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

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Imaging of the atomic structures of two-dimensional materials and organic materials is a challenge for current electron microscopes because of low imaging contrast and high radiation damage. It has been a general trend to develop electron microscopy of lower energies. Thanks to the progress in aberration-correction techniques, transmission electron microscopes with voltages down to 15-40 kV have recently been demonstrated. However, it becomes very difficult to achieve atomic resolution when the electron energy is reduced below 10 keV. An alternative approach is phase retrieval imaging, which requires a sufficiently coherent source, detection of high-angle diffracted patterns with a sufficient resolution, and a sufficiently small detection area on the sample. There is no need to fabricate high-quality lenses with a large numerical aperture.

In this talk, we propose several transmission-type schemes. Both lens-less and with-lens designs will be presented. We use a noble-metal covered W(111) single-atom tip as the emitter. High brightness and fully spatial coherence of electron beams emitted from noble-metal covered W(111) single-atom tips (SATs) have been demonstrated [1], which are ideal for phase retrieval imaging. This type of SATs can be reliably prepared and regenerated in vacuum [2,3]. Their pyramidal structures are thermally and chemically stable, ensuring their long operation lifetime.

Fig. 1a shows a lens-less scheme with a retractable detector to record the transmission patterns at different positions behind the sample. Fig. 1b shows a pattern taken when a MCP screen is moved close to a free-standing graphene sample. The central disk is a bright field image, which can also be treated as an in-line-hologram, of the sample and the surrounding disks are the corresponding dark field images. Cleary, the low-energy electrons are very sensitive to the adsorbates on graphene. In addition, we can detect additional contrast from the dark field images. This scheme can only study samples with thickness less than 1 nm due to the electron energy between 20-500 eV. It is thus desirable to increase the electron energies to 1-10 keV. Fig. 2 illustrates several operation modes of a low-kV electron microscope, which allows independent control of the electron energy. A lens system is needed to extract, accelerate, and focus the electron beam emitted from the single-atom electron source. It allows operation of in-line holography, coherent diffractive imaging, and scanning electron microscopy. A MCP-screen, mounted on a rail, can be moved to different positions behind the sample to record the patterns. The ultimate goal is to achieve high-contrast and high-spatial-resolution imaging of thin materials under low-dose conditions.

In addition, we will propose reflection-type low-energy coherent diffraction imaging for characterization of surface atomic structures of materials. In conventional diffraction methods, such as low-energy electron diffraction (LEED) and reflection high-energy electron diffraction (RHEED), the lateral coherence width (tens of nm) of the electron beam is significantly smaller than the illumanation width (mm) on the sample. If one can focus a fully coherent electron beam to a sufficiently small size (<100 nm) on a surface, the diffraction patterns would in principle allow determination of the local atomic structures of the surface. This can be a powerful new technique to complement scanning probe microscopy, such as STM and atomic force microscopy.

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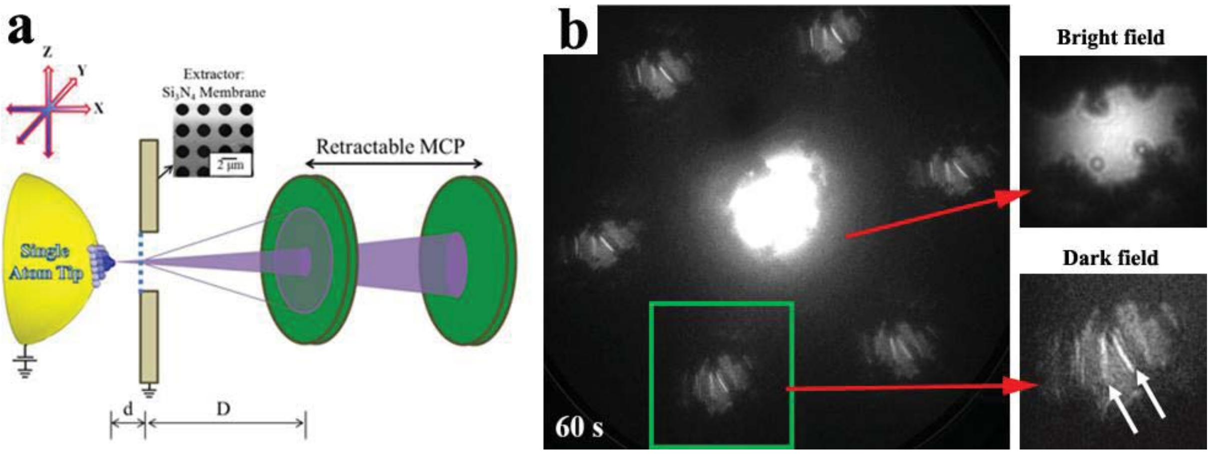

Fig. 1. (a) Schematic of a lens-less electron diffraction microscope with a retractable detector. (b) Diffraction pattern of a freestanding monolayer graphene recorded at 245 eV.

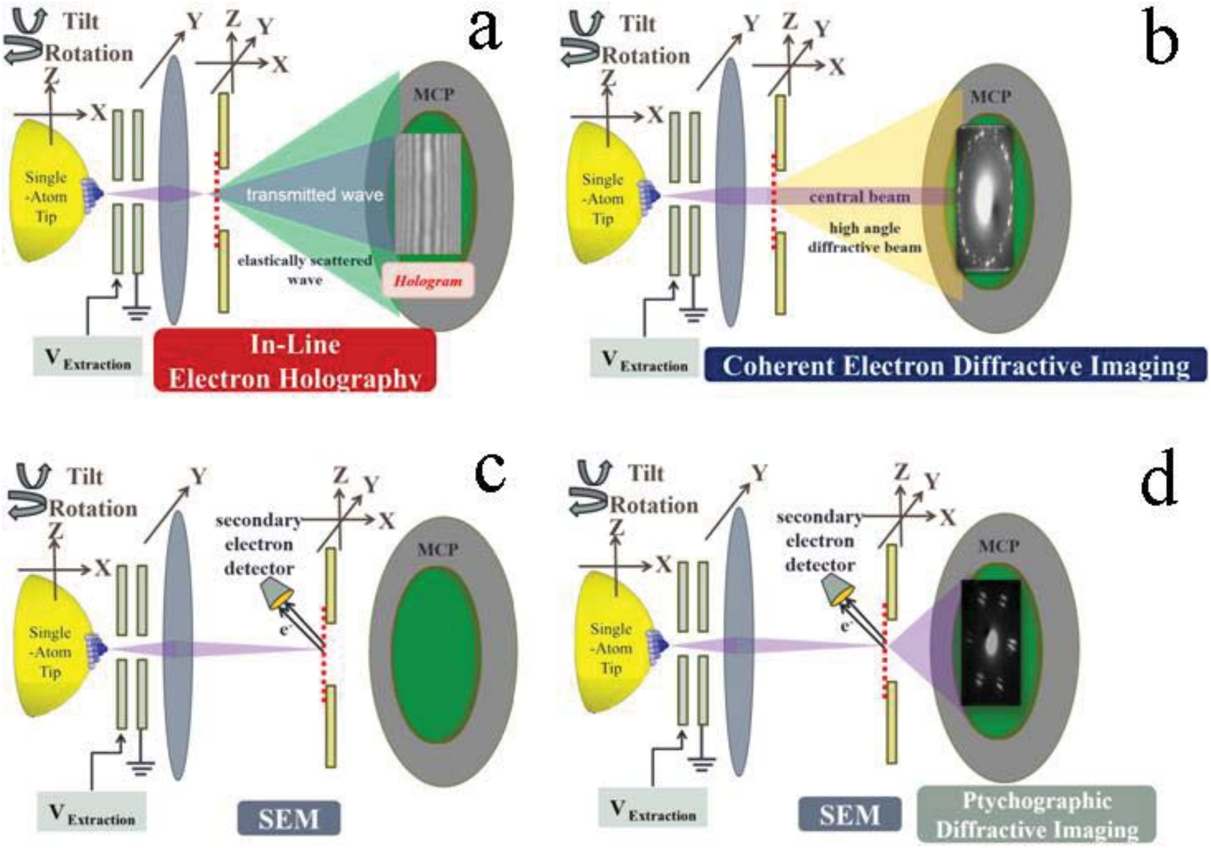

Fig. 2. Several operation modes of the proposed low-keV coherent diffractive imaging. (a) In-line holography. A focused electron beam with a large converging angle is used to produce a hologram of a suspended object. (b) Coherent diffractive imaging with a parallel beam to illuminate the sample. (c) Scanning electron microscopy with the secondary electrons collected by an electron detector. (d) Coherent diffractive imaging with a slightly convergent beam to illuminate the sample. The transmission diffraction pattern of the sample can be recorded. In all of the schemes, the detector can be moved to different positions along the beam propagation direction.