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Advanced Instrumentation for Low Voltage Scanning Microscopy

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The basic electron optical design of the scanning electron microscope (SEM) derives from its distant ancestor the high voltage oscillograph and has remained essentially unchanged for 70 years. Similarly most of the components of the SEM retain a close resemblance to those found in the first commercial instruments 40 years ago. However, the continuous pressure to further enhance the performance of the low voltage SEM in the face of fundamental physical limitations is forcing a reappraisal of both individual components and of the basic electron-optical design.

Since the brightness of all electron sources varies linearly with their energy low voltage guns compare poorly with those used at conventional energies. Consequently there is much interest in new ultra-bright sources, such as nanotip field emitters, which can provide as much, or more, brightness at 1keV or below as older sources operated at 20keV. The energy spread of the source is also a major issue because chromatic aberration results in enlarged spot sizes and poorly shaped probe profiles at the lowest energies. Sources, such a cold field emitters which have an energy spread of ~0.3eV and negative affinity sources which can have an energy width below 0.1eV, will become increasingly important. In order to further minimize the effects of chromatic aberration the convergence angle of the beam must also be restricted. At the lower beam energies, however, this means that the optical performance becomes diffraction limited because of the large wavelength of the electrons. To achieve the highest levels of performance the chromatic and spherical aberrations of the probe lens must also be significantly reduced. This can now be achieved by the use of an aberration corrector[1]. Such a device results in both a significantly smaller probe diameter and higher beam current from the same electron source. However, this is achieved at the expense of a drastically reduced depth of field, which may make conventional operation of the SEM very difficult. Alternatively a cathode lens configuration, in which the incident electron is rapidly decelerated to the desired landing energy just prior to striking the sample, can be employed[2] This arrangement is simple and efficient, however the high electric fields normal to the specimen surface can lead to significant problems with charging. In either case it now becomes possible to maintain the instrumental resolution essentially constant down to beam energies as low as 20eV or so (figure 1) provided that adequate screening against external disturbances can be provided. Advances are also possible and desirable being in the design of electron detectors. The familiar Everhart-Thornley detector is of relatively poor efficiency (DQE~0.1) and collects a signal which a mixture of secondary and backscattered electrons, leading to poor image contrast. Through-the-lens (TTL) detectors, which use the post-field of the lens to collect the secondary signal, have not only a much higher efficiency (DQE~0.8) but are also more selective in the energy spectrum of the electrons that they accept. In the most advanced design the TTL detector can , in effect, be tuned so as to collect either a pure SE signal, or a backscattered signal, or some mixture of the two[3]. This provides great flexibility in imaging, avoids the necessity of a separate BSE detector, and permits backscattered operation at very short working distances. The ultimate goal remains a detector which is both efficient and can be used to select any arbitrary energy window in the emitted spectrum for imaging.

Radically new designs which seek to avoid some of these problems are also now being pursued by several groups. Low Energy Electron Microscope (LEEM) based systems use flood beams of low energy electrons (or light or X-rays) to excite secondary electrons which are then accelerated and imaged through a lens systems onto a CCD or similar recording device[4]. This approach removes the problem of generating a small probe at low energies, and can provide very high sensitivity to surface topography, potentials, and chemistry, although the broad energy spread of the secondary emission means that aberration corrected imaging lenses are still required for high resolution. An additional benefit is that image formation is a parallel rather than a sequential operation which provides a significant speed advantage for some applications. An alternative approach is the point projection microscope (PPM) which consists only of an electron source, the sample, and a detector[5]. Because there are no lenses, the resolution is limited only by the size of the electron source and by the electron wavelength. Since the source must be physically very small, to eliminate penumbral blurring, it is also highly coherent and so the image becomes an in-line Fresnel hologram (figure 2).

References

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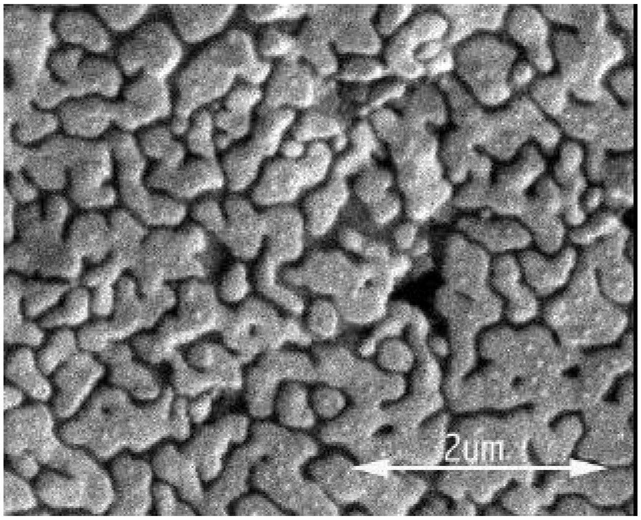

Figure 1. SE image of a gold film at a landing energy of 30eV in a field emission SEM operated with a retarding cathode lens

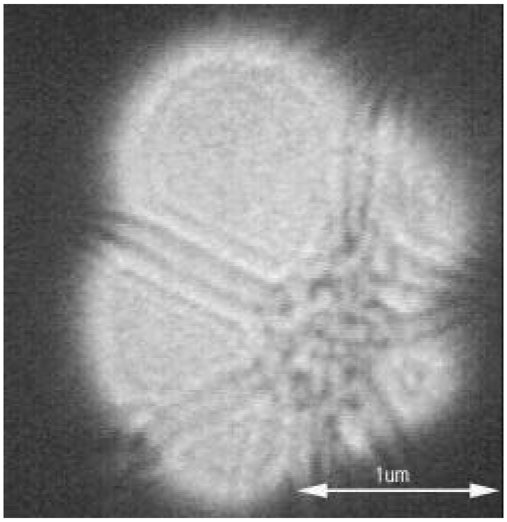

Figure 2. In-line Fresnel hologram of a holey carbon film. 350eV in a point projection microscope