

A Review on Transition Metal Dichalcogenides (TMDCs) based Field Effect Transistor

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Abstract

A new class known as transition metal dichalcogenides (TMDCs) emerged from the graphene inventory because of its impressive characteristics. Motivated by the graphene success, the alternatively layered and unlayered two dimensional (2D) materials, have become the focal point of intensive research because of the unique electronic and mechanical properties. The source of these features was related to the electronic band structure's dimensional impact and the modulation. This review shows the recent advances of state-of-the art research into the characterization of single and few layers in electronic circuits, optical sensors. The analysis completes with the future prospect of heading the rapidly changing 2D materials group in the sciences of next decade.

Keywords: 2D materials, charge carrier mobility, MoS₂ FET, transition metal dichalcogenides.

INTRODUCTION

Beginning from graphene emergence and its unique characteristics, the production of exclusively the two dimensional (2D) atomic crystals has advanced tremendously. This can be seen as single planes of molecular-scale spacing drawn out of bulk crystals such as graphite, multiple transition-metal-dichalcogenides (TMDC) or complex oxides, h-BN. By positioning multiple crystals of atomic layer on top of each one another, multilayered hetero-structures can be produced that offer new devices with engineered electronic characteristics. For example, new transistor concepts based on vertical, lateral transport and opto-electronics also demonstrated to be useful.

While such new materials are clearly potential for implementations, for many reasons, they differ greatly from typical three-dimensional materials. Both atoms are at the surface or interface directly. Furthermore, the electrons are limited to atomically thin structures that are highly sensitive to the specifics of the electrical properties. Vertical volume isolation or piling at an individual particle rate can be used to manage resources such as electronic band gaps. Crucially, atomic density and corresponding electron confining are also typical of different body phenoms. Clearly, structural acuteness means good electron-phonon connection. Therefore, Coulomb interaction is individual in 2D materials owing to decreased filtering and suppression of the kinetic energy.

In other terms, the 2D electronic architecture incorporates the problem of conflicting contacts between multiple bodies with the susceptibility to atomic structure details. Therefore there still exists a clear picture of how modern 2D materials can influence the optical and electronic features and, in particular, a common standard model of the electronic structure. This review focuses on the electronic structure, optical characteristics, interactions and their unified phenomena of 2D materials. Interactive impacts may normally be divided into three groups such as thermodynamic weakness and ground state, renormalization of excitations and emergence of group types. All three types of interaction impacts are observed experimentally in 2D materials. Graphene with Fermi velocity density-dependent renormalization and electronic stage transitions in bilayer graphene into transition metal dichalcogenides (TMDC) that generate super-conductivity, huge exciton binding energies, and charge density wave states. The research papers discuss the issue of the interactions impacts graphene-based systems. Asgari et al [1] address how interactions controlled by Fermi-liquid metrics such as decreased mass and electronically compressible by doped graphene. Ron Bessler et al [2] has shown that, based on the microscopic description of electron to electron contacts,

there are various electronic imbalances that occur in bi-layer graphene. Because 2D material provide an exciting opportunity, for example by screening by metal gates to control the interactions indirectly, it is obvious that a large part of the body impacts can be tailored in 2D materials. The size enables aggregate modes like phonons and plasmons of the two-dimensional (2D) materials to propagate separately from normal bulk 3D materials. 2D plasmons are acoustic for which the amplitude of plasmons decreases at longer wavelengths. Furthermore, 2D freestanding materials become flexible phonones softer than standard acoustic-phonons when they propagate with the wave vector in quadratic and not in linear forms. Such soft group modes can be regarded as typical of 2D materials which effectively control characteristics from the crystal lattice stability to digital low temperature phases. The studies of Slotman et al [3] investigate how the phonons presence in substrates is influenced the graphene including certain contacts with the electrons.

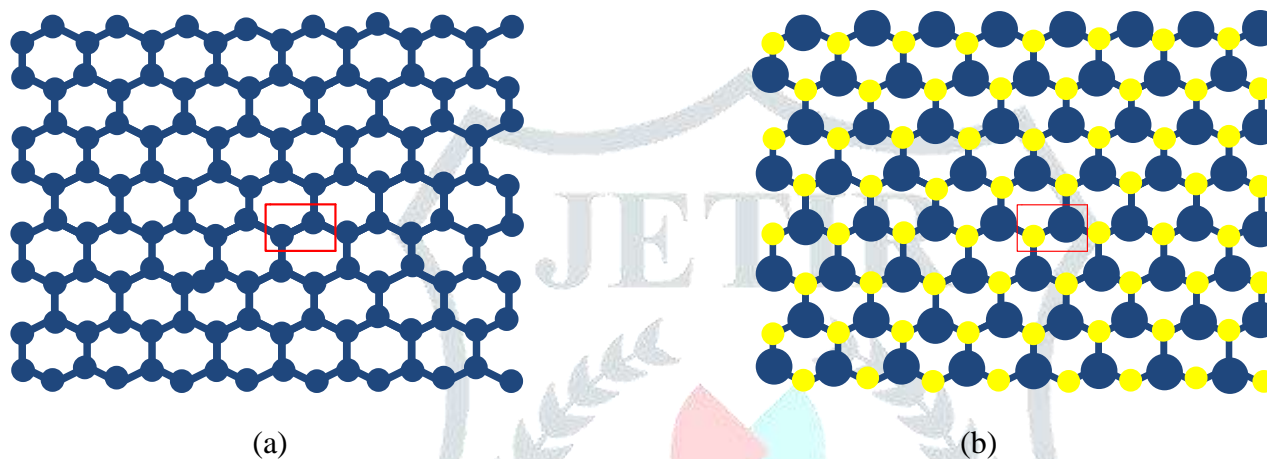


Figure 1: The atomic structures from the top-view of (a) graphene and (b) Single Layer MoS₂. The Rectangle in red color encloses each unit cell structure.

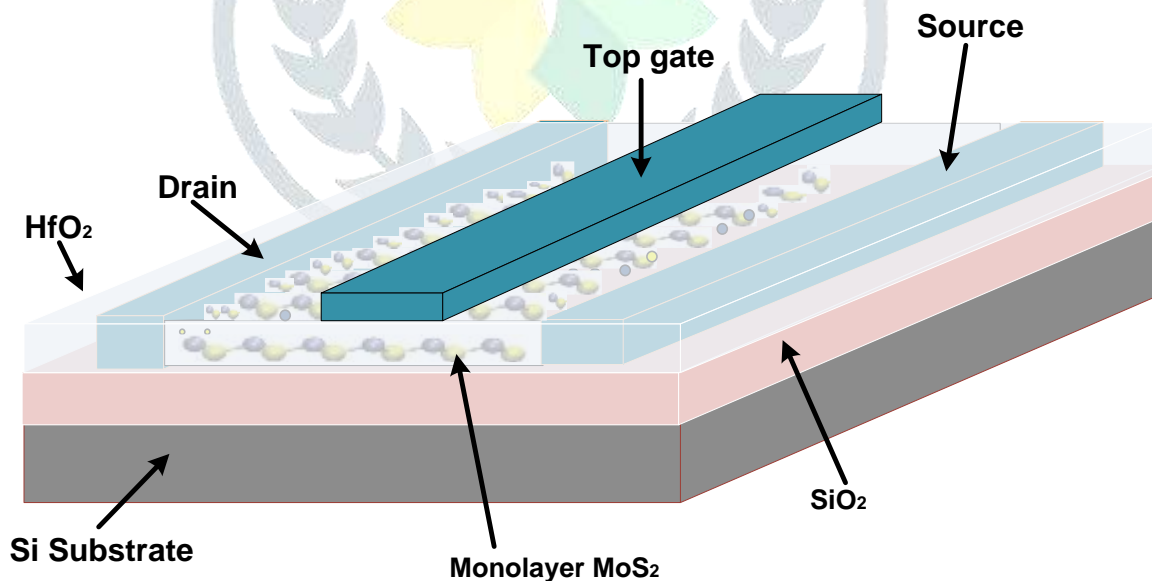


Figure 3: Structure of single layer MoS₂ based transistor

TRANSITION METAL DICHALCOGENIDES (TMDCS)

TMDCs like WS₂ or MoS₂ are the semiconductors which are optically prominent with significant spin-orbit contact and can be accelerated towards semiconducting behavior and even metallic behavior. The Rold'an et al [4] explores its electronic characteristics and also investigates its vulnerability to disorder, deformations, and manybody impacts. TMDCs are a potential substance category for the spintronic implementations, due to the effects of optical operations and spin orbit connections. In addition, optics is one field with various applications, the interaction of light matter with 2D materials is regulated by broad Coulomb interactions impacts. Optically energised electron-hole pairs will combine to form the excitons with bonding sources of energy in the range of more than 100 meV. The family of two dimensional (2D) materials are rising perpetually. Often, the 3D structured transition-metal compositions are instances, and it is intriguing to see whether the recent phenomena or potential uses are present. Figure 1 shows a top visual view of the single layered MoS₂ structure that consists of a trilayer arrangement with a Mo layer, at which the atom is sandwiched between the two S layers of atomic layer.

The TMD is composed of the transition metals M and chalcogen Q i.e., sulfur (S), selenium (se), or terrestrial (te) elements, of the elements of groups IV, V and VI of the periodic table. For example, MoS₂ consists of a one layer of molybdenum (Mo) atoms and two layer comprises of sulfur (S) atoms. Now, about 40 distinct TMDs were known [5]. Many of those with metallic bands are the semi-conductor with the energy bandgaps in the order of 1 to 2 eV. [6]. MoS₂ WSe₂, etc., along with several Hf-, Pt-, Pd- and Zr-based TMDs. TMDs exist in numerous 1T, 1T, 2H, and 3R forms, where T is trigonal, T's twisted-trigonal, H is hexagonal, R refers to rhombohedral. Their numbers 1, 2, or 3 represents the TMD surfaces in a unit cell [7, 8] with different characteristics. For instance, the typical W-based and Mo- TMDs 2Hexagonal polytypes be a semi conductive while the 1T metastable variants are metallic [9].

BANDGAP OF 2D MATERIALS

The important feature of semiconducting materials is the band-gap. Their usefulness for the electronic equipment is profoundly compromised and the detection of a violation is necessary for the proper field effect transistor application. FETs require high on-off ratio when used in digital circuits. Although a FET current would not be relating the EG bandgap, the off current depends heavily on EG.

$$I_{off} \propto e^{\frac{-E_G}{mk_B T}} \quad (1)$$

Based on field effect transistor design the m value will be 2 or higher, k_B is the constant of Boltzmann, T is the temperature. The on to off ratio is as becomes as in equation (2)

$$\frac{I_{on}}{I_{off}} \propto e^{\frac{E_G}{mk_B T}} \quad (2)$$

| Material | Bandgap (eV) | Mobility |
|------------------|--------------|---|
| MoS ₂ | 1.89 | 250 cm ² V ⁻¹ s ⁻¹ |
| Graphene | 0 | 200,000 cm ² V ⁻¹ s ⁻¹ |
| Ge(bulk) | 0.66 | ≤ 3900 cm ² V ⁻¹ s ⁻¹ |
| Si(bulk) | 1.11 | ≤ 1400 cm ² V ⁻¹ s ⁻¹ |
| Si MOS | | |
| GaAs | 1.42 | ≤ 8500 cm ² V ⁻¹ s ⁻¹ |
| InP | 1.35 | ≤ 5400 cm ² V ⁻¹ s ⁻¹ |

| | | |
|--------------|-------|--|
| GaP | 2.26 | $\leq 250 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ |
| GaN | 3.39 | $\leq 1000 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ |
| InAs | 0.354 | $\leq 4 \cdot 10^4 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ |
| 4H-SiC(bulk) | 3.23 | |

Table 1: Table shows the bandgap and mobility values of different materials

The zero bandgap channeled FETs can produce higher current gains and f_T (cutoff frequency) but have low energy and f_{\max} (maximum frequency of oscillation) gains. Effective-mass (m_{eff}) and mobility of the charge carrier. Logic FETs must react faster to changes in their values of a signals at input, i.e. require a higher on current and be able to respond rapidly. This requires fast mobility of the carriers. The mobility of carriers μ , the maximum velocity v_{peak} and the saturation voltage v_{sat} measurements parameters of carrier mobility. If a weak electrical field E operates on a load, the amplitude of the drift velocity v is defined by $v = \mu \times E$. The movement is related inversely to the effective mass m_{eff} and the light is a requirement for a high μ . Higher saturation rates and mobility are often ideal for logical FETs. The design of MOSFETs upon bendable substrate is quite interesting.

CONCLUSION

The research on 2D materials involving transistors which have zero band gap such as graphene and the TMD channels that have recently drawn great interest. Graphene and 2D materials besides graphene can also be bendable substrates thereby not compromising the flexibility of the carrier significantly. As MoS_2 is flexible, it is suitable for versatile devices. MoS_2 based FETs have been proved on bendable substrates. MoS_2 based FETs have the great benefit of a semiconducting stream with a sufficiently large gap contributing to exceptional switching off with a decent drain saturation and therefore a good power gain and f_{\max} . These transistors also show moderate f_T performance relative to graphene MOSFETs because of their quite decent channel flexibility.

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