Characterization of Two Dimensional Materials and Fabrication of the Transistor and Heterostructure

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Introduction

Two-dimensional (2D) material is a material in which the atomic organization and bond strength along two-dimensions are similar and much stronger than along a third dimension. 2D material such as graphene, boron nitride (BN), and transition metal dichalcogenides (TMDCs) have unique electrical, optical, and mechanical properties that can be used in a wide range of applications.[1] By vertically stacking different 2D semiconducting crystals on top of each other with van-der-Waals forces, Van der waals heterostructures are expected to show combined functionality of the individual layers, and also new phenomena resulting from the interface.[2] Here, single/few layers graphene and molybdenum disulfide (MoS_2) obtained and studied by Mechanical Cleavage and Raman spectrum. Further transfer process and electrodes fabrication are conducted to build 2D materials based transistors/heterostructures.

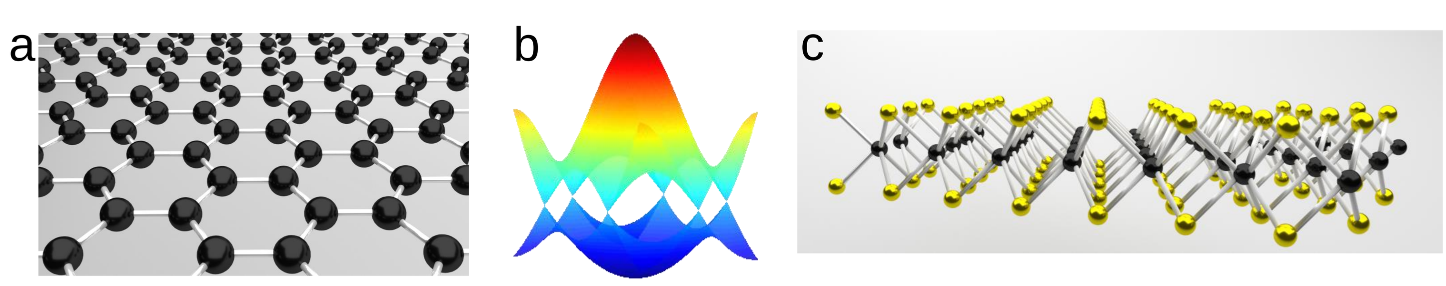

Figure 1. lattice structure of (a) graphene and (b) single layer MoS_2. (b) Band structure of Graphene.

As Figure 1 shows, Graphene is a single layer of carbon packed in a hexagonal lattice (honeycomb), with a covalent bond distance of 0.142 nm. Graphene is a zero-gap semiconductor since its conduction and valence bands meet at the Dirac points.

In each MoS2 layer, hexagonally packed molybdenum atoms are between two layers of sulfide atoms. Bulk MoS2 is semiconducting with an indirect bandgap of 1.2 eV, whereas single-layer MoS2 is a direct gap semiconductor with a bandgap of 1.8 eV.

Method

- **Mechanical Cleavage:** The primary and most effective way comparing with other method, which provide graphene with the highest quality.
- **Raman microscope:** Raman spectra are studied to characterize materials and identify single/few layers from their bulk material.
- PDMS based transfer technique for 2D material.
- Electron Beam Lithography and Thermal Evaporation for electrodes fabrication.

Results and discussion

Raman Characterization of Graphene samples

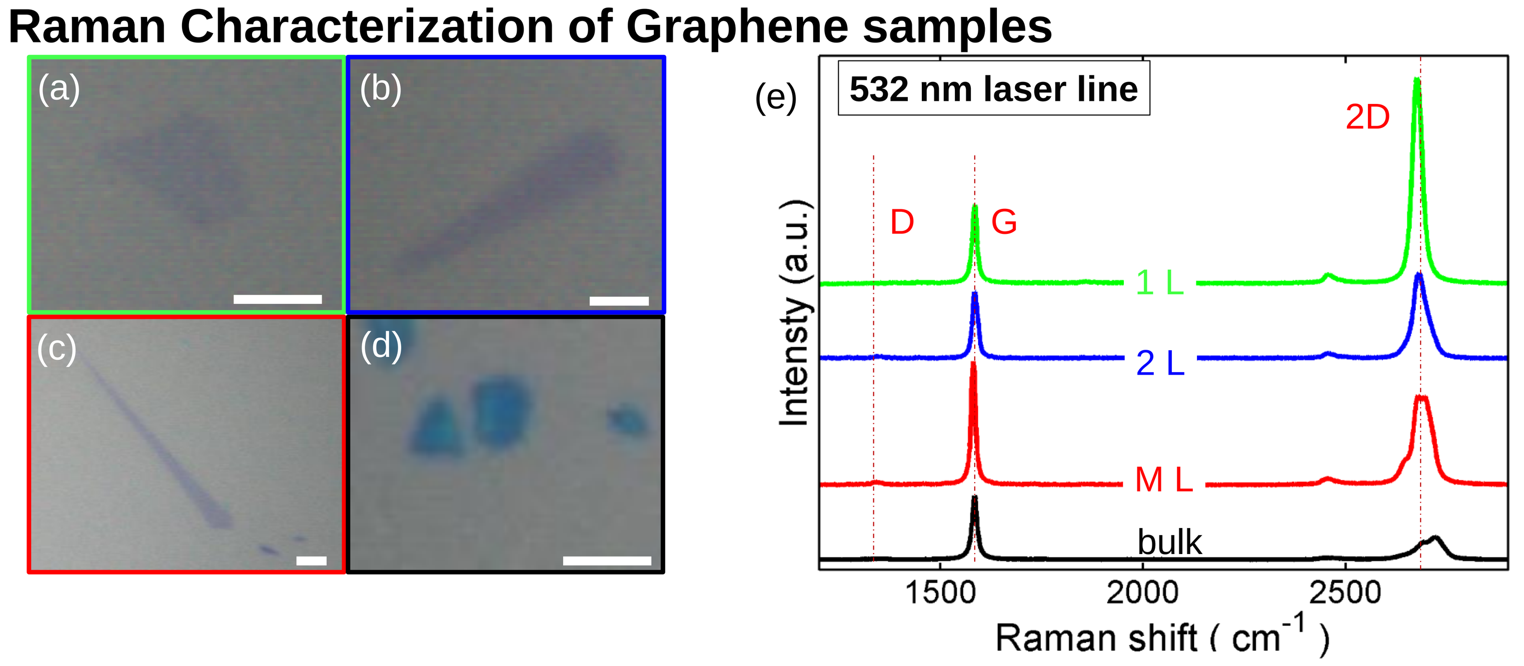

Figure 2. a-d are four graphite samples with different layer numbers. (a) length is 4.62 µm and ROI is 21/8. (b) Length 7µm and ROI is 17/13. (c) Length 21.17µm and ROI is 17/24. (d) Length 5.32µm and ROI is 1/3. (e) Raman characterization of sample a-d using 532 laser line. The spectra are offset vertically for clarity. The scale bars are 5 µm.

Graphene can be identified by the position and shape of its peak G (1580 cm-1) and peak 2D (2690 cm -1). The first-order D peak itself is not visible in pristine graphene because of crystal symmetries. While the number of the graphite layers decreases, the ratio of intensity, I_{2D}/I_G, increases.

Raman Characterization of MoS_2 samples

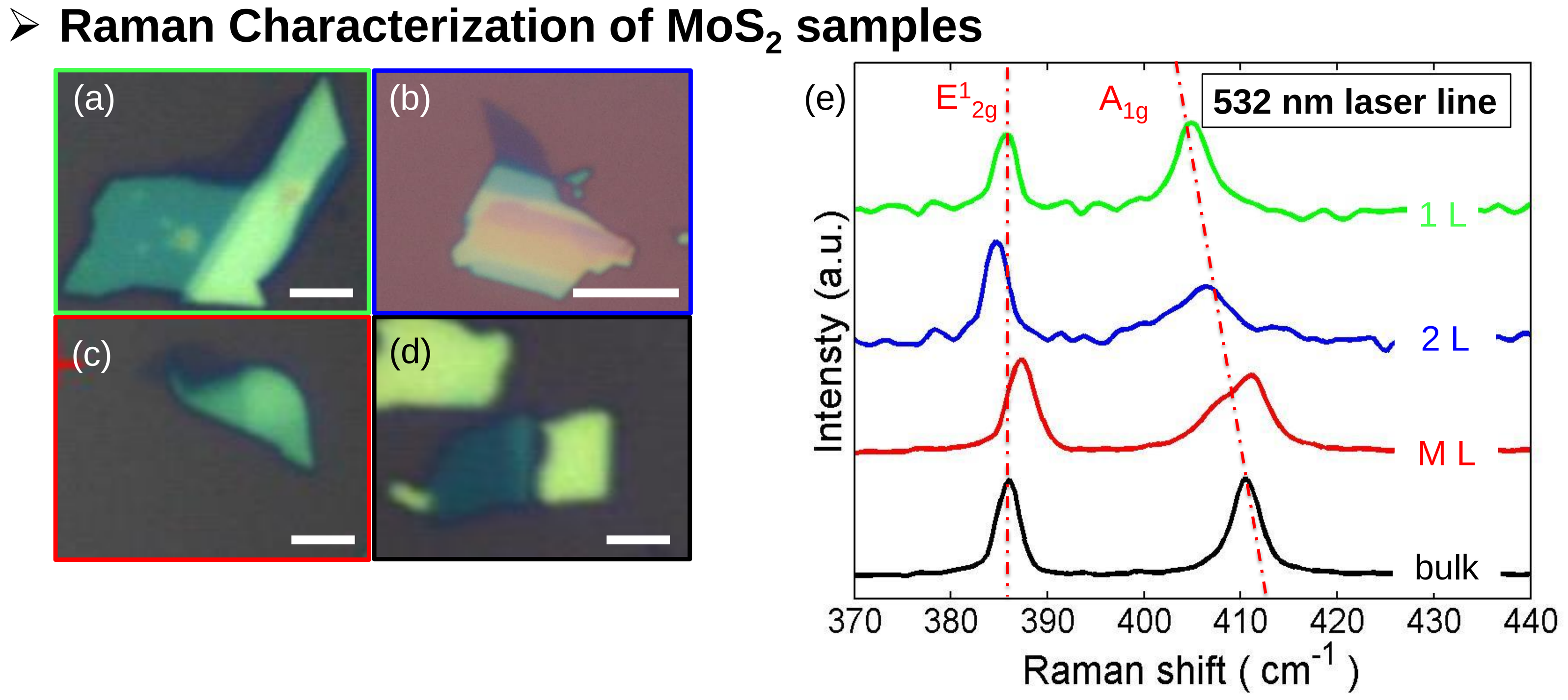

Figure 3. a-d are four MoS_2 samples with different layer numbers. (e) Raman characterization of sample a-d using 532 laser line. The spectra are offset vertically for clarity. The scale bars are 5 µm.

E^1_{2g} (~ 385 cm^{-1} for bulk MoS_2) and A_{1g} (~ 411 cm^{-1} for bulk MoS_2) modes are observed in both monolayer and bulk MoS_2. However, it is found that the intensity of E^1_{2g} peak decreases while that of the A_{1g} peak increases with increasing layer number. Additionally, the distance of these two peaks increase from 19.08 - 24.45 cm^{-1}.

Photoluminescence of MoS_2 samples

Single layer MoS_2 exhibits significantly stronger photoluminescence (PL) ~ 675nm than bilayer MoS_2. The different PL spectra also indicates that a monolayer MoS_2 is a direct bandgap material while a multilayer MoS_2 is an indirect material.[3,4]

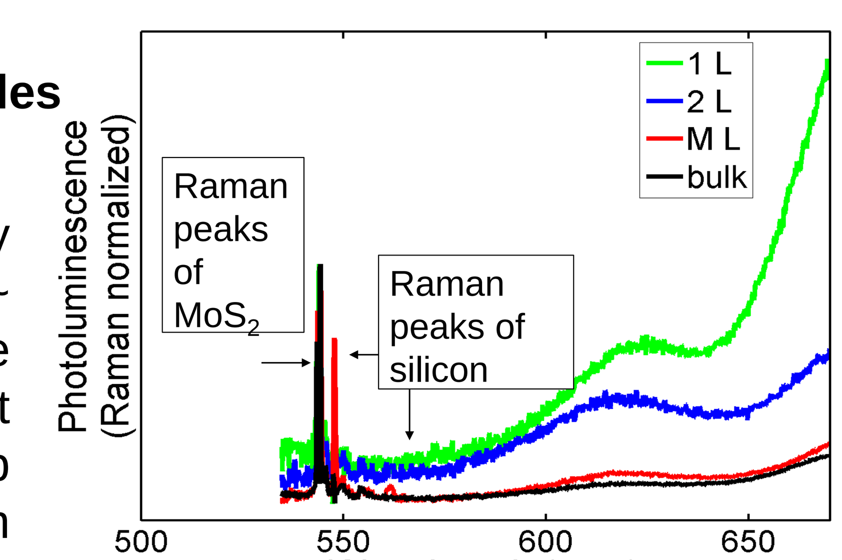

Figure 3. raman intensity normalized photo-luminescence of sample (a)-(d) excited by 532nm laser.

Fabrication of Graphene and MoS_2 transistor

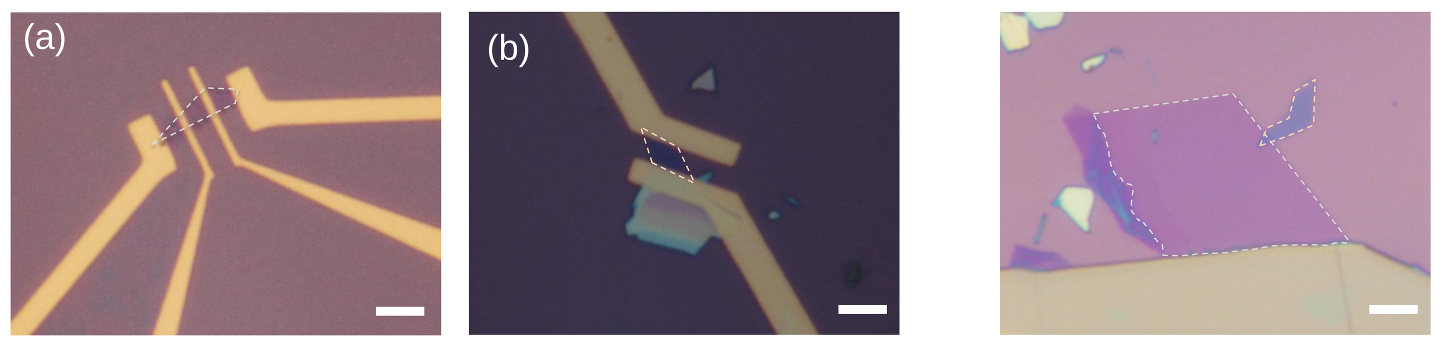

Figure 3. a and b are Graphene and MoS2 transistors. (c) is Graphene/MoS_2 hetero-structure. Graphene and MoS2 pieces are outlined by light gray and orange color dashed lines. The scale bars are 5 µm.

Graphene/MoS_2 heterostructure

Graphene piece are carefully cleaved from their bulk material onto thin Polydimethylsiloxane (PDMS) stamp. Then, a micro-manipulator is used to place the graphene layer on the top of prepared MoS_2 layer through an aligned transfer procedure.[5]

Conclusion

- Through Mechanical Cleavage, graphene and monolayer MoS_2 are successfully obtained from their bulk material. Studying Raman characteristics, we can distinguish unique properties. Transferring 2D material can be done using PDMA, to fabricate transistors and other optical electronics.
- **Future Work**: Fabricating single layer MoS_2 and WSe_2. Creating a N doped and P doped heterojunction for dye sensitized solar cells.

Reference

1. Geim, A. K., et. al. *Nature* **499**, 419–425
2. Butler, S. Z., et. al. *ACS Nano*, **2013**, *7* (4), pp 2898–2926
3. Splendiani, A., et. al. Nano Lett. **2010** Apr 14;10(4):1271-5
4. Li, H., et. al. *Adv. Funct. Mater.* **2012**, *22*, 1385–1390
5. Lee, C. H., et. al. *Nature Nanotechnology* 9, 676–681

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