STM observation of a box-shaped graphene nanostructure appeared after mechanical cleavage of pyrolytic graphite

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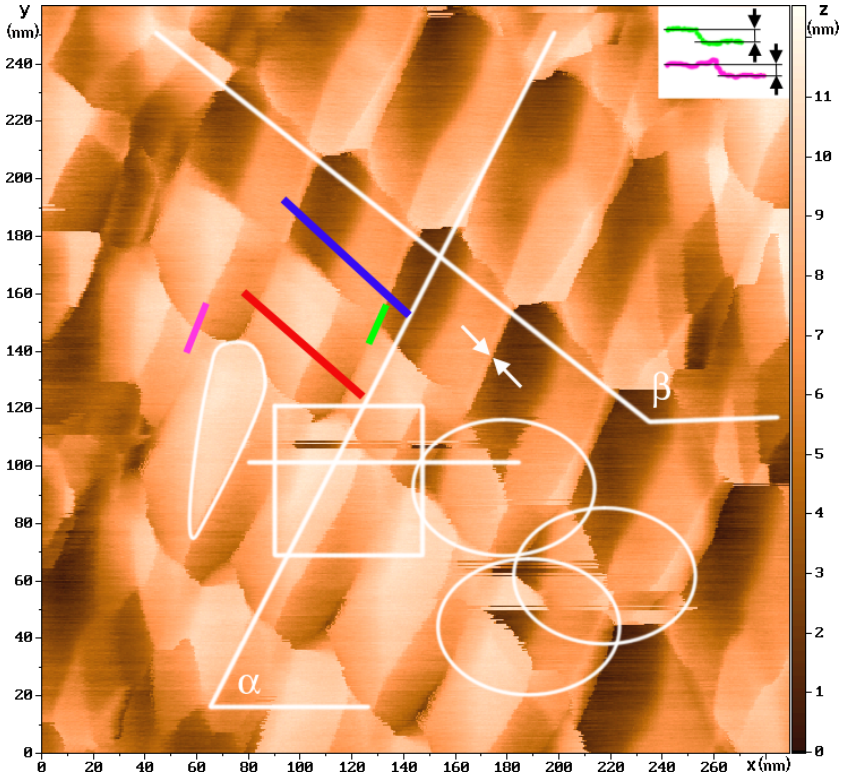
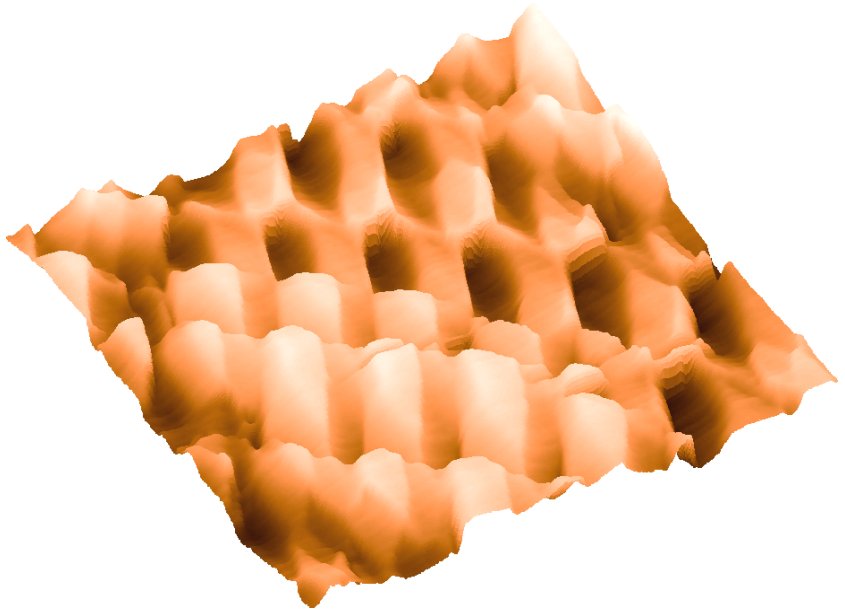
Abstract

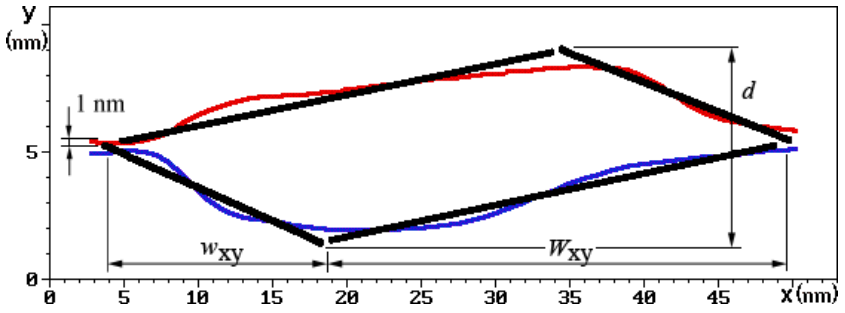
A three-dimensional box-shaped nanostructure of graphene formed/uncovered by mechanical cleavage of a monocrystal of highly oriented pyrolytic graphite (HOPG) is discovered. The nanostructure is a multilayer system of parallel hollow channels having quadrangular cross-section. Wall/facet thickness of the nanostructure is approximately equal to 1 nm. Typical widths of the small and large facets make about 20 nm and 30 nm, respectively. The investigation of the nanostructure by means of a scanning tunneling microscope (STM) allows us to draw a conclusion that it is possible, by mechanical compression, inelastic bending, splitting, and shifting of graphite layers, to make spatial constructions of graphene similar to the discovered one

Box-shaped nanostructure appearance



STM topography 512×512 pixels obtained in air in constant current mode, U_{tun}=50 mV, I_{tun}=890 pA

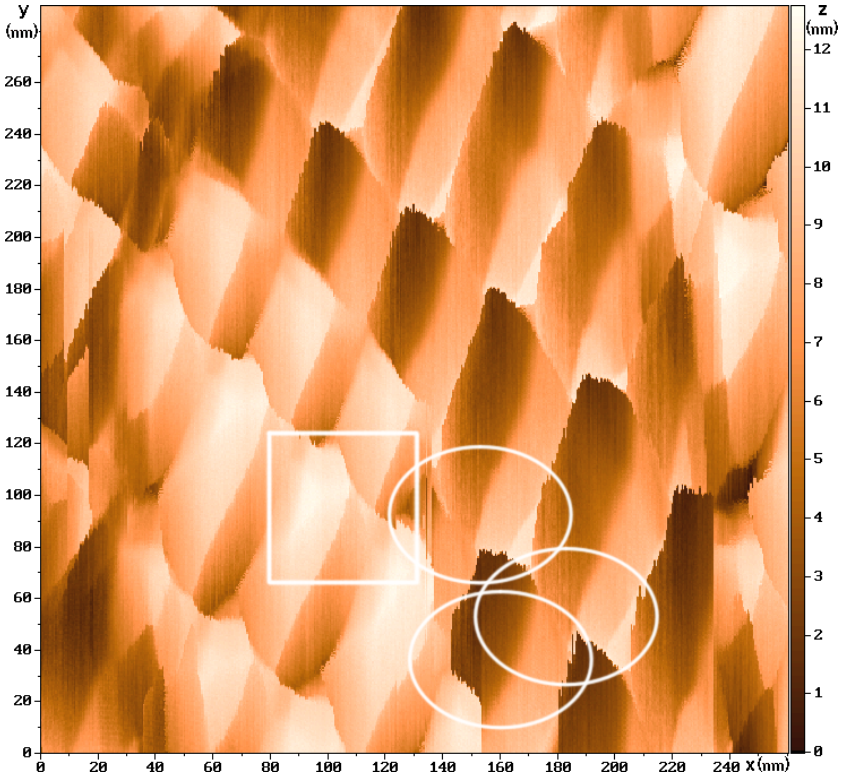


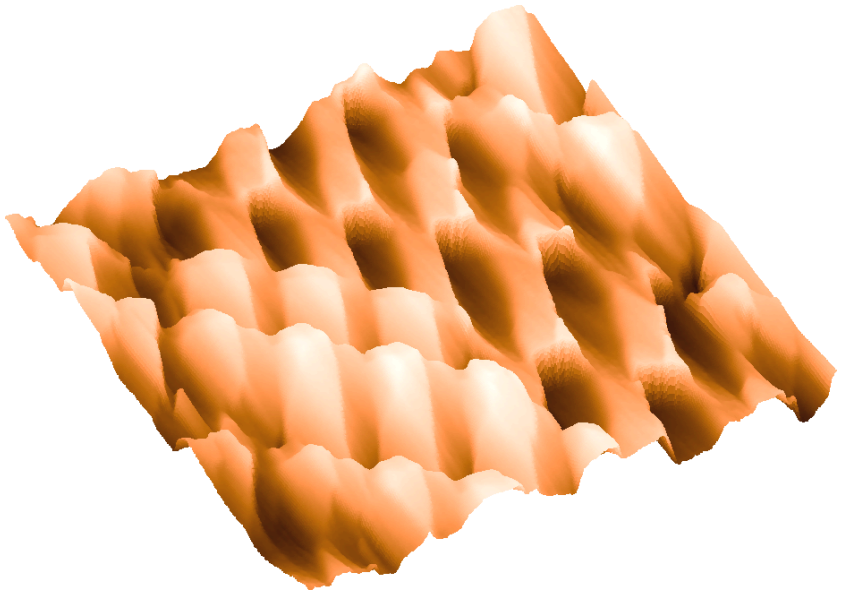


Typical features of the nanostructure

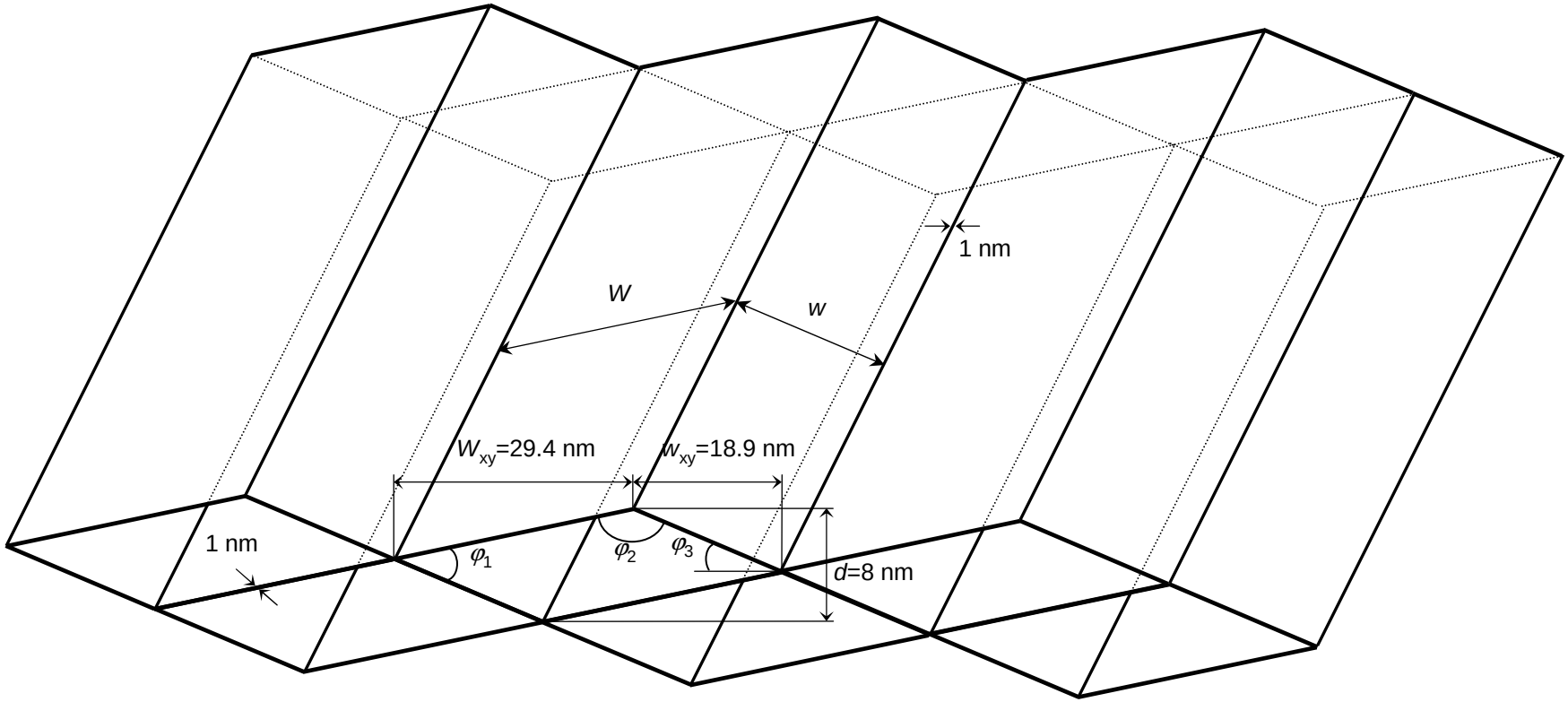
- Material − graphene
- Three-dimensionality
- Availability of cavities (channels)
- Nanometer sizes
- Multilayerness of cavities
- Ordered structure
- Small contact area with substrate
- Large surface area
- Fabrication simplicity

Nanostructure appearance after changing fast scanning direction





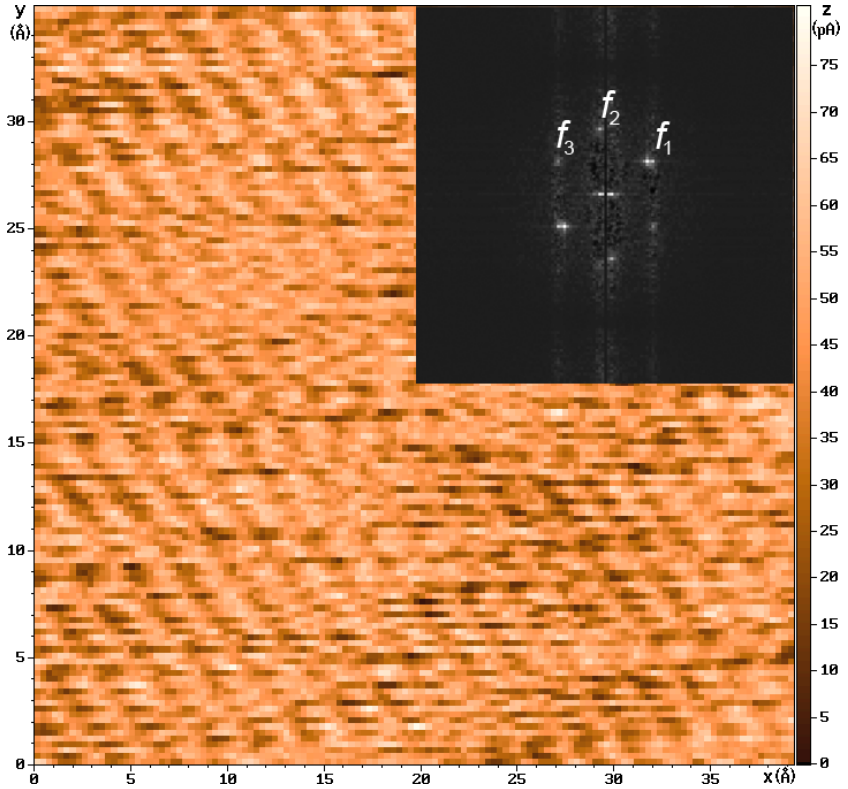
Model representation of box-shaped nanostructure



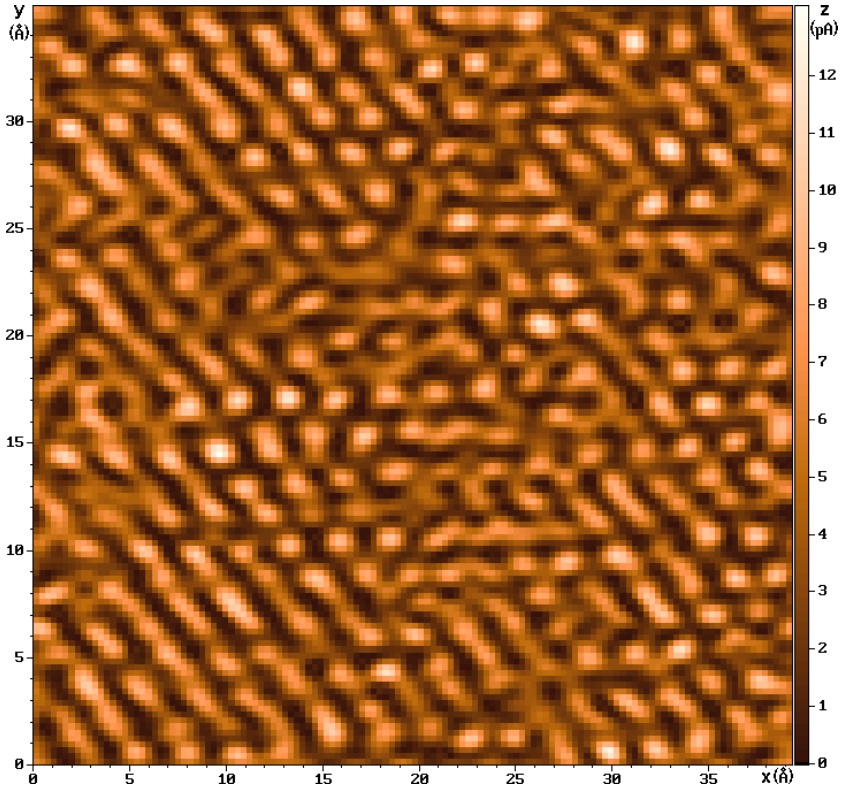
Width of small facet w=19.3 nm, width of large facet W=29.7 nm, φ_1=19.7°, φ_2=160.3°, φ_3=12.0°

Atomic resolution on facet surface

Original STM scan

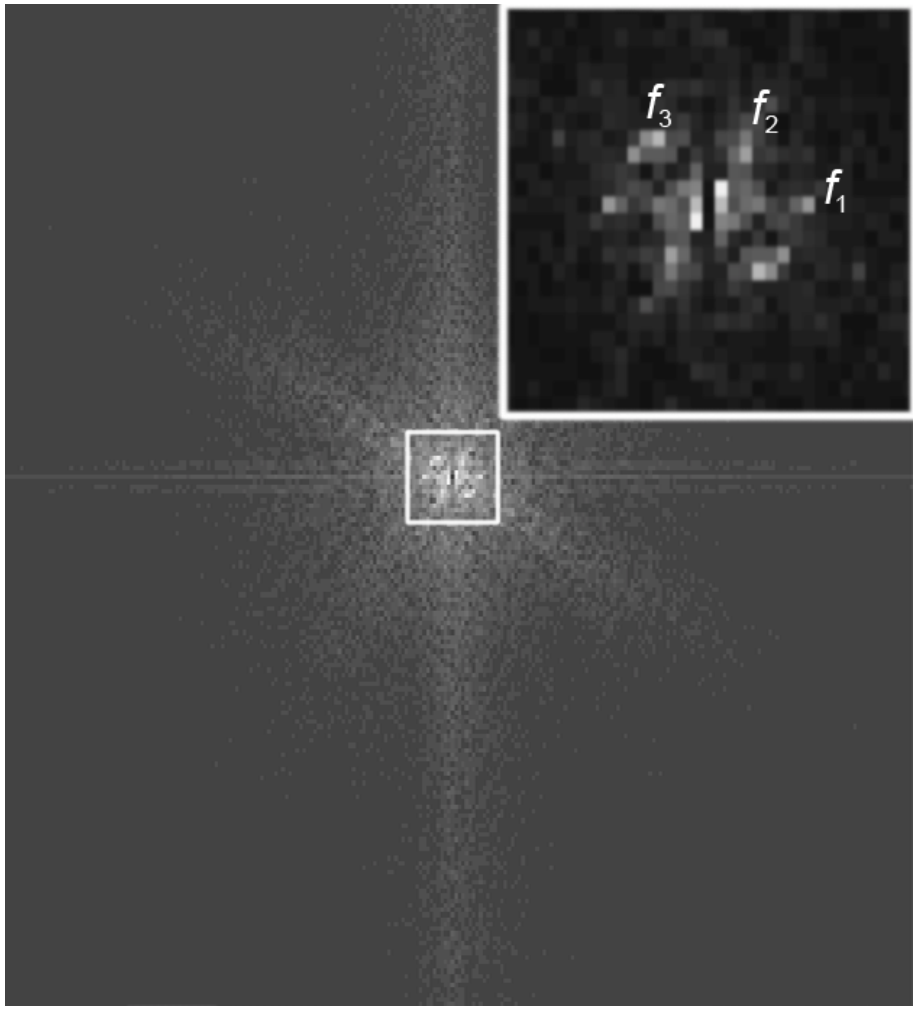


STM scan after Fourier filtering



Lattice constants: a_1=2.1 Å, a_2=2.8 Å, a_3=2.1 Å. Crystallographic directions: θ_1=131.1°, θ_2=4.7°, θ_3=58.0°

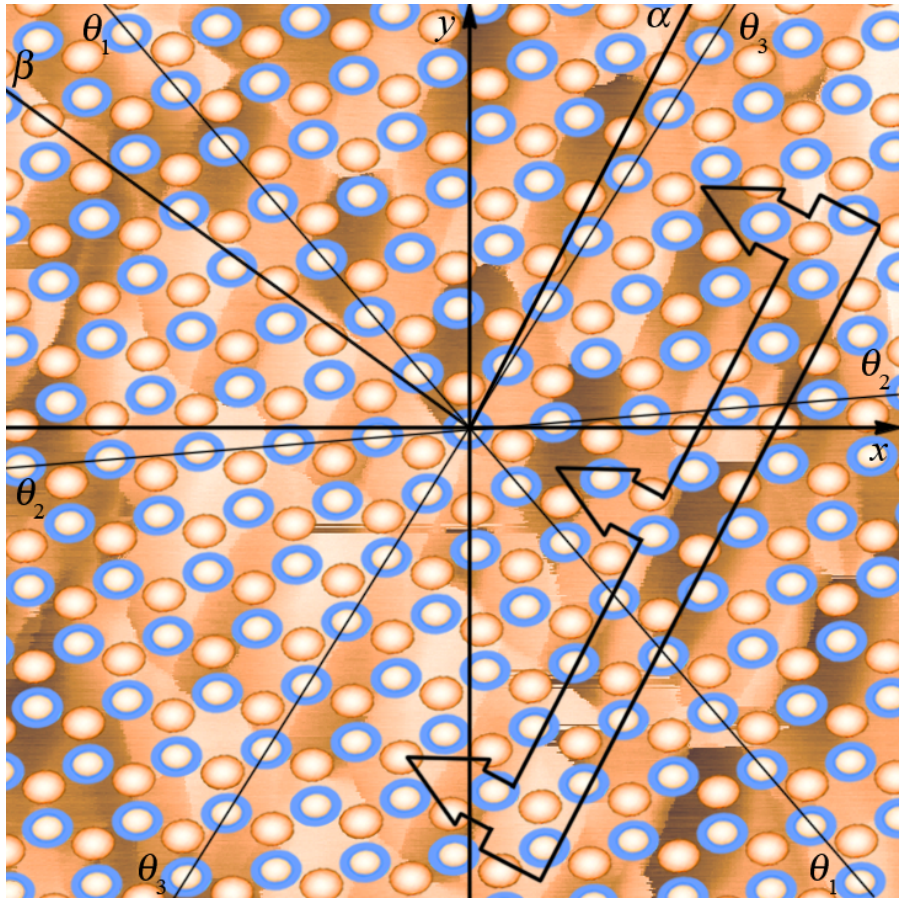
Fourier spectrum of box-shaped nanostructure



Spatial periods: $1/f_1$=36.1 nm, $1/f_2$=64.5 nm, $1/f_3$=48.3 nm

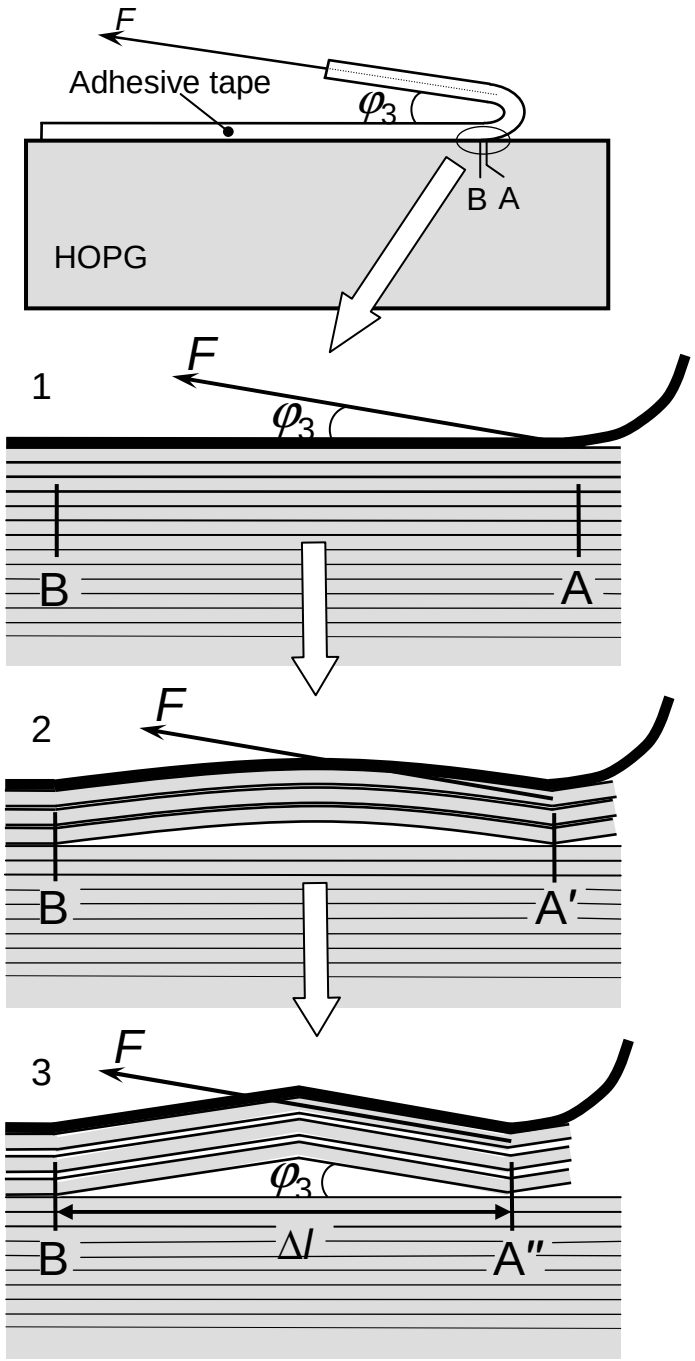
Directions of oscillation propagation: γ_1=0.0°, γ_2=48.1°, γ_3=139.5°

Arrangement of box-shaped nanostructure relative to crystal lattice of graphite



Channel orientation α=62.7°, orientation of cut edges of membranes of open cells β=143.8°

Crystallographic directions on surface of nanostructure facet: θ_1=131.1°, θ_2=4.7°, θ_3=58.0°



Formation of fold and its splitting into graphene layers during plastic bending deformation

F is a cleaving force

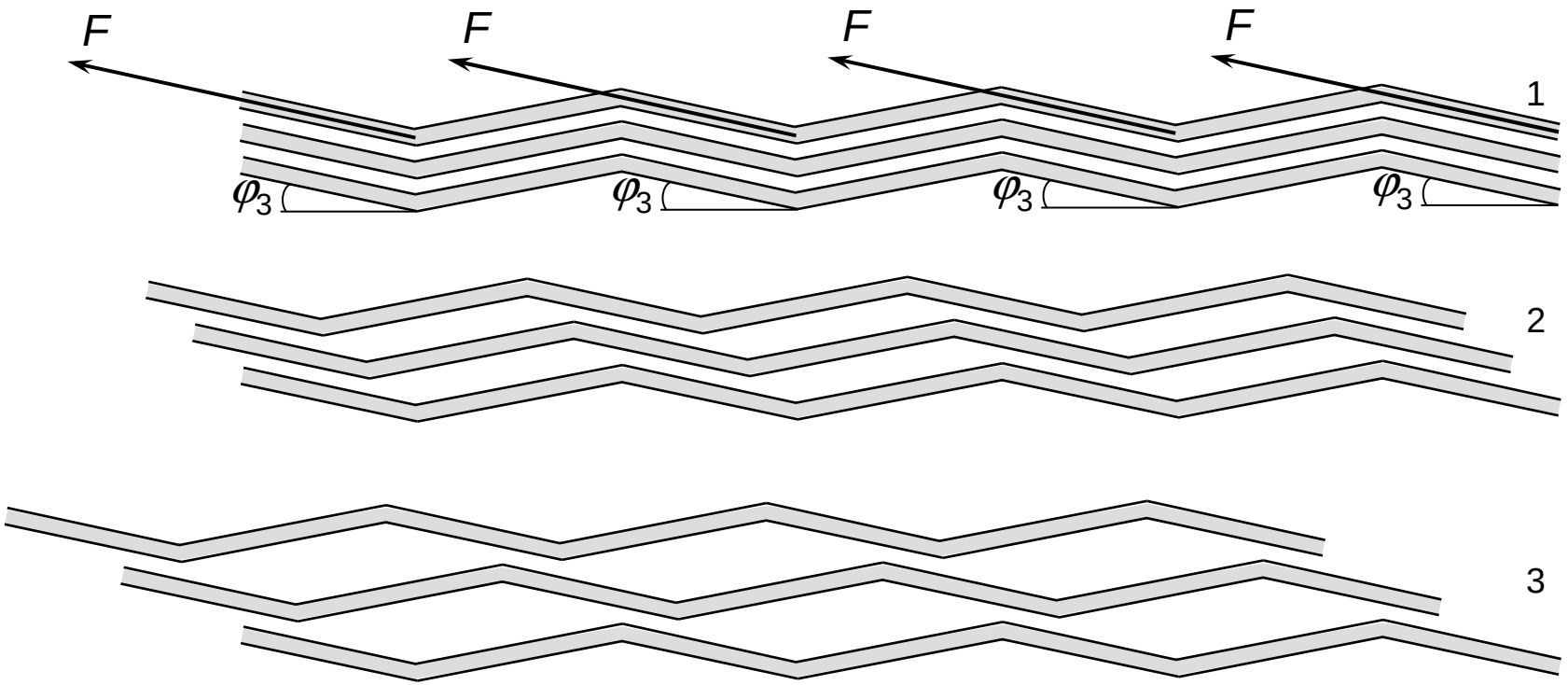
φ_3 is force application angle (≈12°)

AB=*w*+*W*

Δl=A″B=w_{xy}+W_{xy}

Proportions between certain elements are not correct

Simplified formation mechanism of multilayered channels of the box-shaped nanostructure



Two channel layers are composed of three split-in-folds graphene layers by means of relative shifting (sliding) of these layers along plane of a small facet

Possible application fields

- Sensitive elements of detectors
- Catalytic cells
- Nanochannels (molecular sieves) for microfluidic devices
- Sorbents for hydrogen storage
- Heat sinking surfaces