# Coherent Imaging with Low-Energy Electrons (30 – 250 eV)

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Low-energy electron (30 –250 eV) in-line holography (also known as or point-projection imaging) is realized by placing a sample at a few tens of nanometers in front of an electron source (usually a sharp tungsten tip) where electrons are extracted by field emission [1], Fig. 1(a). When electron wave passes through the sample, part of the wave is scattered. The interference between the scattered and unperturbed waves creates an in-line hologram which is acquired by the detector, positioned at a few centimetres from the electron source. Three subjects will be discussed: biological imaging, imaging of charged impurities in graphene with elementary charge precision and imaging three-dimensional surface corrugation of graphene.

***Biological imaging***. Low energy electrons do not damage biological samples, which is usually the case for high-energy electrons. It has been demonstrated in the Biophysics group of Prof. Hans-Werner Fink at the University of Zürich, that individual biomolecules, such as DNA molecules, can withstand low-energy electrons radiation for hours without visible radiation damage [1]. Low-energy electron holograms of individual biological macromolecules and their reconstructions, Fig. 1(b), will be discussed.

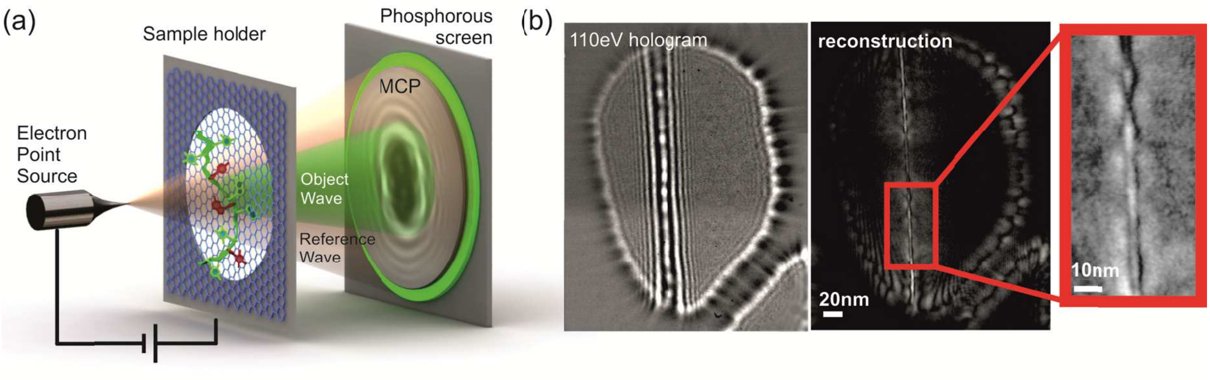


FIG. 1. Principle of in-line holography with low-energy electrons. (a) Sketch of the experimental arrangement. (b) Low-energy electron in-line hologram of DNA molecule and its reconstruction [2].

***Imaging charged impurities of graphene***. Some adsorbates on graphene transfer their charge to graphene thus creating a positively charged impurity. Such objects create large gradients of electric field around itself and deflect the passing electrons. Low-energy electrons are extremely sensitive to the local electric fields. A positively charged impurity thus leads to a distinctive signature in the hologram – a bright spot, see Fig. 2. The strength of the charge can be evaluated from the intensity of the bright spot at a precision of a fraction of an elementary charge. Also, the projected potential of an individual impurity can be recovered from its in-line hologram by applying iterative reconstruction routine.

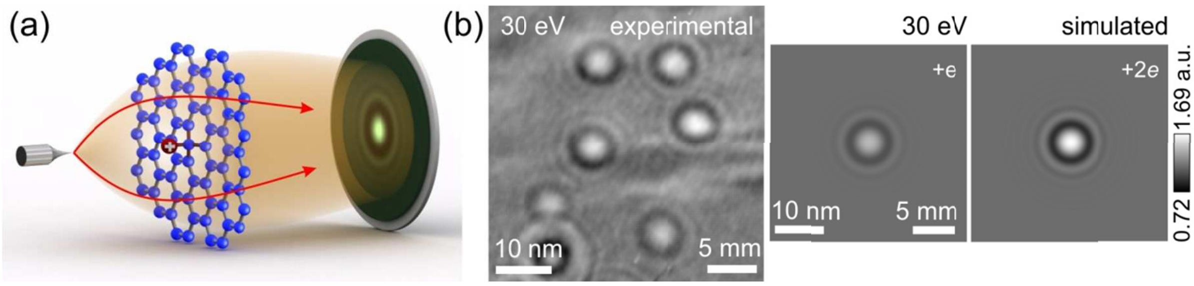


FIG. 2. (a) Sketch of formation of an in-line hologram from a positively charged impurity. (b) Experimental and simulated in-line holograms of charged impurities [3].

***Three-dimensional topography of graphene by divergent beam electron diffraction (DBED)***. DBED is a non-invasive, non-scanning and single-shot imaging technique that offers a possibility of direct visualisation of the three-dimensional topography of thin free-standing materials [4], as illustrated in Fig. 3. The information available from the first order diffraction spots is much richer than that provided in the conventional zero-order diffraction spot and it is related to three-dimensional structure of the sample. For example, ripples in graphene that are only 1 Angstrom in amplitude can be easily visualized by DBED.

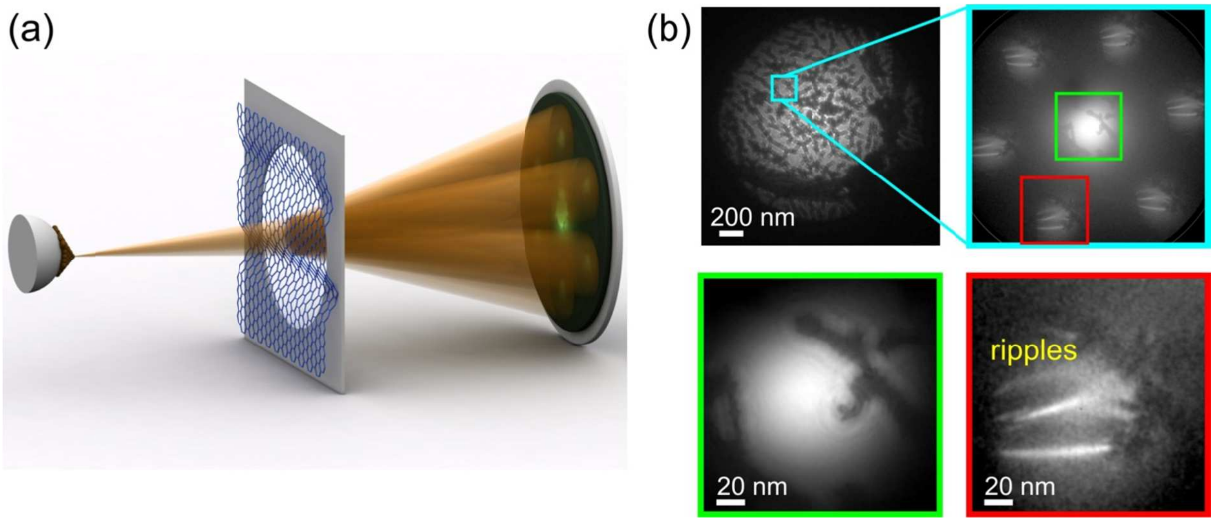


FIG. 3. (a) Principle of divergent beam electron diffraction (DBED) imaging of three-dimensional topography of freestanding graphene. (b) Point-projection image or an inline hologram of graphene sample, its DBED image and magnified regions of the DBED pattern: the central spot where some adsorbates are observed and a first-order DBED spot where ripples between the adsorbates are observed.

**References**

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[2] T. Latychevskaia *et al.*, in *Present and Future Methods for Biomolecular Crystallography* (Springer, 2013), pp. 331.
[3] T. Latychevskaia *et al.*, Nano Lett. **16**, 5469 (2016).
[4] T. Latychevskaia *et al.*, Nat. Commun. **8**, 14440 (2017).