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. 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. Here, single/few layers graphene and molybdenum disulfide (MoS₂) obtained and studied by Mechanical Cleavage and Raman spectrum. Further transfer process and electrodes fabrication are conducted to build 2D materials based transistors/heterostructures.

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 1. a and b are Graphene and MoS₂ transistors. (c) is Graphene/MoS₂ heterostructure. Graphene and MoS₂ pieces are outlined by light grey and orange color dashed lines. The scale bars are 5 µm.

Fabrication of Graphene and MoS₂ transistor

Fabrication of Graphene and MoS₂ transistor

- Through Mechanical Cleavage, graphene and monolayer MoS₂, 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.

Conclusion

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Figure 2. a-d are four graphene samples with different layer numbers. (a) length is 4.82 µm and ROI is 21.8. (b) Length 7µm and ROI is 17/1.3. (c) Length 21.17µm and ROI is 17/2.4. (d) Length 5.32µm and ROI is 17/3. (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_G/I_D, increases.

- Raman Characterization of MoS₂ samples

Figure 3. a-d are four MoS₂ 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 MoS₂) and A₂(1) (~ 411 cm⁻¹ for bulk MoS₂) modes are observed in both monolayer and bulk MoS₂. However, it is found that the intensity of E'₁(2g) peak decreases while that of the A₂(1) peak increases with increasing layer number. Additionally, the distance between these two peaks increases from 19.08 - 24.45 cm⁻¹.

- Photoluminescence of MoS₂ samples

Single layer MoS₂ exhibits significantly stronger photoluminescence (PL) ~ 675nm than bilayer MoS₂. The different PL spectra also indicates that a monolayer MoS₂ is a direct gap semiconductor material while a multilayer MoS₂ is an indirect material.

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