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Far Infrared Photoconductive Detector Based on Multi-Wall Carbon Nanotubes

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ABSTRACT

Far infrared photoconductive detectors based on multi-wall carbon nanotubes (MWCNTs) were fabricated and their characteristics were tested. MWCNTs films deposited on porous silicon (PSi) nanosurface by dip and drop coating techniques. Two types of deposited methods were used; dip coating sand drop –by-drop methods. As well as two types of detector were fabricated one with aluminum mask and the other without, and their figures of merits were studied. The detectors were illuminated by 2.2 and 2.5 Watt from CO_2 of 10.6 m and tested. The surface morphology for the films is studied using AFM and SEM micrographs. The films show homogeneous distributed for CNTs on the PSi layer. The root mean square (r.m.s.) of the films surface roughness indicates a smooth surface of the synthesized films. The Raman spectrum at room temperature for MWCNTs, are dominated by the two typical lines at about 1335.4 cm^{-1} (D line) and 1563.2 cm^{-1} (G line) assigned to the disorder induced by defects and curvature in the nanotubes lattice, and to the in-plane vibration of the C–C bonds, respectively. The results reflect a good IR radiation sensitivity and photoconductive gain, while the specific detectivity was in order of 10^7 $cm.Hz^{1/2}/W$.

Key Words:- MWCNT, porous silicon, infrared, photoconductive detectors**.**

1. INTRODUCTION

Carbon nanotubes has been a source of motivation for scientists and researchers, due to their unique mechanical [1-2], chemical and electronic properties [3-4]. Optoelectronic properties of CNTs makes them very interesting component for infrared sensors. The carbon nanotubes are a unique material that can be either semiconductor or metallic with a small band gap inversely proportional to tube diameter and with interesting optical properties. CNT mats interest for many electronic applications such as electrodes, transistors, and sensors[5,6]. Among CNTs based sensors, photosensors and especially infrared _IR_ sensors have recently attracted much attention, since CNTs exhibit wide absorbance in the infrared range.In this work, the improvement of the photoresposivity and response time of infrared photoconductive detector based on multi-walled carbon nanotubes (MWCNTs) deposited on porous silicon (PSi) layer were carried out.

Porous Silicon is a network consisting of pores separated by thin columns and contains nano-meter sized silicon crystallites [7, 8] as a result; PSi is characterized by a very large internal surface. Porous silicon formed under different anodization conditions exhibits a variety of rich and complex structure with many features [9]. The physical properties of porous silicon (PSi) are fundamentally determined by the shape and diameter of PSi was discovered in 1956 by Uhlir [10]. Infrared (IR) detection has a wide range of military, homeland security, industry, biomedicine, and astronomy applications, since the blackbody radiation of humans and the atmosphere are in the IR spectrum [11].

An infrared detector is a detector that reacts to infrared (IR) radiation. The two main types of detectors are thermal and photonic (photodetectors). The thermal effects of the incident IR radiation can be followed through many temperature dependent phenomena. The response time and sensitivity of photonic detectors can be much higher, but usually these have to be cooled to cut thermal noise. The materials in these are semiconductors with narrow band gaps. Incident IR photons can cause electronic excitations [12].

2.EXPERIMENTAL WORK

Crystalline silicon substrate has been employed in this work in order to prepare porous layer in the front surface of the Si wafer. The PSi layer has been prepared by photochemical etching. Commercially n -type Si wafer of 0.05 Ω.cm resistivity was used as a starting material.The photochemical etching shown in figure (1) process used to prepare the PSi sample is shown in figure (1). After cleaning the sample it was immersed in 10% HF acid of 50% concentration in a Teflon beaker. The sample was mounted in the beaker on two Teflon tablets in such a way that the current required for the etching process could complete the circuit between the irradiated surface and the bottom surface of the silicon sample. Tungsten halogen lamp of 250 Watt was used as the photon beam source. A focus lens of focal length 5 cm was used to focus the photon beam. The irradiation time was 12 minutes.

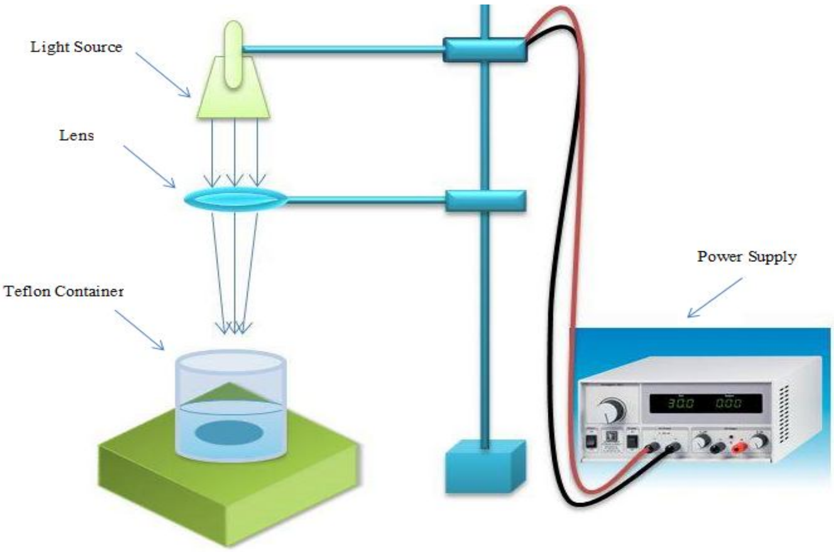


Figure 1 The set up of the photochemical etching process.

Multi-wall carbon nanotubes (MWCNTs), with diameter of 10-20 nm and length about 10-30 µm, are dispersed in 25 ml Di-methylformamide and sonicated for 1 hour, and then stirred for 30 min. The MWCNTs suspenstion was deposited on the PSi layer by dip coating techniques, figure 2, with a controlled withdrowell speed of 1mm/min in the room temperature. The suspension conteneous stirrer during the dipping processe in order to keep the suspension homogeneaus. Three types of samples were used. First sample attended by dip coating method for the MWCNTs suspenstion on the PSi layer and the second was prepared using drop by drop for deposited MWCNTs film. For these two samples, Al mask was used, while the third type has been prepared without using a mask for the purpose of comparison. Figure (2) shows the Schematic diagram of simple dip coating system.

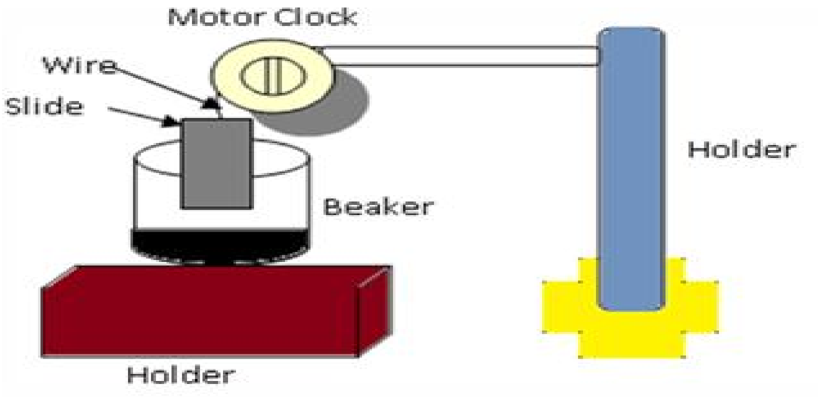


Figure 2 Schematic diagram of simple dip coating system.

The micro mask of 0.4 mm electrode which is used to deposit the Aluminum (Al) electrical electrodes on the film surface by the evaporation technique is illustrated in figure (3a). The distance detween the two electrodes is 0.9 cm. The copper wires were used to connect the electrodes to the operation electrical circuit by the aid of silver paste. Figure (3b) illustrated the final shape for the fabricated photoconductive detector.

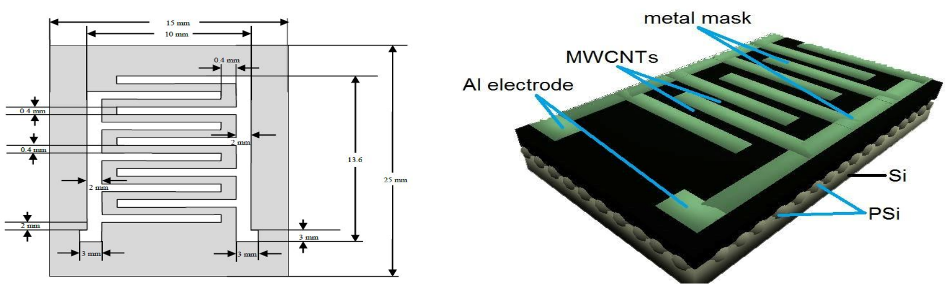


Figure3 (a) Schematic diagram of the IDE masks utilized in this work,
(b) Final shape for the fabricated photoconductive detector.

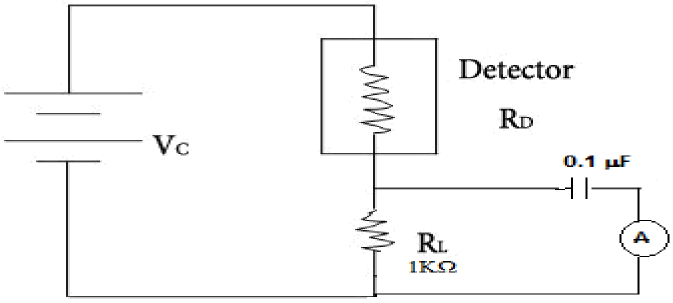


Figure 4 The operation circuit diagram of Infrared photoconductive detector.

3.RESULTS AND DISCUSSION

The atomic force microscopic (AFM) of the PSi/CNTs.is shown in figure 5 . results of surface morphology of the CNTs film had a good a uniform surface homegensity and gives a good indication for formation has nanospikes with regular distribution of the CNTs nanoparticles.. The roughness average (Sa) for this layer of PSi/CNTs was 1.04 nm while the root mean square roughness (Sq) was 1.24nm and ten point height (Sz) was 5.86 nm.

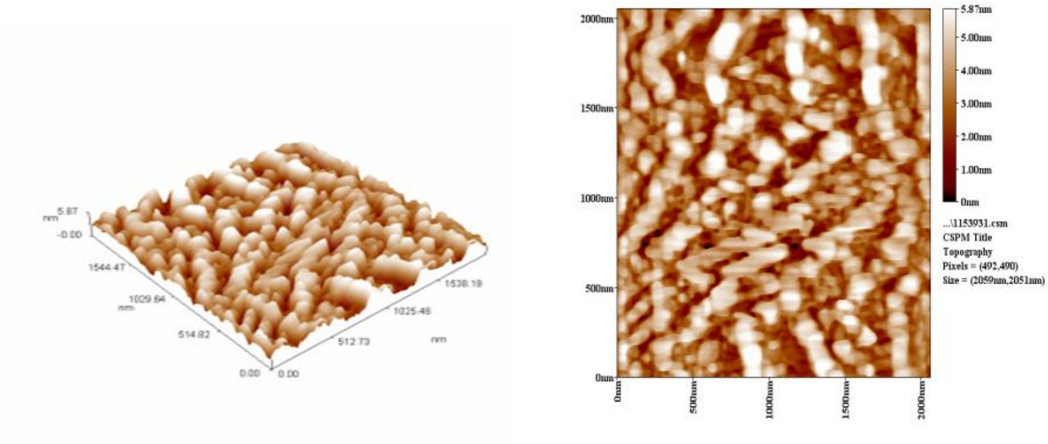
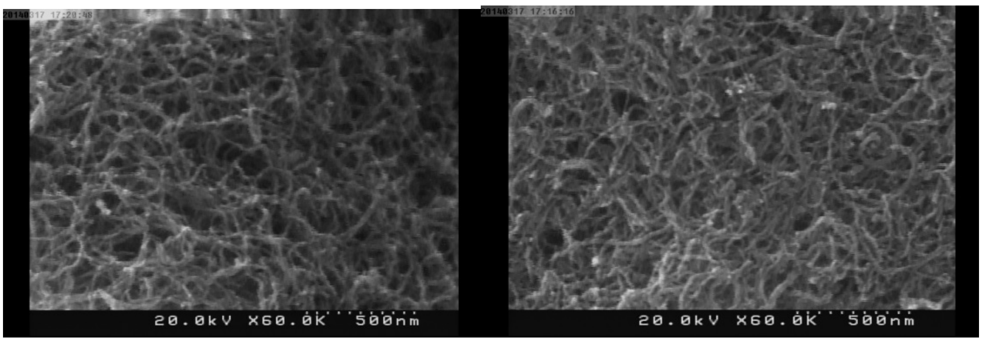


Figure 5 AFM images for the MWCNTs deposited on PSi nanosurface

The scanning electron microscopy (SEM) technique has been applied to study the morphology of the deposited MWCNTs films. Figure (6) shows the SEM images for the deposited CNTs in dip coated and drop-by drop method. It is was found that the films are homogeneous and does not have areas with clusters.



a b

Figure 6: SEM images for the MWCNTs deposited on PSi nanosurface by:
(a) drop and (b) dip coating.

The Raman shift spectrum for the MWCNTs, is shown in figure (7). The spectrum is dominated by the two typical lines D-band and G-band. the D-line for MWCNTs is located about 1335.4 cm^{-1} which to assigned to the disorder induced by defects and curvature in the nanotube lattice, while G-line is located about 1563.2 cm^{-1} due to the in-plane vibration of the C–C bonds. These bands can be used to evaluate the extent of any carbon-containing defects. The D/G intensity ratio is 1.14. Also,G band indicates that the samples contain SP^2 carbon networks**.**

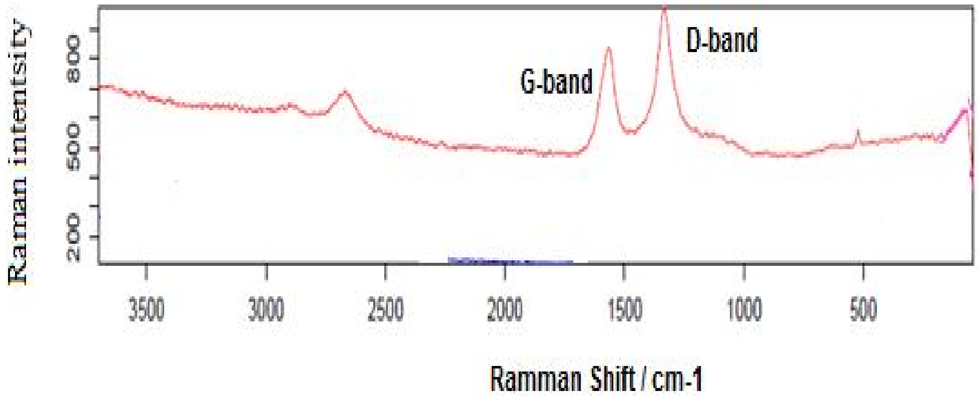


Figure 7 Ramman spectrum the MWCNTs deposited on PSi nanosurface.

The current-voltage (I-V) characteristics of the fabricated photoconductive detector as a function of the bias voltage at dark and under illumination of CO_2 laser were tested under input power. Figure (8) shows the I-V characteristics for 2.2 and 2.5 Watt of radiation power from CO_2 laser of 10.6 m wavelenght. It is clear that the device has low sensitivity when applied low bias voltage and this sensitivity increased under illumination by IR radiation with the increasing of bias voltage. At IR radiation of 2.5 W, the sensitivity of the detector is higher than that at 2.2 W. In this work two types of detector were fabricated one with aluminum mask and the other without, in order to investigate the effect of exist mask. Figure (9) shows this effect. Inspect of the benefit of mask, but in this case it is obvious that the sensitivity of our detector increased for the detector with the present of the mask. Figure (10) given comprise between the sensitivity resulted from the detector fabricated by deposited the MWCNTs film by dip coating method, and the other fabricated by deposited the film using drop-by-drop method. The sensitivity for the first detector (dip) is higher.
The table revealed that the best results achieved for the samples at laser power 2.5 W which are give the higher responsivity, gain 2.44 , quantum efficiency and detectivity reach to $5.42x10^7$ $(cm.Hz^{1/2})/W$. The NEP value is less in these samples than the others.

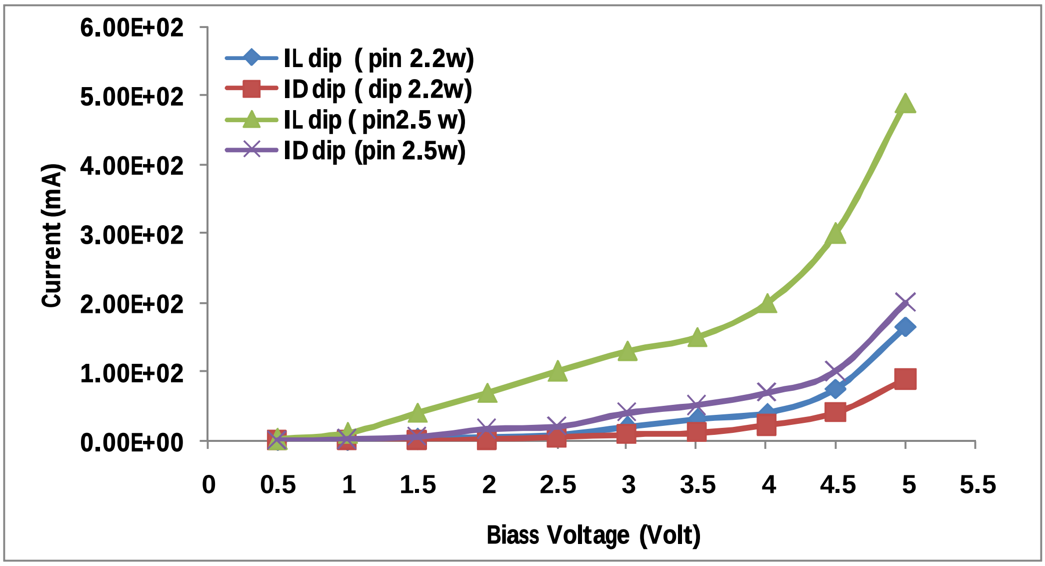


Figure8 I-V characteristics of the MWCNTs-PSi IR detector (a) P_{in} 2.2W,(b) P_{in} 2.5W. IL is the photo current and ID is the dark current.

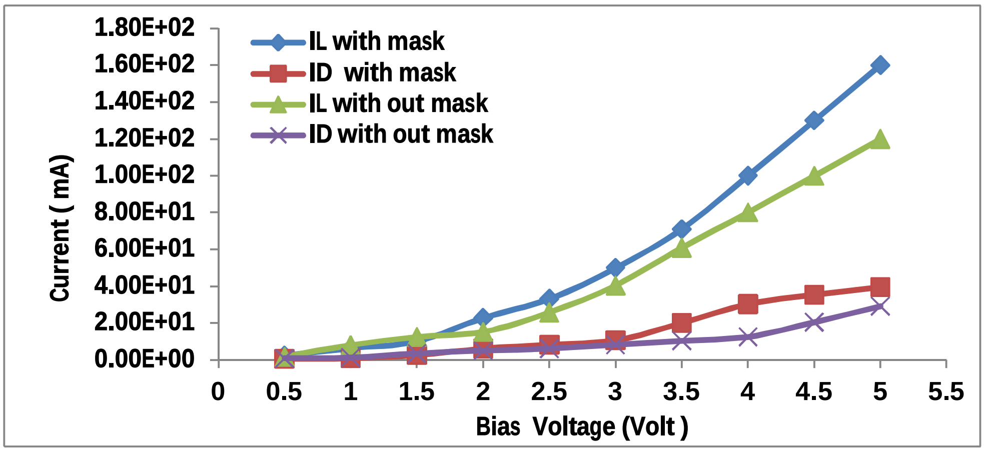


Figure 9 I-V characteristics of the MWCNTs-PSi IR detector fabricated with and without aluminum mask.

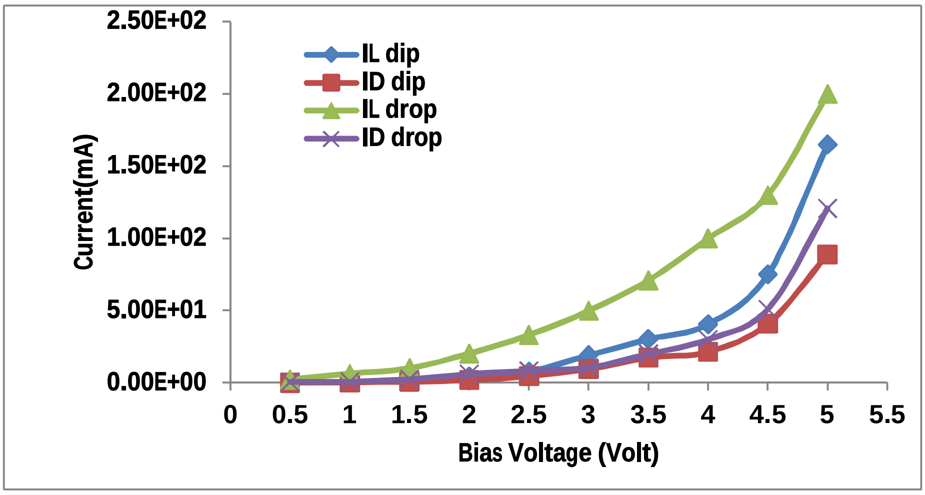


Figure10 I-V characteristics of the MWCNTs-PSi IR detector fabricated by dip and drop methods for the deposited film

Table 1: Figure of merits for the fabricated CNTs IR detector illuminated by 2.2Watt IR radiation of wavelength 10.6μm at 5V bias voltage

Sample case	R□ (A/W)	G	Q.E	NEP (Watt)	D* (cm.Hz$^{1/2}$)/W
MWCNT -dip P_{in} (2.2W)	0.005	1.857	0.00061	3.20E-08	3.12E+07
MWCNT -dip P_{in} (2.5W)	0.013	2.446	0.0016	1.84E-08	5.42E+07
MWCNT -drop with mask(2.2W)	0.006	1.657	0.0007	3.08E-08	3.24E+07
MWCNT-drop without mask (2.2W)	0.003	2.954	0.0004	2.98E-08	3.35E+07

4.CONCLUSIONS

The far infrared photodetectors were prepared by drop-by-drop and dip coating techniques were fabricated on photochemical etched silicon substrates. The MWCNTs-PSi films prepared by both deposited methods give a good photoconductive gain and acceptable photoresponsivity and detectivity, while the noise equivalent power were very low for all the fabricated detectors.

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