DOI: 10.1017/S1431927603447831
Microsc Microanal 9(Suppl 2), 2003

High Performance Digital Imaging for Transmission Electron Microscopy

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Digital imaging for TEM has advanced considerably since the introduction of charge coupled device (**CCD**) detectors [1-4]. Immediate access to data in digital form for online viewing, analysis, processing, refinement, collaboration, and indeed, remote microscope operation has significantly increased experiment efficiency, flexibility, and throughput. Beyond speed and flexibility, CCD imaging systems surpass film recording in many major aspects, including sensitivity, linearity and dynamic range. Complete digital imaging systems for TEM have been produced by several companies, including: Advanced Microscopy Techniques (Rowley, MA), Gatan (Warrendale, PA), JEOL (Peabody, MA), Roper Scientific (Tuscon, AZ), and Tietz-Video (Herbststrasse, Gauting, Germany).

Due to radiation damage to and signal saturation of the CCDs, direct detection of electrons with CCD technology is not practical. Instead, current CCD based systems rely on a scintillation screen to convert high energy electrons to photons which can be relayed to the detector. Depending on the relay scheme, two types of CCD imaging systems can be classified: lens-coupled and fiber-optically coupled systems (Figure 1). Both types of systems have been discussed in the literature [2-8]. The major issues to be considered when designing or choosing a commercially available system are: resolution, sensitivity, dynamic range, detection-quantum-efficiency (DQE), compatibility with the microscope vacuum, x-ray contamination to images, modularity, expandability, fixed pattern noise, physical dimension/packaging, shutter implementation, readout rate, and cost.

Each implementation for TEM digital imaging has its own merits and drawbacks according to the major issues mentioned above. Both systems are equipped with a phosphor scintillator. In fiber-coupled systems the scintillator is deposited directly onto the fiber plug and the image created on the phosphor is relayed to the CCD, while in a lens-coupled system, the scintillator can be suspended in a self supporting manner above a lens, which relays the scintillator image to the CCD (Figure 1). At increasing accelerating voltages, the "footprint" of a single electron in the scintillator increases, becoming the resolution limiting factor in the system design [6]. The fundamental design goal to match this electron point-spread-function (PSF) to the pixel pitch of the CCD has introduced unique challenges for both types of systems. Overall, demagnification of the image is typically required. For fiber coupled systems, this can be accomplished by using fiber tapers; however, fiber tapers introduce point dislocations and other discontinuous distortions that are very difficult to correct [9]. In lens-coupled systems, demagnification can be accomplished more easily, but at the cost of a loss in light collection efficiency.

In this tutorial, we will outline the major issues to be considered when designing or choosing a commercially available CCD based detector for high voltage TEM. We will further describe the design of a high performance lens-coupled system, placing common terminology into context and illustrating the factors associated with achieving single electron detection.

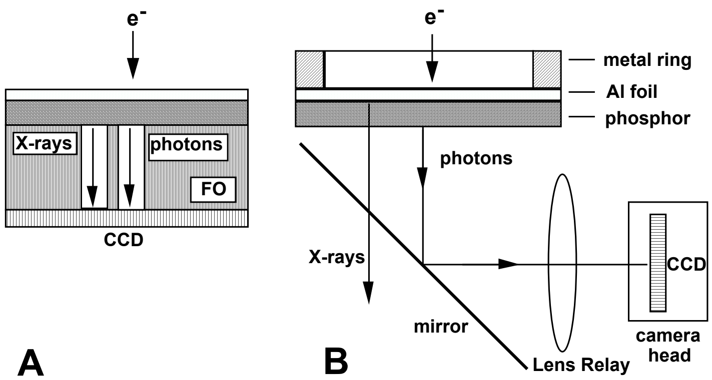

Figure 1. CCD imaging systems for TEM. A: Fiber-optically coupled systems provide better sensitivity and compact size, but have X-ray problems and lower resolution at voltages >200 keV due to the back-scattered electrons from the fiber-optic (FO) plate; B: A lens coupled system is generally less sensitive but actual resolution can maximized using a demagnification lens and a self-supporting screen. X-rays, which cause bright spots on an image, are avoided by a 90° bend in the optical path.

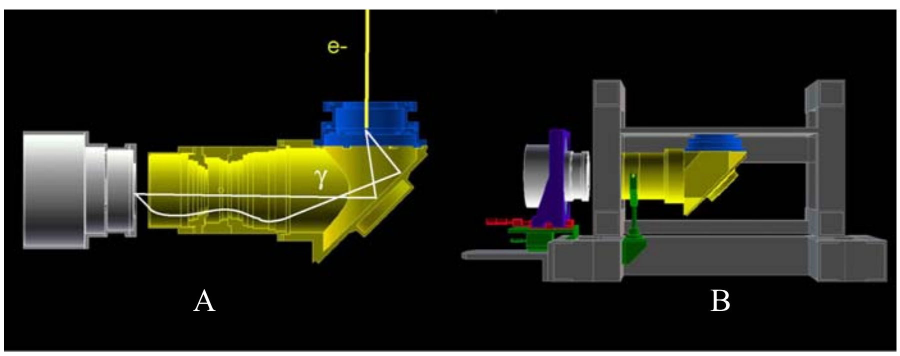

Figure 2. Design scheme of the 2kx2.5k CCD imaging system for a JEM-4000EX microscope. A: Cross-sectional schematic of the ray path through the scintillator, lens, and CCD camera. B: 3D model of the camera system as it is implemented within the lower frame (knee space) of the instrument.

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https://doi.org/10.1017/S1431927603447831 Published online by Cambridge University Press