# Open Topics

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## Low-keV electron diffractive imaging based on a single-atom electron source

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Brightness and spatial coherence of electron sources are two key factors for their application to electron interferometry, electron holography, coherent electron diffraction, and many other electron microscopic techniques. Nanotips or single-atom tips (SATs) are of great interest for emitting coherent and bright electron beams because of their small source sizes. Use of these field emitters may greatly improve the resolution and performance of electron-beam based microscopic techniques. It has been shown that noble-metal covered W(111) SATs can be reliably prepared [1,2]. A process to fabricate tungsten tips with good control of tip profiles has also been demonstrated [3]. The growth of the faceted pyramidal tips is a thermodynamic process. Even if a tip apex is destroyed or contaminated, the single-atom sharpness can be restored through a simple annealing, ensuring a long operation lifetime. These SATs are also chemically stable. When a SAT is exposed to air, a clean SAT can be regenerated after annealing in vacuum. Due to a small source size and a small opening angle, both the brightness and spatial coherence of these single-atom electron sources are orders of magnitude better than those of the state-of-the-art electron sources used in current electron microscopes [4].

We have built a low-energy electron point projection microscope (PPM) to image nano-objects. A schematic is shown in Figure 1. The PPM is a shadow microscope where a specimen is placed between a field emission electron point source and a detector. The detector (Microchannel plate, MCP) is mounted on a retractable support. The magnification of the projected image (bright-field unscattered beam) at the screen is (D+d)/d. A higher magnification bright-field projection image can be obtained as the tip approaches the object (smaller d) or as the detector is retracted (larger D). When the detector is moved close to the sample (small D), the dark-field diffraction patterns of the sample at large angles can also be recorded. The patterns we have obtained at large angles are similar to the convergent-beam electron diffraction patterns obtained in TEM. Combined the low-resolution projection image with the high-angle dark-field diffraction patterns, it will be possible to obtain a high resolution image via some phase retrieval algorithms. Figures 2(a) and 2(b) show a projection image and the corresponding diffraction pattern of a graphene sample, respectively. For the image shown in Figure 2(b), fine structures inside each diffraction disk of graphene can be clearly seen.

Figure 3 illustrates a new design of a low-keV electron microscope based on a single-atom electron source and a focusing lens. The tip is mounted on a holder that can be positioned, tilted, and rotated in nano-meter scale by several piezo-driven positioners. Therefore, the tip-lens alignment can be done in vacuum without any alignment coil. Owing to the small virtual source size and opening angle of the single-atom electron source, it will be possible to focus electron beams into a small spot through a simple electrostatic lens. To equip with appropriate signal collectors, the low-keV electron microscope allows different imaging modes, including secondary electron imaging, coherent electron diffractive imaging, and in-line holographic imaging, etc. This new instrument may allow determination of the atomic structures of individual thin nano-objects, such as graphene, carbon nanotubes, DNA molecules, or protein molecules.

1. H. S. Kuo, I.-S. Hwang, T.-Y. Fu, J.-Y. Wu, C.-C. Chang, and T.T. Tsong, Nano Lett. 4(12) (2004), p. 2379.
2. H. S. Kuo , I.-S. Hwang, T.-Y. Fu, Y.-C. Lin, C.-C. Chang, and T. T. Tsong, Jpn. J. Appl. Phys. 45 (2006), p. 8972.
3. W. T. Chang, I.-S. Hwang, M.-T. Chang, C.-Y. Lin, W.-H. Hsu, and J.-L. Hou, Rev. Sci. Instrum. 83 (2012), p. 083704.
4. C. C. Chang, H.-S. Kuo, I.-S. Hwang, and T. T. Tsong, Nanotechnology 20 (2009), p. 115401
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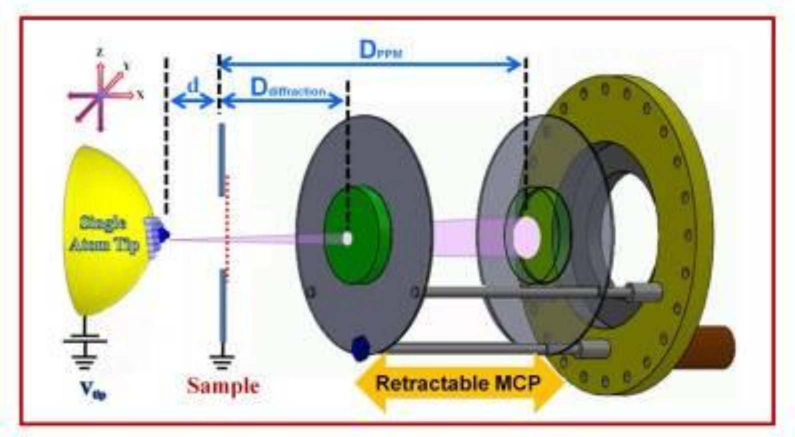

**Figure 1.** Schematic of an electron point projection microscope with a retractable MCP. The bright-field projection images can be obtained when $D = D_{PPM}$ =13 cm, and the diffraction patterns of the object at large angles can be recorded when $D = D_{diffraction}$ = 3 cm.  The magnification of the bright-field image is M = (D+d)/d.

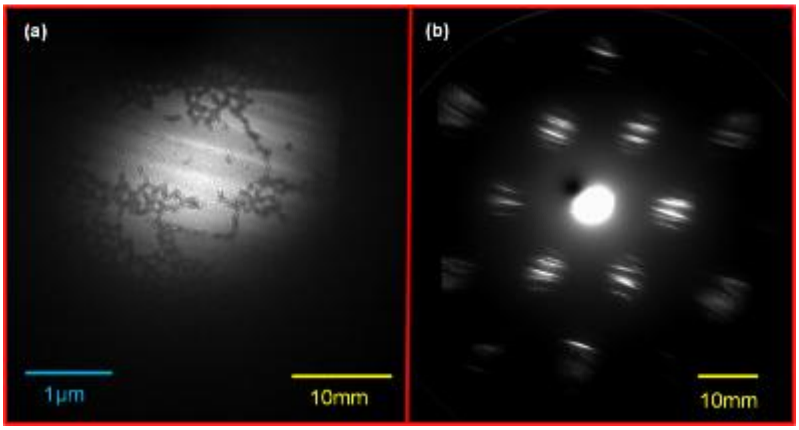

**Figure 2.** Study of a suspended graphene sheet. (a) Bright-field PPM image taken at $D = D_{PPM}$. (b) Diffraction pattern taken at $D = D_{diffraction}$. The yellow scale bar at the lower right-hand corner indicates a length on the screen; the blue scale bar at the lower left-hand corner indicates a length on the sample plane.

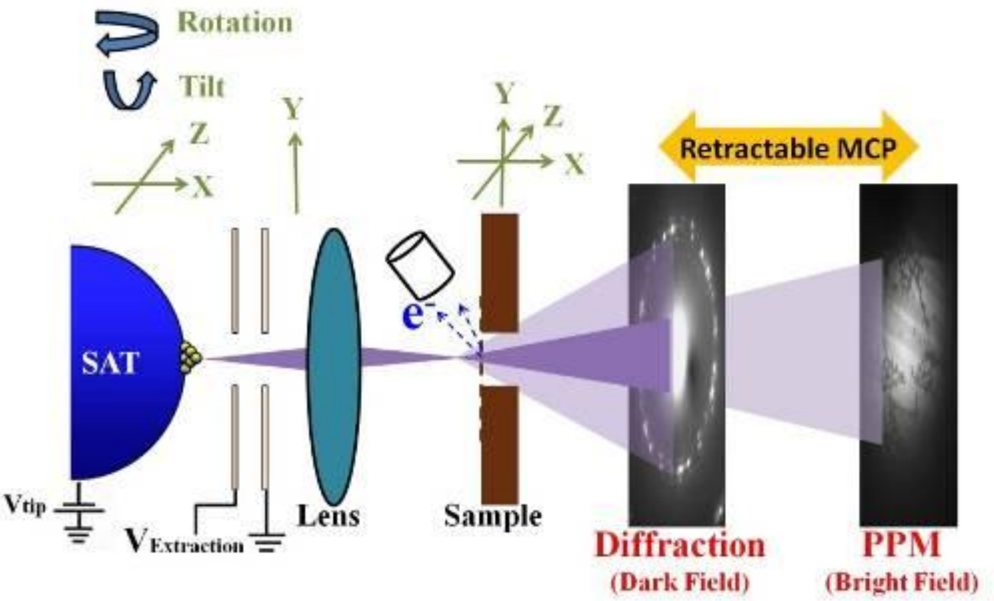

**Figure 3.** Schematic of a low-keV electron diffraction microscope.