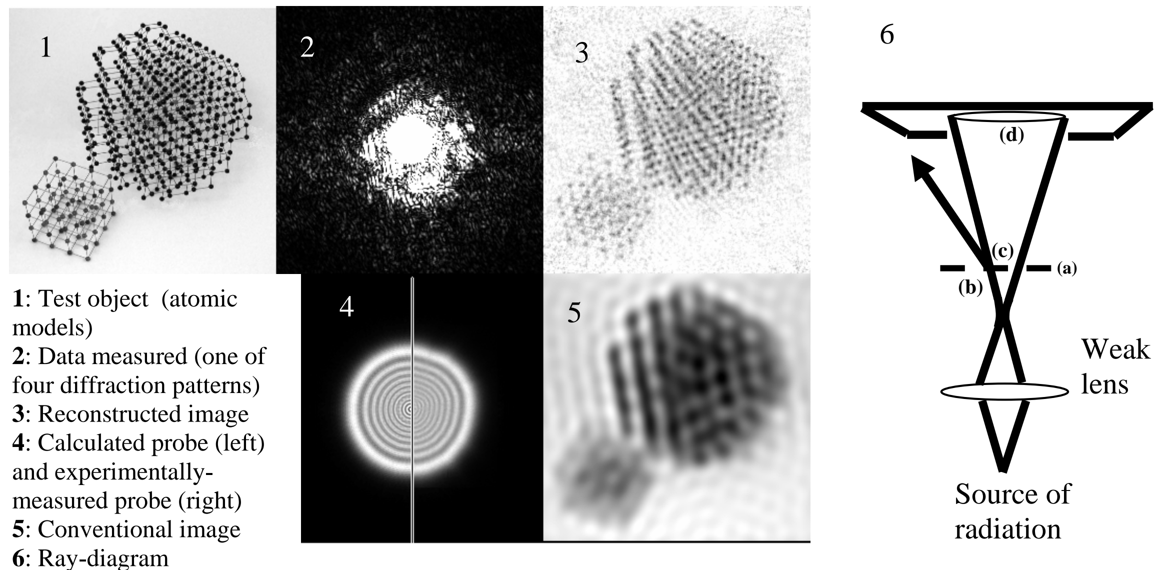
Ultimate Microscopy

With ever-decreasing electronic component sizes, it is becoming increasingly important to be able to image atomic structure at the very highest resolution possible. For example, in a state-of-the-art field effect transistor, the insulating layer of SiO_2 can be only a few atomic bond lengths thick. In principle, a high-energy electron has a wavelength which is short enough to image directly every single atom in a 3-dimensional structure (about 1/100 of the atomic diameter). Unfortunately, electron lenses are too myopic (by a factor of about 50) to achieve this goal. We can image atomic columns in the electron microscope, but we cannot resolve their three-dimensional position.

Recent work in this laboratory has suggested a revolutionary approach to the resolution problem in electron microscopy. Instead of forming an image, a series of diffraction patterns, each collected from a small area of the specimen, is used to synthesise a very high resolution image of the object. Diffraction patterns do not suffer from the same limitations as conventional image, because the atoms in the object itself are used as an interferometer – there is no need for a very stable, perfect electron lens. The high scattering angles involved also contain 3D information, instead of just a two-dimensional projection of the atomic potential.

So far, we have demonstrated a very efficient way of processing many diffraction patterns in order to create an ultimate resolution microscope. Work is currently underway to test the technique in both the optical and electron microscopes.



1: Test object (atomic models)
2: Data measured (one of four diffraction patterns)
3: Reconstructed image
4: Calculated probe (left) and experimentally-measured probe (right)
5: Conventional image
6: Ray-diagram

Fig. 5 shows the conventional diffraction-limited image of the object corresponding to that obtained in a standard electron microscope, for this low numerical aperture lens – i.e. high frequency data is lost. By employing our method and using four diffraction patterns with high angle information (of the type modelled in Fig 2) taken from 4 different beam (or object) positions, we can reconstruct numerically the very high resolution image in Fig. 3, which took only about 4 minutes to obtain on a Pentium 4 PC (compare with Fig. 5). The illumination (Fig. 6b) can in theory be of any roughly localised form. Our algorithm can be extended to any field of view. We have shown that the method is robust to the presence of noise and that experimental variables such as the probe defocus, or positional errors induced by hysteresis in moving the specimen or probe do not give false minima in the iterative solution method (which effectively solves for millions of unknown phase values in parallel).