

Synthesis and Characterization Of Layered Molybdenum Disulfide Thin Films For Opto Electronics Applications

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ABSTRACT

MoS₂ is highly potential candidate when compared to other two dimensional Material because of its light weight, flexible, Direct band gap, Excellent conductors of heat and electricity. It can be used to fabricate devices like field effect transistors (FET) and photo detectors. Among all TMD's **MoS₂** is a potential candidate because of its excellent optical and electrical properties. When Silica is used we have problems of short channel effects include DIBL, fringe field effect, Hot carrier generation so in order to overcome this MOS2 can be used. Aim of the technology is to increase the performance (speed) and reduce power consumption.

Keywords : field effect transistor (FET), Transition metal dichalcogenides (TMD's), Molybdenum Disulfide(**MoS₂**), optical microscope, lithography, Raman spectroscopy.

I. INTRODUCTION

Molybdenum is a Block D, Period 5 element, and sulfur is a Block P, Period 3 element. Molybdenum does not occur naturally as a free metal on Earth. Molybdenum disulfide (**MoS₂**) is a two dimensional layered semiconductor material. **Molybdenum disulfide** is an **inorganic compound** composed of **molybdenum** and **sulfur**. Its **chemical formula** is **MoS₂**. Molybdenum disulfide (**MoS₂**), consisting of layered S-Mo-S units structures bonded by van der Waals forces. **MoS₂** is a typical semiconductor with a band gap ranges from 1.2 eV to 1.8 eV as the thickness decreases from bulk to monolayer.

The compound is classified as a **transition metal dichalcogenide**. It is a silvery black solid that occurs as the mineral **molybdenite**, the principal ore from which molybdenum metal is extracted. In its appearance and feel, molybdenum disulfide is similar to graphite. Indeed, like graphite, it is widely used as a solid lubricant because of its low friction properties and robustness.



Fig.1.1 : Structure Of **MoS₂**

MOS_2 is relatively unreactive. It is unaffected by dilute **acids** and oxygen. Bulk MOS_2 is a diamagnetic, indirect bandgap semiconductor similar to **silicon**, with bandgap of 1.23 eV.

Molybdenum Disulfide (MOS_2) Like Graphite, MOS_2 has a low friction coefficient, But, unlike graphite, it does not rely on adsorbed or moisture. In fact, adsorbed vapours may result in a slight, but insignificant, increase in friction. MOS_2 has greater load carrying capacity, and its manufacturing quality is better controlled. Thermal stability in ion oxidizing environments is acceptable to 1100 °C (2012 °F), but in air it may be reduced to a range of 350 to 400 (662 to 752 °F).

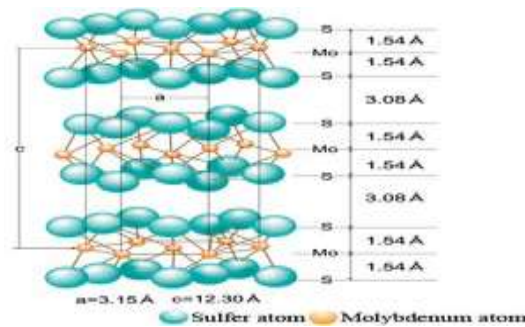
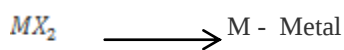


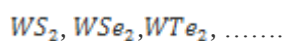
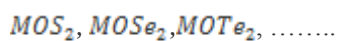
Fig.1.2 : Wavelength between atoms.

There are currently no clear lubrication alternatives to molybdenum disulfide or the very similar tungsten disulfide that can resist temperatures higher than 350°C in oxidizing environments. Research has been conducted on compacted oxide layer glazes, which form during metallic surface sliding wear at several hundred degrees Celsius. However, because these oxide layers are physically-unstable, their use has currently not proven practical.

MOS_2 is a layered semiconductor material. It belongs to Transition Metal Dichalcogenide (TMD) family.



X - Chalcogenide(S, Se, Te,)



II. SYNTHESIS AND CHARACTERISATION

Synthesis

Exfoliation

Characterization

Raman Spectroscopy

2.1 CLEANING OF Si SUBSTRATE

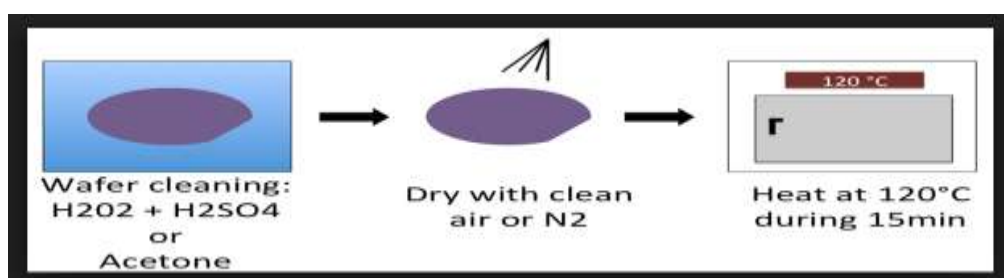


Fig 1.2.1. schematic representation of cleaning of substrate

- Wafer cleaning means removing contaminations on the substrate.
- Rinse with Deionized water for 5 mins to remove dust particles.
- Ultrasonification Acetone and isopropyl alcohol for 5 mins to remove organic and oil residues from the surface of silicon wafers.
- Piranha etch cleaning is also known as piranha solution. It is a mixture of 3 parts of sulphuric acid and 1 part of 30 percent hydrogen peroxide. The mixture is a strong oxidizing agent; it mostly removes organic matter.
- Rinse with Deionised water for 1 or 2 mins.
- Dry nitrogen flushing and heat the sample at 120°C is used to remove moisture.
- After cleaning of Si substrate, exfoliate MoS₂ on to the substrate using the scotch tape method.

2.2 Exfoliation

Scotch tape Method

It is a technique used to separate the multilayer of MoS₂ using adhesive tape which is a scotch tape. **ANDRE GEIM** and **KOSTYA NOVOSELOV** were awarded the 2010 noble prize in physics for inventing this scotch tape which is used for separating the many layers from MoS₂.

The small amount of MoS₂ crystal is placed on the scotch tape. By repeated peeling off, we will get the Monolayer MoS₂. We have to continue this process until it becomes thin. Then the scotch tape is placed on the substrate, apply some force for a while, then detach the tape from the substrate.

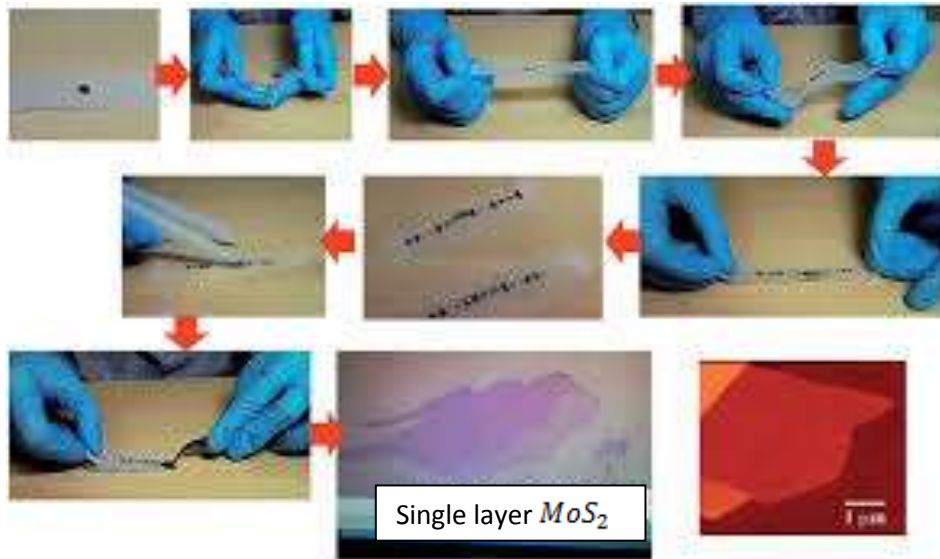


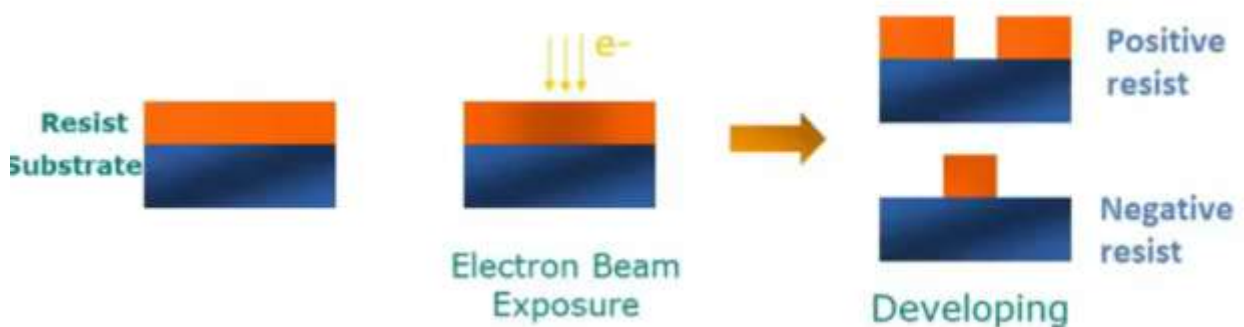
Fig.2.2.1. process of exfoliation

2.3 LITHOGRAPHY

Litho means *stone*. Graphy means *writing*. It is a process of producing patterns on semiconductor crystals, Lithography has an important role in the fabrication and mass production of integrated circuits in the microelectronics industry.

Electron beam lithography

e-beam lithography is a direct writing technique that uses an accelerated beam of electrons to pattern features down to sub-10 nm on substrates that have been coated with an electron beam sensitive resist. Exposure to the electron beam changes the solubility of the resist, enabling selective removal of either the exposed or non-exposed regions of the resist by immersing it in a developer



Optical Microscope

To identify thin and thick flakes present on the Si substrate.

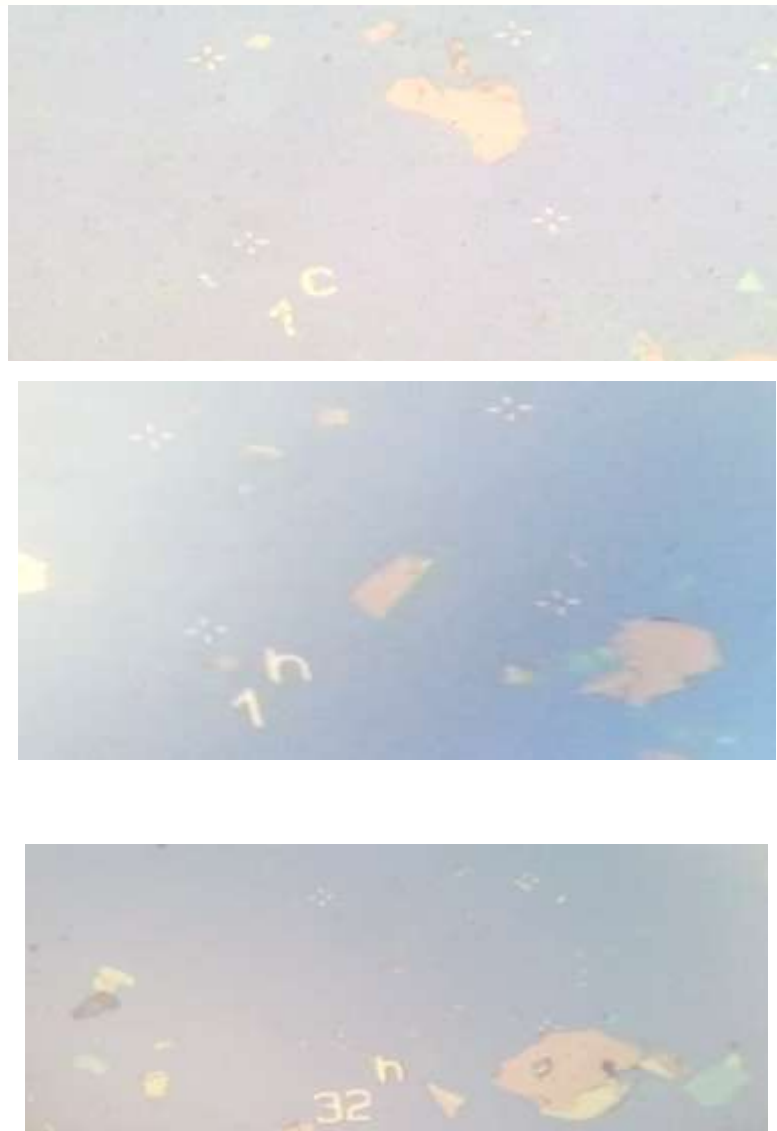


Fig 5

III. CHARACTERISATION

Raman Spectroscopy

Spectroscopy is a interaction of light and matter.

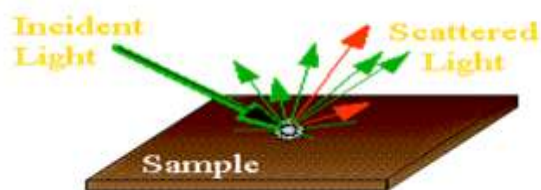


Fig 6

The scattering of radiation with change of frequency is Raman scattering. It is used to observe vibrational, rotational, and other low frequency modes in a system.

The energy of the scattered radiation is less than the incident radiation for the **Stokes line**, and the energy of the scattered radiation is more than the incident radiation for the **anti-Stokes line**. Rayleigh scattering, is an elastic scattering process in which a photon bounces off a molecule like a billiard ball, emerging with the same energy as it entered.

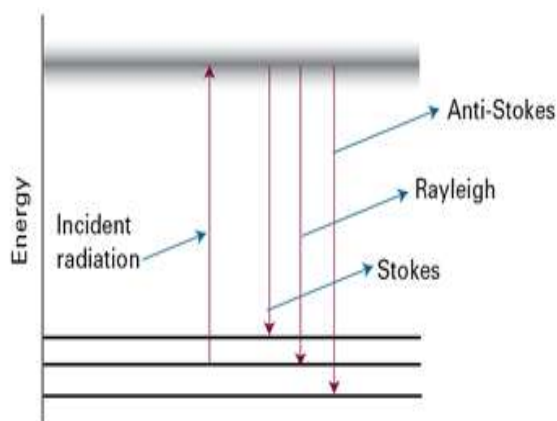


Fig 7

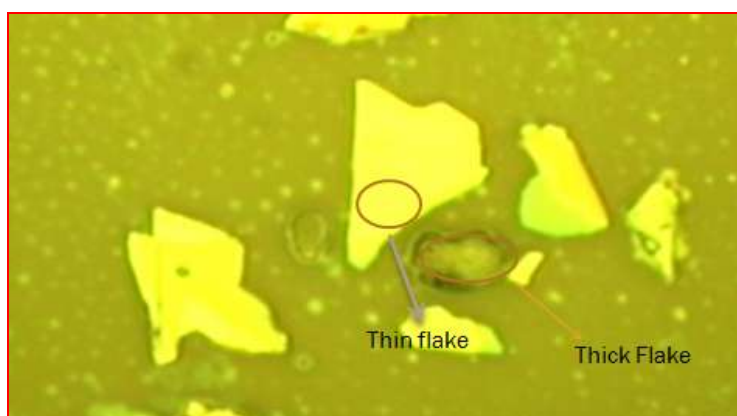
The anti-Stokes line is less intense than the Stokes line. This occurs because only molecules that are vibrationally excited prior to irradiation can give rise to the anti-Stokes line. In Raman spectroscopy, only the more intense Stokes line is normally measured.

Raman scattering is a relatively weak process. The number of photons Raman scattered is quite small. There are several processes which can be used to enhance the sensitivity of a Raman measurement.

Raman scattering, is an inelastic scattering process in which the light scattered by a molecule emerges having an energy that is slightly different (more or less) than the incident light.

This energy difference is generally dependent on the chemical structure of the molecules involved in the scattering process.

It is used to find the number of layers present on the substrate.



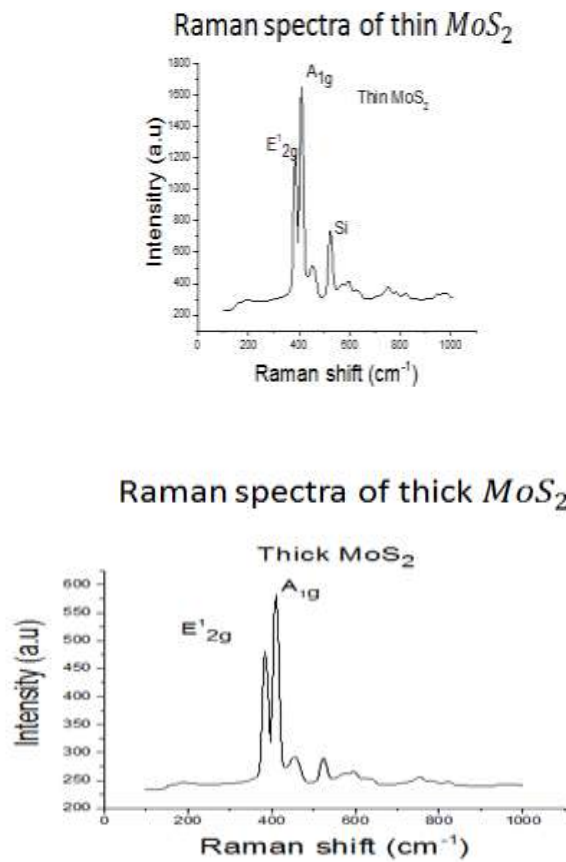


Fig 8

Four orders of raman active modes are $E'_{2g} = 32 cm^{-1}$, $E_{1g} = 286\ 32 cm^{-1}$, $E'_{2g} = 383\ cm^{-1}$, $A_{1g} = 408\ cm^{-1}$ increases with thickness. And values of Si is $500 - 550\ cm^{-1}$, Bulk MOS_2 $400\ cm^{-1}$, Single layer MOS_2 $384\ cm^{-1}$. Frequency differences between the modes E'_{2g} , A_{1g} robust and convenient diagnostic of the layer thickness.



Fig 9

IV. APPLICATIONS

The study of 2D materials is one of the newest and most exciting areas of material science and engg. 2D materials have the potential to revolutionize many electronic applications such as **solar cells, transistors, camera sensors, digital screen and semiconductors.**

Synthesis techniques and characterization of 2D materials and their potential applications **in optoelectronics, energy conservation, electronics, biotechnology, photodetectors.**

V. CONCLUSION

Single layers of MoS_2 were exfoliated from commercially available crystals of molybdenite using the scotch tape method. Highly responsive photodetectors based on MoS_2 have been demonstrated, which have a photoresponsivity of $1.6 \times 10^4 \text{ AW}^{-1}$ and a photogain of 2.4×10^7 . Raman spectra obtained from different locations on as grown MoS_2 films with different thicknesses.

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