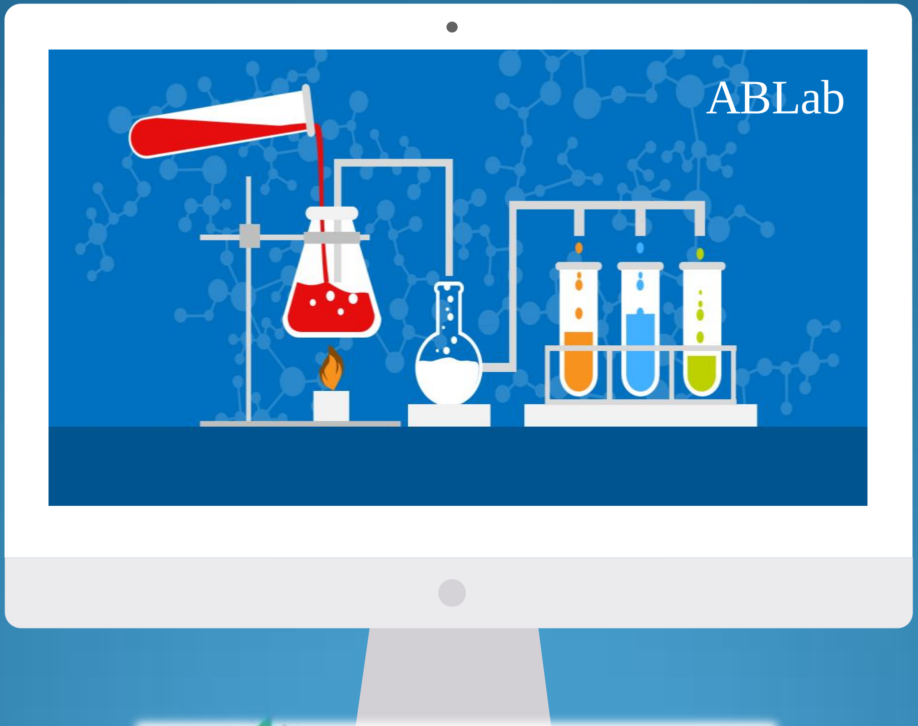
MoS_2/Graphene heterostructure to develop flexible electronics



五邑大学
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生物纳米材料应对当前健康挑战研讨会
Bionanomaterials for Current Health Challenges

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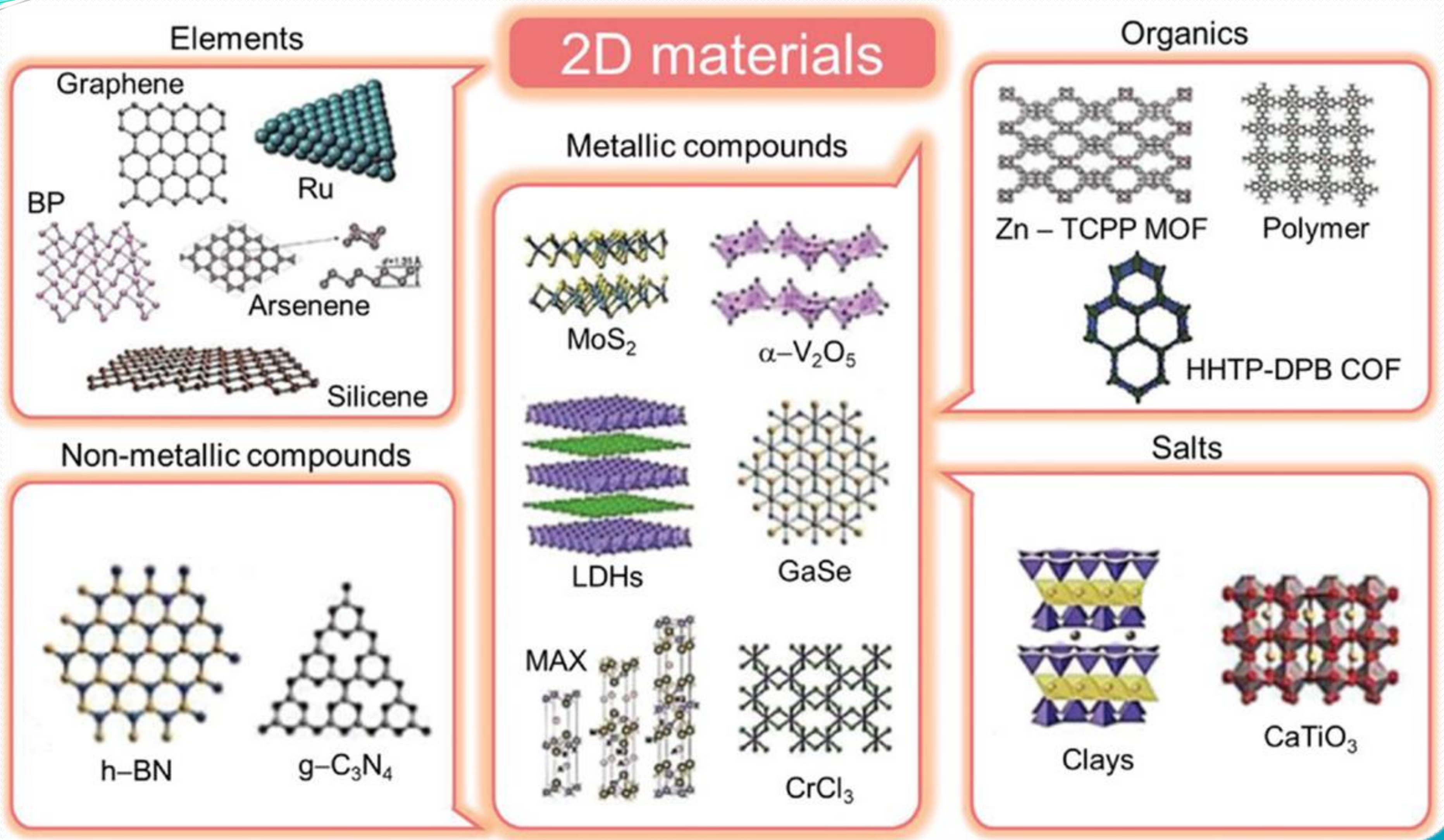
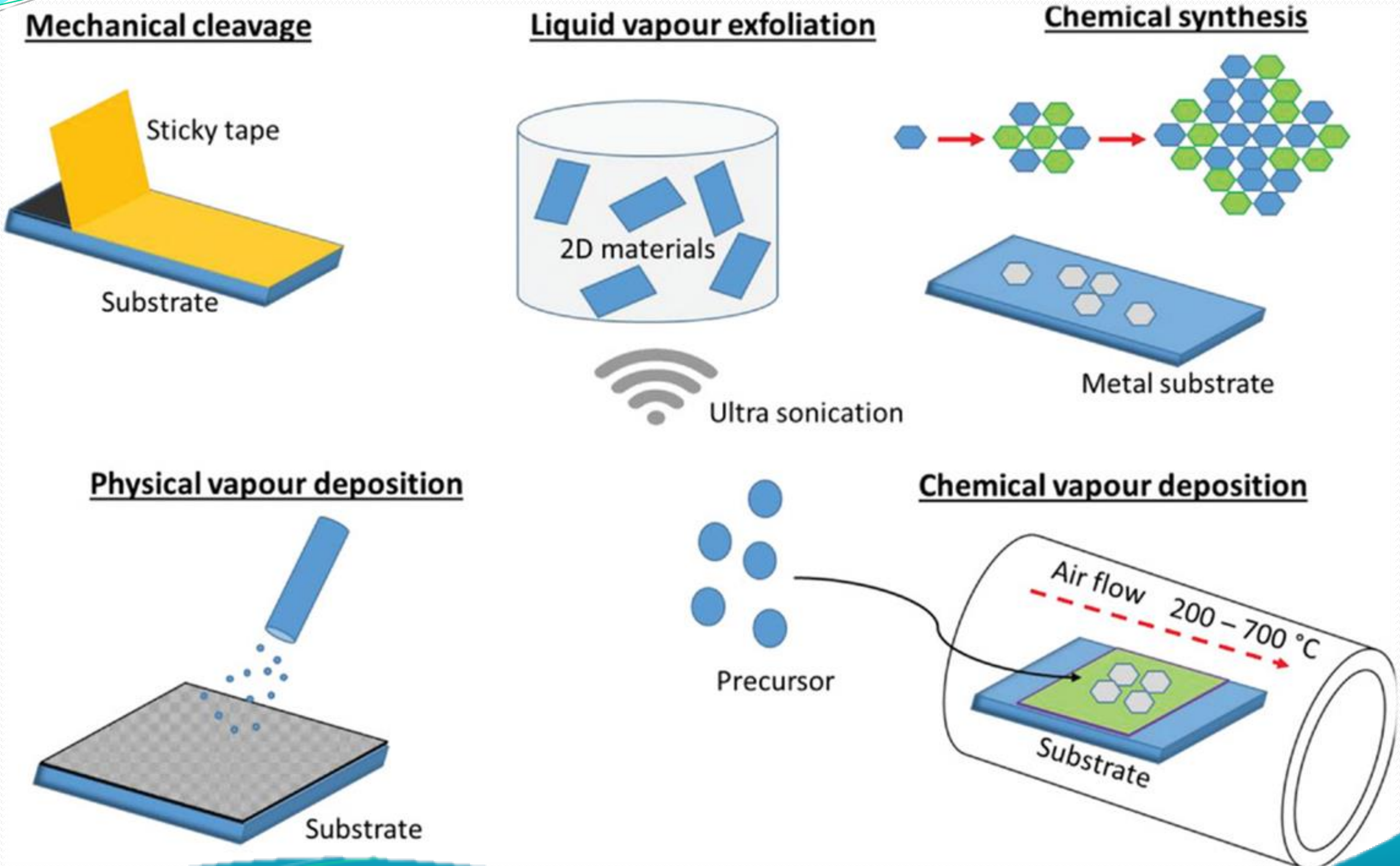
Ivan Babichuk
2023.09.05

Structure and classification of different 2D materials

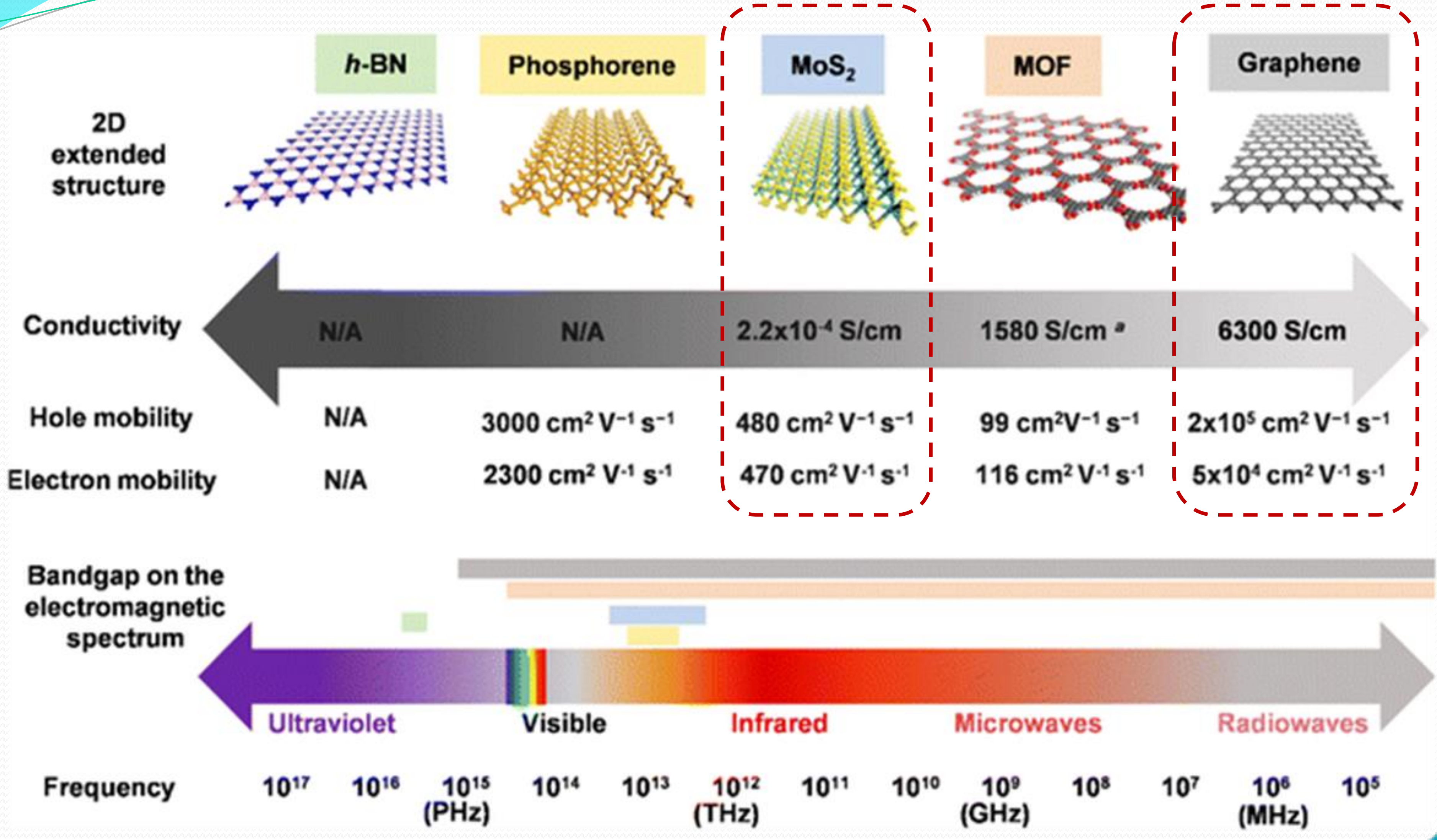


Particle, 2022, 39(6), 2200031 DOI: 10.1002/ppsc.202200031



Particle, 2022, 39(6), 2200031 DOI: 10.1002/ppsc.202200031

Why 2D materials for sensing?

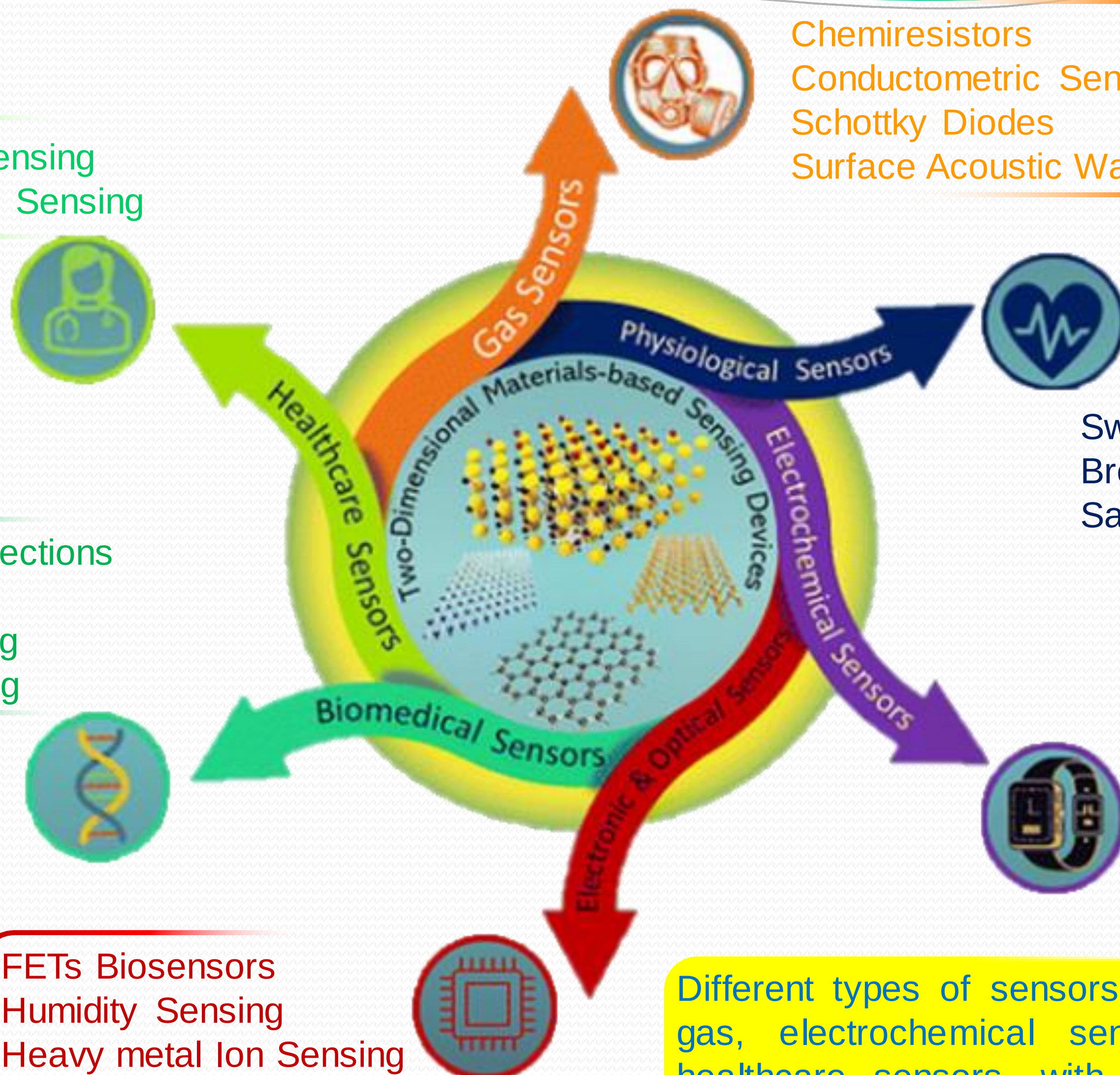


J. Mater. Chem. A, 2023, 11, 6016-6063 DOI: 10.1039/D2TA07653E

Highlights of 2D materials in various sensing devices

Ontogenetic Sensing
Ophthalmology Sensing

Chemiresistors
Conductometric Sensors
Schottky Diodes
Surface Acoustic Wave Sensors



Sweat Analysis
Breath Monitoring
Saliva Analysis

Single-cell Detections
DNA Sensing
Protein Sensing
Cancer Sensing

Wearable Biosensors
Interstitial Fluid Sensors

FETs Biosensors
Humidity Sensing
Heavy metal Ion Sensing
Fluorescent Sensors

Different types of sensors is presented, including gas, electrochemical sensing, biomedical, and healthcare sensors, with recent studies on the active application areas of 2D materials.

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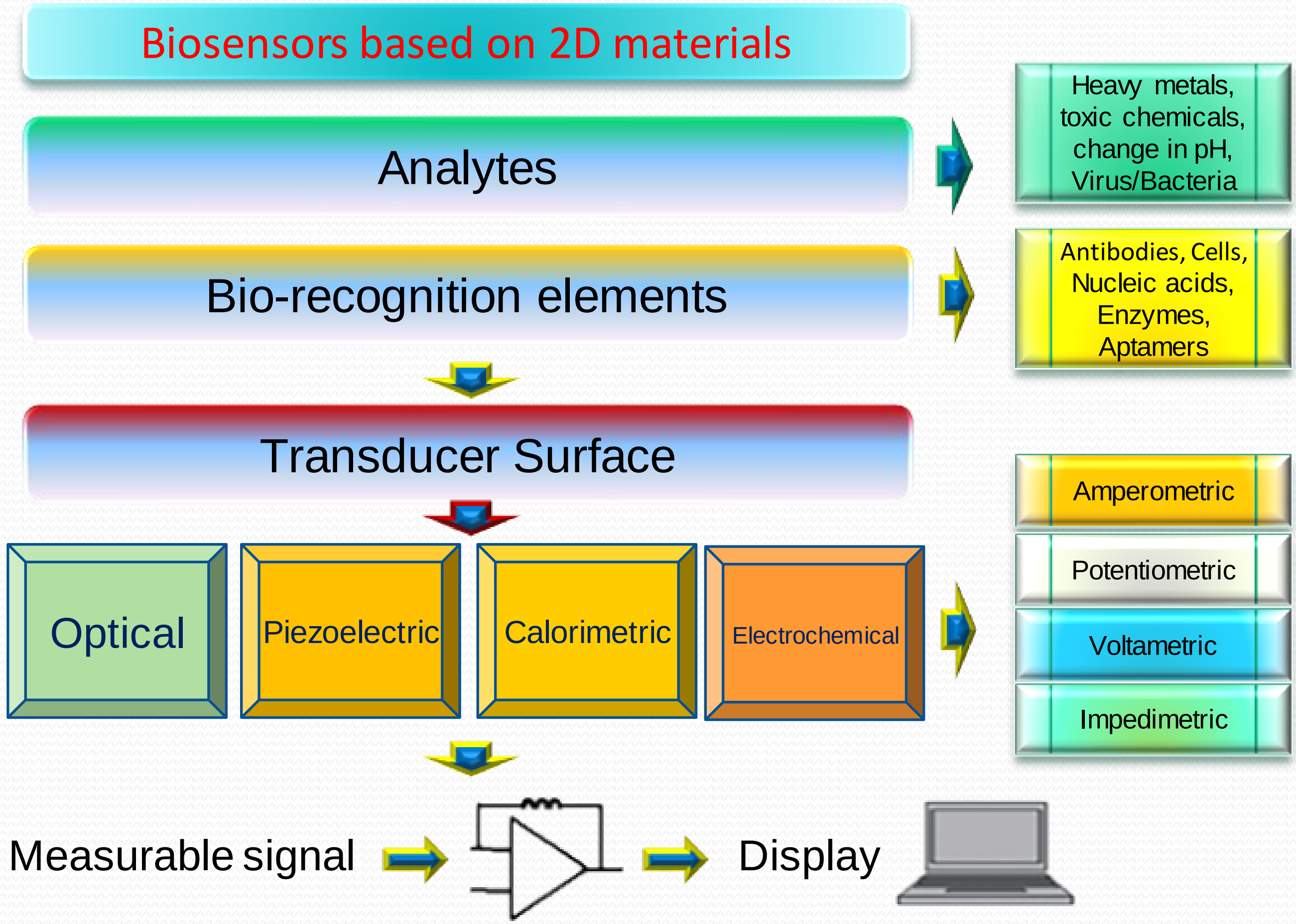
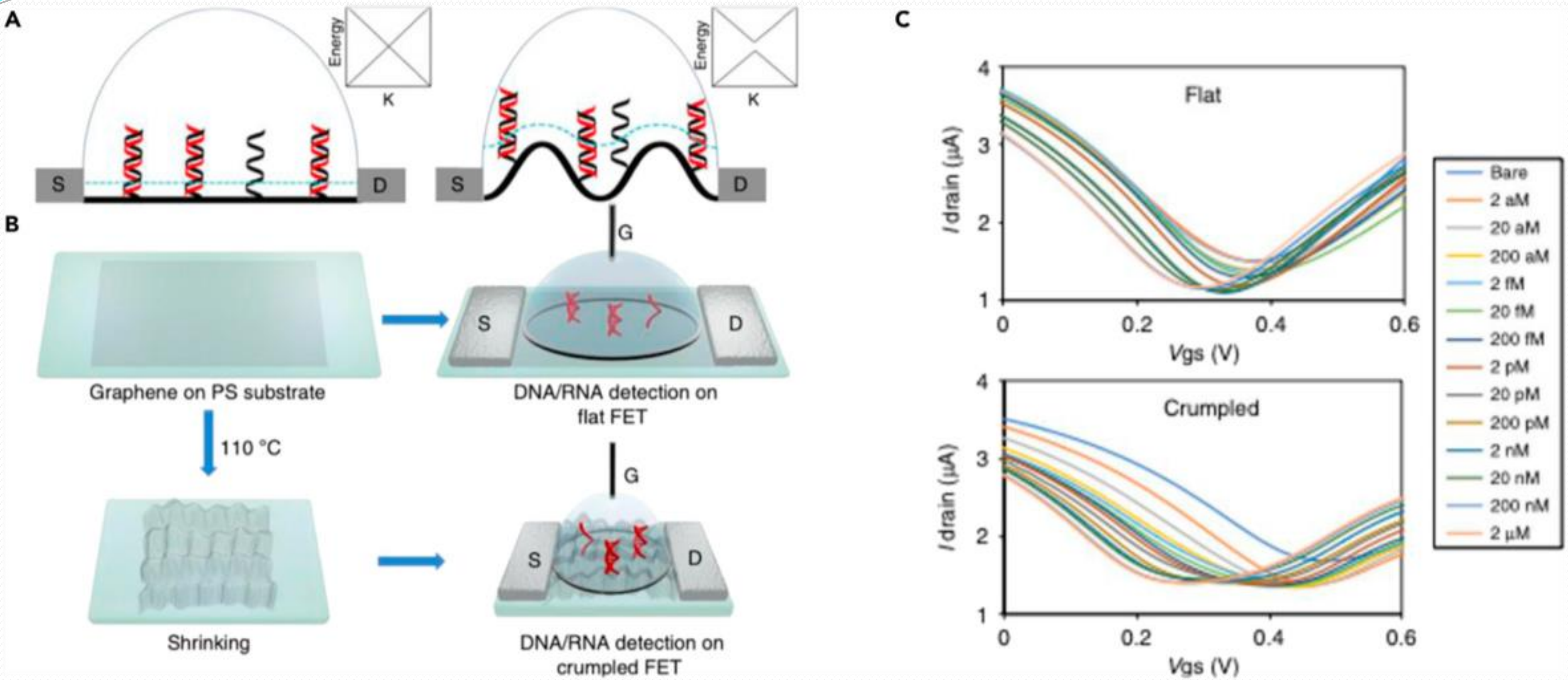
Biomedical sensors



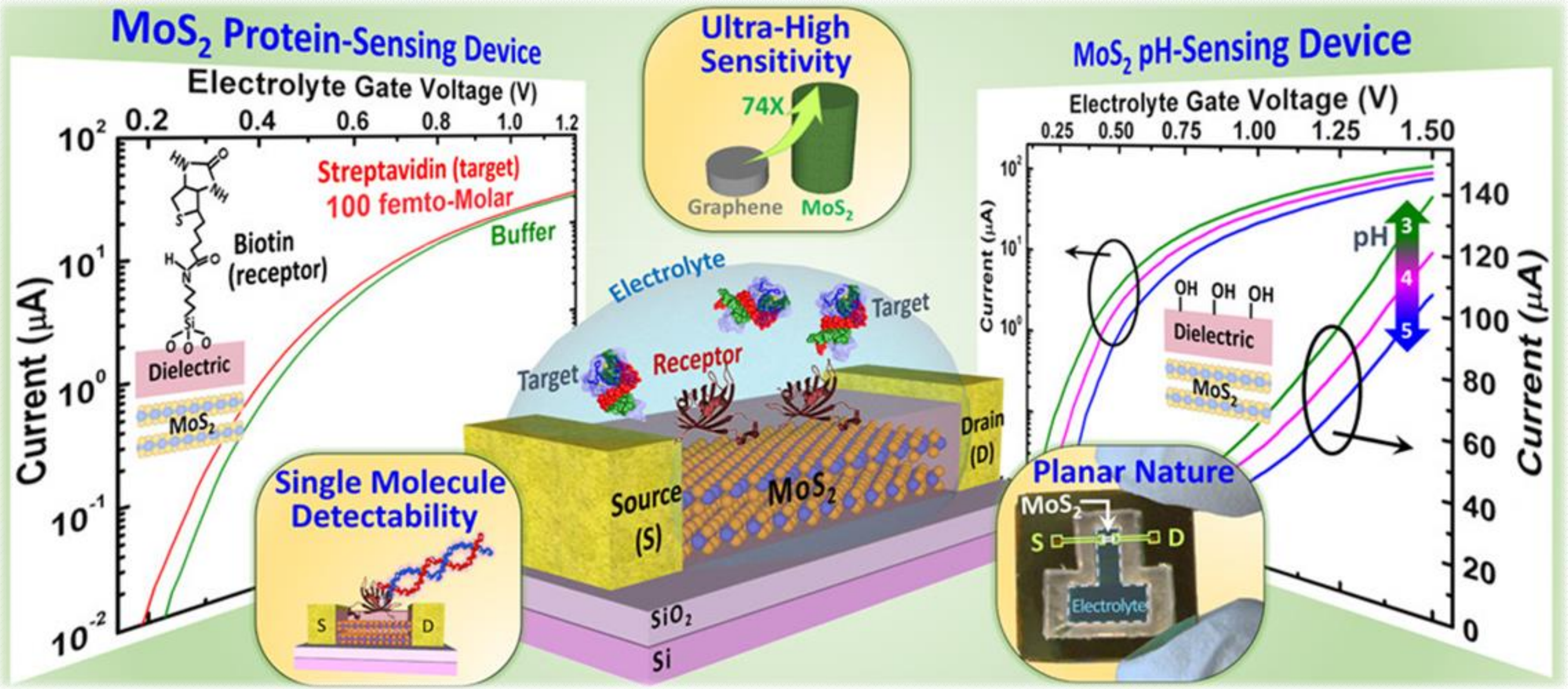
Biosensors based on 2D materials can be categorized, according to the usage of nanoscale components, into physical or chemical types. These are extremely sensitive in different practical applications over a diverse range of concentrations of analytes, including proteins, organic or inorganic molecules, viruses, and others. These sensors have three basic components transistors, resistors, and capacitors located in integrated circuits.



(A) Schematic diagrams of a flat (left) and a crumpled (right) graphene-based FET DNA sensor. DNA strands stay on the surface of graphene. The crumpled graphene is more sensitive to the negative charges of DNA than the flat version does. (B) Fabrication of graphene-based FET biosensors. The PS substrate is annealed to shrink and crumple the graphene. (C) IV characteristics of the flat and the crumpled graphene-based FET biosensors upon DNA absorption.

iScience 24, 103513, December 17, 2021 DOI: 10.1016/j.isci.2021.103513

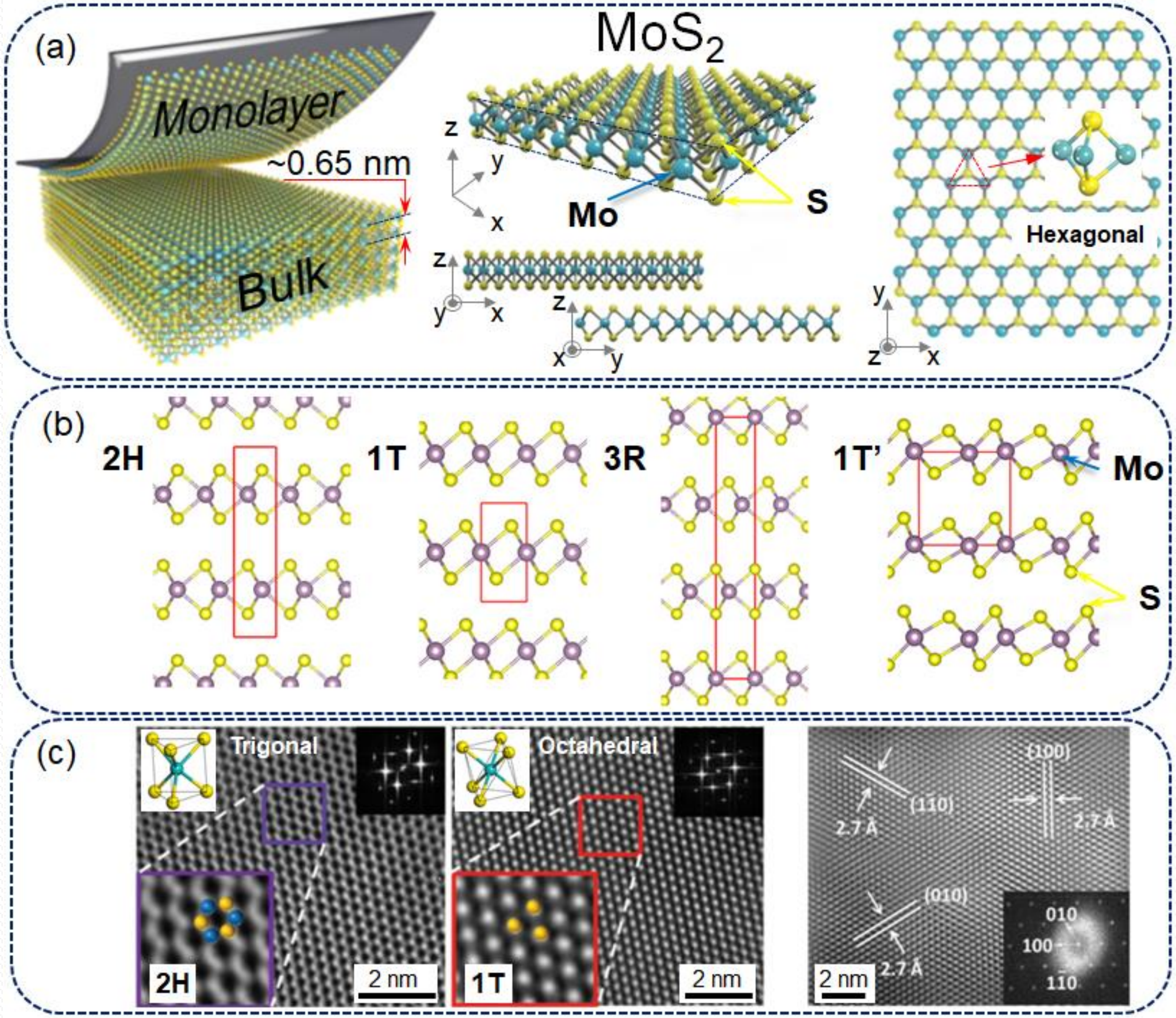
MoS_2 based biomolecule sensing



Schematic diagram of a MoS_2-based FET-based biosensor. For specifically capturing the target biomolecules, the dielectric layer above the MoS_2 channel is functionalized with receptors. The charged biomolecules after being captured induce a gating effect, modulating the device current. IV characteristics MoS_2-based FET biosensors. A critical problem of poor electric contact limits the development of more optimal MoS_2-based sensors. The problem stems from Fermi-level pinning in the interface between the MoS_2 and a metal.

ACS Nano 2014, 8, 4, 3992–4003 DOI: 10.1021/nn5009148

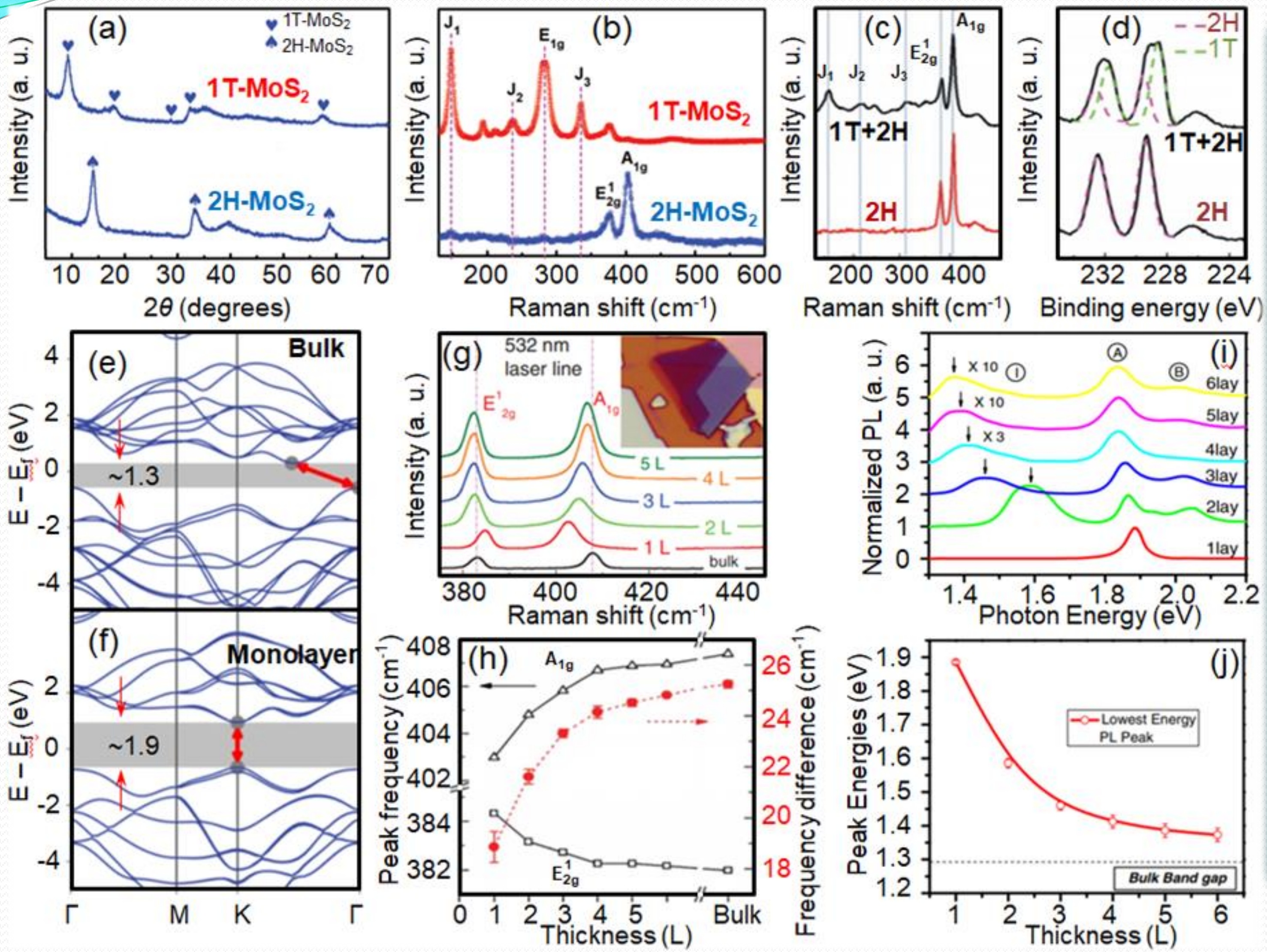
The crystal structure of MoS_2



(A) Mechanical exfoliation is performed by successive peeling of adhesive tape from the surface of the bulk crystal. (B) This part figure shows the atomic configurations of MoS_2 in different phases (2H, 1T, 3R, and 1T'). (C) Atomic-resolution structural information and their corresponding fast Fourier transforms (FFTs) of trigonal prismatic (2H) and octahedral (1T) unit cells are shown thanks to the higher magnification HRTEM images of an exfoliated-MoS_2.

https://www.ossila.com/pages/molybdenum-disulfide-mos$_2$

Characterization of the crystal structure of MoS_2



Phase and crystal structure of different polytypes MoS_2: (a) XRD patterns and Raman spectra (b) of the 1T-MoS_2 and 2H-MoS_2. The Raman and (d) XPS spectra show Mo 3d peak region of (1T+2H)-MoS_2 and 2H-MoS_2. The band structure diagram of bulk (e) and monolayer (f) MoS_2 shows the crossover from indirect to direct bandgap accompanied by a widening of the bandgap. (g) Raman characterizations of different thicknesses of sample MoS_2 using a 532 nm laser line. Inset: the optical image of the sample. The left and right dashed lines indicate the positions of the E^1_{2g} and A_{1g} peaks in bulk MoS_2, respectively. (h) Frequencies of E^1_{2g} and A_{1g} Raman modes. (i) Normalized PL spectra by the intensity of peak ***A*** of different thicknesses of sample MoS_2. (j) Band-gap energy of thin layers of MoS_2.

Aim (target) of the our Applied Bionics Laboratory (ABLab)

Development and fabrication
Applied Bioelectronics Devises

Development and automatization of mechanical test system

Synthesis and research of polymers and TMDs for creation sensors

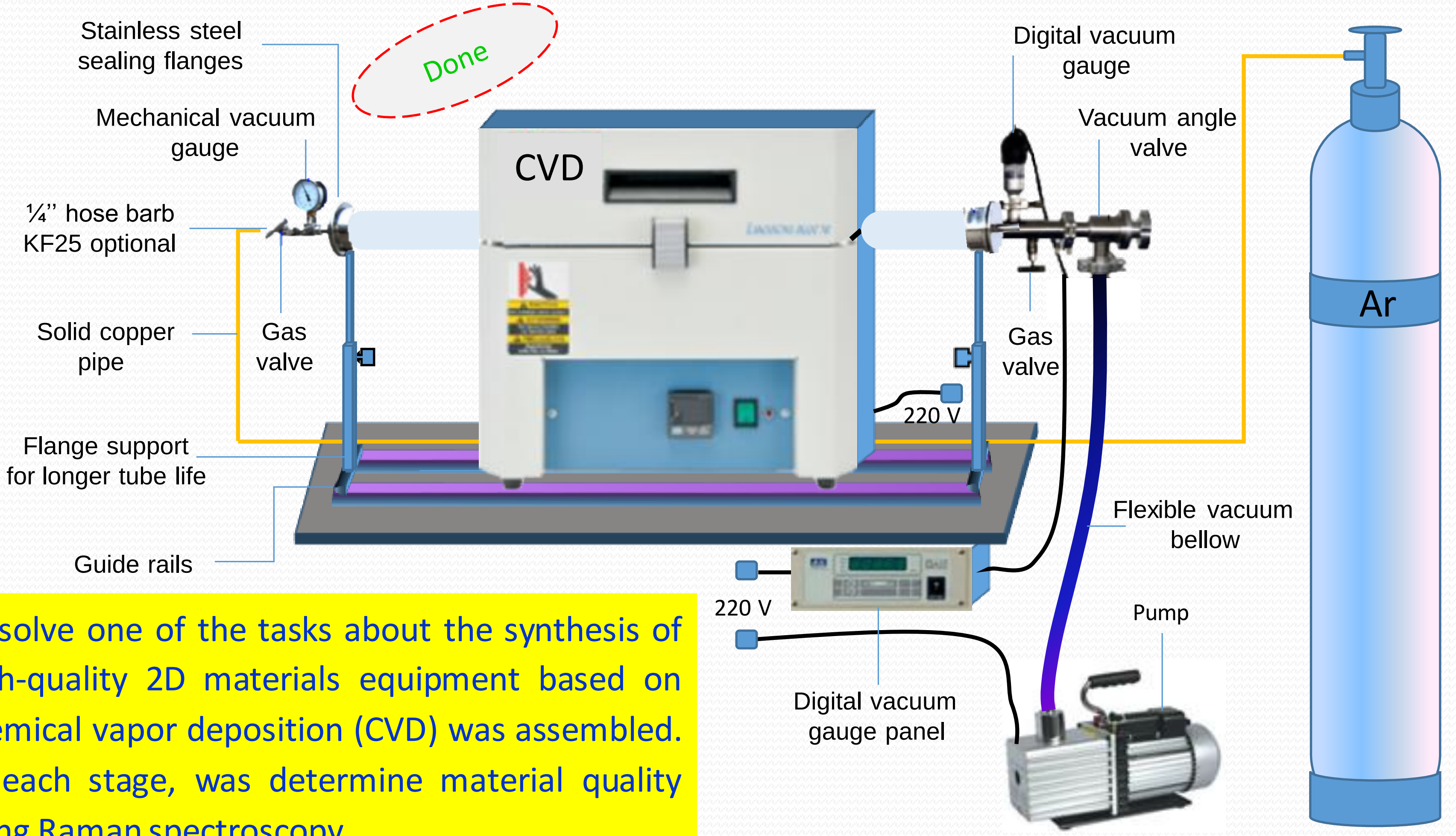
Development 3D printing system for photo polymerization

Development of software (based on LabVIEW) for automatic control of the mechanical and optical measurements of the flexible electronic devices.

Synthesis in the laboratory of flexible polymers (PDMS, PLLA or other) and 2D materials (MoS_2, graphene or similar). Creation of sensors on their basis. Research of mechano-electrical properties.

Development of design of necessary optical and mechanical elements of the equipment. Creating software for efficient operation of equipment.

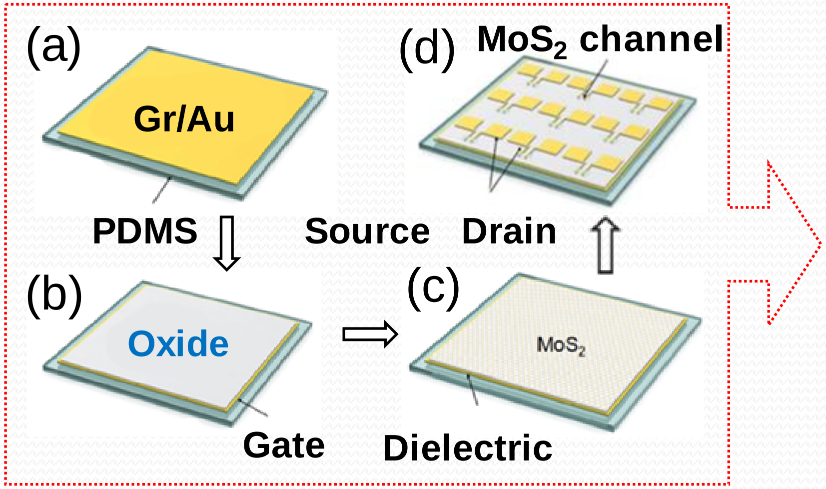
1. Collection of equipment for synthesis of 2D materials (**molybdenum disulfide (MoS_2)** or similar).

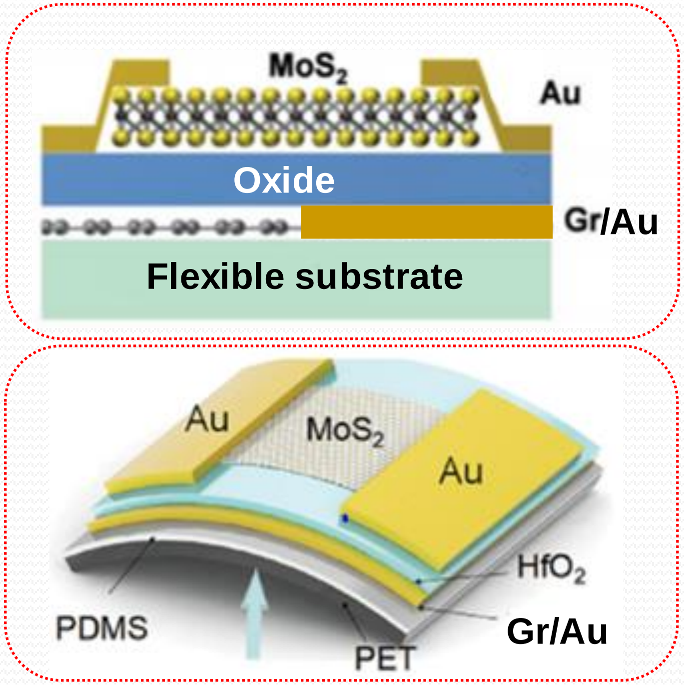


To solve one of the tasks about the synthesis of high-quality 2D materials equipment based on chemical vapor deposition (CVD) was assembled. At each stage, was determine material quality using Raman spectroscopy.

2. Design of flexible field effect transistors (FETs) based on MoS_2

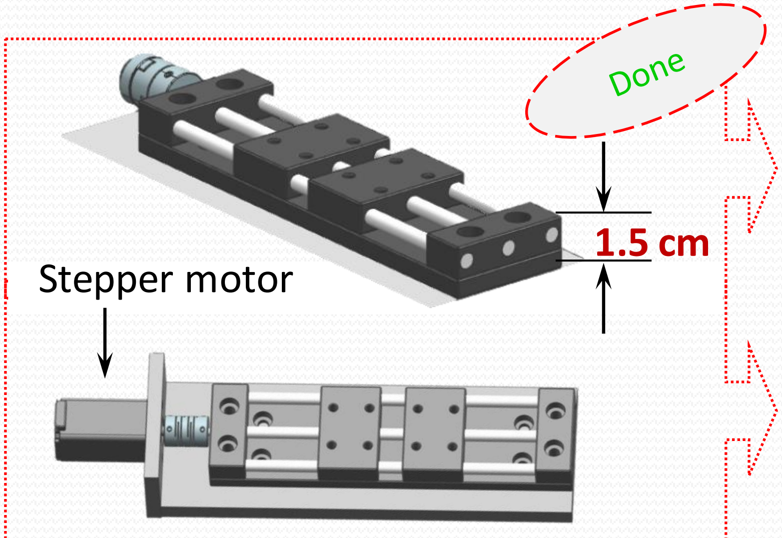
In progress

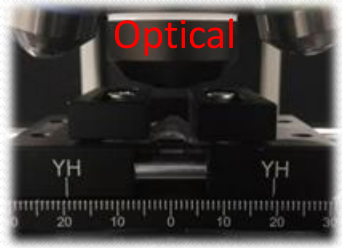


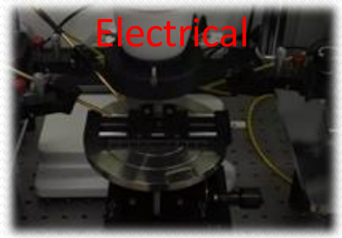


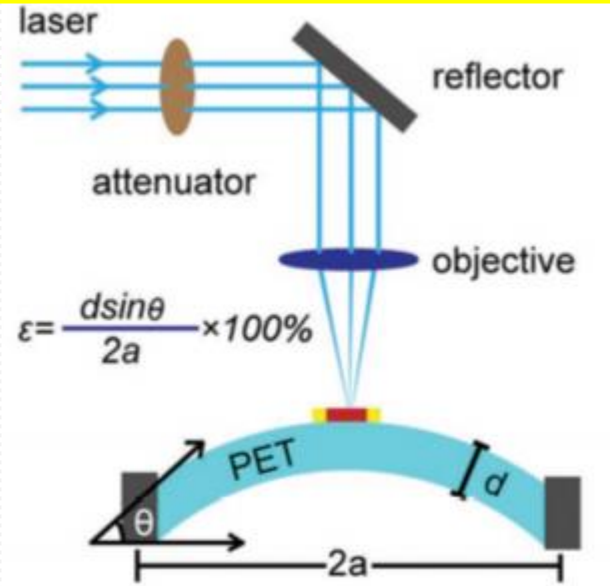
On the schematic description of the device fabrication process shown: **a)** deposition of Au (or transferred graphene monolayer) as a back gate on flexible PET (polyethylene terephthalate) substrate pre-coated PDMS (polydimethylsiloxane); **b)** deposition of oxides (as example, HfO_2 layer) on the substrate; **c)** transferring MoS_2 film on the high-*k* HfO_2 layer; **d)** fabrication of two-terminal MoS_2 device.

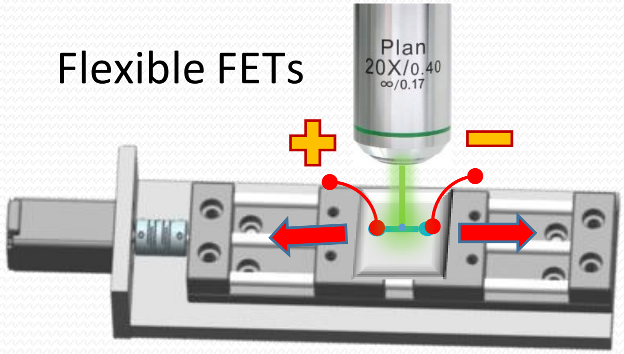
3. Development and improvement of a micro-strain system for optoelectrical tests





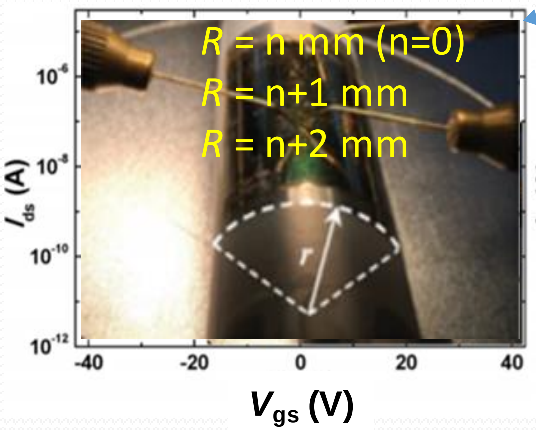




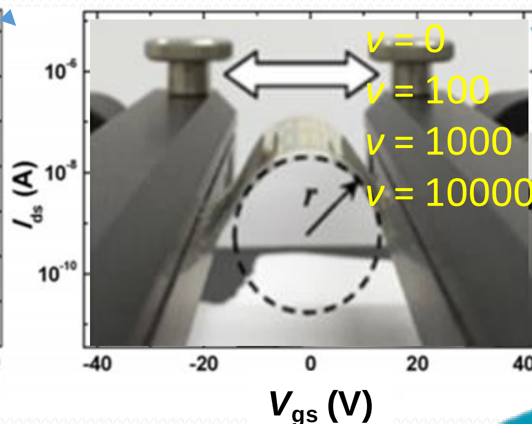


Use of the control strain system for optoelectrical tests

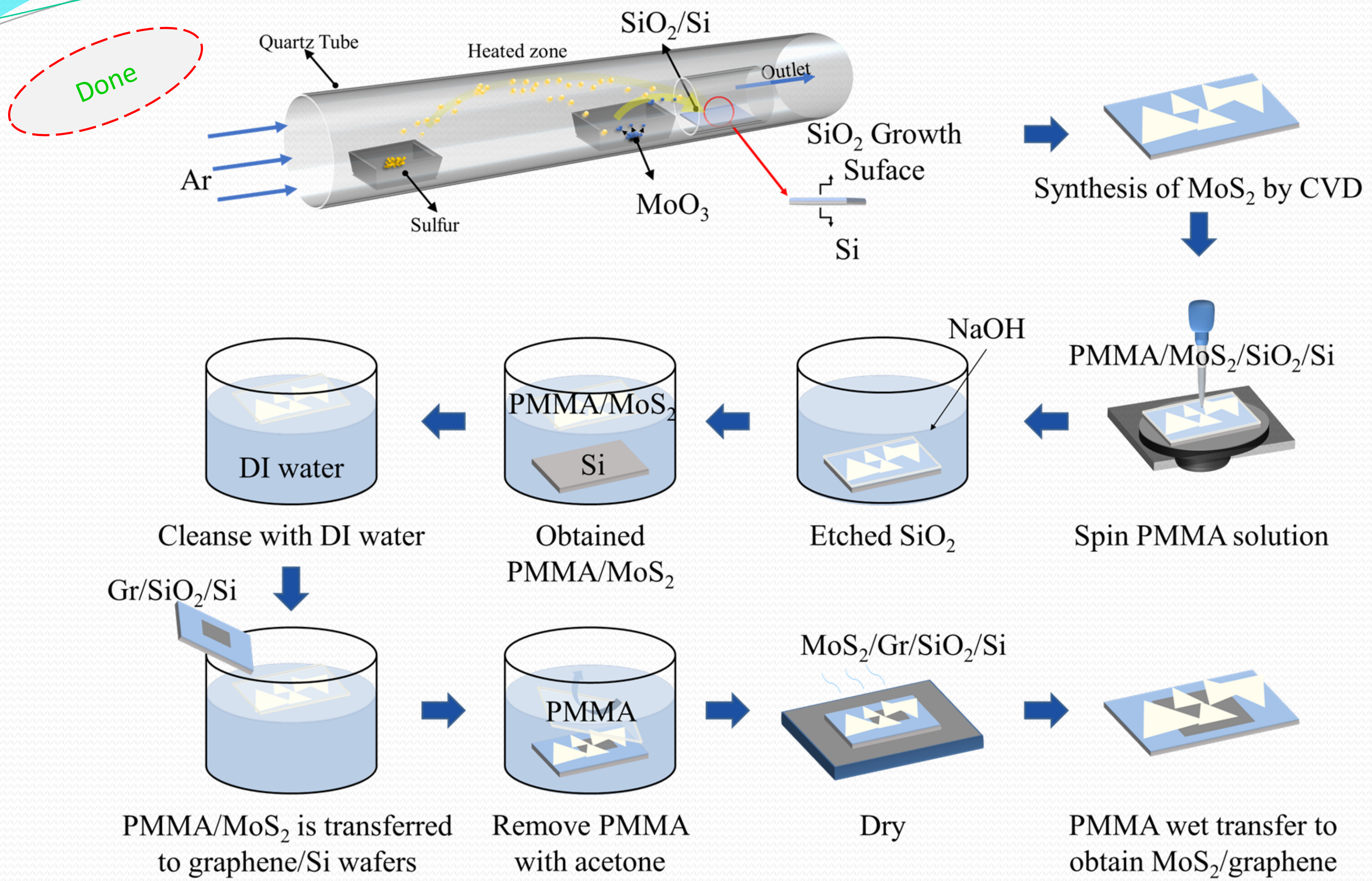
Stretching and compression



Frequency



Grown and transfer MoS_2 on the flexible substrates



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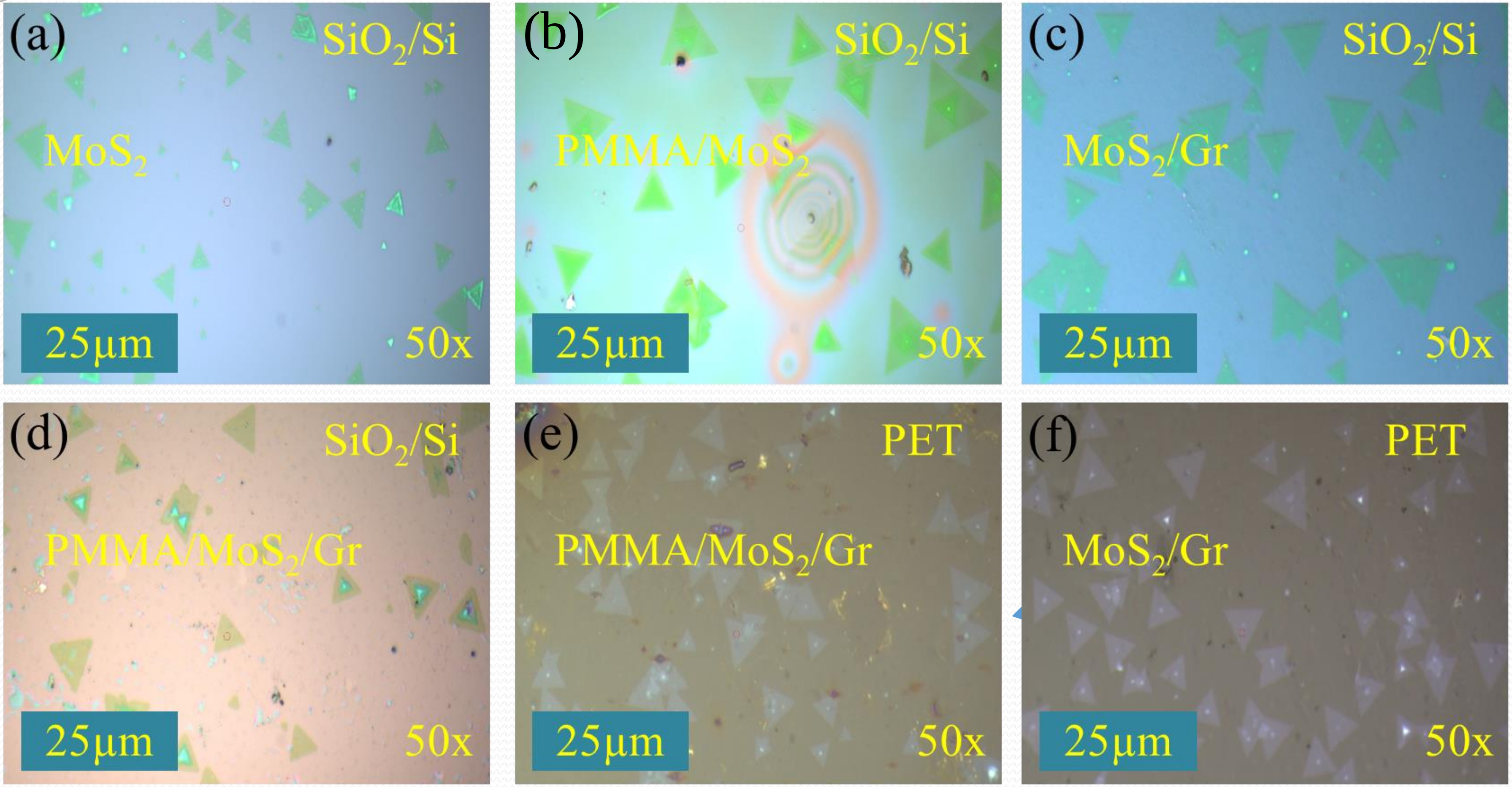
Optical surface morphology of MoS_2



High-quality two-dimensional semiconductors were prepared by chemical vapor deposition (CVD). Optical surface morphology of MoS_2 on Si/SiO_2 (a). MoS_2/Gr is prepared by PMMA transfer and transferred to a flexible substrate (b-f).

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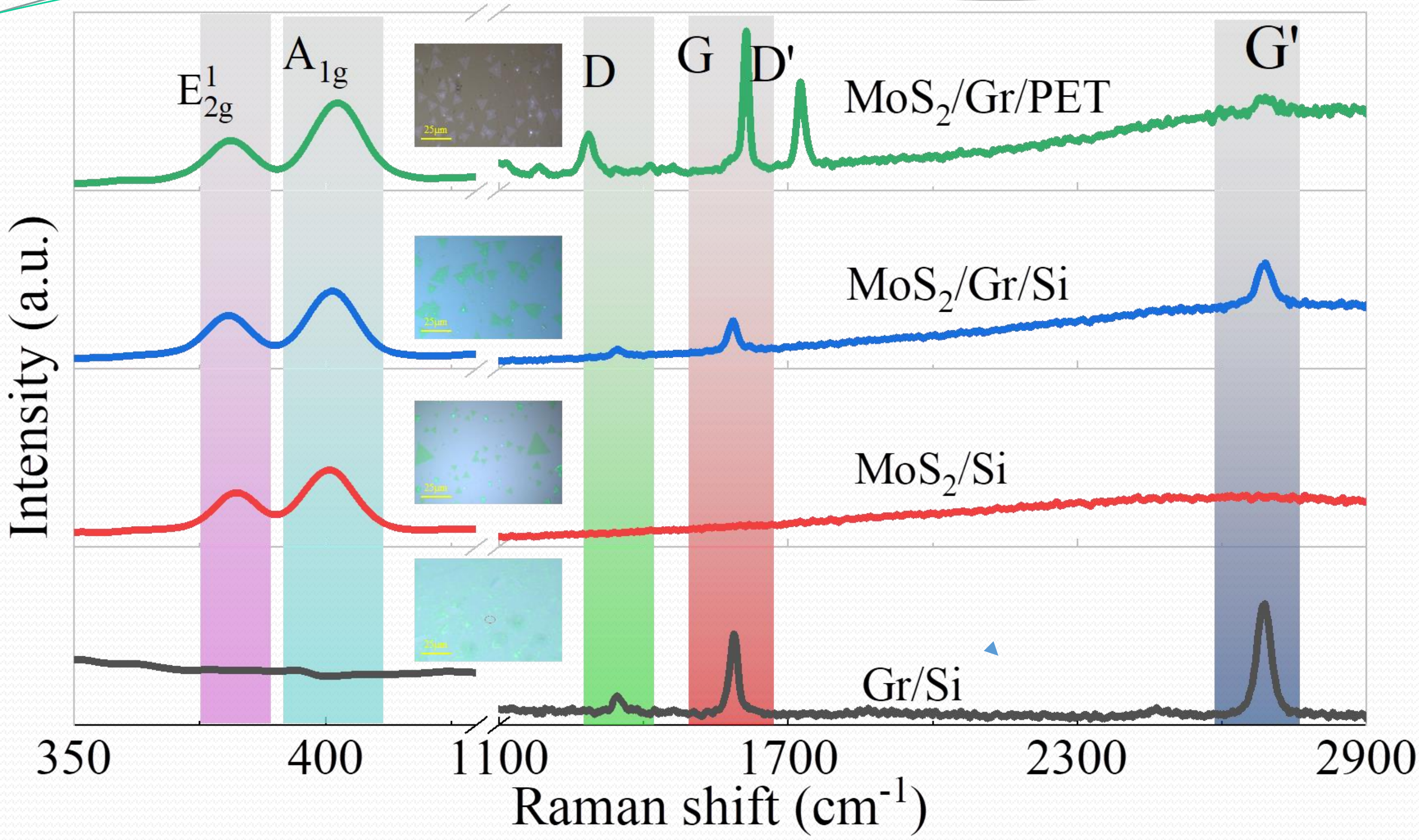
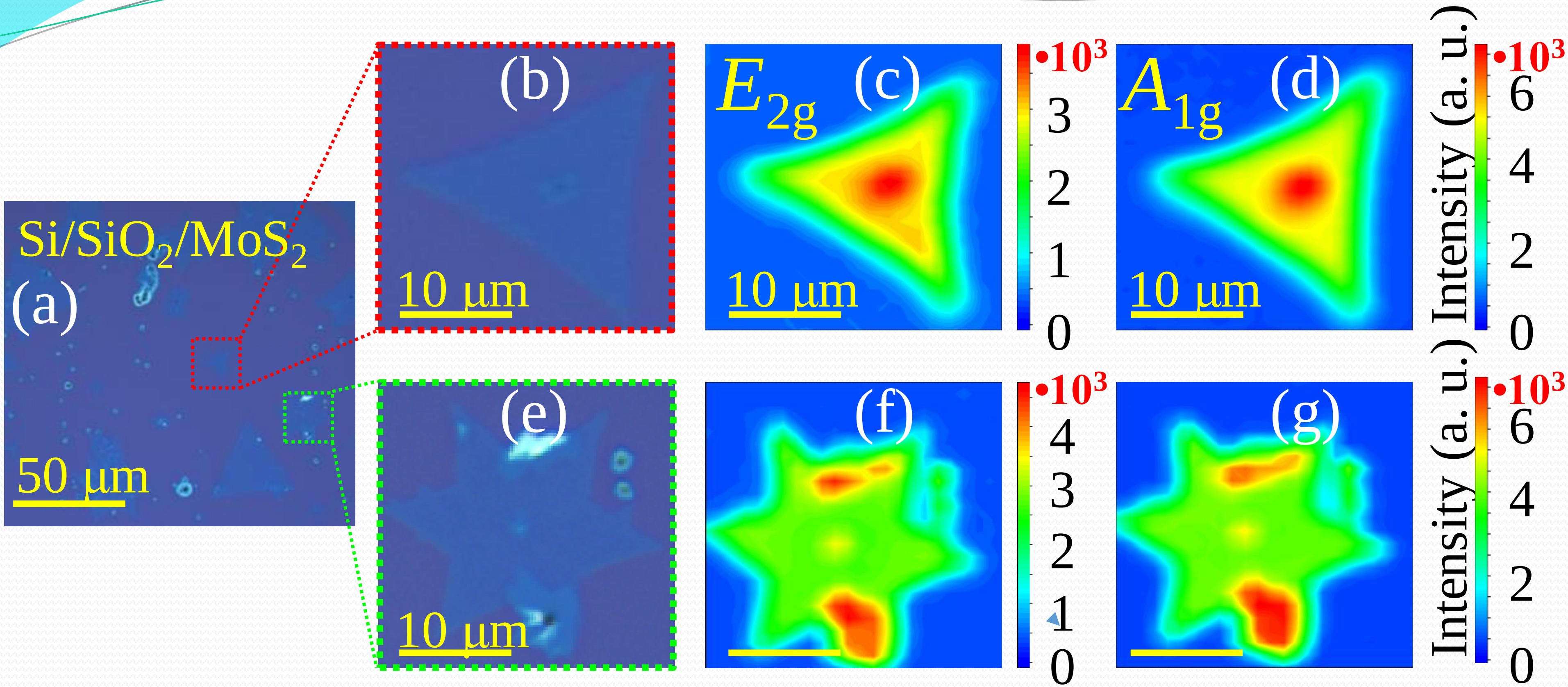


Raman spectra of monolayer-MoS_2/graphene structures on different substrates and precursor ones, as well as their morphology images. λ_{exc} = 532 nm.

Raman mapping of MoS_2



(a) The optical photo of surface MoS_2 flakes grown on SiO_2/Si substrate by CVD method. (b, e) The Raman mapping area of MoS_2 flakes (triangle and star). The mapping of E_{2g} (c, f) and A_{1g} (d, g) bands corresponds to the area in the optical photo.

Raman mapping showed good quality MoS_2 monolayers, but that area is not large and only flakes. We need to continue studying the growth modes to get large monolayers, that are easier to use in flexible electronics.

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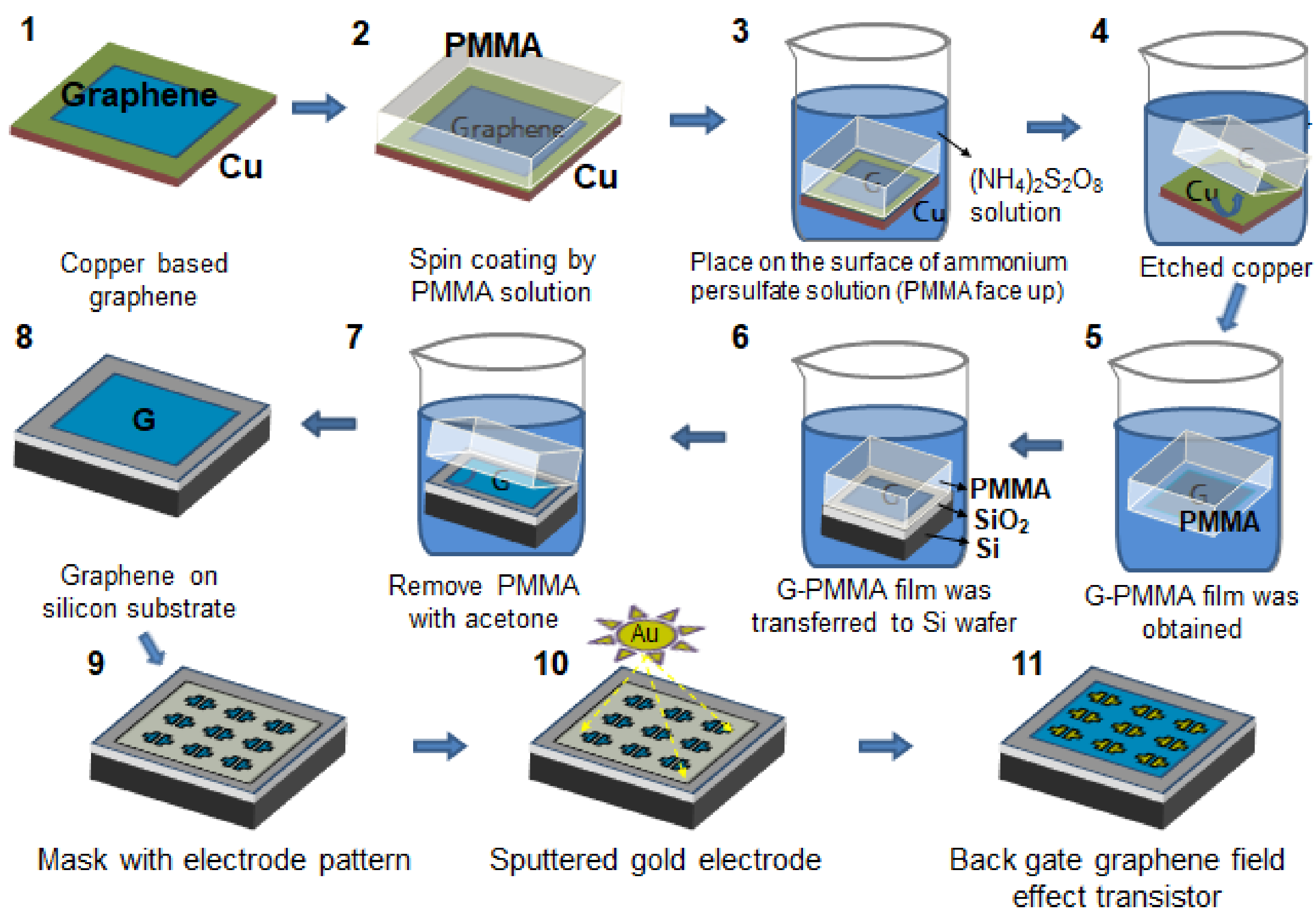
Done

@Zhu Huiyu

Diagram of transferring monolayer Graphene on a SiO_2/Si substrate.



In progress

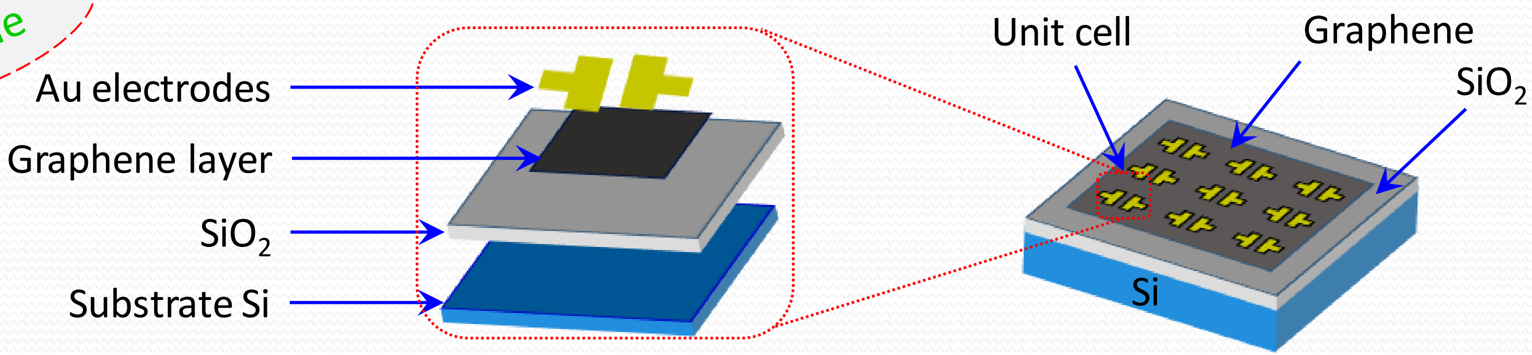
To perform selective detection of Cu^+ ions, valinomycin ($C_{54}H_{90}N_6O_{18}$) based ion selective membrane (ISM) with 5 µm nominal thickness will be spin-coated on the entire transferred graphene area and kept at room temperature for 20 minutes for complete solvent volatilization and stable film formation.

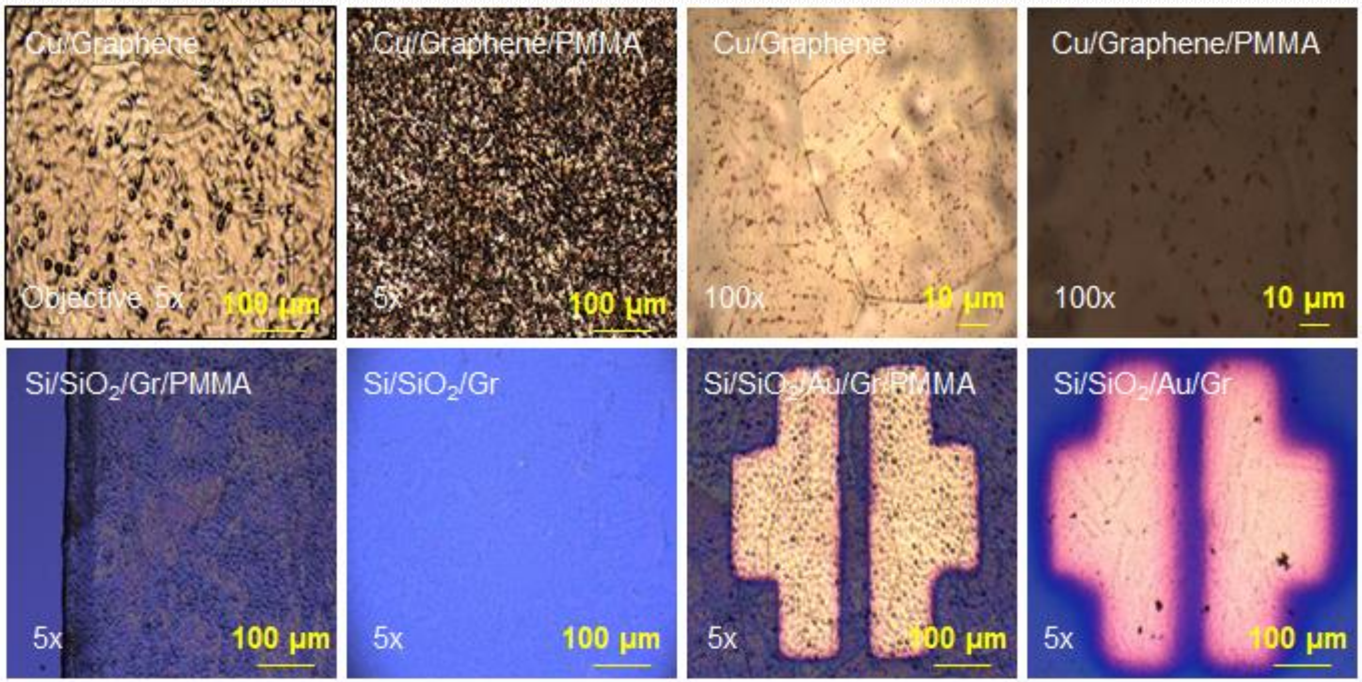
Transferring monolayer on a SiO_2/Si substrate (morphology)

Done

Diagram of sensor unit cell

Back gate graphene field effect transistor





Optical surface morphology of graphene layer on Cu foil and covered by PMMA. Graphene layer transferred to Si/SiO_2 substrate with prepared Au contacts.

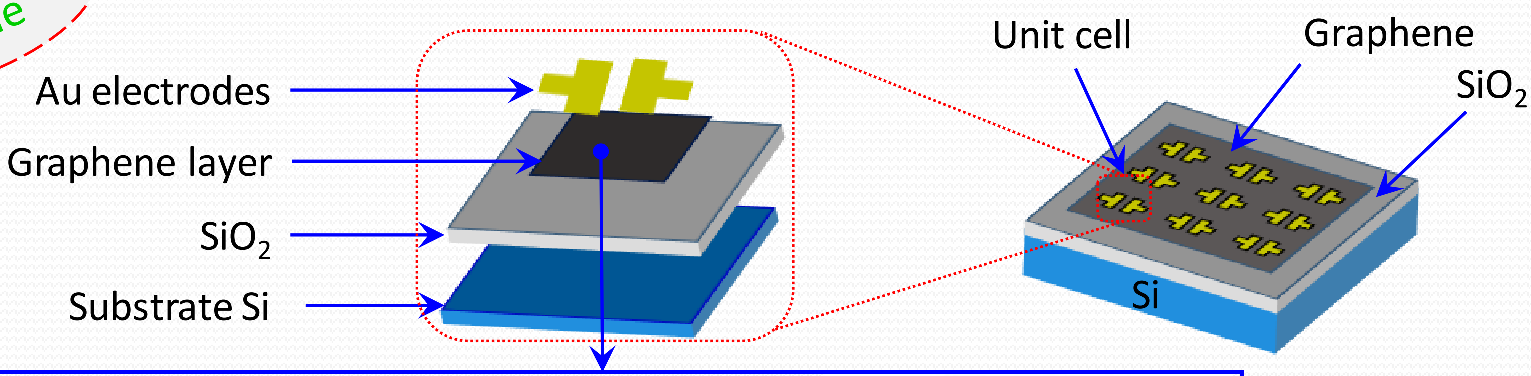
@Zhu Huiyu

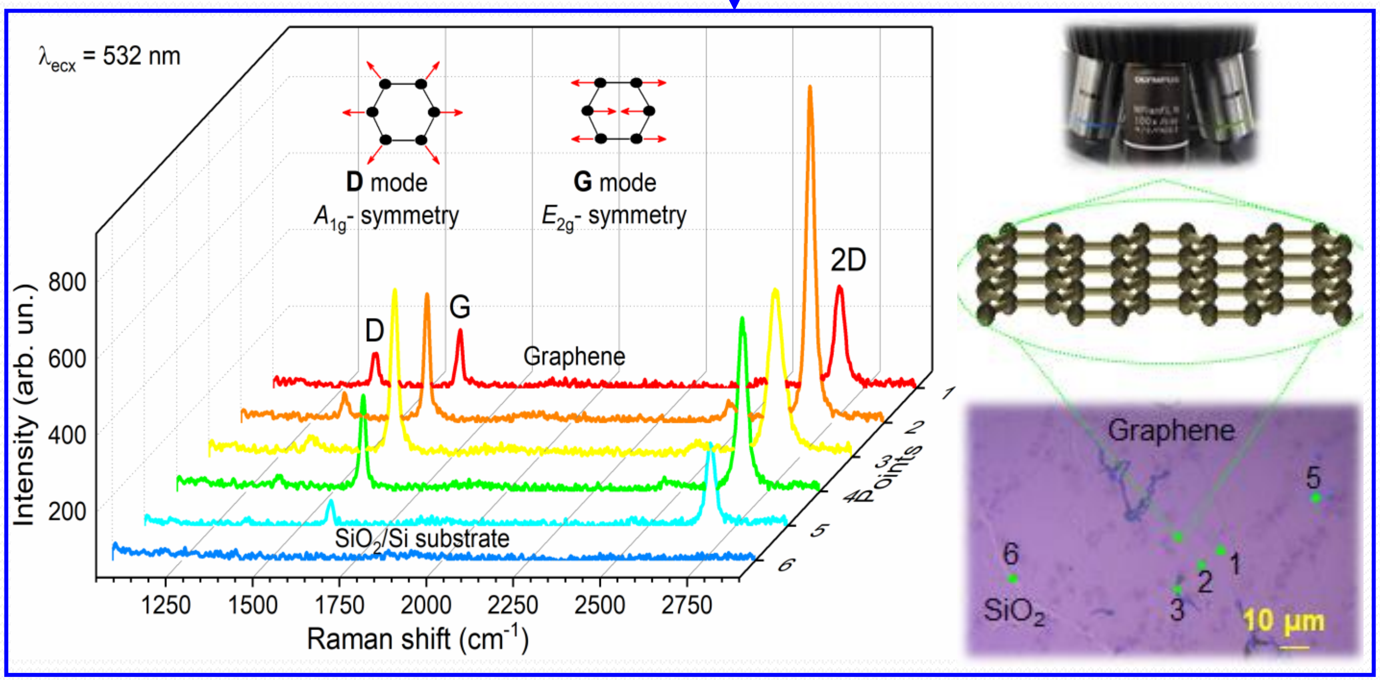
Vibration properties graphene monolayer

Done

Diagram of sensor unit cell

Back gate graphene field effect transistor



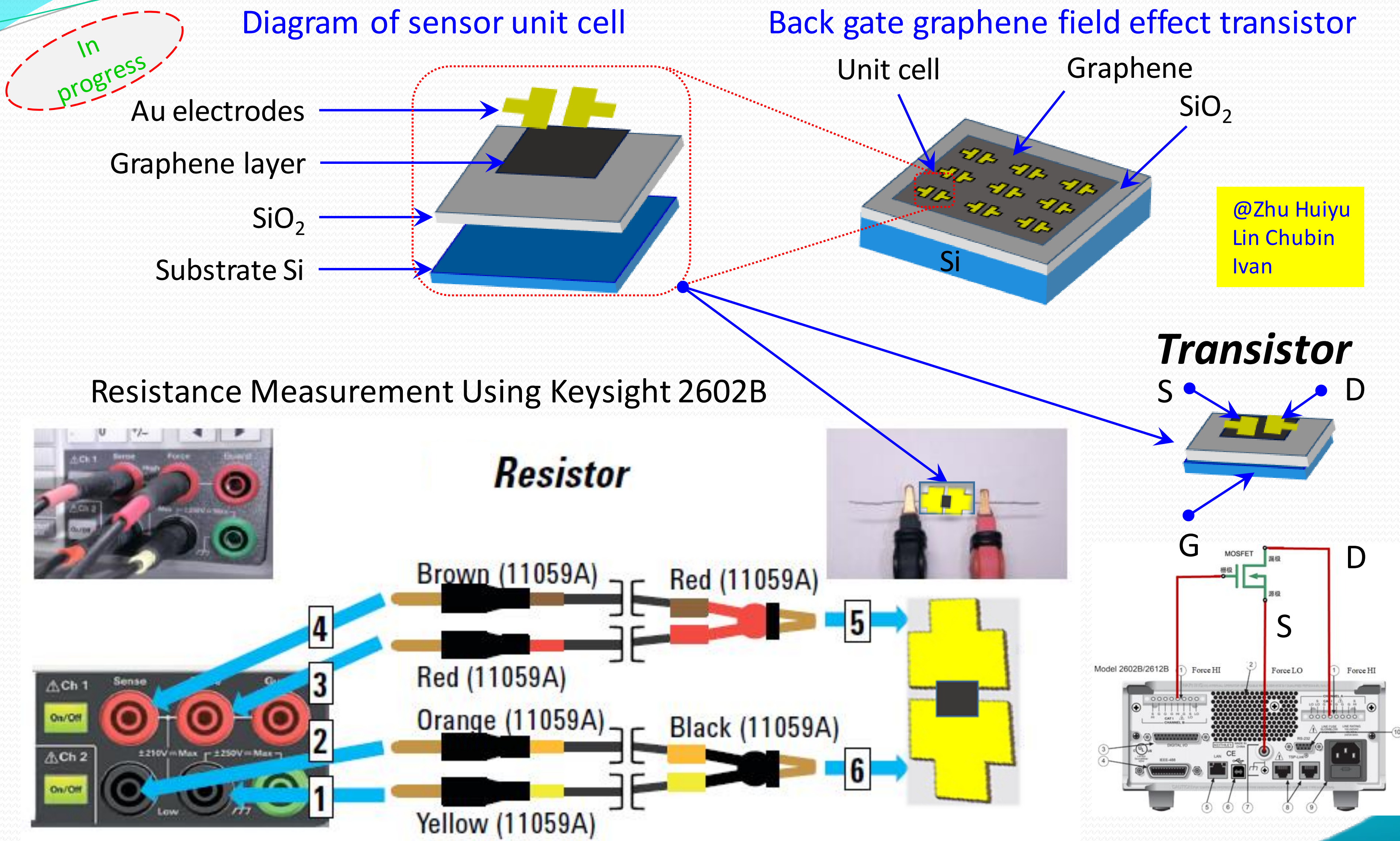


Raman spectra of a graphene monolayer on a Si/SiO_2 substrate at different points on the surface and an image of this layer in the objective lens of an optical microscope.

Raman vibrational modes of graphene were responsible for the G-, D- and 2D-bands.

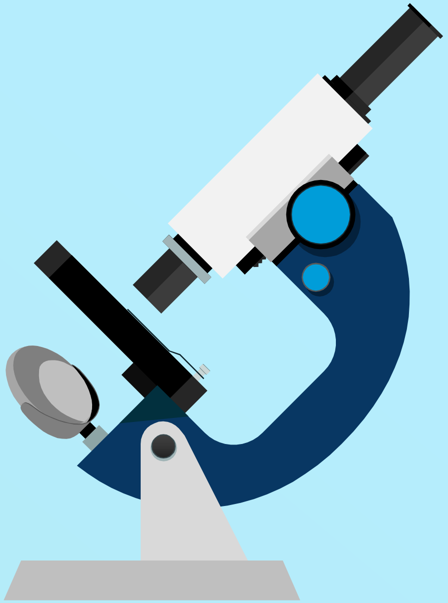
@Zhu Huiyu
Yuhui Qiu
Lin Chubin

Electrical properties of G-FET



1) 2D materials contribute to developing physical, chemical, bio, and wearable sensors. The large contact surface area in a small volume ratio is one of the key points for this type of 2D-based sensor, achieving a good limit of detection and sensitivity.
2) The mono- and few-layer of MoS_2 flakes (triangles and stars) were grown. Raman spectroscopy was used to get information about the quality of the MoS_2/graphene structure.
3) MoS_2 flakes were transferred to a flexible substrate to develop a flexible electronic device.

The growth of a high-quality defect-free MoS_2 monolayer on large areas is still open and will give prospects for implementation in flexible electronics.



Thank you for your consideration!