIIth ICEM (1990), 164.
5. O.L. Krivanek, et al, (to be published in Proc. 1991 EMAG Meetings)

Fig 1. Ciliated epithelium. 100 kV, 3 secs exposure. Macintosh Quadra image using the Gatan 679 1kV SSC camera on a Jeol 100S and a dye-sublimation printer.

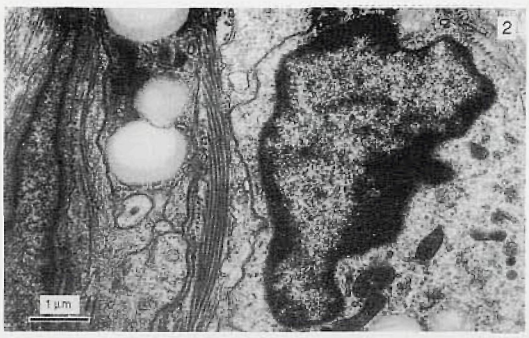

Fig. 2. Histiocyte in skin dermis. 120 kV, 2 sec exposure. Macintosh Quadra image using the Gatan 679 1K x 1k SSC camera on a Philips CM12 and a dye-sublimation printer.