Coherent Diffraction Imaging Methods for 2D Materials and Nanostructures

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high-resolution 3D diffraction imaging methods

coherent diffraction imaging

iterative phase retrieval algorithms

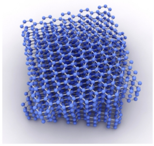
holography

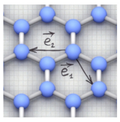
convergent beam electron

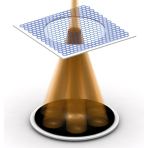
2D materials

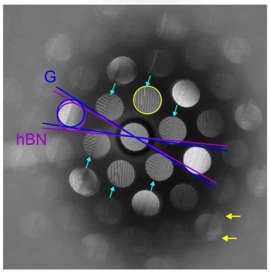
Convergent Beam Electron Diffraction (CBED)

on 2D materials (graphene, borone nitride (BN), Transition Metal Dichalcogenide (TMD), ...)









Experimental projects:
- preparation of clean graphene
- imaging and characterization of graphene
- deposition of nano-particles on graphene

Numerical projects:
- simulation of CBED patterns
- optimization and parallelization of the simulation code

Development of fully coherent electron source based on 2D materials for quantum electron microscope

with Soichiro Tsujino (PSI)

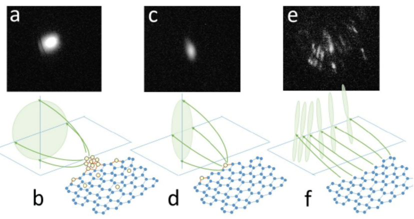


Figure: (a-b) Field emission (FE) pattern and schematic of emission from pristine graphene dominated by a single emitter (nanoprotrusion). (c-d) FE pattern and schematic of emission from thermally cleaned graphene. The local environment is no longer symmetric: the emitted electrons tend to focus along the graphene edge direction, but less in the perpendicular direction. (e) Field ion microscopy (FIM) patterns and (f) schematic from the field desorbed graphene using oxygen. As field desorption eliminates local asperities until the field is more even, emission is no longer dominated by a single spot but multiple emitters are now visible [R. Diehl, et al, Phys. Rev. B 102, 035416 (2020), 10.1103/PhysRevB.102.035416].

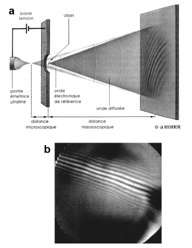
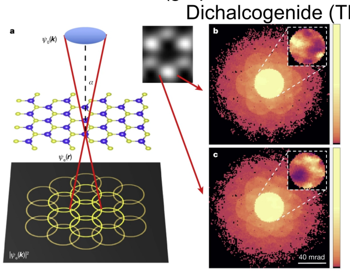


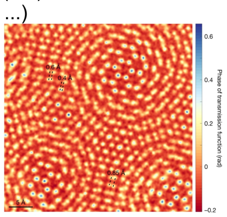
Figure: Electron in-line holography with coherent sources. (a) Experimental arrangement and (b) Interference pattern (hologram) produced on the detector screen when a carbon fiber is positioned into the electron wave [H.-W. Fink, La Recherche 234, 22 (1991)].

Experimental Master project:
Fabrication and characterization of coherent sources made of graphene.

3D Ptychography

on 2D materials (graphene, borone nitride (BN), Transition Metal Dichalcogenide (TMD), ...)

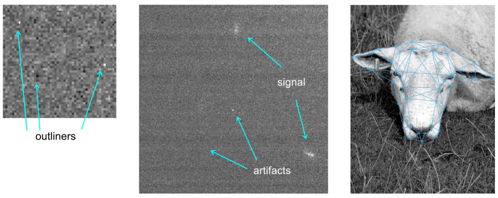




Left: (a) At each scan position, the incident probe ($\psi_0(k)$) is focused on the sample and the entire diffraction pattern of the exit wave ($|\psi_e(k)|^2$) is recorded. The blue and yellow atoms represent Mo and S atoms. ψ_0 and ψ_e refer to the incident and exit wavefunctions respectively; r is the (x, y) positional coordinate in the real-space plane; and k is the (k_x, k_y) wavenumber coordinate in the conjugate momentum-space plane. (b, c) Averaged diffraction pattern intensity (on a logarithmic scale) from the electron beam at the marked scan positions near a Mo column. Insets show the intensity (on a linear scale) of the bright-field disks.
Right: Real-space resolution test of full-field ptychography using twisted bilayer MoS_2.
Jiang et al. Nature 559, 343–349 (2018). https://doi.org/10.1038/s41586-018-0298-5

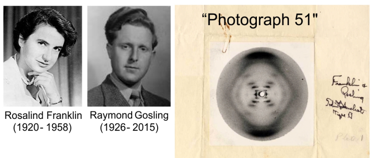
Numerical projects:
3D simulation and reconstruction of ptychographic datasets.

Artificial Intelligence (AI) methods for image analysis

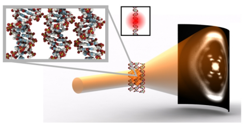


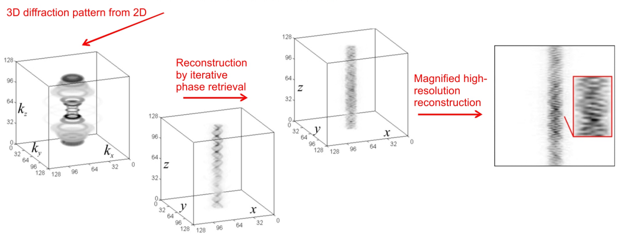
Numerical project:
Developing numerical methods for automatic recognition detector defects in transmission electron microscope images.

Fiber diffraction on helical structures



Rosalind Franklin (1920- 1958) — Raymond Gosling (1926- 2015)





Numerical project (Master):
3D reconstruction from 2D fiber diffraction pattern.

Quantum recognition

The project is working on developing a new generation of microscopes which employ so-called "Quantum Sorters", able to probe delicate specimens with extremely low sample damage.

http://www.qsort.eu/

"… we recognise familiar people from just a few small details: it means that only a few measurements are taken compared to traditional approaches – yet these are still sufficient to extract all the relevant information…"

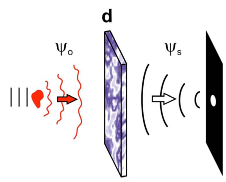


Figure: The scheme to transform the object wave O from aspecimen to a converging spherical wave S by use of the diffractive element d. The structure of the diffractive element is computed numerically. [Okamoto et al, Appl. Phys. Lett. 88, 164103, 2006]

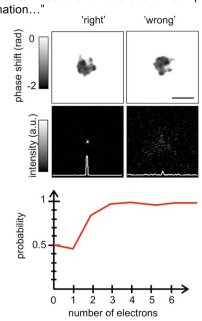


Figure: Numerical experiments for recognizing different orientations of a ribosome S70 molecule.
Upper row: Phase shifts of the specimens. Scale bar: 20 nm.
Middle row: The intensity distribution on the screen. A single spot is observed on the screen when the object is in the "right" orientation and a spread distribution is observed when the ribosome is rotated by 90° right pictures.
Bottom row: The confidence level for the hypothesis about the molecular orientation as a function of the number of detected electrons in a typical numerical experiment.
[Okamoto et al, Appl. Phys. Lett. 88, 164103, 2006]

Electrons (Master project):
with Penghan Lu (Jülich)
Simulation of phase-shifting diffractive element, numerical experiments and data analysis of electron images.

X-rays (Master project):
with Yasin Ekinci (PSI)
Fabrication of phase-shifting diffractive elements and performing experiments using coherent X-rays at the PSI.