Optoelectronic Devices Based on Chemical Vapour Transport Grown $NbSe_2$ Crystals

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Abstract. Transition metal chalcogenides have shown great potential in the field of solar cell fabrication owing to their strong light matter interactions and favourable band gap. Here in, chemical vapour transport grown $NbSe_2$ crystals are exploited for their optoelectronic applications. The $NbSe_2$ crystals are used for fabrication of working electrode of PEC solar cell. The PEC cell is tested by current-voltage characteristics in dark and illumination of power intensity 30 to 100 mW/cm^2. Typical performance parameters such as efficiency, fill factor, short circuit current and open circuit voltage are calculated. Besides, photodetector based on $NbSe_2$ crystal is fabricated and is tested under white light of 100 mW/cm^2 intensity. The devices show good photoresponse, suggesting the intended application in field of optoelectronics.

Keywords: Crystal growth, Photo electrochemical (PEC) Solar Cell, transient photo response, EDAX, efficiency.

INTRODUCTION

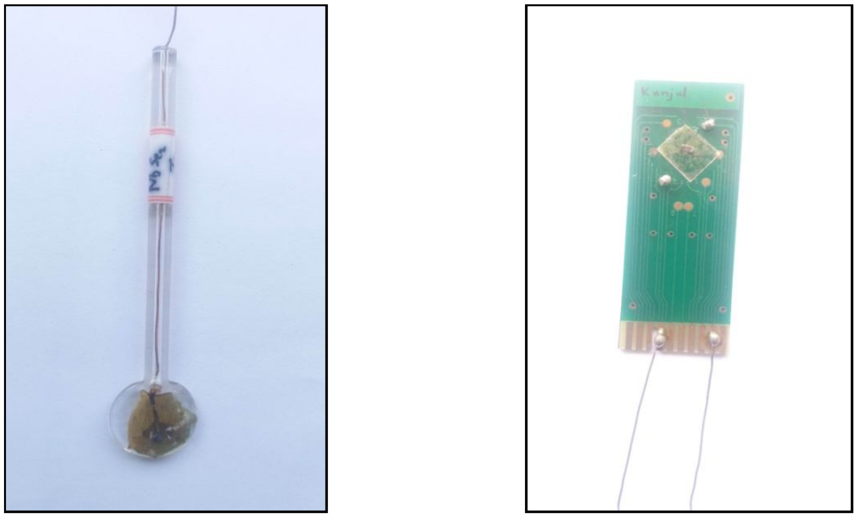
Recently, Transition metal dichalcogenides (TMDCs) have attracted intense research attention in electronics and optoelectronics due to their unique electrical and optical properties. TMDCs are most suitable materials for technical applications due to high chemical and environmental stability. Besides, tunable band gap and high carrier mobility make them most appropriate for applications optoelectronics [1-7]. The intensively studied members of TMDC family such as MoS_2, WS_2, WSe_2, WS_2 etc. have shown potential for flexible electronic devices including photovoltaic applications [8]. In this regards $NbSe_2$ crystals are relatively less studied layered compounds consisting of staked sandwiches of Se-Nb-Se tri-layers with strong covalentintra layer bonds and weak Van der Waals interlayer interactions. In present research, the $NbSe_2$ crystals are grown by chemical vapour transport technique with Iodine (I_2) as transporting agent [9]. The optoelectronic devices are based on $NbSe_2$ crystals are fabricated and studied under white light.

EXPERIMENTAL

The chemical vapour transport grown $NbSe_2$ crystals [9] were employed for fabrication of working electrode of photo-electrochemical solar cell. The $NbSe_2$ crystal is stacked on glass substrate, as shown in FIGURE 1. The copper wire was bounded on back surface of crystals using conducting silver paste for electrical measurements. The PEC solar cell was tested using Keithley- 2400 SMU in dark and under white light illumination of power intensity 30 to 100 mW/cm^2.For fabrication of photodetector, the $NbSe_2$ crystal is stacked on mica sheet and two copper wires are bounded on crystal periphery using silver paste, as shown in FIGURE 1. The switching action of photodetector is measured under white light of 100 mW/cm^2 intensity.

RESULTS AND DISCUSSION

The $NbSe_2$ crystals were mechanically cleaved using scotch tape to get fresh surface. The surface of cleaved crystal is observed under optical microscope. The crystals with clean surface were selected for fabrication of optoelectronic devices namely, photoelectrochemical solar cell and photodetector. For PEC solar cell, copper wire was used as counter electrode which completes the electrochemical reactions in a cell for better performance of solar cell. A mixture of 0.025M I_2 + 0.1M [$K_4Fe(CN)_6$] + 0.1M [$K_3Fe(CN)_6$] consisting of oxidized and reduced species having ionic nature was used as an electrolyte which helps in transfer of photo generated carriers from the photo-electrode to the counter electrode.



(a) $NbSe_2$ electrode (b) $NbSe_2$ photodetector

FIGURE 1. Digital image of (a) $NbSe_2$ electrode for PEC solar cell and (b) photodetector.

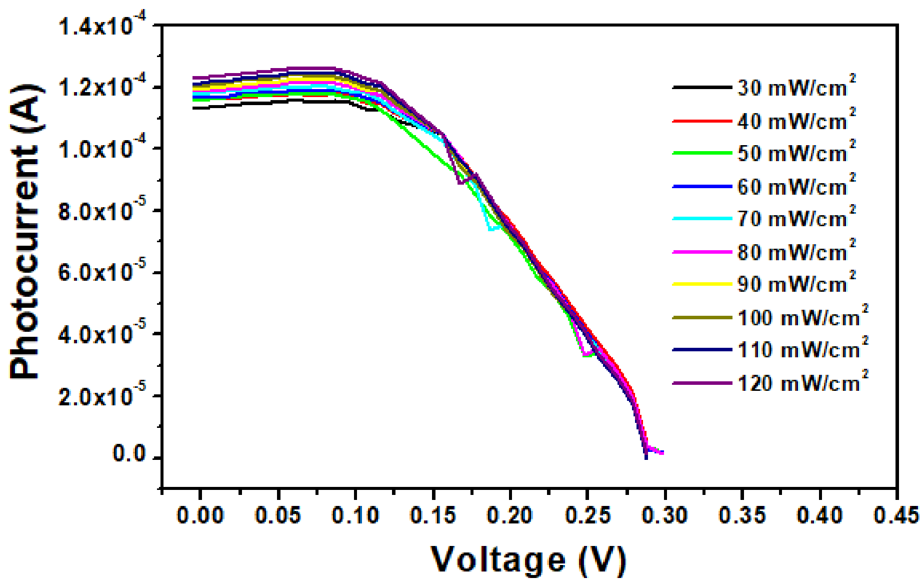


FIGURE 2. I-V Characteristics of $NbSe_2$ crystal.

The semiconductor electrode prepared in the manner outlined above was dipped in an appropriate electrolyte contained in a glass beaker. Copper grid (2cm x 2cm) played the role of the counter electrode. Illumination of the cell was provided with different light intensity from a tungsten filament bulb (incandescent lamp). The illumination intensity I_L was changed by changing the distance between the electrode and the bulb. The incident intensity of illumination was measured using solar meter (LUX meter). Voltage in the range -0.5 V to +0.5 V was applied across the electrodes and corresponding Photocurrent was recorded using Keithley 2400 multimeter operated using LAB TRACER software. The dark and polychromatic solar cell responses were recorded with the help of incandescent lamp with varying illumination intensity between 30 mW/cm^2 to 120 mW/cm^2 as shown in FIGURE 2.

The solar cell characteristic output parameters like Short Circuit Current (I_{sc}), Open Circuit Voltage (V_{oc}), Fill Factor (FF) and photo conversion efficiency (η) for $NbSe_2$ cell have been determined using standard formulae and tabulated in TABLE 1. The obtained results are tabulated in reference to the intensity of incident radiation.

TABLE 1. Output Parameters of the investigated PEC solar cell.

Illumination Intensity mW/cm^2	**I_{sc}(A)**	**V_{oc} (V)**	**Fill Factor**	**Efficiency (η %)**
30	1.13E-04	2.88E-01	5.18E-01	2.25
40	1.16E-04	2.88E-01	5.25E-01	1.74
50	1.16E-04	2.98E-01	4.78E-01	1.32
60	1.16E-04	2.98E-01	4.98E-01	1.15
70	1.17E-04	2.98E-01	4.90E-01	0.98
80	1.19E-04	2.98E-01	4.91E-01	0.87
90	1.19E-04	2.88E-01	5.07E-01	0.77
100	1.21E-04	2.88E-01	5.00E-01	0.69
110	1.21E-04	2.88E-01	5.07E-01	0.64
120	1.23E-04	2.88E-01	5.04E-01	0.59

$NbSe_2$ crystals were cleaved and fixed on mica sheet. The two copper wires were bonded on crystal using adhesive silver paste. A pulsed photo response was studied under polychromatic light of 100 mW/cm^2 intensity and 0.2 V applied DC bias voltage and the values of photoconductive rise time (t_r) and decay time (t_d) are determined from FIGURE 3 which comes out to be 47 sec and 55 sec respectively [10].

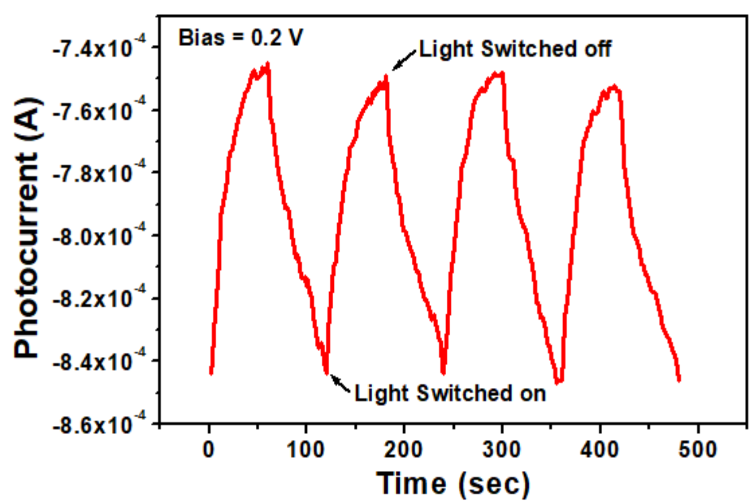


FIGURE 3. Pulsed Photo response for $NbSe_2$

The slow rise and decay of photo current is attributing the less absorption indicating poor usage as a photodetector and slow decay in photo current is resulting due to presence of trap states caused by the defects or charge impurities present in $NbSe_2$ crystals. Also the measurements were done in open environment at room temperature which promotes adsorption of molecules on free surface of crystal due to the large surface-to-volume ratio to work as an additional charge trapping centres. Defects are also introduced by manual exfoliation which involves mechanically terminated layers by uneven applied force [11, 12].

CONCLUSION

$NbSe_2$ crystals were successfully grown by CVT technique using iodine as transporting agent. The elemental composition of as-grown crystals have been characterized by EDAX. We have used this crystal as an electrode in photo electrochemical solar cell with different illumination intensities and interpreted the variation of solar cell characteristic output parameters like Open circuit Voltage V_{oc}, Short circuit Current I_{sc}, Fill Factor and Efficiency η%. Pulsed photo response under constant illumination was also done and authors observed rise and decay time of the order of few ten seconds and hence these crystals are useful for fabrication of low processing cost solar cells.

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