# Comparing Microscopes

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We will compare VPPEM with other microscopies in two ways. First, we will look at the electron optical properties, and second, we will compare VPPEM with PEEM from a functional prospective.

VPPEM does not fit the conventional formal descriptions of electron optical practice. The forms of spherical and chromatic aberration are very different, and the diffraction limit is negligible. These differences stem largely from the fact that VPPEM does not have an objective lens, it is a not a focusing technique. However, it is worthwhile trying to get a feel for the 'goodness' of the equivalent VPPEM 'lens', to bring out its advantages, and limitations compared to a conventional magnetic lens and the electrostatic PEEM.

Spherical aberration is normally defined as the radius of an imaged point at the disc of least confusion:

$$r_a = \frac{1}{2} C_s \alpha^3 \qquad (1)$$

Where the radius of the aberration $r_a$ is equal to half the coefficient of spherical aberration $C_s$ times the cube of the half angle α. As angle is dimensionless the coefficient of spherical aberration is a distance. In contrast, the change in resolution with acceptance angle depends on *sin(α)* for a VPPEM as this radius depends on the cyclotron orbit radius at the sample.

$$r_{cl} = \frac{\sqrt{2mE}\sin(\alpha)}{eB} \qquad (2)$$

Where E is the energy of the electron and B is the field.

Although, we cannot compare the aberration coefficients directly, we can compare in certain situations. Taking a conventional magnetic lens we would expect that the coefficient of spherical aberration would be similar to the focal length of 1.0 mm, and at angle of $10^{-2}$ radians we would have a 1.0 nm disk of confusion due to spherical aberration. This would be a typical performance for a lens in a transmission electron microscope. If we used a conventional magnetic lens for photoelectron spectroscopy we would expect to need a greater working distance to allow the beam to illuminate the sample. This would imply a working distance of at least 10 mm, and $C_s$ would then be on the order of 10 mm.

For a VPPEM with a 20T field. For VPPEM with acceptance angle of 90 degrees (1.5 radians) working back from the 20-80% edge spatial resolution defined by:

$$\rho = \frac{3\sqrt{E}}{B} \qquad (3)$$

If we identify the radius of confusion with half of this, the equivalent disk of confusion would be 75 nm for a 1eV electron. The equivalent coefficient of spherical aberration at 1.5 radians is therefore 44nm. The coefficient of spherical aberration for VPPEM is at least 10,000 times smaller than a conventional magnetic lens by this measure.

Chromatic aberration in VPPEM is due to the difference in angles at the exit from the field with different energies. This is not analogous to chromatic aberration in the focusing lenses. Chromatic aberration in VPPEM is a percentage of the field of view. If we take a 75eV electron exit energy, and an energy resolution of 0.5eV, chromatic aberration will change the maximum angle by:

$$Error\% = 100\left(\sqrt{\frac{E+\Delta E}{E}} - 1\right) \qquad (2)$$

Which for 75 eV and 0.5 eV is 0.3% or 3 parts in 1000 at the edge of the image.

The diffraction condition for VPPEM is due to diffraction from the smallest aperture in the system. As this is the 2 mm aperture at the CHA, it follows that diffraction in the VPPEM can be disregarded.

Although it is difficult to tell the whole story in one graphic we want to compare VPPEM with the objective lens focusing techniques of conventional magnetic lenses, and electrostatic PEEM.

The figure below shows this comparison for photoelectron energies from 1-1000eV for the PEEM/LEEM type of microscopes, and the conventional electron microscope lens. the VPPEM is operating at the normal 1 eV working energy.

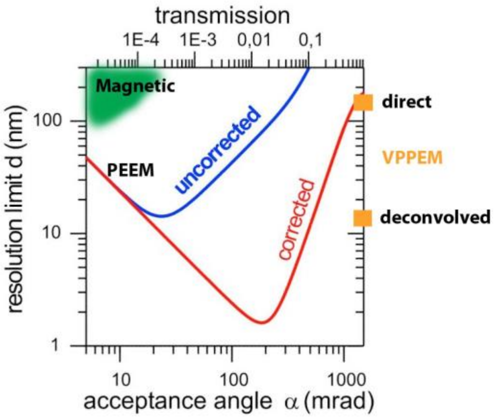

Figure 1 Comparison of VPPEM with PEEM

The PEEM graphics are derived from published data for the corrected PEEM and published comments about realistic operating conditions. The conventional magnetic optic calculation assumes a 10mm working distance, and 0.25eV energy spread. The PEEM and VPPEM work better at low energies, while conventional optics work better at higher energies as chromatic aberration dominates the focus at the low energies used in photoelectron spectroscopy. This graphic is not the whole story. The photoelectron specifications for PEEM, as compared to the LEEM optics appear to be nearly an order of magnitude worse, perhaps because a longer working distance is required. It is not very clear from the literature what the case is. The best uncorrected PEEM resolution we have found is 20 nm. We have only taken one slice through the operating conditions. We could add depth of field, range of operation, and other factors. But this gives a general idea of where VPPEM stands in respect to the objective lens techniques.

The second comparison we can make is in the functional area, what the PEEM and VPPEM microscopes can do. The Photo-Emission Electron Microscope (PEEM/LEEM) uses an immersion electrostatic field (cathode lens) instead of a magnetic field, to produce an image. However, while both PEEM and VPPEM can produce chemical images of a surface, the imaging properties, and fields of application are very different. There are significant differences with respect to PEEM.

VPPEM has:

1. A large depth of focus (1-2mm), and consequent insensitivity to topographic effects.
2. Axial (sample normal) illumination, and coaxial electron signal detection.
3. Ability to image poorly conducting (or non-conducting) samples.
4. Ability to image magnetic samples.
5. Clear working area around the sample.

The final spatial resolution, and the sensitivity of VPPEM are similar to PEEM. Both techniques are best used with synchrotron light source imaging using Near Edge X-ray Absorption Fine Structure (NEXAFS), and X-ray Photoelectron Spectroscopy (XPS).

VPPEM does not have:

1. High spatial resolution at higher energies.
2. Angle dependent NEXAFS response.
3. Easily interpretable images.
4. A high number of lines per image

The less obvious differences are in the type of signal imaged, and the information depth which is tunable in VPPEM. Microscopic non-destructive depth profiling may be a significant VPPEM output, which even could be done on fibers. This would be an impossibility with PEEM.

PEEM/LEEM has been in development for nearly 50 years and has well recognized fields of excellence. However, the differences in the imaging properties suggest that VPPEM would be immediately valuable for real world samples: metal particles on rough catalyst supports, fracture surfaces, three dimensional semiconductor devices, microstructure of rare earth magnets, corrosion pits, and etc.