Low-Voltage Coherent Electron Imaging Based on a Single-Atom Electron Source

Chun-Yueh Lin, Wei-Tse Chang, Wei-Hao Hsu, Ing-Shouh Hwang
Institute of Physics, Academia Sinica, Taipei, Taiwan 11529
monsterjam@sinica.edu.tw

Developing low-voltage electron microscopes has been a general trend due to high imaging contrast and low radiation damage. Recently, atom-resolved transmission electron microscopes with voltages as low as 15-40 kV have been demonstrated. However, achieving atomic resolution at voltages lower than 10 kV is extremely difficult. An alternative approach to obtaining high resolution images is coherent imaging or phase retrieval imaging, which requires a sufficiently coherent source as well as detection of high-angle scattering patterns. In this work, experimental schemes of both lens-less and lens-containing designs to achieve coherent imaging are proposed. Preliminary results based on a highly coherent single-atom electron source are presented.[1,2]

Electron point projection microscopy (PPM) is a lens-less technique to implement coherent imaging. Fig. 1 shows a schematic of a PPM with a detector mounted on a rail. High-magnification PPM images can be directly obtained when the detector is moved to the far end. If the detector is moved close to the sample to increase the collection angle, divergent beam electron diffraction (DBED) patterns can be recorded. Three-dimensional displacement of atoms as small as 1 Å can be detected through low-energy DBED.[3] Figs. 2(a) and 2(b) shows a PPM image and the corresponding DBED patterns of a suspended graphene sample. With a sufficiently small detection area on the sample to fulfill sampling requirements of coherent diffractive imaging (CDI), atomic structures of the sample can be reconstructed.

The lens-less scheme is simple and can achieve a high imaging contrast due to the use of low-energy electrons (20-500 eV). However, it can only be applied to samples of thickness less than 1 nm. Thus, a low-kilovolt electron diffraction microscope with energies between 1 and 10 keV was developed.[4] Fig. 3(a) shows a schematic of a low-kilovolt CDI instrument. High-angle coherent diffraction patterns of a suspended graphene sample corresponding to $(0.62\ \text{Å})^{-1}$ were recorded, as shown in Fig. 3(b).

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[1] H.-S. Kuo, I.-S. Hwang, T.-Y. Fu, Y.-C. Lin, C.-C. Chang, and T.-T. Tsong, *Jpn. J. Appl. Phys.* **45**, 8972 (2006)
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[4] C.-Y. Lin, W.-T. Chang, Y.-S. Chen, E.-T. Hwu, C.-S. Chang, I.-S. Hwang and W.-H. Hsu, *J. Vac. Sci. Technol. A* **34(2)**, 021602 (2016)

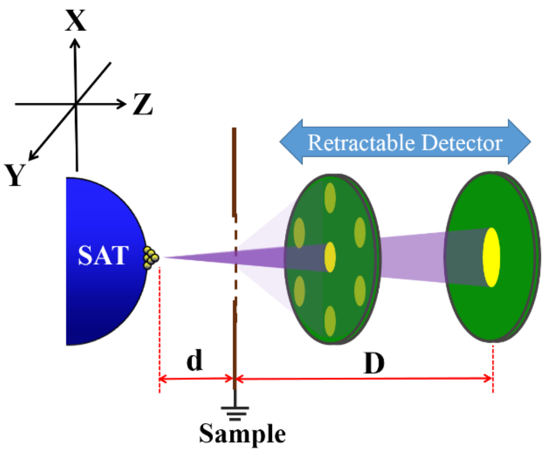

Figure 1: Schematic of an electron PPM with a retractable detector.

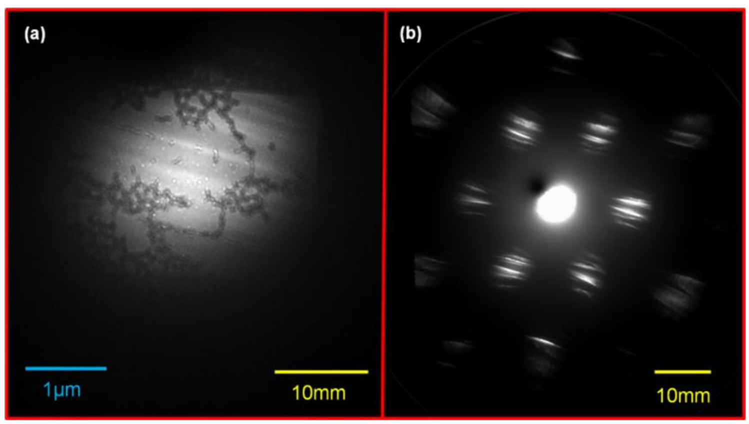

Figure 2: (a) A PPM image of a suspended graphene. (b) The corresponding DBED pattern of the same region. The yellow scale bar at the lower right-hand corner indicates a length on the detector; the blue scale bar at the lower left-hand corner indicates a length on the sample plane.

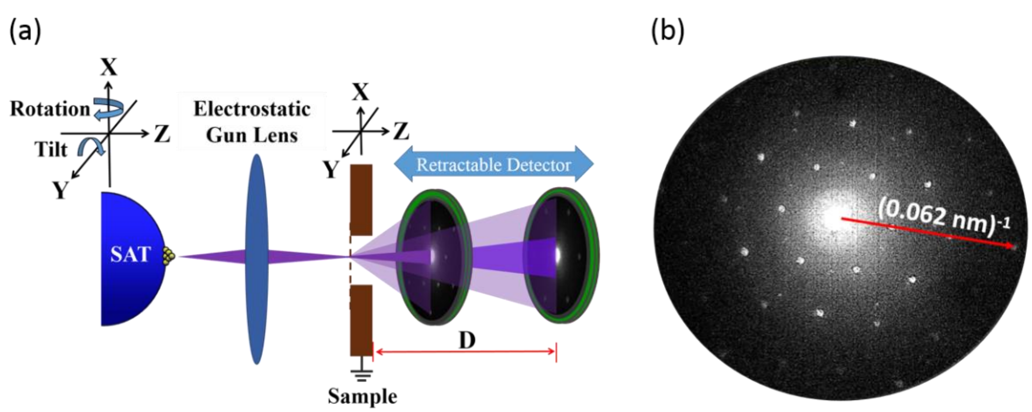

Figure 3: (a) Schematic of a low-kilovolt CDI instrument. (b) Coherent electron diffraction pattern of a suspended graphene. The outmost diffraction spots corresponds to $(0.062\ \mathrm{nm})^{-1}$. [4]