Developing a broadband X-ray excited optical luminescence microscope (XEOM)

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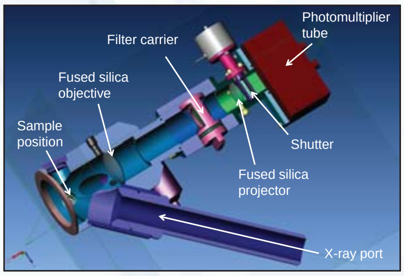
The battle to understand, prevent, or stabilise corrosion of heritage metals sometimes requires sophisticated tools. X-ray excited optical luminescence (XEOL) is process whereby optical photons are emitted from a sample under bombardment by X-rays. The intensity of light emission can be measured as a function of incident X-ray energy to produce spectra of the same form as those obtained by conventional X-ray absorption spectroscopy (XAS). The result is that a sample surface may be non destructively (and if necessary, non-invasively) chemically mapped on the micron scale. A XEOL instrument [1] for obtaining broadband 1-D spectra has already been built and development of a system capable of image formation is now underway. It is anticipated that the new instrument will be capable of recording wavelength-resolved 1D spectra and 2D images in parallel. Moreover, when used in conjunction with a novel electrochemical/environmental cell (eCell) [2], information about the reaction of a sample to a controlled environment will be obtained. Phenomena such as corrosion and passivation can be studied on real or simulated heritage metal surfaces.

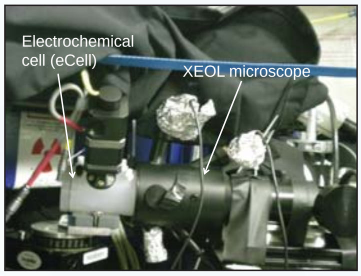
XEOM Mk. I

The first iteration of the XEOL microscope is a proof-of-concept instrument designed simply to capture as much of the emitted light as possible.

- Simple optics since no image formation required.
- Photomultiplier tube in place of CCD camera.

The microscope is designed to couple directly with the electrochemical cell. This allows samples to be kept in a controlled environment while being monitored using electrochemical and XEOL measurements.

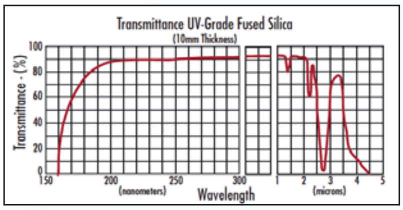




Materials

The choice of optical glass for the lenses is determined by some basic requirements of the system:

- Flat transmission profile across the trans-visible region (200-1000 nm).
- Low X-ray fluorescence.



Fused silica meets the requirements of the optical glass with a flat transmittance of ~90% from near UV to infra-red.

Acetal copolymer (a black plastic) is chosen as the material for the housing due to its structural properties and ease of machining. Importantly, it also has low X-ray fluorescence.

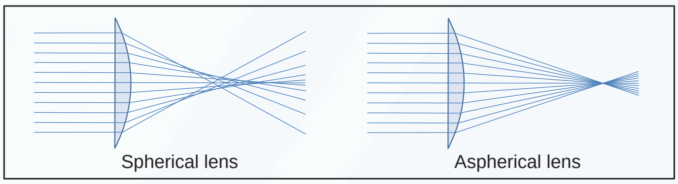
Lens design

The restriction of using a single glass type imposes some significant restrictions on the lens design:

- Using glass of a single refractive index makes it impossible to produce an achromatic lens system i.e. one which focuses all wavelengths to a single point.
- It is also more difficult to correct higher order off-axis aberrations.

To focus all wavelengths onto the CCD array, movement of one (or more) of the lenses, or the CCD camera itself will be necessary.

Spherical aberration is the most significant monochromatic aberration and is corrected by the use of one or more aspherical lenses.



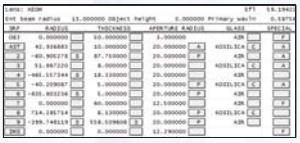
Off-axis rays passing through a positive spherical lens are focused short compared to paraxial rays – by deviating from a spherical surface, this can be corrected.

Magnification

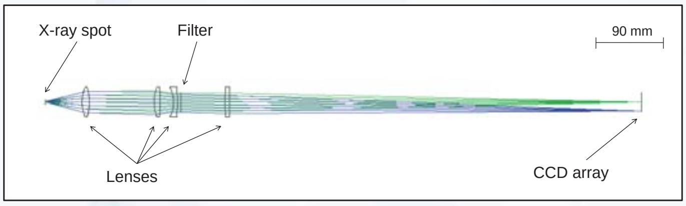
The magnification is limited by the longest wavelength of light that is collected (infra-red at ~1 micron). This leads to a maximum useful magnification of ~12x (but digital zooming will give us up to 1000x).

Design software

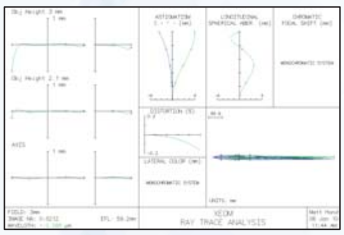
'Optics Software for Layout and Optimization' (OSLO) is a ray tracing package which is being used to design and optimise the optical system.

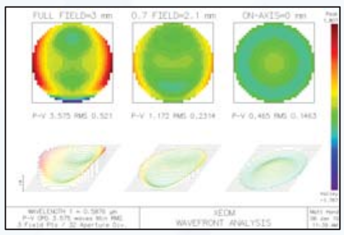


In OSLO, the lens data are entered into a spreadsheet and light rays are then traced through the system allowing the optical performance to be analysed. Optimisation routines can be used to further improve the design.



Below: Typical ray diagnostic tools used to determine the quality of the image formation. The on-axis performance is almost diffraction-limited, but the off-axis is affected by coma and astigmatism.





The next step...

In addition to 2D imaging, the next iteration of the XEOL microscope will include a second optical path for parallel recording of wavelength-resolved 1D spectra. This will be achieved using a diffraction grating and additional lenses to focus the light onto a second CCD array.

References

[1] M. G. Dowsett et al., *Anal. Chem.* ***80,*** *8717–8724* (2008)
[2] M. G. Dowsett and A. Adriaens, *Anal. Chem.* **78,** 3360-3365 (2006)

Acknowledgements

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