Ptychography: a revolution in atomic-scale microscopic imaging

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Ptychography is a high-resolution lensless imaging method that works over all wavelength scales. Because it does not need a lens, its main field of application is in X-ray and electron imaging, because lenses of high numerical aperture (i.e. which deliver high-resolution images) are very hard to manufacture at atomic-scale wavelengths. It has now been widely adopted by the X-ray synchrotron community where it is quickly becoming a routine imaging and tomographic technique. It has been shown to work with high-energy electrons, although its development with matter waves has been rather slower (for reasons which will be discussed in this presentation): it nevertheless holds great promise for ultimate resolution sub-atomic scale 3D imaging. In fact, it also has some unique capabilities in the visible light domain because the phase image that it yields is extraordinarily sensitive and quantitative – invaluable, for example, for stain-free live cell imaging.

It is analogous to holography in that it deduces an estimate of both the amplitude and the phase of a wavefield. However, unlike holography, it does not need a reference wave: instead the object is illuminated with a roughly localised 'probe' which is moved across the object. The probe can be formed by any sort of poor quality lens, or even just an aperture upstream of the object. At each probe position, a diffraction pattern is collected downstream of the object. The probe is generally much larger (100s of times) than the resolution of the final image of the image obtained from the technique. Because there is no reference wave required, the constraints on the stability of the experimental set up is far lower (unlike in electron holography, say, where instrumental and environmental interference effects must be very tightly – and expensively – controlled). The key innovation that made the technique tenable was the development of fantastically efficient methods for solving the phase problem (the diffraction pattern is recorded only in intensity) using redundancy in the collected data: each area of the object is illuminated more than once as probe is shifted.

This talk will first briefly describe the technique and its history. Examples will then be given for X-ray, electron and visible light ptychography. Latest developments will be described, indicating that there is still a huge potential for the development and application of the technique.