Transition metal dichalcogenide metamaterials with atomic precision

Battulga Munkhbat[1,2], and Timur Shegai[1]

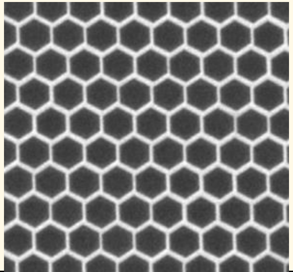
[1] Department of Physics, Chalmers University of Technology, Gothenburg, Sweden

[2] Department of Photonics Engineering, Technical University of Denmark, Copenhagen, Denmark

Abbreviated abstract: Here I will discuss our novel anisotropic wet etching method that allows scalable fabrication of TMD metamaterials with atomic precision, combined with traditional nanolithography techniques. [1] We show that TMDs can be etched along certain crystallographic axes, such that the obtained edges are atomically sharp and exclusively zigzag-terminated. This allow us to fabricate interesting hexagonal nanostructures of predefined order and complexity, including few nanometer thin nanoribbons and nanojunctions.

Related publications:

– B. Munkhbat et al, Nature Comm., 11, 4604 (2020)



bamunk@fotonik.dtu.dk

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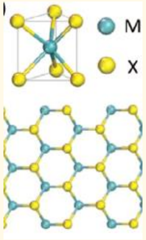
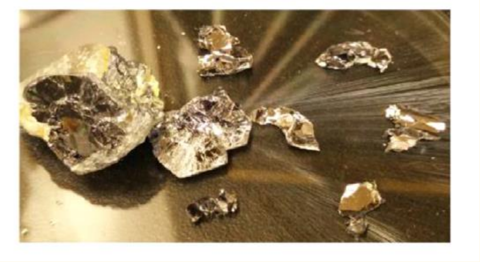
TMDC: Transition Metal Dichalcogenides (vdW materials)

MX_2:



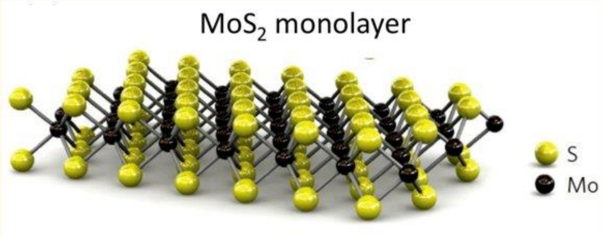


MoS_2 mineral rock

Key properties:

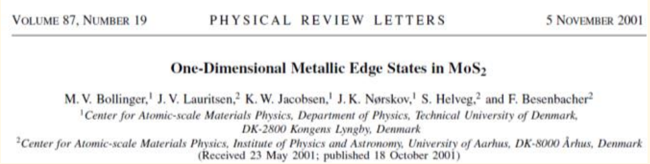
- Excellent platform for light-matter interactions
- 15-20% absorption at room T!
- Monolayer, thickness <1nm
- Interesting exciton physics
- Relatively stable
- Relatively simple to fabricate
- **Existance of trions!**

M (Metal): Mo, W, Ta …
X (Chalcogen): S, Se, Te …



Unique physical and chemical properties, including:

- Semiconducting (excitonic) property
- Optical (high absorption)
- Availability of reactive sites for redox reactions etc.,
- Multifuncational 1D zigzag edges



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One-Dimensional Metallic Edge States in MoS_2

M. V. Bollinger,[1] J. V. Lauritsen,[2] K. W. Jacobsen,[1] J. K. Nørskov,[1] S. Helveg,[2] and F. Besenbacher[2]
[1]Center for Atomic-scale Materials Physics, Department of Physics, Technical University of Denmark, DK-2800 Kongens Lyngby, Denmark
[2]Center for Atomic-scale Materials Physics, Institute of Physics and Astronomy, University of Aarhus, DK-8000 Århus, Denmark
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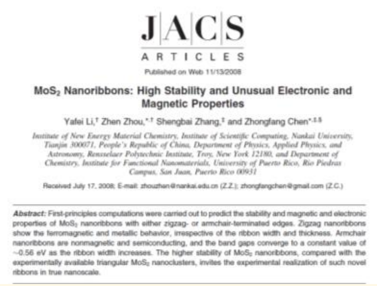

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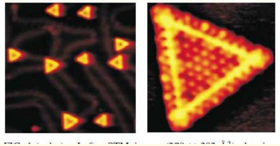
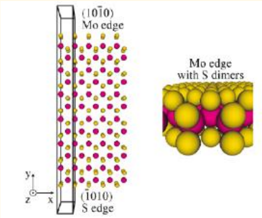
MoS_2 Nanoribbons: High Stability and Unusual Electronic and Magnetic Properties

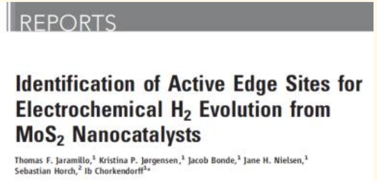
Yafei Li,† Zhen Zhou,*,† Shengbai Zhang,‡ and Zhongfang Chen*,‡,§
Institute of New Energy Material Chemistry, Institute of Scientific Computing, Nankai University, Tianjin 300071, People's Republic of China, Department of Physics, Applied Physics, and Astronomy, Rensselaer Polytechnic Institute, Troy, New York 12180, and Department of Chemistry, Institute for Functional Nanomaterials, University of Puerto Rico, Rio Piedras Campus, San Juan, Puerto Rico 00931

Received July 17, 2008; E-mail: zhouzhen@nankai.edu.cn (Z.Z.); zhongfangchen@gmail.com (Z.C.)

Abstract: First-principles computations were carried out to predict the stability and magnetic and electronic properties of MoS_2 nanoribbons with either zigzag- or armchair-terminated edges. Zigzag nanoribbons show the ferromagnetic and metallic behavior, irrespective of the ribbon width and thickness. Armchair nanoribbons are nonmagnetic and semiconducting, and the band gaps converge to a constant value of ~0.56 eV as the ribbon width increases. The higher stability of MoS_2 nanoribbons, compared with the experimentally available triangular MoS_2 nanoclusters, invites the experimental realization of such novel ribbons in true nanoscale.







REPORTS

Identification of Active Edge Sites for Electrochemical H_2 Evolution from MoS_2 Nanocatalysts

Thomas F. Jaramillo,[1] Kristina P. Jørgensen,[1] Jacob Bonde,[1] Jane H. Nielsen,[1] Sebastian Horch,[2] Ib Chorkendorff[1]*

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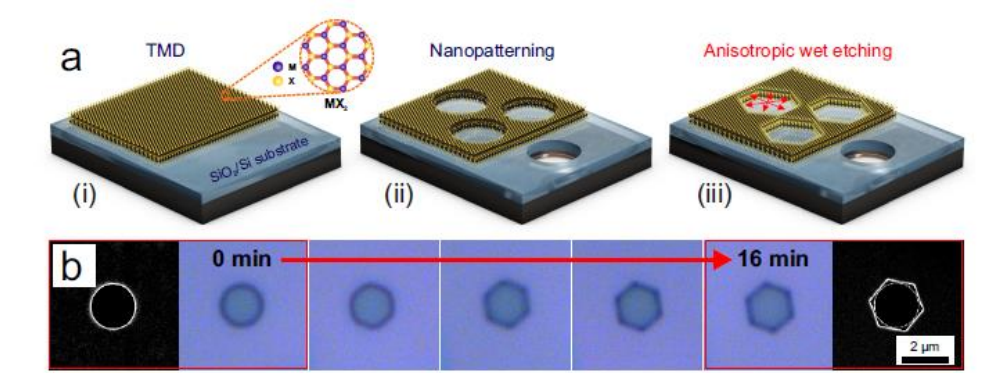
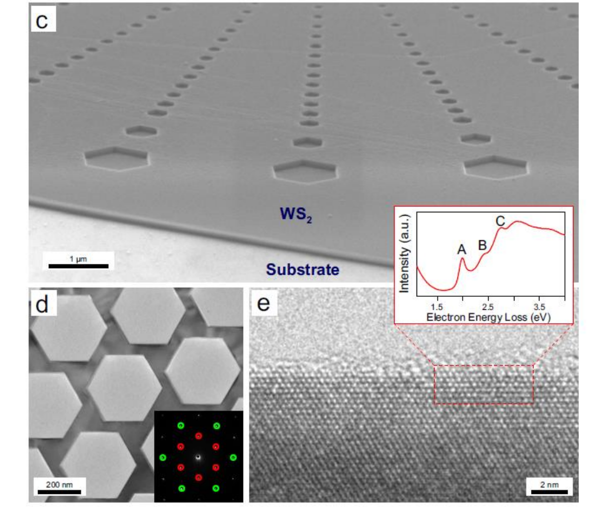
How do we create exclusively ”multi-functional zigzag edges” in TMDCs?

Exfoliation and Transfer

Nanolithography:
EBL, FIB etc.,

Wet-etching





Circular: mixture of armchair and zigzag

Hexagonal: Only zigzag edges

TEM and EELS study: Only zigzag edges

B. Munkhbat et al, Nature Comm., 11, 4604 (2020)

bamunk@fotonik.dtu.dk

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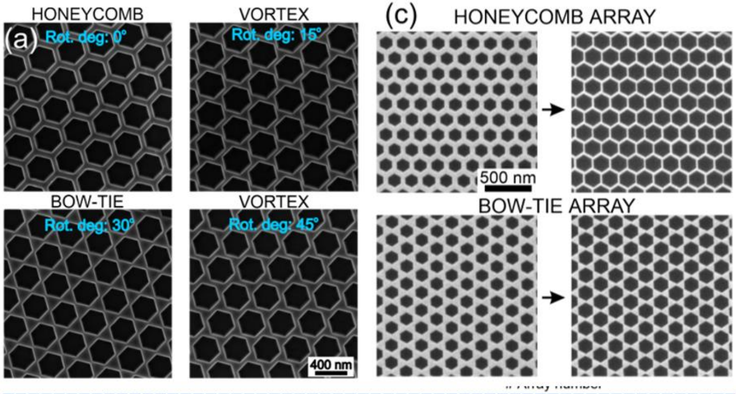
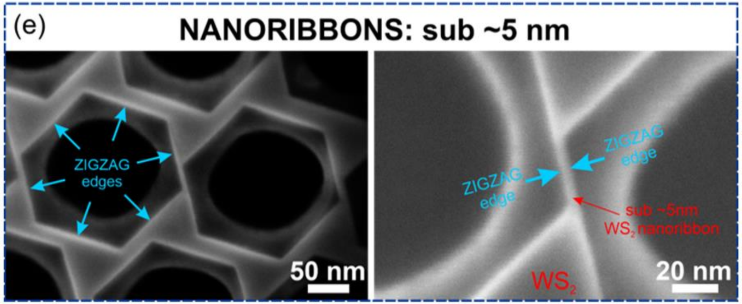
Optical and electrical properties

Nanostructured 2D material: TMD WS_2





Advanced nanostructures: Ultrathin sub-5 nm nanoribbons and nanojunctions are extremely challenging to fabricate. These structures are comparable in size to small Bohr radius TMD excitons and hence will introduce quantum confinement effects.

Only the "right" edges: zigzag edges are the ones which are catalytically active, ferromagnetic, and conductive.

Nonlinear optics at the edge: the symmetry break at the edge naturally leads to emergence of second order nonlinear coefficient and thus will boost optical non-linearities, e.g. second harmonic generation (SHG). Combined with atomic sharpness, tight confinement, and resonant nano-photonics effects, TMD metamaterials promise to say a new word in nano-optics.

Sounds interesting?

What's next?, a lot!!!

B. Munkhbat et al, Nature Comm., 11, 4604 (2020)

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