Atomic Resolution Imaging of Highly Air-Sensitive Twisted-Bilayer 2D Structures

Guangming Cheng, Nan Yao

Microscopy and Microanalysis, **30** (Suppl 1), 2024, 1092–1093
https://doi.org/10.1093/mam/ozae044.543

Microscopy AND Microanalysis

Meeting-report

Atomic Resolution Imaging of Highly Air-Sensitive Twisted-Bilayer 2D Structures

Guangming Cheng[1],* and Nan Yao[1],*

[1]*Princeton Materials Institute, Princeton University, Princeton, NJ, USA*

*Corresponding author: gcheng2@princeton.edu, nyao@princeton.edu

The field of two-dimensional (2D) crystals and artificial structures is rapidly expanding and providing new opportunities in many areas of physics, chemistry, and engineering. The physical properties of the majority of 2D crystals in this large class remain unexplored or poorly explored, especially those beyond the air-stable materials, such as graphene and semiconducting transition-metal dichalcogenides (TMDs). In general, many 2D crystals and van der Waals structures are sensitive to their environment, though their bulk phases may or may not be stable in air. Hence, the investigation of 2D crystals requires careful processing to avoid degradation and contamination, which often calls for the development of new synthesis, fabrication, and measurement techniques [1-6]. Bulk orthorhombic *Td*-WTe_2 is a semimetal, while its monolayer counterpart is a 2D topological insulator. Recently, electronic transport resembling a Luttinger liquid state was found in twisted-bilayer WTe_2 with a twist angle of ~5°. Despite the strong interest in 2D WTe_2 systems, little experimental information is available about their intrinsic microstructure, leaving obstacles in modeling their physical properties. The monolayer, and consequently twisted-bilayer WTe_2, are highly air-sensitive, and therefore, probing their atomic structures is difficult. Here, we demonstrated a robust method for atomic-resolution visualization of monolayers and twisted-bilayer WTe_2 obtained through mechanical exfoliation and fabrication. We observed the high crystalline quality of mechanically exfoliated WTe_2 samples by using high-resolution scanning transmission electron microscopy (STEM) (no serious beam damage issue [7, 8]).

We developed a methodology to prepare plan-view TEM samples from air-sensitive Scotch-tape-exfoliated monolayer and twisted-bilayer WTe_2 samples. The procedure results in clean and suspended monolayer and twisted-bilayer WTe_2 specimens. We established that the in-plane crystal structures of monolayer WTe_2 are the same as its form in the bulk parent, confirmed by their identical in-plane *d*-spacings. We investigated the moiré patterns of twisted-bilayer WTe_2 with twist angles of approximately 5 and 2° and observed no noticeable lattice reconstruction. This observation is an important input for modeling of the atomic and electronic structures in this highly interesting material system. The direct visualization procedure described in this work deepens the understanding of the intrinsic microstructure of monolayer and twisted-bilayer WTe_2, which is important for understanding and manipulating their quantum properties [9].

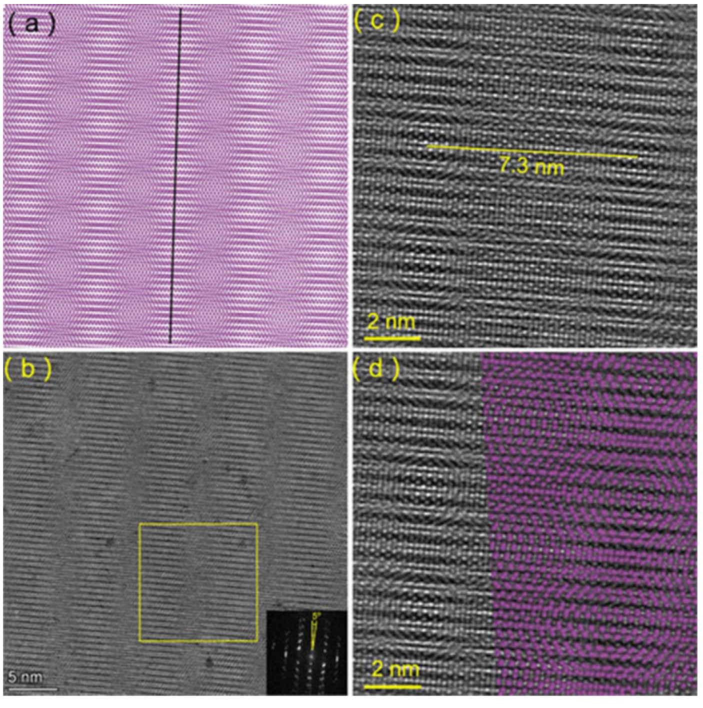

Fig. 1. Moiré patterns of twisted-bilayer WTe_2 with a twist angle of ~5°. (a) Simulated moiré pattern formed by W atoms. The direction of 1D W stripes is highlighted by a black line. (b) High-resolution STEM image of twisted-bilayer WTe_2 with a twist angle of ~5°. The inset is the FFT pattern. (c) Enlarged STEM images labeled by yellow frame in (b). (d) Overlay of enlarged experimental STEM images with simulated W moiré pattern.

References

1. F Yuan *et al.*, *Nano Letters* **23** (2023), p. 6868.
2. Y Jia *et al.*, *Nature Synthesis* (2023). 10.1038/s44160-023-00442-z
3. X Song *et al.*, *Science Advances* **9** (2023), p. eadd6167.
4. X Song *et al.*, *Chemistry of Materials* **35** (2023), p. 5487.
5. G Villalpando *et al.*, *ACS Nano* **16** (2022), p. 13814.
6. X Song *et al.*, *Chemistry of Materials* **33** (2021), p. 8070.
7. G Cheng *et al.*, *Nature nanotechnology* **10** (2015), p. 687.
8. GM Cheng *et al.*, *Small* **12** (2016), p. 818.

9. The authors acknowledge the use of Princeton's Imaging and Analysis Center (IAC), which is partially supported by the Princeton Center for Complex Materials (PCCM), a National Science Foundation Materials Research Science and Engineering Center (DMR-2011750).