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MIM.6.079
Future Trends in Electron Optics and Instrumentation

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Analytical electron microscopy enables (a) the visualization of the atomic structure of thin objects owing to the extremely short wavelength of the electrons at voltages above about 10kV and (b) the determination of the elemental composition and the electronic properties of the object on an atomic scale. Unfortunately, the attainable resolution is limited by the aberrations of the electron lenses, mechanical and electromagnetic instabilities, pure vacuum, and by radiation damage. Solid objects such as metals are primarily damaged by atom displacement resulting from knock-on collisions of the incident electrons with the atomic nuclei, whereas organic objects are mainly damaged by ionization destroying bonds and by etching caused primarily by water molecules and hydrocarbons. In order to further improve the capabilities of the electron microscope, it is necessary to eliminate or to reduce sufficiently the performance-limiting effects of present electron microscopes, to design novel electron optical elements, and to introduce improved techniques which enlarge the attainable information about the static and dynamic properties of the object. At present, several promising developments are proposed which will be discussed in detail. These developments are

1. Dynamic TEM with time resolution in the range between 1µs to 10ps. Such microscopes equipped with a pulsed electron source will enable the observation of reactions, phase transformations, the movement of dislocations and knock-on cascades.
2. High-performance monochromator providing quasi-monochromatic electron beams with an extremely small energy width of about 10meV. If this monochromator is combined with a spectrometer with the same energy resolution, local phonon spectroscopy will be possible with electrons.
3. Improved correctors enabling usable apertures up to 80mrad because these aperture angles are necessary for effective optical sectioning by means of “*holographic*” phase-contrast imaging in STEM. This imaging mode requires a segmented bright-field detector and a Fresnel phase plate which can be formed with a sufficient degree of accuracy by adjusting appropriately the third-order spherical aberration and the defocus of the corrected objective lens, as illustrated schematically in Fig. 1. By subtracting the signals of the annular detector segments covering the region of destructive interference of the scattered wave with the non-scattered wave from that recorded by the annular segments covering the regions of constructive interference (Fig. 2), we obtain a pure phase contrast image which may be conceived as a holographic image because the terms of the intensity which depend quadratic on the scattering amplitude cancel out.
4. Pulsed cathode triggered by laser pulses for DTEM and spin polarized sources for investigating magnetic fields.
5. Cold stable double-tilt stage to reduce radiation damage and for enabling controlled shift and motion-free tilt of the sample in two perpendicular angular directions.
6. Ultra-high vacuum (UHV) to reduce contamination and specimen etching.
7. Incorporation of a superconducting objective lens which eliminates the motion of adsorbed surface atom and provides stable focusing.
8. Fast 8K detectors with high DQE at low voltages.
9. Obstruction-free phase plate for increasing the image contrast of weak phase objects.

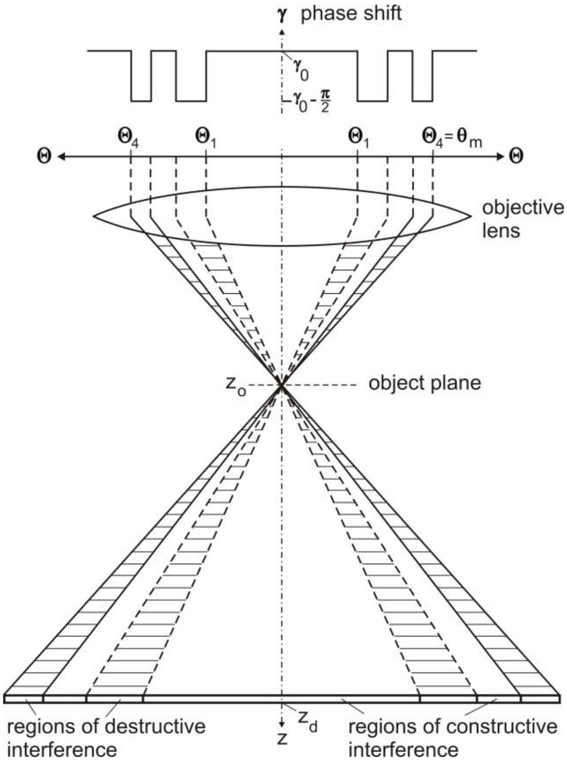

Figure 1. Formation of regions with low and high intensity beneath the object plane in STEM by interference of the scattered wave with the non-scattered wave whose phase is modulated by a Fresnel phase plate located behind the object. In practice, the phase plate is formed approximately in an aberration-corrected STEM by choosing appropriately the defocus and the third-order spherical aberration of the objective lens.

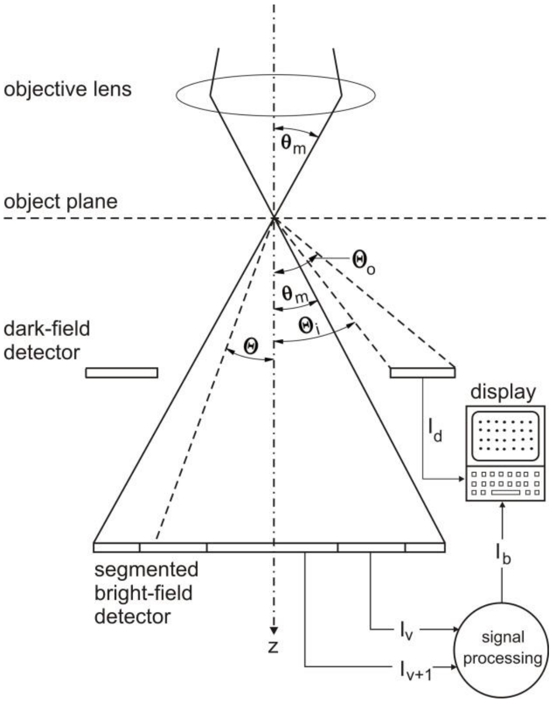

Figure 2. Holographic phase contrast in STEM formed by the difference of the signal recorded by the segmented detectors covering the regions with constructive interference from that of the regions with destructive interference