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On the reconstruction of ultra low-energy electron holograms and diffraction patterns

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Low-energy electrons (50-250 eV) have been proven to be the best known radiation for imaging individual biological molecules at high resolution, as they have a sufficiently short wavelength (0.7-1.7 Å) and inflict the least radiation damage [1]. Two dedicated low-energy electron microscopes for imaging individual biomolecules are operated in our group: performing either holographic or coherent diffractive imaging (CDI). In both microscopes, a coherent divergent spherical electron wave is generated by field emission from a sharp tungsten tip. In the holographic microscope, part of the divergent wave is scattered by a sample, and the scattered and unscattered wave form an interference pattern – the hologram [2]. In the CDI microscope, the divergent electron wave is collimated by a microlens [3] and the parallel plane wave impinges onto the sample. The far-field diffraction pattern is recorded at a distant detector. Holograms and diffraction patterns are then subject to numerical reconstruction.

We will present holograms of individual biomolecules such as DNA [4-5], bacteriophage [6] and functionalized nanotubes [7] and discuss the key issues concerning their reconstruction. This includes: Problems associated with the elimination of the twin image [8] intrinsic to Gabor's type holography [9-10], and implementing low-energy electron wave scattering properties into classical light optics wave propagation integrals. Numerical solutions and artifact-free reconstructions of experimental holograms will be presented, see an example in Figure 1. We recently showed how holography and CDI can be merged into one superior technique: holographic coherent diffraction imaging (HCDI) [11]. In HCDI, two records of the same sample, a hologram and a diffraction pattern, are used. In the reconstruction, HCDI employs an iterative phase retrieval algorithm where the initial phase distribution is not random as in conventional methods, but directly obtained from the hologram. Such well-defined initial phase distribution provides a stable convergence of the iterative procedure towards a unique solution. Thus, reconstructions obtained by HCDI combine the highest possible resolution and uniqueness of the solution. Reconstructions of experimental low-energy electron diffraction patterns of carbon nanotubes and of free-standing graphene at 2.13 Å resolution will also be presented.

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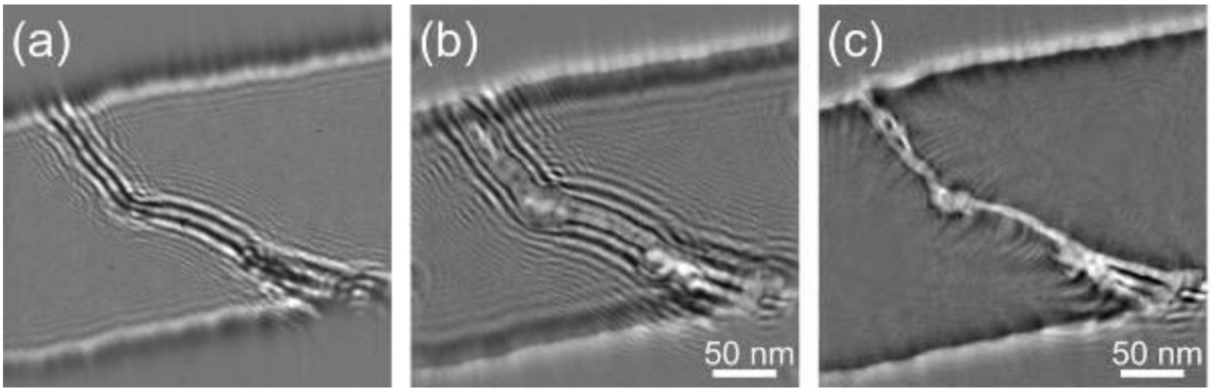

Figure 1. (a) 100 eV low-energy electron hologram of a bundle of nanotubes. (b) Conventional reconstruction of the hologram. (c) Optimized reconstruction of the hologram.