Growing Atomically Thin MoS_2 for Advances in 2D Technology

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ABSTRACT

We report a novel technique to grow atomically thin MoS_2 using vapour phase epitaxy. The technique heats bulk MoS_2 beyond the sublimation point with the resultant vapor being deposited onto a silicon oxide surface. The MoS_2 wafers were characterised using atomic force microscopy and X-ray photoelectronic spectroscopy to analyse surface roughness and determine the thickness of the deposited MoS_2 on the oxide surface. AFM images show a reduction in rms roughness ρ_q from 6.4 nm down to 0.3 nm. 4 point probe characteristics confirm deposition of MoS_2 with the samples sheet resistivity R_{sh} decreasing from 4.2×10^7 Ω/☐ to 3.1×10^7 Ω/☐.

INTRODUCTION

Molybdenum Disulfide (MoS_2) is a indirect band-gap semiconductor which has attracted the interest of researchers over recent years as a promising alternative to graphene[1]. For many years graphene has become the standard for 2D technology[1], however due to the lack of a band gap it cannot be used in semiconductor devices such as CMOS logic gates. MoS_2 has an atomic structure similar to that of graphene[2], consisting of continuously stacked Sulfur - Molybdenum – Sulfur layers bonded together by Van der Waals bonding. By breaking the bonds between the layers of MoS_2, a single layer of MoS_2 can be extracted. Methods for producing atomically thin MoS_2 have been developed over recent years including Chemical Vapour Deposition (CVD), Physical Vapour Deposition (PVD), and hydrothermal intercalation and exfoliation - just like graphene. The research presented shows the attempt towards realising a novel method of creating MoS_2 wafers using Vapour Phase Epitaxy (VPE) [3-5].

MoS_2 Atomic Structure

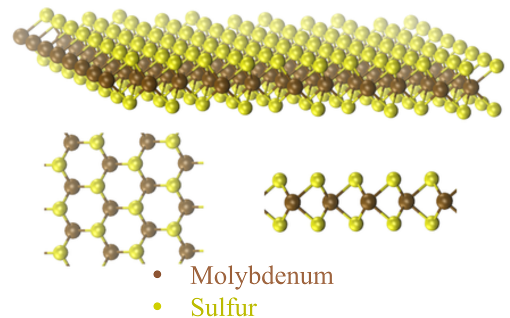

Figure 1. Atomically thin MoS2. From top clockwise 3D view, side view, plan view

EXPERIMENTAL

The VPE technique used consists of heating up bulk MoS_2 above its sublimation to form a vapour, This vapour is then deposited onto the surface of a silicon oxide sample. The experiment was conducted in a chamber maintained at 10^{-2} Torr atmospheric pressure to ensure no oxygen contamination in the MoS_2 film. X-ray Photoelectronic Spectroscopy (XPS) was used to confirm the deposition and composition of MoS_2 followed by Atomic Force Microscopy (AFM) and X-Ray Diffraction (XRD) to analyse the surface roughness of the deposited MoS_2. The $Si/SiO_2/MoS_2$ samples where electrically characterised using 4 point probes to measure the conductivity of the MoS_2 and correlated with the AFM and XRD data,

RESULTS AND DISCUSSION

Figure 2 shows the data from XPS showing the binding energy of the MoS2. The peaks represent low deposition of MoS2 with low levels of binding energy for sulfer and amorphous values for Molybdenum which could easily be present from other elements. The low energies imply that vapour pressure of MoS_2 was too low to allow for an accurate reading to be confirmed from XPS.

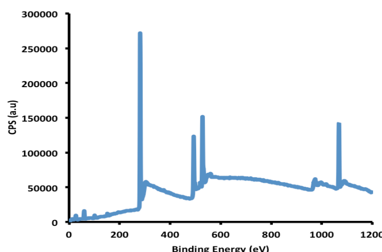

Figure 2. XPS data showing Binding Energy signature for deposited MoS_2

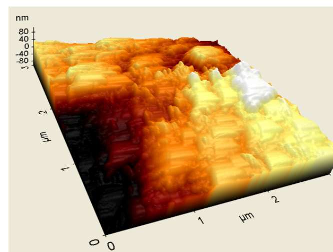

Figure 3. AFM image showing surface roughness of MoS2 sample after 3 hour VPE.

AFM results showed that increasing substrate temperature from 30° to 110° resulted in a reduction of MoS_2 rms surface roughness from 6.4nm to 0.3 nm. Surface roughness was also shown to be reduced for longer deposition times with the lowest ρ_q being measured after 3 hour VPE. Figure 2 shows the surface roughness for the sample with the lowest rms ρ_q of 0.305 nm.

Deposition of MoS_2 was confirmed with 4 point probe resistivity measurements. The sheet resistivity of pure SiO_2 was calculated to be 4.2×10^7 Ω/☐ while the 240 nm MoS_2 sample had a sheet resistivity of to 3.1×10^7 Ω/☐ as shown in figure 4. As it can be seen the resistance of the MoS2 wafers increases from to 3.1×10^7 Ω/☐ to 3.9×10^7 Ω/☐ when wafer thickness increases from 240 nm to 1µm which is a result of surface defects causing nucleation sites which lowered conductivity.

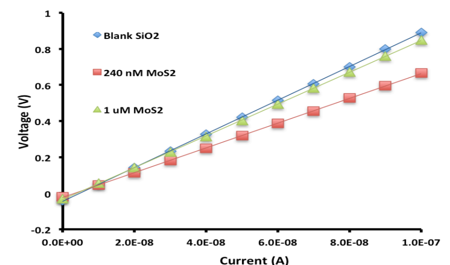

Figure 4. I-V Characteristics for SiO_2, 240 nm MoS_2, and 1µm MoS_2 samples taken from 4 point probe

CONCLUSION

This paper reports the results of epitaxially grown MoS_2 using VPE. The surface roughness and composition are compared by AFM and XPS and it can be seen that longer deposition time along with higher sample temperature results in smoother MoS_2 wafers. These observations are confirmed supported by observations in the I-V characteristics taken using 4 point probe measurements which show a higher conductivity with increasing substrate temperature. Any work undertaken from here shall be done so to optimise the VPE technique to ensure a consistent method of growing 2D MoS_2 can be achieved.

[1]V. K. Nagareddy *et. al.*, IEEE Sensors Journal, Vol. 13, No. 8, p. 2810, 2013

[2]D. J. Late *et. al.,* ACS NANO, Vol. 6, No. 6, p. 5635, 2012

[3]J. Dong, *et. al.,* Thin Solid Films, Vol. 515, p. 2116, 2006

[4]E. S. Kadantsev *et. al.,* Solid State Communications, Vol. 152, p. 909, 2012

[5]Y. D. Liu *et. al.,* Journal of Alloys and Compounds, Vol. 571, p. 37, 2013