Multilevel Conductance State in Chemical Vapor Deposited WS_2 Based Resistive Memory Device

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Abstract. Resistive switching properties of tungsten disulfide (WS_2) as a functional material arereported. The WS_2 film was grown over Pt/Ti/SiO_2/Si substrate by chemical vapor deposition method inside a horizontal tube furnace. X-ray diffraction pattern of as-deposited WS_2 layer confirms the crystalline nature of the film. The current-voltage measurements of the Al/WS_2/Pt device reveled typical bipolar resistive switching characteristic with high on/off ratio. Moreover, the multilevel capability of the Al/WS_2/Pt device promises its potential as a high density data storage device along with significant retention upto 10^4 sec.

INTRODUCTION

Transition Metal Dichalcogenides (TMD's) are one of the emerging materials in the field of electronic devices. The unique two dimensional architecture of TMD's offers remarkable feasibility to explore in most of the electronic applications such as transistors [1], photovoltaics [2], sensors[3], memories[4] etc. Out of all the available TMD's, molybdenum disulfide (MoS_2) has been explored vigorously and found to be extremely suitable in every electronic application and in resistive switching devices too. However, tungsten disulfide (WS_2) being a TMD, did not get much attention like MoS_2. Thus, exploration of WS_2 is very much demanding, since it possesses high thermal and chemical stability, higher effective mass and higher band gap (1.3 eV-2.1 eV) [5]. In resistive memory device, WS_2 can offer higher on/off ratio due to its higher electronic band gap and can retain data for a long duration due its thermal and mechanical stability. The resistive switching application is mostly incorporated as non-volatile memory and artificial synapse as well, in neuromorphic computing [6]. The conductor-insulator-conductor structure of such devices makes the fabrication simple and always seeksattention to work on various materials. The mechanism of resistive switching devices is based on the shift in conductance state of the device, i.e. from lower conductance state to higher conductance state or vice versa upon the application of electric field [7]. The switching operation of the resistance/conductance state is mainly due to the formation and rupture of a conductive path through the functional material [7, 8]. Here in, we report a resistive switching device with multilevel resistance state, comprising of WS_2 insulating matrix, sandwiched between aluminum (Al) top and platinum (Pt) bottom electrode.

EXPERIMENTAL SECTION

WS_2 growth process was carried out using an optimized chemical vapor deposition method [9]. An alumina crucible containing 0.1 g of tungsten oxide (WO_3) powder was kept inside a tube furnace and the Pt/Ti/SiO_2/Si substrate was placed above the crucible boat facing down as shown in figure1. Prior to deposition, the Pt/Ti/SiO_2/Si substrates were ultrasonically cleaned with acetone followed by methanol and de-ionized water for 10 minutes each. At the upstream locale of the quartz tube, another alumina boat containing sulfur powder (0.7g) was placed to be warmed up. At first, the tube was pumped down to pressure -600 torr and held heated at 200^o C for 10 minutes to remove any moisture inside the tube. In the next step, argon (Ar) gas was supplied through the inlet at 120 sccm and the gas stream was kept up at this steady stream rate until the whole deposition process was over and the heater was warmed up to 900°C gradually at a warming rate of 10° C/min. After reaching the desired 900° C at the middle section, the temperature was maintained for 15 minutes for the proper deposition. Afterwards, the tube was allowed to cool down to the room temperature naturally. At last, the aluminum top electrodes were deposited on WS_2 film by thermal evaporation technique using shadow mask of diameter 240 µm to fabricate Al/WS_2/Pt metal-semiconductor-metal structure. X-ray diffraction technique (XRD) and field emission scanning electron microscope (FESEM) were utilized to study the structural and morphological analysis respectively. The current–voltage (I–V) characteristics of the as-fabricated devices were measured using a Keithley 4200 semiconductor characterization system.

RESULTS AND DISCUSSION

Structural and morphological characterization

Figure 1(a) shows GI-X-ray diffraction (GIXRD) pattern of the as grown WS_2thin film, clearly demonstrating the crystalline nature of the depositedlayer. The collected X-ray diffraction pattern have two sharp peaks from(002) and(110) planes at 2θ values of14.50 and 57.80 respectively [10,11].Figure 1(b) displays the cross-sectional FESEM image of the WS_2 thin film on Pt/Ti/SiO_2/Si substrate.From figure, it is observed that 250 nm thick layer of WS_2 is deposited on the substrate.

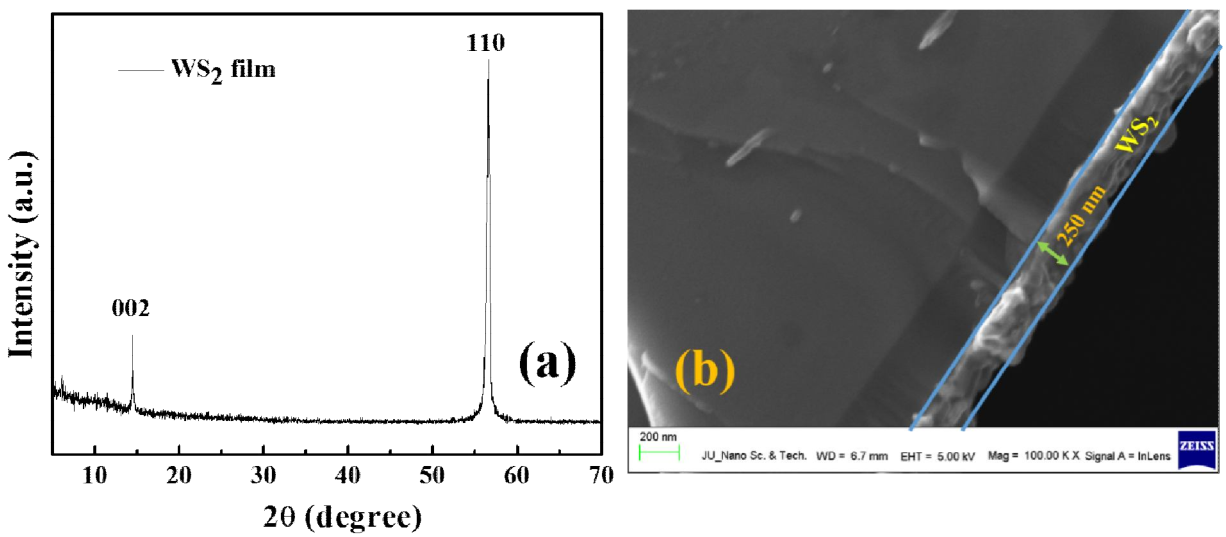

FIGURE 1. (a) XRD pattern of WS_2 thin film (b) Cross-sectional FESEM image of the grown film.

Electrical characterization

Figure 2 (a)depicts the bipolar current versus voltage characteristics of the Al/WS_2/Pt switching device. The high resistance state (HRS) and low resistance state (LRS) of the device is termed as OFF and ON state respectively. For the 1^{st} cycle, the device undergoes a transition at voltage (<2V) from OFF state to ON state by SET operation and from ON to OFF state by RESET process. Similar behavior of the I-V curve, observed up to 50^{th}cycle,confirms the uniformity and reproducibility of the Al/WS_2/Pt switching device. Further, the low operating voltages (± 2 V) and current on/off ratio of about 10^3 signifies the practical application of the device as non-volatile memory.

The multilevel conductance capability is the additional feature of the device for high density data storage, shown in figure 2 (b). The multilevel resistance state is achieved by limiting the compliance current to 10 µA, 30 µA and 100 µA. The three distinct conductance state of the device offers multi bit storage capacity and enhances its' applicability in data storage field. Figure 2 (c) shows the data retention property of the Al/WS_2/Pt memory device for different resistance state. From figure, it is evident that the device retains the data for almost 27 hours (10^5 s) for

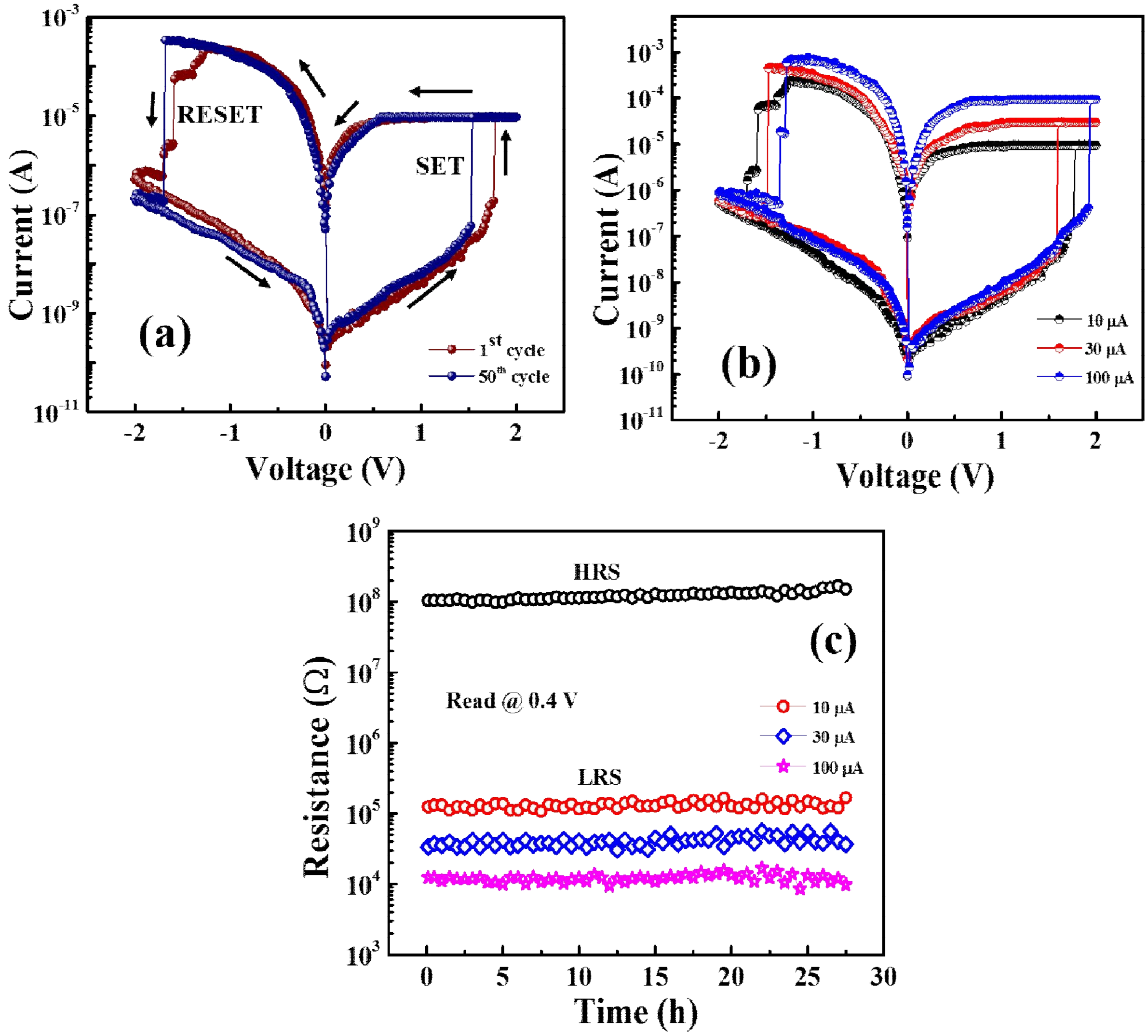

FIGURE 2. (a) Bipolar current versus voltage graph of the Al/WS_2/Pt memory device (b) Multilevel conductance curve for various compliance current (c) retention characteristic of different resistance states under a constant read voltage (0.4 V).

all the resistance states without any severe degradation.

CONCLUSION

Tungsten disulfide (WS_2) film of thickness 250 nm was grown inside a tube furnace by CVD method. The film was found to be crystalline in nature with preferred orientation confirmed by XRD analysis. Current-voltage characteristic demonstrated a uniform and reproducible bipolar resistive switching behavior of the Al/WS_2/Pt device withadded multi bit operation. The retention characteristics over a long period of time without noticeable degradation revealed the practical application of the device in high density data storage field.

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