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Low-Energy Electron Diffractive Imaging Based on a Single-Atom Electron Source

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Electron-beam based instruments, such as scanning electron microscope, transmission electron microscope, are important in current technology. A major limitation on the performance of these techniques is electron source. Brightness and spatial coherence of electron sources are two key factors of their application in electron interferometry and holography, electron diffraction, and electron microscopies. Nanotips or single-atom tips (SATs) are of great interest for emitting coherent and bright electron beams because of their small source size. Use of these field emitters may greatly improve the resolution of current electron microscopy.

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. These SATs are both physically and chemically stable and can be regenerated through a simple annealing in vacuum, ensuring a long operation lifetime. Due to the smallest 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 Fig. 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 supporter. The magnification of the sample projection image (bright-field unscattered beam) at the screen is (D+d)/d. A higher magnification bright-field projection image is 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 data collection angle increases and the dark-field diffraction patterns of the sample at large angle can be recorded. The high collection angle image we obtain is similar to the convergent beam electron diffraction pattern 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. Figs. 2(a) and 2(b) show a projection image and the corresponding diffraction pattern of a graphene sample, respectively. For the image shown in Fig. 2(b), fine structures inside each diffraction disk of graphene can be clearly seen.

Fig. 3 illustrates a new design of a low-energy 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 the 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-energy 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.

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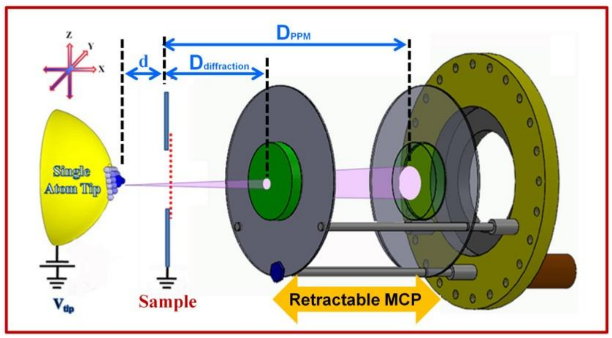

Figure 1. Schematic of an electron point projection microscope with a retractable MCP. The bright-field projection images is obtained when D = D_{PPM} =13 cm, and the diffraction patterns of the object at large angles can be recorded when D = $D_{diffraction}$ = 3 cm. The magnification of the bright-field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

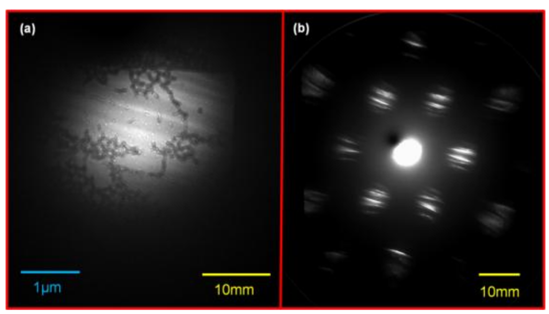

Figure 2. Study of a suspended graphene sheet. (a) Bright-field PPM image taken at D = D_{PPM}. (b) Diffraction pattern taken at D = $D_{diffraction}$. The yellow scale bar at the lower right-hand corner indicates a length on the screen; the blue scale bar at the lower left-hand corner indicates a length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

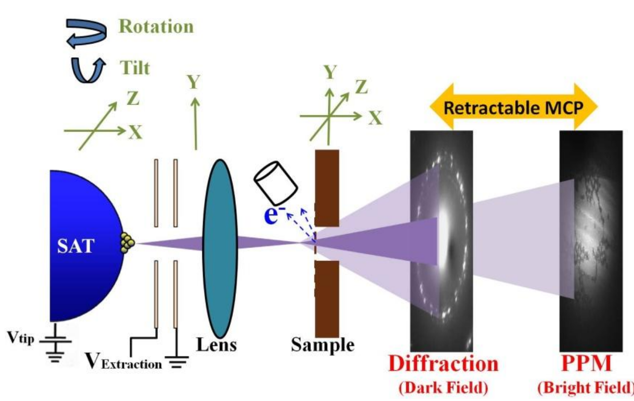

Figure 3. Schematic of a low-energy electron diffraction microscope.

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