Low-Energy Electron Diffraction Microscopy Based on a Single-Atom Electron Source

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A single-atom tip (SAT) can be an ideal field emitter of electron beams. It has been shown that noble-metal covered W(111) SATs can be reliably prepared[1,2]. 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. Both the brightness and spatial coherency 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.

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 an object is placed between a electron point source and a detector screen. A higher magnification image is obtained when the tip approaches the object (Fig. 2). In Fig. 2(c), the fringe pattern extends throughout the entire beam width, indicating good phase correlation at all points transverse to the propagation direction[3]. This fully coherent electron beam would be ideal for coherent electron diffractive imaging of an isolated nano-object.

Based on the scheme in Fig. 1, we have built a retractable MCP, so that projection images can be obtained when ***D*** is large and the diffraction patterns of the object at large angles can be recorded when ***D*** is small. Figs. 3(a) and 3(b) show a projection image and the recorded diffraction pattern of a graphene sample, respectively. Fine structures inside each diffraction disk of graphene can be clearly seen. We will discuss the meaning of the diffraction pattern. A new scheme of a low-energy electron diffraction microscope based on the single-atom electron gun and a focusing electrostatic lens will be presented, which allows different imaging modes, including SEM, PPM, in-line electron holography, and coherent electron diffraction imaging. This new instrument may allow determination of the atomic structures of individual thin nano-objects, such as carbon nanotubes, DNA molecules, protein molecules, etc.

[1] H.-S. Kuo, I.-S. Hwang, T.-Y. Fu, J.-Y. Wu, C.-C. Chang, T.T. Tsong , NANO Lett. **4**(12), 2379(2004).

[2] H.-S. Kuo, I.-S. Hwang, T.-Y. Fu, Y.-C. Lin, C.-C. Chang, T. T. Tsong, Jap. J. Appl. Phys. **45**, 8972 (2006).

[3] C.-C. Chang, H.-S. Kuo, I.-S. Hwang, T. T. Tsong, Nanotechnology **20**, 115401(2009).

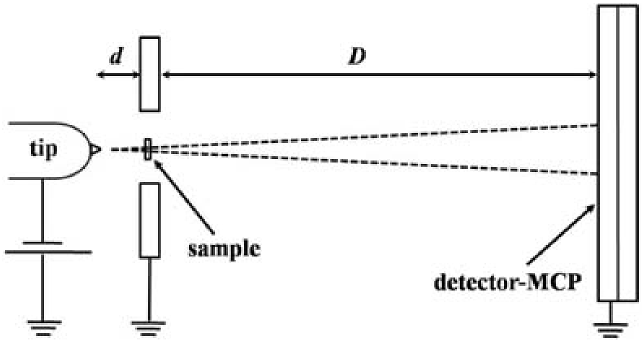

Figure 1: Schematic of an electron point projection microscope.

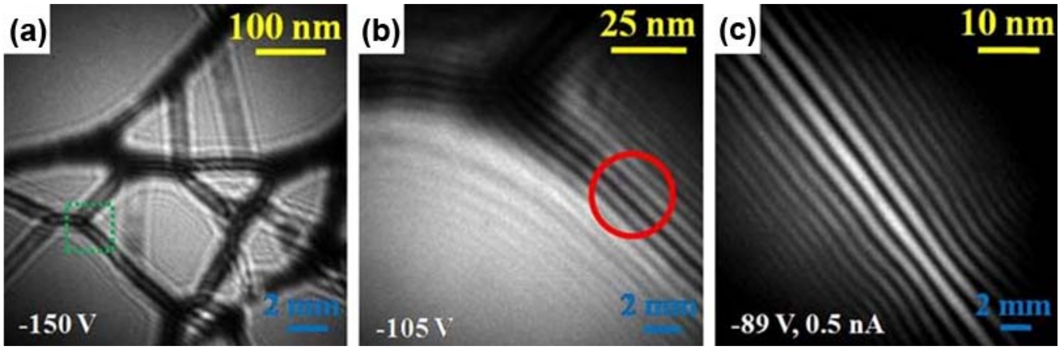

Figure 2: PPM images of interconnected carbon nanotube bundles taken at different tip-sample separations. (a) ***d*** = 5 µm. (b) ***d*** = 1.1 µm. T (c) ***d*** = 425 nm. The scale bar at the lower right-hand corner indicates a length on the screen; the yellow scale bar at the upper right-hand corner indicates a length as indicated on the sample plane.

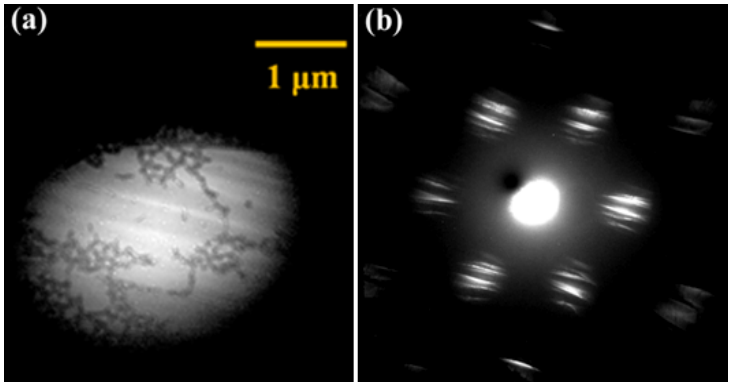

Figure 3: Study of a suspended graphene sheet. (a) PPM image taken at ***D***=13 cm. (b) Diffraction pattern taken at ***D***=3 cm.