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Fabrication of PS- MSM Device for Ultraviolet (UV) light Detection

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Abstract**: *In the present work we have reported Porous Silicon- Metal Semiconductor Metal (PS- MSM) device for ultraviolet (UV) light detection. PS is prepared by photo assisted electrochemical etching of n-type silicon (Si) wafer in HF based medium by alternate variation of etching current density (J) for different etching times. Surface morphology of the prepared PS sample is characterised by FESEM. PS-MSM device is fabricated by thermal evaporation of high purity (99.99%) aluminium (Al) under high vacuum of 10^{-5} torr, using an interdigitated mask on the PS substrate. The photo-detection properties of the device are recorded for UV range of light using computer interfaced Keithly 2400 source meter. The maximum responsivity (R_λ) and external quantum efficiency (η) of the device are also calculated and are found to be 1.47 AW^{-1} and 709 % for UV light. Whereas the response times in the corresponding range are found to be 0.87 and 1.07 s. The maximum values of normalised photo to dark current ratio (NPDR) for the device is 2.85 A^{-1}. These results recommend this device for application as a good UV light photo detector.*****

Keywords**: *PS- MSM, UV, responsivity, external quantum efficiency, NPDR, photo detection*****

I. INTRODUCTION

Uhlirs', a husband and wife team working at Bell Laboratories inthe mid-1950s accidentally discovered Porous Silicon (PS). They were trying to develop an electrochemical method to fabricate silicon wafers for use in microelectronic circuits. Under the appropriate electrochemical conditions, the silicon wafer did not dissolve uniformly as expected, but instead fine holes appeared, propagating primarily in the (100) direction in the wafer [1]-[3]. The easy and cost effective process of fabrication of PS and its hybrid structures, attracts many researchers and industrialists for using them in various fields of applications [4]. Porous silicon has been widely used in fabricating optoelectronic switches, displays, lasers, various biomedical sensors etc. [5]. Ultra violet light detection has also been performed based on porous silicon and its hybrid structures. Our work aims for fabricating PS- MSM device which can effectively acts as a UV light photo detector.

II. EXPERIMENTAL

A. Materials Used

1) Silicon wafer: Phosphorus doped n-type (100) oriented having resistivity 1-10 Ω cm and thickness 500 µm.

2) Hydrofluoric acid (HF) and Ethanol (C_2H_5OH): Concentration of HF is 48% and that of C_2H_5OH is 99.99%.

B. RCA Cleaning of the Silicon Wafer

n-type silicon (n-Si) wafer is first sonicated successively in chloroform ($CHCl_3$), acetone and ethanol for 10 min in each solvent followed by soaking in RCA 1 (H_2O : NH_4OH : H_2O_2 :: 5 : 1 : 1) and RCA 2 (H_2O : HCl : H_2O_2 :: 5 : 1 : 1) for 15 min at temperature 75^0 C and finally wafer is rinsed several times with ethanol and deionised water, dried and stored in a vacuum chamber for further applications [6].

C. Preparation of Porous Silicon

For fabrication of porous silicon we use photo-assisted electrochemical etching process as shown in fig. 1, here the electrolyte used is a mixture of HF (48%) and C_2H_5OH (99.99%) taken in a volumetric ratio of 1:1 in a electrochemical cell of Teflon. Platinum is used as a cathode, which acts as a counter electrode and on the back of the silicon wafer Al as the anode, which acts as the working electrode. Here the surface area is a circular with an effective etching surface area of 4.53 cm^2. The etching process is carried out by cyclically varying the etching current densities (J) in the limits of 13.2, 17.6 and 22.1 $mAcm^{-2}$ for total etching time of 54 s under front side photo-illumination by 155 W Mercury-Xenon light source (Newport-66901) placed at a distance of 50 cm from the electrochemical cell. Light illumination is required for the creation of holes which are necessary for pore formation in n-type Si wafer. On completion of the chemical reaction, the sample is rinsed and sonicated with ethanol, dried and stored in vacuum for further use [7].

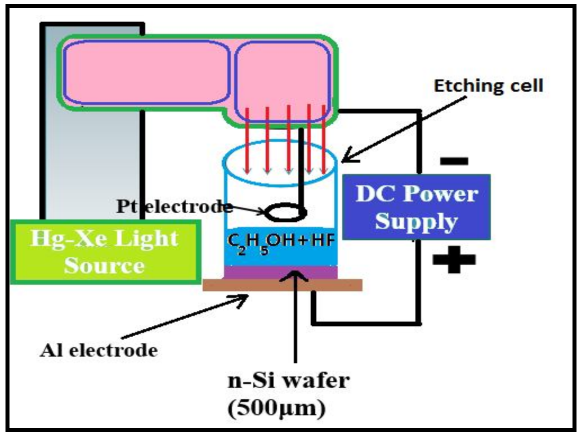

Fig. 1 Experimental set-up for PS fabrication process

D. Fabrication of PS MSM Structure

digited electrode of width and spacing of 1mm is deposited on the top of PS surface for the study of the electrical properties of it using a shadow mask by thermal evaporation of high purity (99.99%) aluminium (Al) wire under high vacuum of 10^{-5} torr in a coating Unit (12A4D Hind High Vacuum Unit) [8]. The schematic of thus obtained PS- MSM device is shown in fig. 2. The electrode has an effective surface area of 7x8 mm and thickness of the electrode is maintained at 50 nm using digital thickness monitor (DTM) attached to the unit.

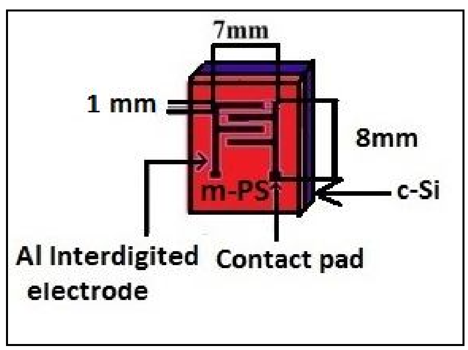

Fig. 2 Schematic diagram of the PS- MSM device

The photocurrent properties of the fabricated PS- MSM device for UV radiation is recorded for an applied voltage range of -5V - +5V using computer interfaced source meter (Keithly 2400) at room temperature. The ON-OFF time response characteristics for different wavelengths are also measured. For wavelength range of 250nm-500 nm the spectral responsivities are measured at bias voltage of -2V. The schematic of the experimental set up for the study of electrical properties is shown in fig. 3 below.

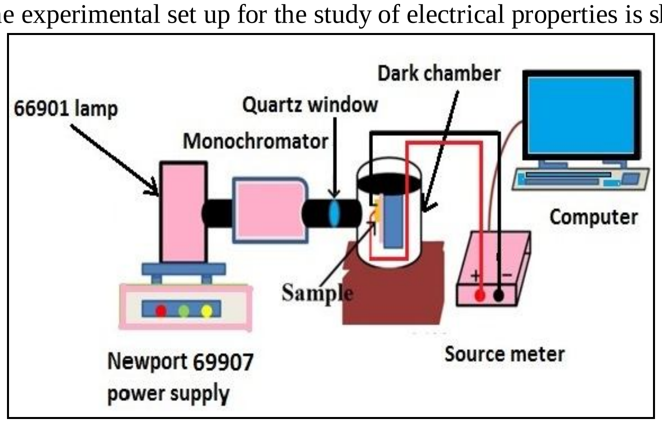

Fig. 3 Experimental set-up for photocurrent measurement

III.RESULTS AND DISCUSSION

A. Microstructural Features

Fig. 4(a) and (b) show the FESEM micrographs to observe surface morphology of prepared PS. Fig 4(a) shows the planer view of FESEM of the PS, here uniform porous layer are observed along with some randomly distributed Si nano clusters. The cross-sectional view of the PS shown in fig. 4(b) gives the visualisation of the interface between the PS and c-Si layers. From the interface it can be seen that throughout the whole c-Si surface the thickness of the porous layer is almost uniform. Thus from this micrograph the measured PS layer thickness is found to be 2.45 µm.

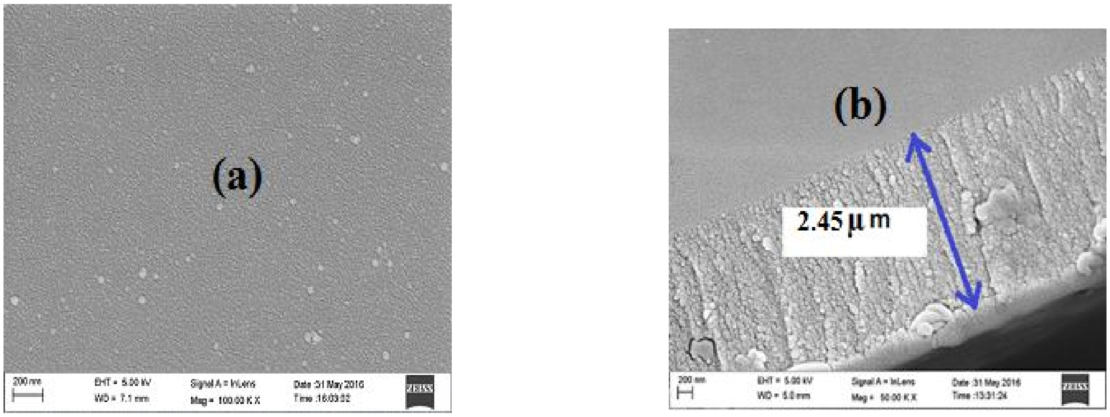

Fig. 4 (a) Planer view of FESEM micrograph of the PS sample (b) Cross-sectional view of FESEM micrograph of the PS sample

B. Electrical Features

1) *Responsivity (R_λ) and External quantum efficiency (EQE) of the PS MSM device:* The spectral responsivity (R_λ) and
External quantum efficiency (Ƞ) are among the key parameters of a photo detector [9], [10]. To observe the photo-response

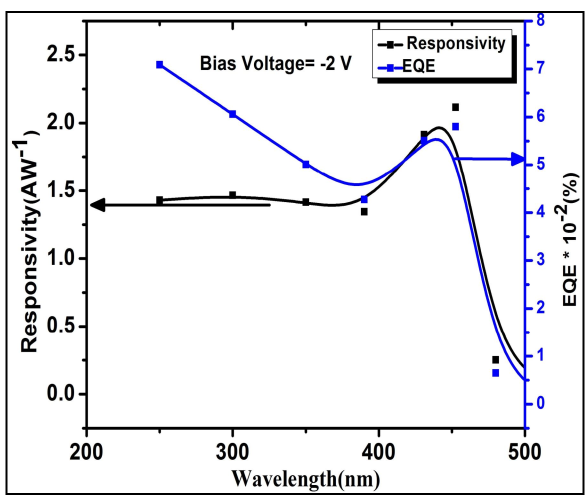

Fig. 5 Plots of R_λ and EQE of the device as functions of wavelength at constant bias voltage of -2V

of the heterostructure for wavelength (λ) range 250-500 nm, variations of R_λ and EQE vs. λ at bias voltage of -2V are plotted (fig. 5). These show good spectral response of the device in UV region for wavelength range of 250-390 nm with maximum R_λ and EQE values of 1.47AW^{-1} and 709% respectively at 250 nm. Calculated values of R_λ's and EQE's are listed in table 1.

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2) Current-Voltage (I-V) characteristics of the PS- MSM device: The I-V characteristics of the device for UV wavelengths (250-390 nm) at applied voltage range of -5V - +5V are shown in fig. 6. It is observed that rectification of the device increases and reveals Schottky diode nature with increasing wavelengths (250-390 nm). The calculated values of the normalised photo to dark current ratio (NPDR) [11] for UV light (250 to 390 nm) at -2V are found to be 2.61- 2.85 (A^{-1}) and are also listed in the table1.

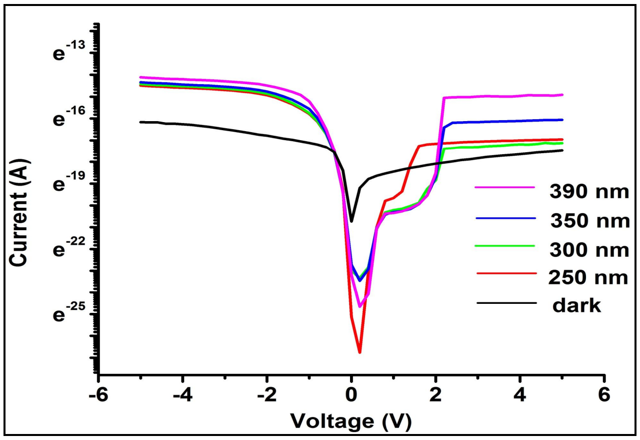

Fig. 6 I-V characteristics of the device for UV-light of different wavelengths (250-390 nm)

3) Time response kinetics of the PS- MSM device for UV light: For particular photo irradiation, time response kinetics reveals the switching behaviour of a particular photodetector. Fig. 7 shows the on-off kinetics of the device for UV light of different wavelengths (250-390 nm) for a bias voltage of -5V. From the graph it is observed that with increasing wavelength, the photocurrent increases remarkably, while on periodically on and off the irradiated UV radiation, device shows excellent switching behaviour [9]. Rise and decay time for 390 nm light at applied voltage of -5V are found to be 0.87 and 1.07 s respectively (table 1).

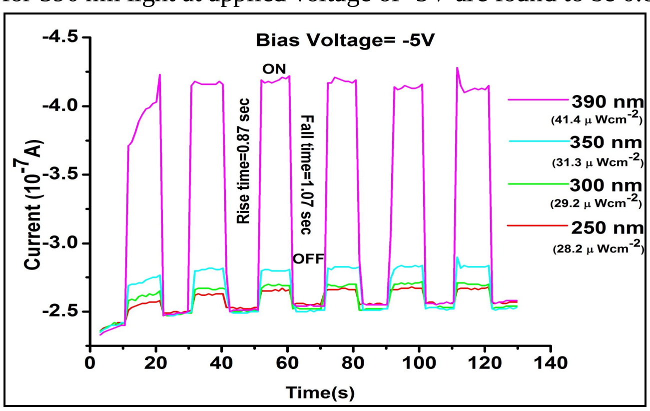

Fig. 7 On-off kinetics of the device for UV light at different wavelengths (250- 390 nm) at -5V

TABLE I

THICKNESS, NPDR, TIME RESPONSES, RSPONSIVITY AND EQE OF THE PS- MSM DEVICE

Sample	Thickness of PS(µm)	Incident Wavelength (nm)		NPDR	Time Responses		Responsivity of the Device R_λ (AW^{-1})	EQE η (%)
				$= \frac{R_\lambda}{I_{dark}} \times 10^{-7}$ (A^{-1})	Rise-Time (s)	Fall-Time (s)		
Porous Silicon-MSM Device.	2.45		250	2.77			1.47	709
			300	2.85			1.43	606

		UV	350	2.75	0.87	1.07	1.41	501
			390	2.61			1.34	427

IV. CONCLUSIONS

Porous Silicon (PS) has been successfully prepared from n-type silicon wafer by photo-assisted electrochemical etching method alternately varying current densities for different intervals of time. Formation of uniform porous layer on the Si surface with some randomly distributed silicon nano clusters has been confirmed by planer and cross-sectional FESEM images of the sample. The spectral response of the device in UV region for wavelength range of 250-390 nm is good with maximum R_λ and EQE values at 250 nm. From the I-V characteristics of the PS-MSM device, it is observed that for UV light the device reveals schottky diode nature and the rectification increases with increasing incident light wavelengths. Time response kinetics of the device show that with increasing wavelengths of the incident light, the photocurrent increases remarkably. While on periodically on and off the irradiated UV radiation, device shows excellent switching behaviour with a time response of 0.87 and 1.07 s, which suggests application of it as a good UV light photo detector.

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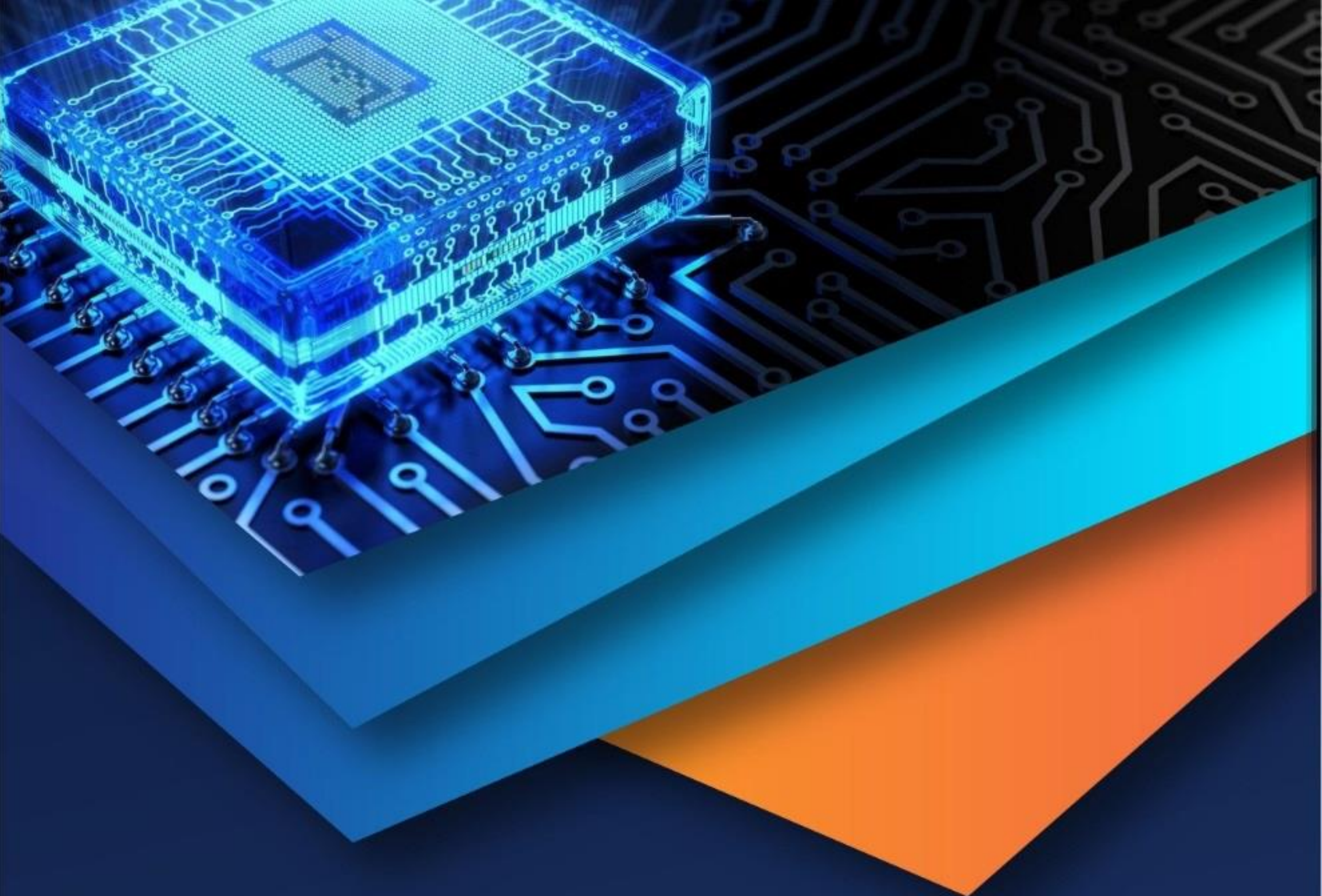

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