



Solar light sensitive molybdenum disulfide photodiode for thin electronic devices

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The p-Si/MoS₂ diode was prepared using molybdenum disulfide and p-type silicon wafer. The rectifying properties of the diode were analyzed using current-voltage (I-V) and capacitance-voltage (C-V) characteristics. The photoresponse properties of the diode were prepared with solar irradiation from 20 mW/cm² to 100 mW/cm². The increase in current of the diode with light illumination suggests that the diode exhibited a photoconducting behavior. The prepared photodiode having photoconducting behavior can be used in optoelectronic applications.

Keywords: Photodiode, Solar irradiation

Submission Date: 08 June 2021

Acceptance Date: 27 July 2021

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1. Introduction

2D dimensional materials have recently played an important role in the production of thin electronic devices. Especially transition metal dialcogenide (TMD) materials are used extensively in these applications. Self-switching diodes (SSDs) are diodes that do not require doping for rectification. SSD is able to detect microwaves in the 0.9–10 GHz range. The rectification process in these diodes is provided with 2D dimensional materials. MoS₂ is among the most studied 2D transition metal dialcogenide (TMD) materials. It is widely used in microwave switches, field-effect transistors, energy-harvesting, tunable microwave circuits, photovoltaic (PV) devices and wide range electronic applications. In addition, Molybdenum disulfide (MoS₂) exhibits properties such as high electrical conductivity, stable chemical properties, biocompatibility, high color quality, very good electron mobility, intrinsic broadband emission and large surface area. It is also widely used in optoelectronic applications due to its excellent light absorption in the visible and IR region.

Bulk MoS₂ has mostly been observed to have an energy gap of 1.2 eV and an indirect transition around the direct energy gap of 1.8 e. Carrier

mobility is between 1-40 (cm²/Vs). MoS₂ has a high current switching ratio (~108) and a good excitonic binding energy and fast photo-response. Sungjin Wi et al., [1] have fabricated plasma-assisted p-n junctions in multilayer MoS₂ photovoltaic (PV) devices which results good power, high photocurrent up to 20.9 mA/cm² and high external quantum efficiencies. Meng-Lin Tsai et al. observed the peak power conversion efficiency of 5.23% for PV cells based on single-layer TMD. Atomically thin MoS₂ for RF detection has been used to demonstrate microwave radio.

In present study, photoconducting diode has been prepared using molybdenum disulfide and p-type silicon wafer. The photoconducting properties of the diode have been analyzed under solar light irradiation intensities.

2. Materials and Methods

The molybdenum disulfide and p-type silicon wafer were used to prepare a MoS₂/p-Si photodiode on silicon substrate. The silicon substrate was cleaned with successive chemical baths under sonication process. The top contact of the diode was prepared

by thermal evaporation of Al. The structure of the diode is shown in Fig.1.

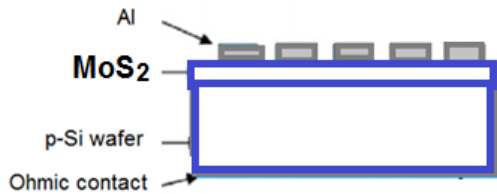


Fig. 1. The physical structure of MoS₂/p-Si photodiode diode

The electrical and photoresponse properties of the diode were measured by FYTRONIX solar simulator IV and CV characterization (Fig.2). The solar simulator automatically adjusts the solar intensities from 0.1 mW/cm² to 100 mW/cm² with an illumination intensity step (1 SUN).

The phototransient current time (I-t) of photodiode also measured by FYTRONIX solar simulator IV and CV characterization.



Fig. 2. FYTRONIX 8000 Solar IV and CV characterization system

3. Results

3.1. Electrical characteristics of MoS₂/p-Si photodiode diode

The electrical characteristics of MoS₂/p-Si photodiode diode is shown in Fig.3. The current of the diode is increased with bias voltages ranging from negative and positive. The current of the diode under reverse bias is higher than forward current due to barrier between MoS₂ semiconductor and p-type silicon semiconductor. The current under reverse bias region is increased with solar light. The increase light irradiation causes an increase of the current of the diode, whereas the current under forward bias did not increases with solar light. This suggest that the diode exhibited a photo conducting behavior. This behavior is due to active layer of the diode. This layer absorbs the solar light and the light excites the electrons at interface region of the diode. The difference between reverse current and forward

current is due to the separation of charges at interface of the diode. The charge separation at reverse region causes a photo conducting behavior.

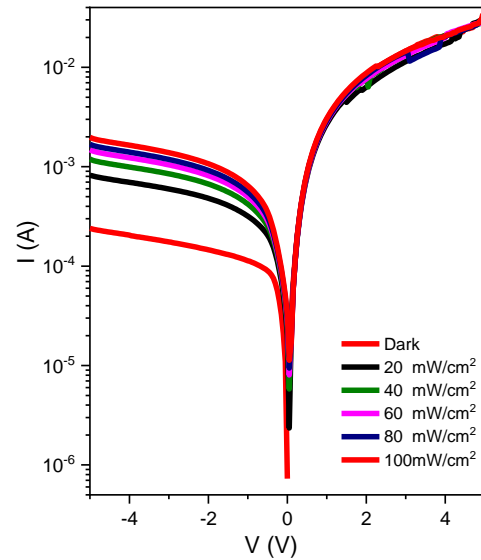


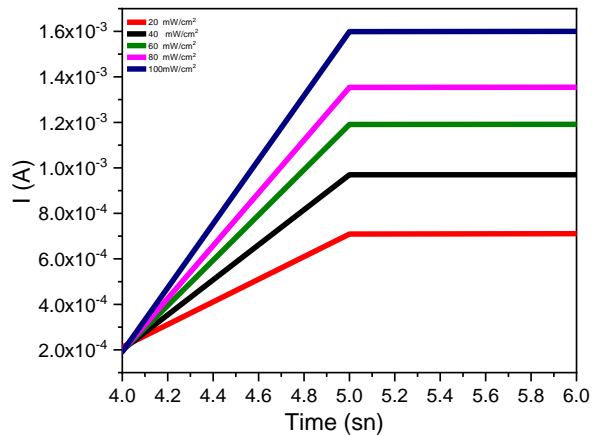
Fig. 3. Dark and photo characteristics of MoS₂/p-Si photodiode diode

The current voltage characteristics of the diode obeys the following relation [19,20];

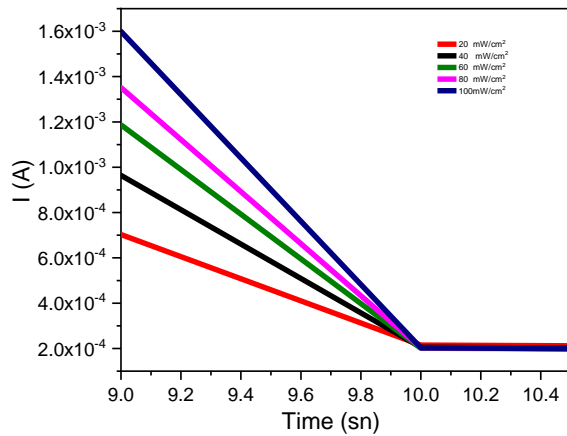
$$I = I_s \left[\exp\left(\frac{qV - IR_s}{nkT}\right) - 1 \right] \quad (1)$$

where, e is the electron charge, A is the diode area, n is the ideality factor and k is the Boltzmann constant. This equation suggests that the current of the diode exponentially increases with voltage. This behavior is defined by rectifying behavior of the diode if the reverse current is lower than forward current. The rectifying behavior of the diode is attributed the forward and reverse characteristics of the diode

The rise and decay current characteristics of the diodes are shown in Fig.4 a and b. The rise current is increase to plateau in a second and then current has a stable behavior. The rising time is about a 1000 ms for all illuminations. Whereas the decay current is switching photocurrent to dark in a second. This suggest that the phototransient characteristics of the diode exhibit a symmetric phototransient behavior.



-a-



-b-

Fig. 4. Phototransient characteristics of MoS₂/p-Si photodiode diode a) rise current behavior b) decay current behavior

3.2. Capacitance characteristics of MoS₂/p-Si photodiode diode

The depletion region of the diode was analyzed by capacitance voltage characteristics under various frequencies from low frequency to high frequency. The capacitance vs voltage plot is shown in Fig.5. The capacitance is increased with voltage and shows a peak. The peak magnitude is highest at the lowest frequency. The decrease in magnitude of capacitance plot is due to charge carriers at interface between MoS₂ and p-Silicon semiconductors. This decrease in peak is due to decrease numbers of charge carries with frequency of applied electric field.

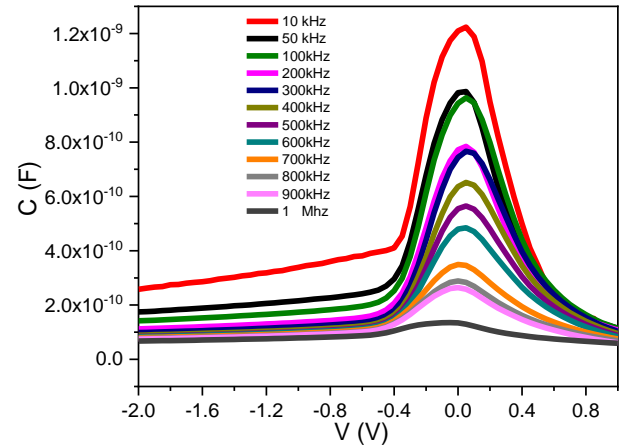


Fig. 5. Capacitance behavior of MoS₂/p-Si photodiode diode

The decrease in numbers of charge carriers at the interface of the diode from low frequency to high frequency. The area under capacitance peak is related to numbers of charge carriers. The highest the area suggests that the numbers of the charge carriers is maximum. The decrease in area under capacitance peak indicates the distribution of charge carries at interface of diode

The change in area under capacitance peak is dispersive [30-35].

The rise and decay plots of capacitance-time characteristics of MoS₂/p-Si photodiode are shown in Fig.6. The photo transient capacitance behavior of the diode is characterized by rise and decay plots. The capacitance of the diode is increased with solar illumination and shows a constant capacitance under light on. The capacitance of the diode is the lowest at dark condition, whereas illumination condition, the capacitance is the highest. The difference between dark capacitance and light capacitance is defined as photocapacitance. The photocapacitance is due to photo-generated charge carries at interface of the diode. The charge carries at interface of the diode is switched by solar irradiation. The decay plot of the diode is switched by solar light on and light off. The capacitance of the diode is switched by light. The photocapacitance is highest when light is on, whereas the capacitance is lowest when light off.

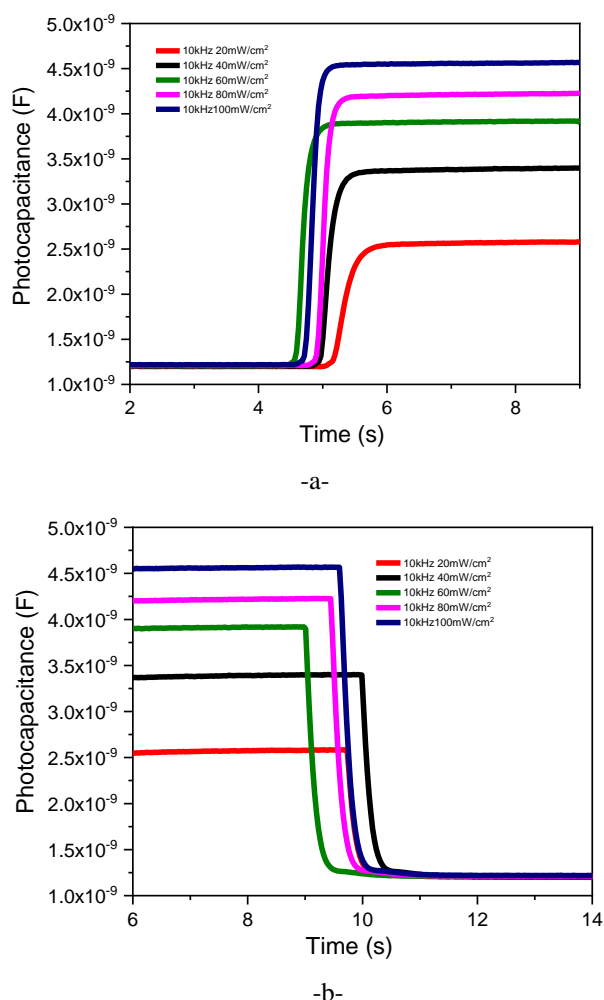


Fig. 6. Capacitance-time behavior of MoS₂/p-Si photodiode a) rise plot b) decay plot

The capacitance under dark and solar irradiation of the diode suggests that the diode exhibits a photocapacitance. This behavior indicates that the MoS₂/p-Si photodiode can be used in optic applications.

Conclusion

In the study, TiO₂ and ZnO doped TiO₂ photodiodes were produced using sol gel method. Optic properties were checked, it was seen that photodiodes show good high transmittance with low reflectance. Using UV-vis data bandgap energies of the photodiodes were calculated. ZnO doping decreases the bandgap energies of the photodiodes. Photovoltaic properties of the photodiodes confirmed that photodiodes are responsive to the light where increased photocurrent and photocapacitance were observed for increased illumination intensity. Such a case was confirmed that photodiodes have the potential to be used in solar tracking applications.

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