ISSN 2347-3487

Characterization of Carbon nanotubes Near- Infrared Photoconductive Detector

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ABSTRACT

Carbon nanotubes (MWCNTs,F-MWCNTs,SWCNTs) with different structure were fabricated into near-infrared photodetectors. Indium Tin Oxide (ITO) was used as a substrate to deposit CNTs by the drop casting method. The CNTs carrier concentrations, conductivity and carrier mobility were measured. Different types CNTs photodetectors exhibit a good photoconductive performance at a wavelength (980-1200nm) especially SWCNTs, responsivity was found to be (0.295 A W^{-1}), specific detectivity (D^*) 1×10^9 cm.$Hz^{1/2}$ .W^{-1} and response time 0.049ns.

Keywords: carbon nanotubes, indium tin oxide, IR detector, photoconductive detector

ISSN 2347-3487

1. INTRODUCTION

Carbon nanotubes (CNT) are one dimensional material that has been widely explored in nanoelectronic and optoelectronic due to the unique band structure and excellent electrical properties. CNTs are empty cylinders made of carbon atoms. They are neither semiconductor nor metals, and are classified as semimetals. There are two different structures for nanotubes: Single Wall Carbon Nanotubes (SWCNT) and Multi Walls Carbon Nanotubes (MWCNT). MWCNTs appear as several concentric SWCNTs with different tube diameter and with different values of the chiral vectors [1,2]. Recently the photoconductivity of carbon nanotubes (CNT) has attracted great interest due to possible applications of their unique optoelectronic properties for the development of novel photosensitive nanomaterials for photovoltaics photodetectors, and bolometers [3,4,5].

In the past few years, there were intensive studies on the infrared response of carbon nanotubes, the researches of photodetector of CNT show that carbon nanotubes exhibit strong infrared light absorption with broad band and fast light responses up to picoseconds, which indicated that CNTs have potential application in IR detection. Optoelectronic properties of carbon nanotubes make them very interesting component for infrared sensors [6] .

There are two types of IR detectors: photon and thermal types. In general, photon types are preferred primarily due to their superior sensitivity and resolution. Un cooled thermal sensors have attracted much attention because they operate at room temperature. These devices offer the advantage of low cost fabrication and a wide band of 8 - 14 µm [7].

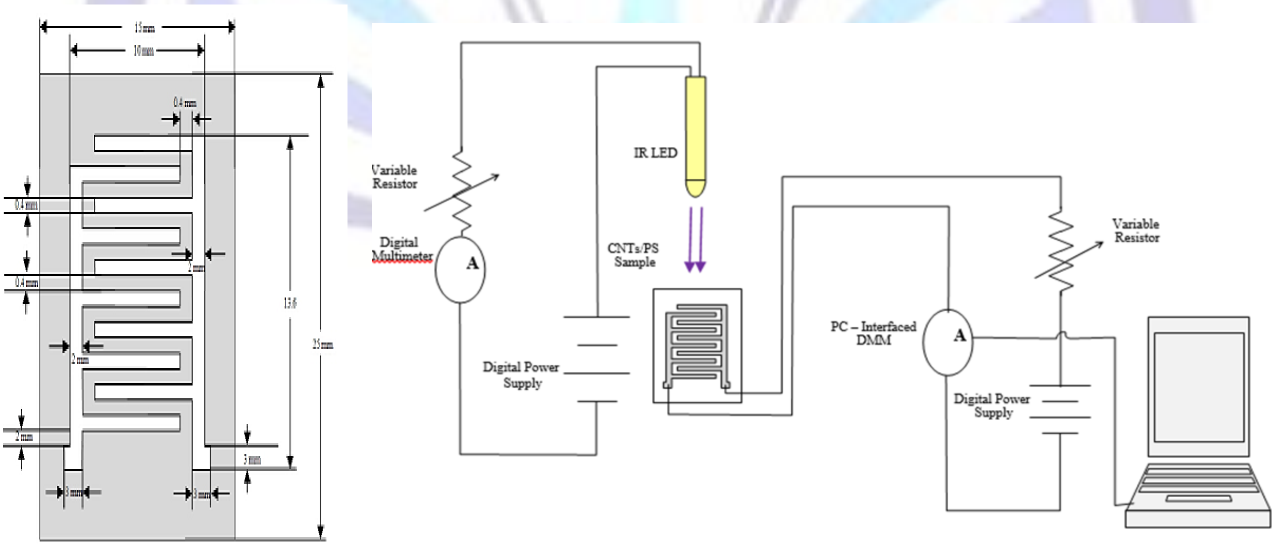
Optoelectronic materials that are responsive at the wavelengths in the near-infrared (NIR) region (e.g., 800–2000 nm) are highly desirable for various demanding applications such as telecommunication, thermal imaging, remote sensing, thermal photovoltaic, and solar cells[8,9]

In this work, the photoconductive response of different types CNTs (SWCNT, MWCNT and functioned MWCNT) deposited on ITO glass in the NIR spectral range was obtained.

2. EXPERIMENTAL WORK

Indium tin oxide (ITO) with thickness 320 nm and 20 Ohm/sq was used as a substrate to deposit Aluminum electrodes, these electrodes are usually in millimeter (0.4mm) as shown in figure.1a. The substrate with electrodes is then covered with CNTs. At this step carbon nanotubes can be deposited from a solution by drop casting directly on the sample surface.

Three types of CNTs were used to prepared the solution, single wall carbon nanotubes (SWCNTs) with a diameter (1-2nm) and length 30µm, multi wall carbon nanotubes(MWCNTs) with a diameter (10-30nm) and length (1-2µm) and functionalzation multi wall carbon nanotubes (COOH-MWCNT) with a diameter (8-15nm) and length 50 µm are dispersed in 25ml DI-methylformamide, sonicated for 2hour, and stirred for 1hour. After depositing the solution on electrodes by drop method, the samples were left to dry in room temperature. The spectral response of the samples is measured by using a laser diode with wave length 980nm and power (50mW) as the source of illumination. The light is modulated by a mechanical chopper; figure.1b shows a schematic diagram of the experimental setup.



(a) (b)

Fig1a: Schematic diagram of interdigital electrodes, b: Schematic diagram of the experimental setup.

ISSN 2347-3487

3. RESULT AND DISCUSSION

The Hall Effect setting type (HMS3000) was used to study the electrical properties of CNTs (conductivity, carrier mobility, charge carrier concentration). Table1. Shows the Hall measurements for different types CNTs.

The table shows that all types of CNTs are p -type semiconductor, with different carrier mobility and conductivity depending on the types of CNTs.

Table 1. The Hall measurements for different types CNTs.

Parameter	SWCNT	MWCNT	F-MMWCNT
Bulk concentration 1/cm^3	$5.58\times10^{1}1$	1.264×10^{16}	3.702×10^{12}
Conductivity 1/ Ω cm	2.575×10^{1}	5.577	1.47810^{-5}
Mobility cm^2/Vs	2.881×108	2.753×10^{3}	2.49×10^{1}
Average Hall coefficient m ^{2}/C	1.12×10^{7}	4.937×10^{2}	1.686×10^{6}

Electrical characterization of three different types CNTs photoconductive detectors are shown in figure (2a, b, c). The CNTs dispersion between electrode is illuminated by IR laser diode (50mW).The overall increase in current was observed at room temperature.

Figure 2. Reflect a good IR photoconductive detector sensitivity, the measured gain was calculated from the ratio between the photocurrent to dark current. The measurements were carried out for F-MWCNTs, MWCNTs and SWCNTs the photoconductive gain were 258.3,41.6 and 44.96 as shown in table 2.

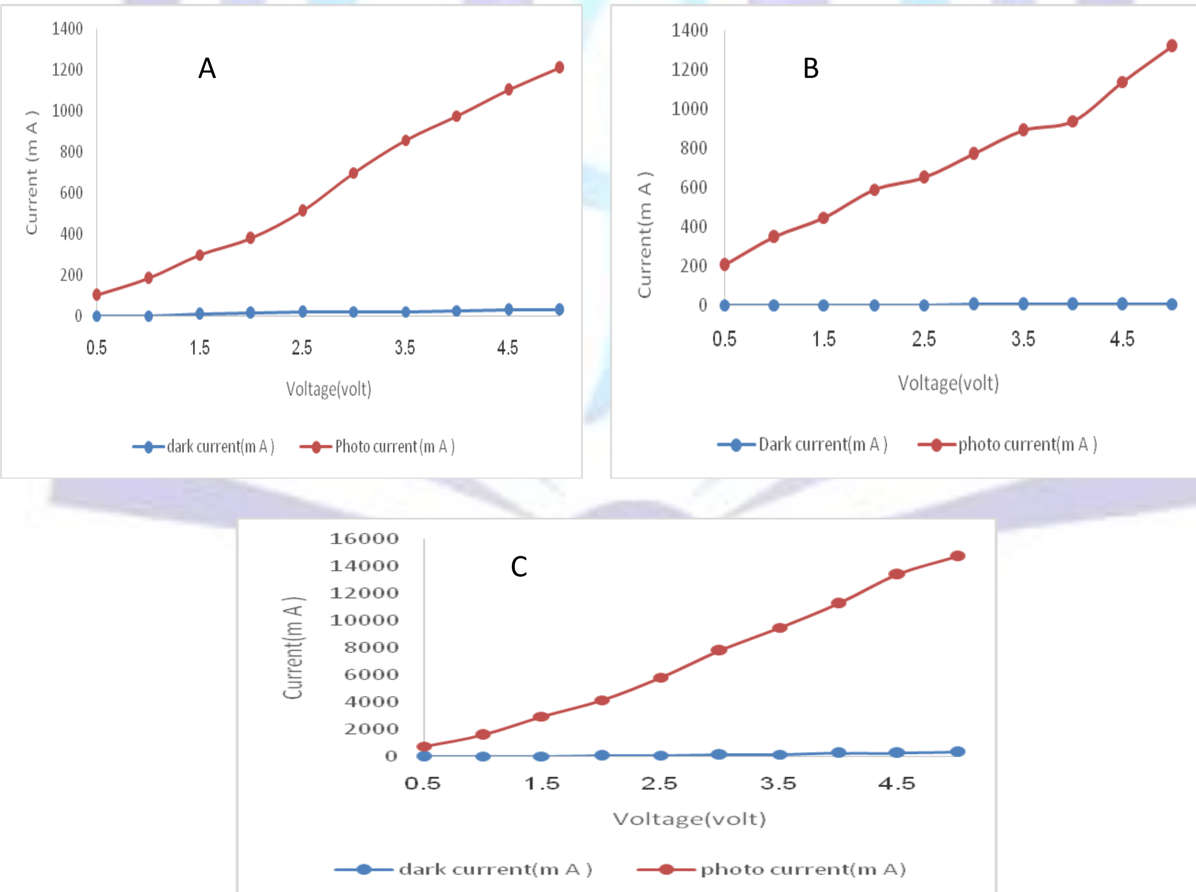


Fig2: I-V characterization for A-MWCNT, B- F-MWCNT, C- SWCNT.

ISSN 2347-3487

Table 2. Figure of merit parameters for CNT detector.

TYPE OF CNTs	G	τ	I_n (AMP)	R_λ(AMP/Watt)	NEP (Watt)	D ($Watt^{-1}$)	D* (Watt-1 .Hz1/2 .Cm)
SWCNTs	44.96	0.049 ns	3.2×10^{-10}	0.295	1.1×10^{-9}	9.11×10^{8}	1×10^{8}
MWCNTs	41.6	4.8 µm	9.6×10^{-11}	0.024	4×10^{-9}	2.5×10^{8}	2.85×10^{8}
F-MWCNTs	258.8	3.3ms	4×10^{-11}	0.0264	1.53×10^{-9}	6.53×10^{8}	7.45×10^{8}

The response time of the prepared detectors was calculated from the relation between gain and transient time ($G= \tau/T$) where τ = is the charge carries a lifetime, and T is the transient time between the detector electrodes. The transient time is related to the electrode spacing and the carrier mobility by the relation; $T=L^2/\mu V$, where L is the electrodes spacing (0.4mm), μ is the carrier mobility found from Hall measurements and V is the bias voltage (5Volt). The response time of the fabricated SWCNTs detector was 0.049ns where the response time for MWCNTs and F-MWCNTS were 4.8 µs, 3.3ms. These results of photo response can be attributed to the metallic electrode-CNTs interface due to a Schottky barrier, when the laser light (980nm) is illuminated at the samples exciton generated (electron and hole) at the interface followed by charge transport and collection at the external electrodes.

4. CONCLUSIONS

Different types CNTs photoconductive detector were fabricated on ITO glass, the device exhibiting a good response and responsivity to near –infrared (980nm) wavelength especially SWCNTs the responsivity was 0.295A/W.

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