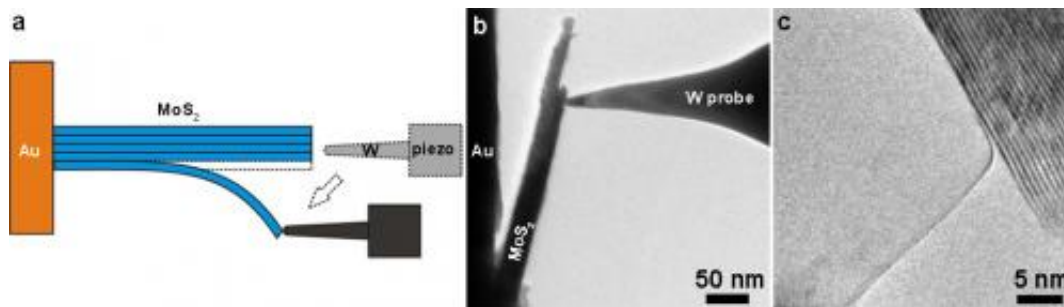


# Revealing the "Scotch-tape" technique mechanism

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Nanomechanical cleavage of molybdenum disulphide atomic layers. (left) Schematics of the experimental setup inside HRTEM. (center) TEM image of a sharply etched tungsten nanoprobe in contact with the MoS<sub>2</sub> single crystal deliberately placed with (0002) basal atomic planes viewed edge-on. (right) HRTEM image of a cleaved MoS<sub>2</sub> atomic monolayer.

The simplest mechanical cleavage technique using a primitive "Scotch" tape has resulted in the Nobel-awarded discovery of graphenes and is currently under worldwide use for assembling graphenes and other two-dimensional (2D) graphene-like structures toward their utilization in novel high-performance nanoelectronic devices.

The simplicity of this method has initiated a booming research on 2D materials. However, the atomistic processes behind the micromechanical cleavage have still been poorly understood.

A joined team of experimentalists and theorists from the International Center for Young Scientists, International Center for Materials Nanoarchitectonics and Surface Physics and Structure Unit of the National Institute for Materials Science, National University of Science and Technology "MISiS" (Moscow, Russia), Rice University (USA) and University of Jyväskylä (Finland) led by Daiming Tang and Dmitri Golberg for the first time succeeded in complete understanding of physics, kinetics and energetics behind the regarded "Scotch-tape" technique using molybdenum disulphide ( $\text{MoS}_2$ ) [atomic layers](#) as a model material.

The researchers developed a direct in situ probing technique in a high-resolution transmission electron microscope (HRTEM) to investigate the mechanical cleavage processes and associated mechanical behaviors. By precisely manipulating an ultra-sharp metal probe to contact the pre-existing crystalline steps of the  $\text{MoS}_2$  single crystals, atomically thin flakes were delicately peeled off, selectively ranging from a single, double to more than 20 atomic layers. The team found that the mechanical behaviors are strongly dependent on the number of layers. Combination of in situ HRTEM and molecular dynamics simulations reveal a transformation of bending behavior from spontaneous rippling (

By considering the force balance near the contact point, the specific surface energy of a  $\text{MoS}_2$  monoatomic layer was calculated to be  $\sim 0.11$  N/m. This is the first time that this fundamentally important property has directly been measured.

After initial isolation from the mother crystal, the  $\text{MoS}_2$  monolayer could be readily restacked onto the surface of the crystal, demonstrating the possibility of van der Waals epitaxy.  $\text{MoS}_2$  atomic layers could be bent to ultimate small radii (1.3 ~ 3.0 nm) reversibly without fracture. Such ultra-reversibility and extreme flexibility proves that they could be mechanically robust candidates for the advanced flexible electronic

devices even under extreme folding conditions.

**More information:** "Nanomechanical cleavage of molybdenum disulphide atomic layers." Dai-Ming Tang, et al. *Nature Communications*, 5:3631 (2014). [DOI: 10.1038/ncomms4631](https://doi.org/10.1038/ncomms4631)

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