Interaction and Fabrication of Optical Sensors based on OPV functionalized Single Walled Carbon Nanotubes

A thesis submitted towards partial fulfillment of
BS-MS Dual Degree Programme

By

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Declaration

This thesis entitled **“(Interaction and Fabrication of Optical Sensors based on OPV Functionalized Single Walled Carbon Nanotubes)”,** is a presentation of my original research work. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions.

The work was done under the guidance of Dr**. Harsh Chaturvedi** at Indian Institute of Science Education and Research

Abhishek Singh

In my capacity as supervisor of the candidate’s thesis, I certify that the above statements are true to the best of my knowledge.

Dr. Harsh Chaturvedi

Acknowledgements

I owe great many thanks to many people who helped and supported me during the writing of this thesis.

I am very grateful to the Dr. Harsh Chaturvedi for reviewing the manuscript in spite of his very busy schedule. He made several important suggestions which enhanced this project.

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I would also thank my Institution and my faculty members without whom this project would have been a distant reality. I also extend my heartfelt thanks to my family and well wishers who encourage me since my childhood.

Abstract

OPV is an optically active polymer. SWNT functionalized with OPV acts as hybrid donor acceptor system which have diverse potential applications such as electro optics and foldable electronics. We functionalized pristine and preseparated metallic and semiconducting SWNT with OPV. Critical coagulation concentration was determined for each of the solution. Interaction in the aggregated, functionalized SWNT was further characterized using high resolution microscopy and spectroscopy. Specific binding of OPV with semiconducting SWNT was acertained. Photon induced aggregation only for Semiconducting SWNT functionalized with OPV observed with time. Metallic SWNT do not show any interaction with OPV neither photon induced aggregation nor kinetic aggregation with highest concentration. Devices such as molecular FET or thin film of SWNT were fabricated using lithography.

In this thesis, we provide the IV measurements of non-functionalized and OPV functionalized pristine and Semiconducting SWNT (*Oligophenylynevinylene*) in absence and presence of light. Utilizing the charge transfer of optically active molecule OPV, we modulate the conductivity of SWNT. These functionalized tubes used to fabricate electro optical sensor and devices.

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Chapter 1

Nanotechnology

1.1 Introduction

The “nano” originated from Greek word for dwarf which implies one billionth of a meter, or 1 nanometer. It’s an art and technology of manipulating matter at nanoscale to create unique materials. At this level, matter displays amazing properties. Nanotechnology is a new approach that refers to building, understanding, mastering and using materials, devices and machine at the nanometer scale. It has incredible surface area per unit mass and better performing materials.

In 1959, the concepts that seeded nanotechnology were first discussed by renowned physicist Richard Feynman in his talk “There's Plenty of Room at the Bottom”, in which he explained the feasibility of synthesis by direct manipulation of atoms. It can be difficult to imagine exactly how this greater understanding of the world of atoms and molecules has and will affect the everyday objects around us. Nanotechnology is the natural continuation of the miniaturization revolution that witnessed over the last decade, where millionth of a metre (10 -6 m) tolerance (micro-engineering) became commonplace, for example, in the aerospace and automotive industries enabling the construction of higher quality and safer vehicles and planes.

The chips used in computer pushing the limits of miniaturization, and many electronic devices have nano features that owe their origins to the computer industry – such as cameras, car airbag pressure sensors and inkjet printers, CD and DVD players,.

1.2 Nanostructures

Nanostructures can be so small that the body may clear them too rapidly for them to be effective in detection or imaging. It has been extensively used in semiconductor research, diode making and many other things. Nanorods, nanoshell, quantum dot, nanoparticle are the unique nanostructure present in the nanotechnology.

1.3 Applications

In daily life, nanotechnology handles the current progress in physics, chemistry, material science and biotechnology to form innovative materials which have unique properties because of their structure of nanoscale. There are varieties of uses of nanotechnology applications i.e.

(i)In electronics, by reducing weight and power consumption, we might increase the capabilities of electronics devices.

(ii)In medicine, the nanosize molecules that can deliver drugs directly into diseased cells in your body. This application can reduce the damage of healthy cells in chemotherapy.

(iii)In fuel cells, nanotechnology used to produce hydrogen ions from fuel such as methanol to improve the efficiency of membranes used in fuel cells to separate hydrogen ions from other gases such as oxygen.

(iv)In solar cells, quantum dots should be able to reach higher efficiency levels.

(v)In food, nanomaterials used for food safety and the health benefits that food delivers.

(vi)In space, nanomaterials used to make lightweight spacecraft and cable for space elevator.

(vii)The best example is mobile phones which dramatically becoming smaller and smaller, cheaper, faster and cleverer.

Chapter 2

Field Effect Transistor

2.1 Introduction

It is invented by Austrian-Hungarian physicist Julius Edgar Lilienfeld in 1925.It is a Voltage controlled device which operation depends only on one type of charge carriers. There are two types of field effect transistor i.e. Junction Field Effect Transistor and Metal Oxide Semiconductor Field Effect Transistor (Insulated Gate FET). Conduction between source and drain is correlated to the drain-source voltage by the resistance of the intermediate material. Field Effect Transistor consisting of a semiconducting current pathway, the conductivity of which Variated by the applications of transverse electric field. Device is consisting of n-type semiconductor with a ohmic semiconductor at each end p-type semiconductor between the ends. This p-type region called as a gate and n-type region as a source and drain. Source and drain are interchangeable.[1,6]

2.2 Basic Theory

FET has three terminals:

1. Source (by which the carriers enter the channel)
2. Drain (by which the carriers leave the channel)
3. Gate (terminal that varying the channel conductivity).

For conduction, it is compulsory to make the conducting channel between Source and drain. In our fabricated FET devices, single walled nanotubes acts as a conducting channel.

When there is no gate voltage applied, electrons are completely free to flow through the channel. So the source drain resistances pretty much zero ohms. In this state, we say that Junction FET is saturated.[11,12]

2.3 Working

In normal operation, JFET is always reversed biased. When we reverse biase the gate, an interesting phenomenon happens. Reverse biasing the p-n junction causes the depletion layer to appear as diode and part of the p and n semiconductors converted to the insulators. But depletion layer causes the n-channel to become the narrower. So the less electrons flow through the channel which raises the resistance of channel. As increasing negative voltage of the gate, the n-channel becomes narrower and n-channel resistance rises further. If we increasing the voltage further, at some point the depletion region block the n-region. No current flow through the channel and the channel resistance becomes virtually infinite. At this stage, Field Effect Transistor is in cut-off stage.

Its called pinch-off voltage. This is how the FET works.

In p-type channel JFET, the gate made up of n-material and the source –drain consists of p-material. This is called p-channel JFET. This also works as a n-type channel except the polarities are reversed. Electrons still flow from source to drain but the gate is reversed biased with positive voltage controlling the resistance.[6]

2.4 Advantages

Carbon nanotubes are macromolecular systems and allotropes of carbon. In 1998, the CNTFET was fabricated. In the same year, R Martel fabricated FETs based on single and multi walled carbon nanotubes and investigate their performance. It exhibits near ballistic transport properties which resulting in high speed devices. In this, a single SWNT used as a bridge between two metal electrodes prefabricated by lithography on an oxidized silicon wafer. So, SWNT acts as a channel and metal electrodes acts as source and drain. The heavily doped silicon itself acts as a back gate. [7]

Chapter 3

Carbon Nanotubes

3.1 Introduction

Carbon is a non metallic element with atomic no. 6. Carbon is very useful element as it forms huge number of molecules .It exists in many allotropic forms which show many distinct properties on their own. There exist many allotropes of carbon but graphite, diamond and amorphous carbon are well known out of it. It shows a lot of versatile properties as diamond is highly transparent on other hand graphite are opaque. Out of several molecules, fullerenes are also wholly made up of carbon

The discovery of fullerenes led to the discovery of Carbon Nanotubes. Carbon nanotubes (CNTs) were fortuitously discovered by Iijima while studying the surface of graphite electrodes in an electric arc discharge. It is also one of the most important allotropes of carbon readily used in research now-a-days .At molecular level the chemical bonding of nanotubes entirely have sp2 bonds hybridization , similar to those of graphite. This hybridization is stronger than the sp3 bonds which other carbon forms like alkanes and diamond, provide nanotube a unique strength. So far Carbon nanotubes are the strongest and stiffest materials discovered in terms of tensile strength and elastic modulus respectively. It is due to the covalent sp2 bonds formed between the individual carbon atoms.[3,13,14]

3.2 Structure

There are two types of nanotubes: single-walled nanotubes (SWNTs) and Multi Walled Nanotubes (MWNTs). Multi Walled Nanotubes aligned of multiple layers of graphene. Due to the structural complexity and variety, MWNT not much analyzed. Each nanotube on their own arranges themselves into long thread like structures held together by Vander Waals forces, resulting due to pi-stacking. For making SWNTs we can take one single layer from the graphite stack and wrap it to cylindrical shape. The fashion in which graphene sheet is wrapped is represented by a pair of indices (n, m). The integer's n and m signifies the number of unit vectors along two directions in the honeycomb crystal lattice of graphene. For $m = 0$, the nanotubes are called zigzag nanotubes, and if $n = m$, the nanotubes are called armchair nanotubes else they are called chiral. In general, nanotubes are ideal systems to check for electron transfer. SWNTs shows metallic as well as semiconductor behavior. It is very useful in making of electrical appliances[4]

Single Walled Carbon Nanotubes

Single Walled Carbon Nanotubes discovered by Dr. Richard Smalley were imagined in high resolution mode using a transmission electron microscope (TEM). Its difficult to find the end of these types of nanotubes. Tubes have a length of hundred of microns which produced by decomposition of hydrocarbons on patterned metal lines evaporated over a quartz substance. These nanotubes have been observed between 0.4 nm and 5nm.Diameter between 0.7 nm and 2nm interesting for transistor and diode applications which provide suitable bandgaps. It have huge potential to carry high current density of the order 10 µA/nm2. The conductivity of a single walled nanotubes rely on the number of scattering agents, number of charge carriers and the availability of states into which the electron or hole can be scattered. The chirality of the Single Walled Carbon Nanotubes affects the properties whereas it have also achiral properties. Conduction properties of SWNT can be varied from metallic to semiconducting and vice versa .These nanotubes used to make the Field Effect Transistor.It can change the conduction of these nanotubes by varying the gate voltage.[2,4,9,11]

3.3 Properties

MWNTs display better properties over SWNTs, such as ease of production, low product cost per unit, enriched thermal and chemical stability. In general, fictionalization of SWNTs affects the electrical and mechanical properties, due to the structural defects occurred by C=C bond breakages during chemical processes. Due to the Lennard - Jones interaction, retraction force that occurs to telescopic motion between shells, its value is about 1.5 nN.

However, intrinsic properties of carbon nanotubes can be preserved by the surface modification of MWNTs. Integrated graphene CNT structure has the high surface area and three dimensional framework. At edges, graphene hand over higher charge density and reactivity than basal plane. It’s difficult to align CNTs in three-dimensional, high volume-density geometry. As similar to basal plane, the sidewalls of the CNTs exhibit low charge density except where edge defects exist.[4]

3.4 CNT in electronics

Semiconducting nanotubes can work as transistors. The tube can be turned “on” – i.e. made to conduct – by applying a negative bias to the gate, and turned “off” with a positive bias. Promising application of CNTs are their use in chemical sensors and nanoscale electronic devices and the ability to promote the electron-transfer reactions of biomolecules. In upcoming future, MWNTs can make breakthrough in electronic due to their unique mechanical properties.[11]

Chapter 4

Oligo Phenylene Vinylene

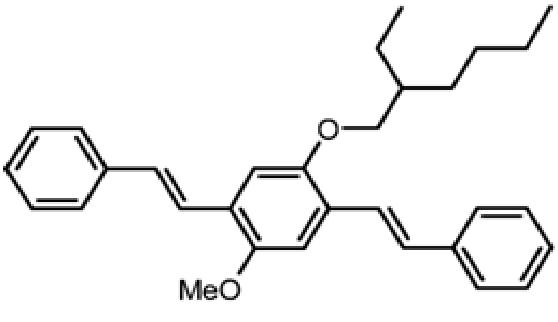
4.1 Introduction

Oligo Phenylene Vinylene is a conducting polymer of the rigid-rod polymer host family. OPV and its derivative have potential applications in optoelectronic devices such as light emitting diodes etc. Suitable electron rich and good solubility in common organic solvents are some of the interest of OPV. Aromatic pi-pi conjugation is high tendency of conjugated polymer chains which advanced to the arrangement of weakly emissive aggregated species. It's used as an active element in vast area light emitting diode. OPV can easily make into high thin films and shows good photocurrent in a band centered near 2.2 eV, just below the threshold. They are intractable and stable at room temperature. Failure due to bad polymer/thin metal interface because of joule heating phenomenon.[8]

4.2 Synthesis of OPV

1-(methoxy)-4-(2-ethylhexyloxy)-2,5-distyrylben-zene (MEH-OPV) was prepared by starting from 1,4-bis-(bromomethyl)-2-methoxy-5-(2-ethylhexyloxy) benzene, and then following the Wittig reaction conditions by treating with benzaldehyde as described for BTCD-OPV. Yield) 39%, mp) 53-54°C.1H NMR (CDCl3) ‰: 7.50 - 7.06 ppm (m, 16H, Ar-H and vinylic H), 3.90 - 3.88 ppm (m, 2H, Ar-OCH2), 3.86ppm (s, 3H, Ar-OCH3), 1.75 - 0.82 ppm (m, 15H, aliphatic). 13C NMR (CDCl3)‰ : 151.4, 138.0, 128.9, 127.4, 126.9, 123.5, 110.3, 109.2 (Ar-C), 71.8 (Ar-OCH2), 56.4 (Ar-OCH 3), 39.8, 30.9, 29.7, 29.3, 24.2, 23.1, 14.1, 11.3 ppm (cyclic-C) FTIR(cm -1): 3340, 2923, 2857, 1739, 1591, 1495, 1459, 1410, 1256, 1201, 1038, 960 (HC d CH, trans), 875 (HC d CH, cis), 866, 839, 798, 749 cm-1 . HRMS (Mw: 440.6): m/z) 440.3 (M+). Anal. Calcd for C 31H36O2: C, 84.50; H, 8.24. Found C, 84.15; H, 8.52.[8]

4.3 Structure



MEH-OPV

Figure 1: Structure of OPV [8]

4.4 Properties

Research concerning π-conjugated polymers much beneficial to the world in the last decade. The quantum efficiency of the device depends on the balance of the injection and transport of holes and electrons. Halogenation decreases the luminescence quantum yield of an organic dye, due to the high electronegativity and heavy-atom effect of the halogen atom.

A pair of stacked conjugated chains held in well-defined arrangements by single walled carbon nanotubes is a useful strategy to explore interactions between π systems.[17]

Chapter 5

Functionalized And Non Functionalized SWNT based FET Fabrication

4.1 Introduction

Single Walled Carbon Nanotubes (SWNT) exhibits the properties of electronic and structural properties. Because of its geometrical smallness, it is the future of nanofield. SWNTs bring together molecular dimension and the macro-world, and predetermined to be well known in forthcoming technology. FET (Field Effect Transistor) is a voltage-controlled device. These devices assembled from source to drain in which the carriers flow from the source to drain suitable for switching analog signals between paths. The performance set up on the unipolar carriers (h or e). High impedance on the order of 10 MΩ or more and Low voltage low current operation is the achievement of these types of FETs.

Investigated the performance of OPV functionalized and non functionalized fabricated field-effect transistors based on individual single walled carbon nanotubes. Regulated the conductance of a single walled carbon nanotubes by altering the gate voltage .The aim of the project was to investigate the change of current of pristine, semiconducting, metallic type Single Walled Nanotubes with *Oligophenylynevinylene* (OPV) in absence of light, the presence of light, and UV light . Fabrication of Field Effect Transistor (FET) based on these carbon nanotubes functionalized with these optically active molecules had done. OPV played a crucial role in modulating the current. Also experimented that parallel connections are better than series connections. Pristine SWNT is an intermixture of one-third metal and two-third semiconducting Carbon Nanotubes. It can help in modulating the current. These FET devices help in industries.

As discussed, the CNTs have rare effect such as rigidity, durability and inflexibility compared to other materials especially to silicon. There is currently no industrial science for their mass production and high manufacturing cost. Direct growth, various transfer printing techniques have been studied to overcome the fabrication problems. SWNTs represent as a ideal materials for creating reliable, high-density device. Integrated single molecular devices in the development of molecular electronics for the research of SWNT FETs.

4.2 Fabrication of SWNT based devices using lithography

FET (Field Effect Transistor) are the devices which modulate the analog and digital signals. In semiconductors, current enter through the source and leave from the drain. Variation in gate voltage causes variation in the current from the source to drain.

(i) Substrate Cleaning

In this Nanofabrication process, p-doped silicon wafer of thickness (275 ± 25) which have the diameter of 2″ and resistivity of 1~10 Ωcm was used as a back gate.

(ii) Piranha Cleaning

Piranha is a strong oxidizing agent which uses to remove organic matter and hydoxylates the surface means adding OH group to make it hydrophilic. It is a mixture of three-fourth sulphuric acid and one-fourth ammonium hydroxide. Taken silicon wafer rinsed by Piranha solution (H_2O_2 and H_2SO_4) at 100 C for ten minutes and after heating, rinsed with distilled water.

(iii) Standard Cleaning

It is a mixture of fifth-seventh of distilled water, one-seventh of ammonium hydroxide and one – seventh of hydrogen peroxide. The Si wafers placed in the placed in the solution and sonicated for 10 minutes. This helps in removing trace metals and other contaminating particles. After sonication, the si wafer rinsed with distilled water.

(iv) SIO_2 Deposition:

It's an oxide of silicon. Its deposition favours the protection of Si wafer and storing of charge.

SIO_2 acts as an electric insulator with high chemical stability.

The method of RF sputtering helps in deposition of SIO_2 on silicon wafer.

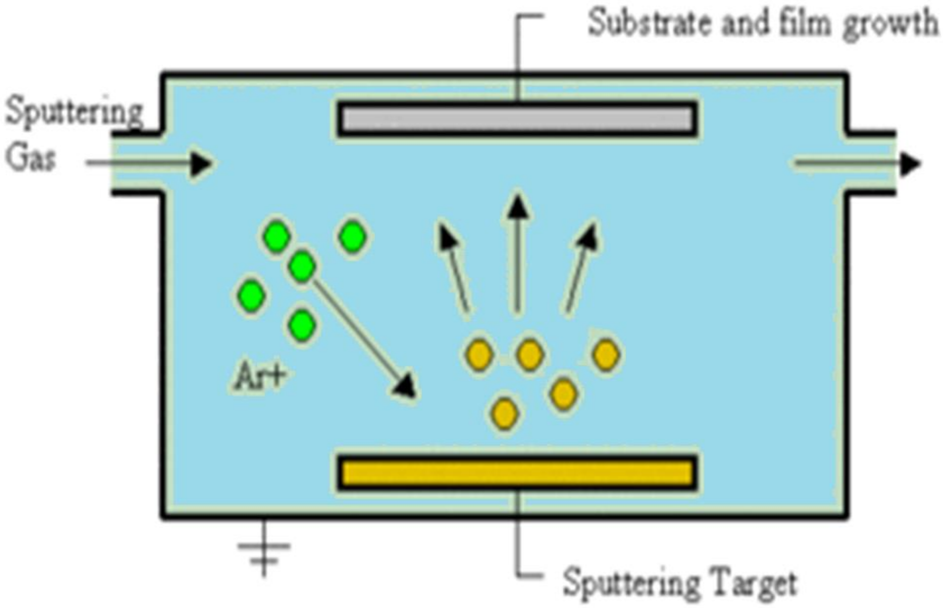


Figure 2: Diagrammetic Representation of SIO_2 Deposition

The target SIO_2 of thickness of 5kÅ deposited at the rate of 0.6Å/s on silicon wafer by the power supply of 80W at the base pressure of 10^{-5} mBar and gas flow of 300 sccm. As shown in figure, target material set at negative potential terminal. Sputtering argon gas enters into the vacuum chamber and creation of plasma happens by the ionization of gas. Plasma is a form of matter composed of negative and positive ions. Plasma is electrically conductive. The positive ions attract and attack to the target material SIO_2 .The target material eroded and deposited itself on the silicon wafer and ions moved by magnetic field and electric field. In this way, SIO_2 gets deposited.

(v) Photoresist Coating

The substrate then coated with positive photo-resist named AZ1512HS (Methoxy propyl acetate) at the rate of 4000rpm for 1 minute with the help of spin coater and heated at 80℃ for a minute to cure the photo resist.

(vi) Patterning

Photolithography is the method used for making patterns on the thin films or the bulk of substrate. The Laser Light used as a source of wavelength of 405nm.No mask used. Lens of unit 5 (1um aperture) used to make design of 3406 x 3406 um structure of strip width of 99.08 um. No autofocus used. After the formation of patterns on the wafer, the wafer removed from the laser writer and developed. The patterned wafer dipped in the mixture of 2ml of Developer polymer AZ400K and 8ml of DI water. The substrate was left in the solution for 40s. Pattern as shown in figure3 and figure4.

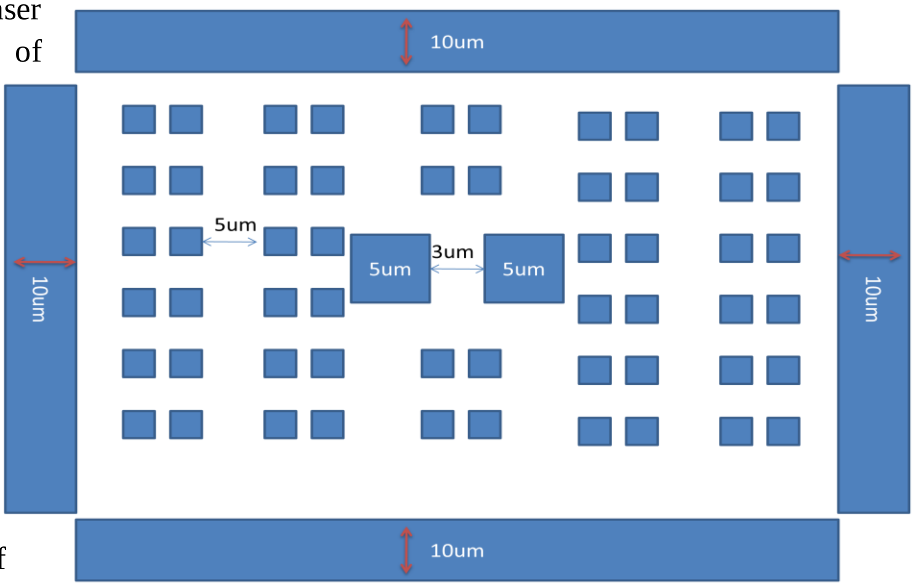


Figure 3: Patterns formed by laser writer

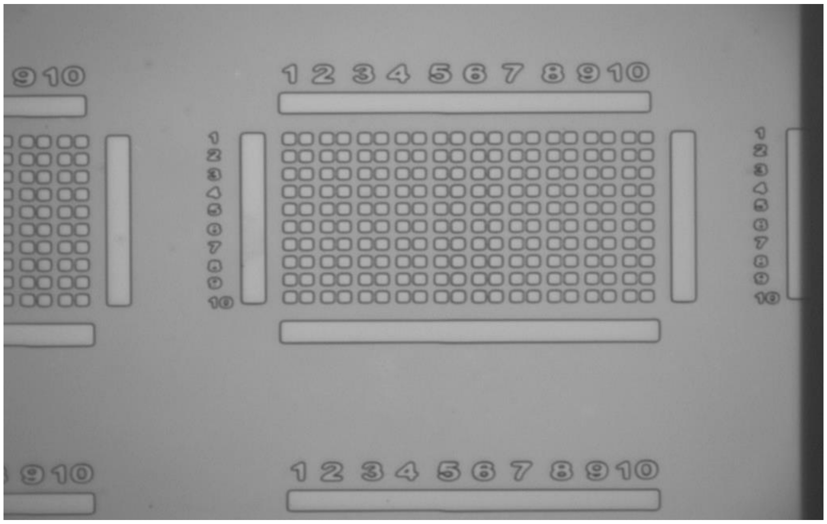


Figure 4: Patterns formed by laser writer

(vi) Metal Deposition

In deposition, titanium used as a metal. It deposited on the patterned substrate which serves as source and drain. DC sputtering method used. Titanium coated of thickness of 2.8kÅ at the rate of deposition of 3 Å/s (Voltage of 420V) and current of 300mA .After depositions, the substrate then rinsed with the acetone and sonicated for a minute for lift process.

Lift off process used for removal of sacrificial layer (photo resist).Metal deposition shown in figure5 and figure6.

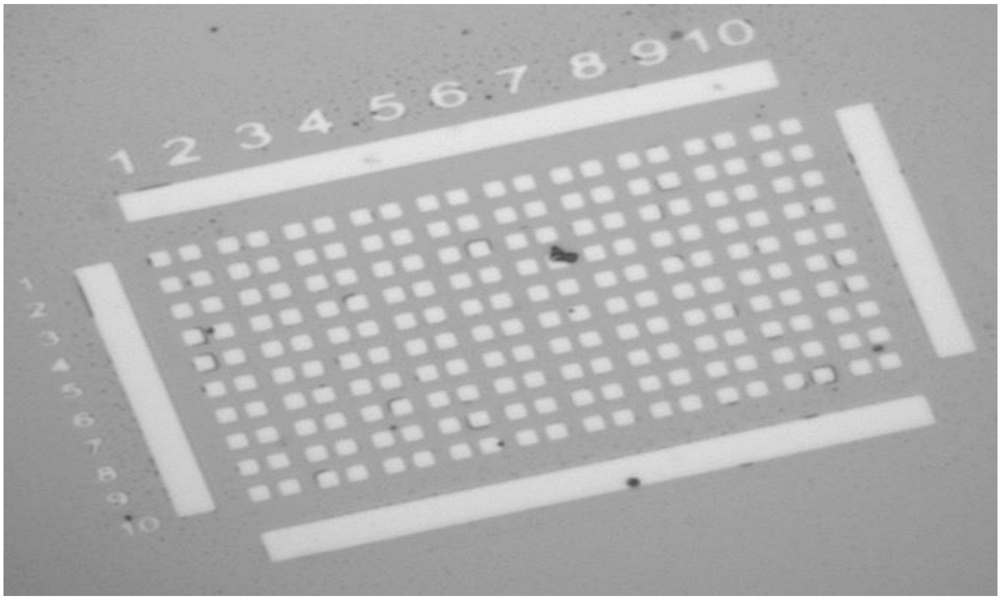


Figure 5: Ti deposition

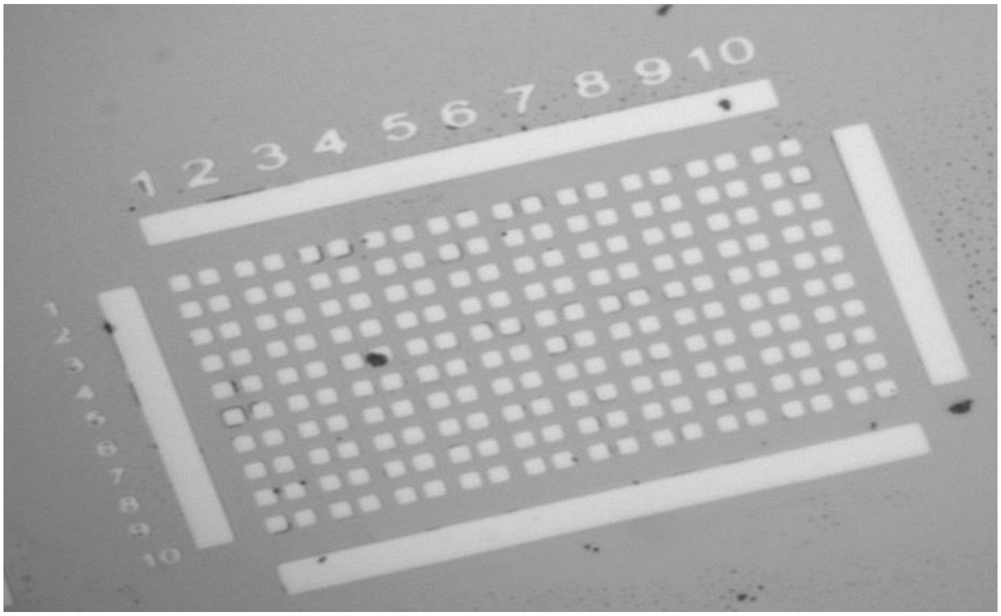


Figure 6: Ti deposition

(vii) CNT deposition

Then, SWNTs dispersed on the Ti deposited Si wafer by the method of DROP CASTING. Analyzed the SEM images.

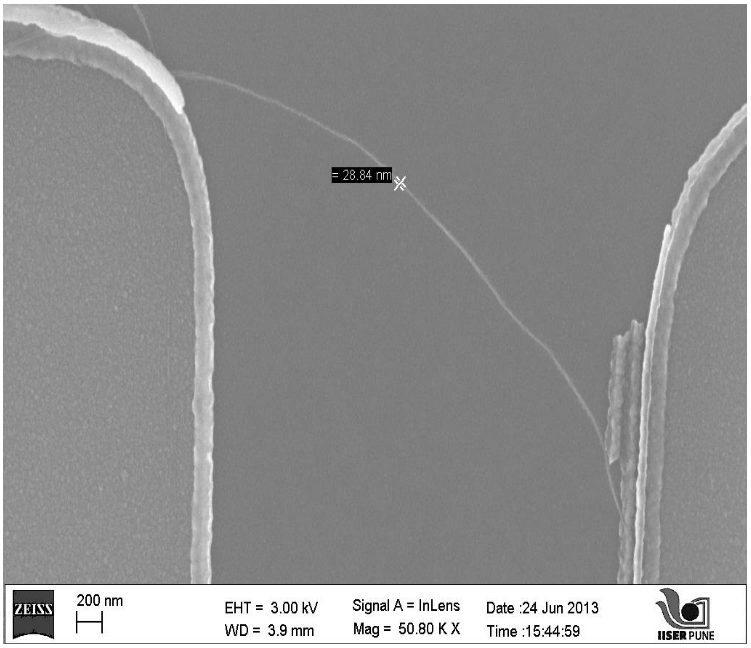


Figure 7: SWNT based Field Effect Transistor

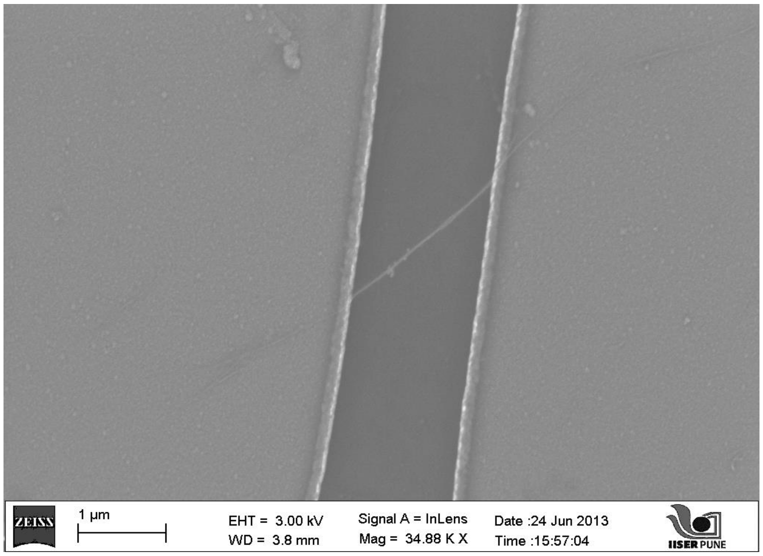
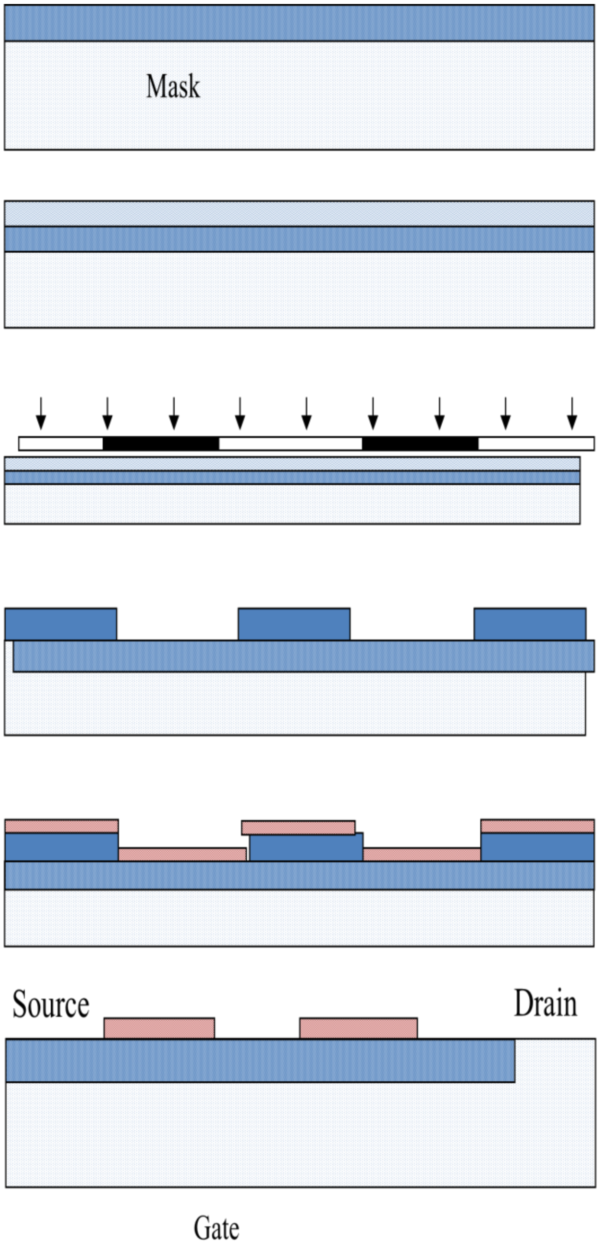
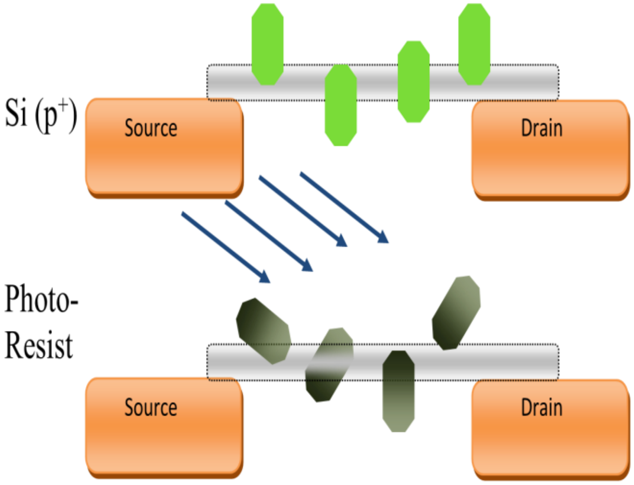


Figure 8: SWNT based Field Effect Transistor





- Thermally grown oxide(~120nm)
- Spin Coating
- Positive Resist
- Laser Writer
- Exposure & Development
- "Buried Electrodes"
- Metal deposition
  (Ti~100nm)
- Standard "Lift off"

Figure 9: Diagrammatic representation of Fabrication of FET

5.3 Results and Discussion

OPV plays crucial role in some of these graphs which acts a donating system when they exposed to the light. PCNT have good electron affinity so they are good acceptor. When they binds to the OPV, the lower band gap of the larger nanotube makes holes transfer to the OPV (donor).A desired binding is, essential for good conductivity in the molecular SWNT complexes.

In **figure10**, In the presence of light, it shows proper metallic characteristics. In presence of light, OPV gets activated and there is a role of charge carriers and energy transfer from the polymer in ScSWNT blends. Here OPV acts as a Donor molecule and Semiconducting SWNT acts as a acceptor molecule.

In **figure11**, in the absence of light, Semiconducting SWNTs display the properties of diode. A higher SWCNT concentration usually leads to more closely spaced SWCNT strips. In dark, range around e-05. The graph is similar each time. In light, they are showing metallic properties of range around e-06. When these nanotubes exposed to the light, thus suppressing the current. In UV, range around e-06 when UV light strikes to the ScSWNT.

Figure12 shows the metallic character. Composites are one-third of metallic SWNTs and two-third of semiconducting SWNTs. So the electrons choose path where less band gap occurs. Means electrons choose the metallic band gap.

In **figure13**, Current increment takes place in the presence of light. The conductivity in OPV functionalized Pristine SWNTs complexes arises from the arrangement of appropriate batches of electron donor and acceptor molecules and a certain degree of charge transfer between the blends.

In **figure14**, in dark, range around e-03. Little increments in the presence of light. Current range is better than other SWNTs because band gap between valence band and conduction band is less.

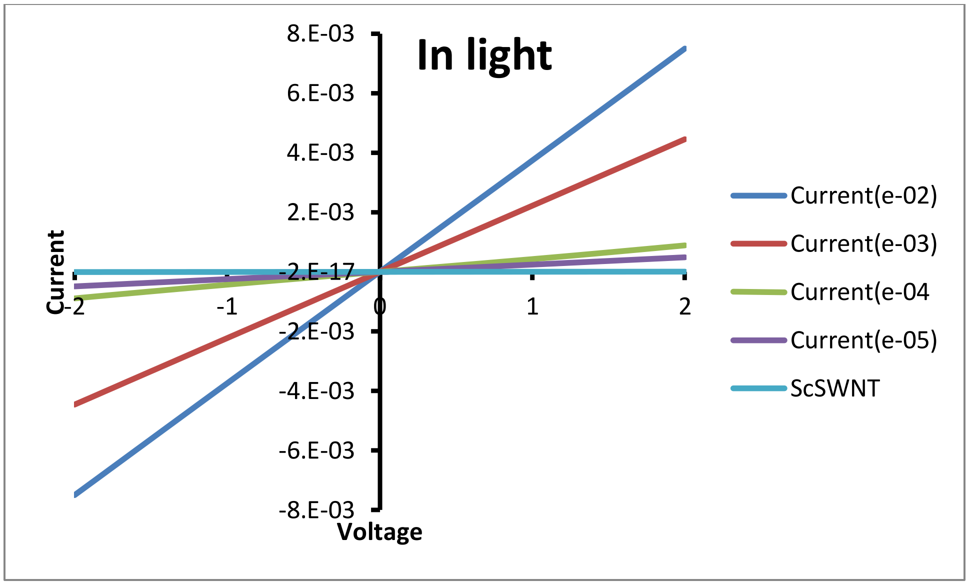


Figure10 : I-V measurements of OPV functionalized Semiconducting SWNTs of concentration of 10^{-2}, 10^{-3}, $10^{-4}$and 10^{-5}

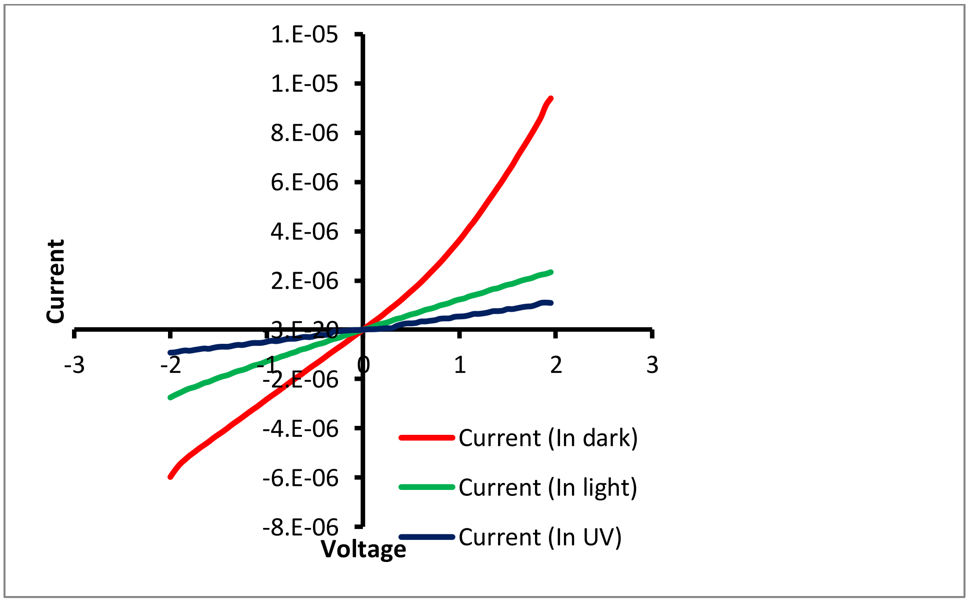


Figure11 : I-V measurements of Semiconducting SWNTs

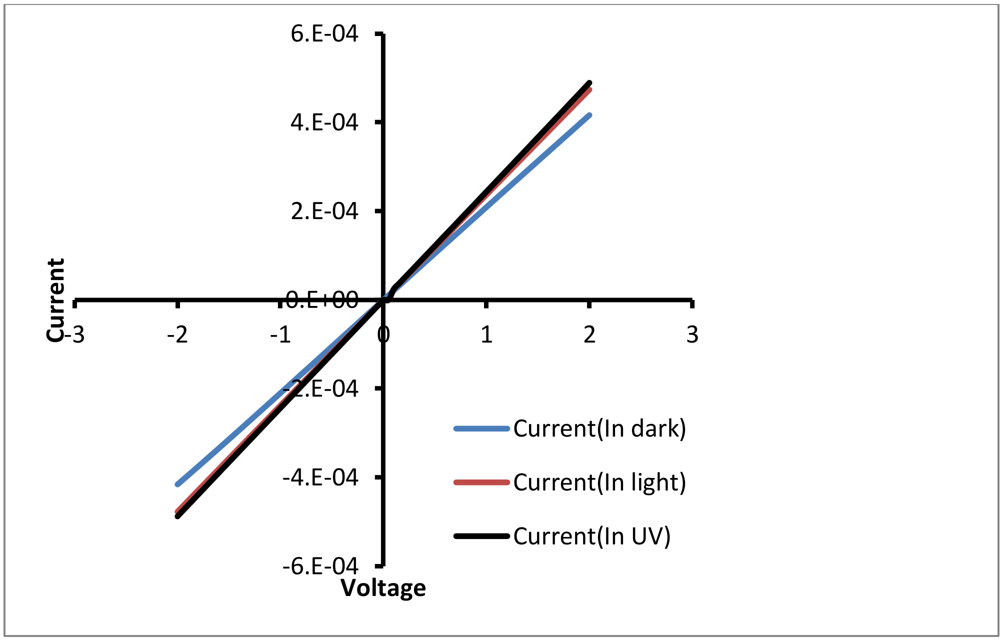


Figure12 : I-V measurements of Pristine SWNTs

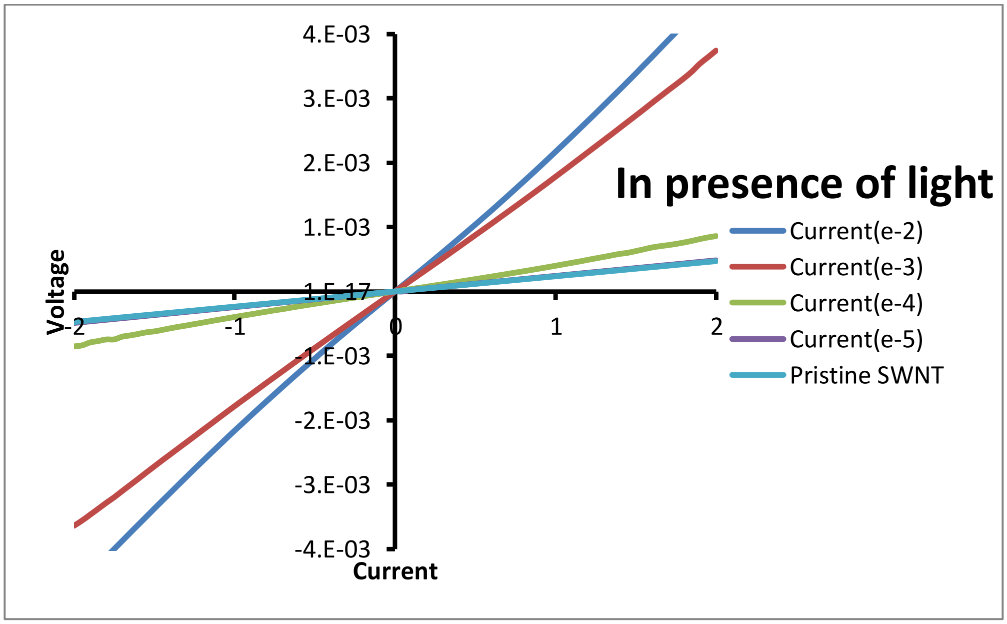


Figure13 : I-V measurements of Pristine SWNTs and OPV functionalized Pristine SWNTs of concentration of 10^{-2}, 10^{-3}, $10^{-4}$and 10^{-5} .

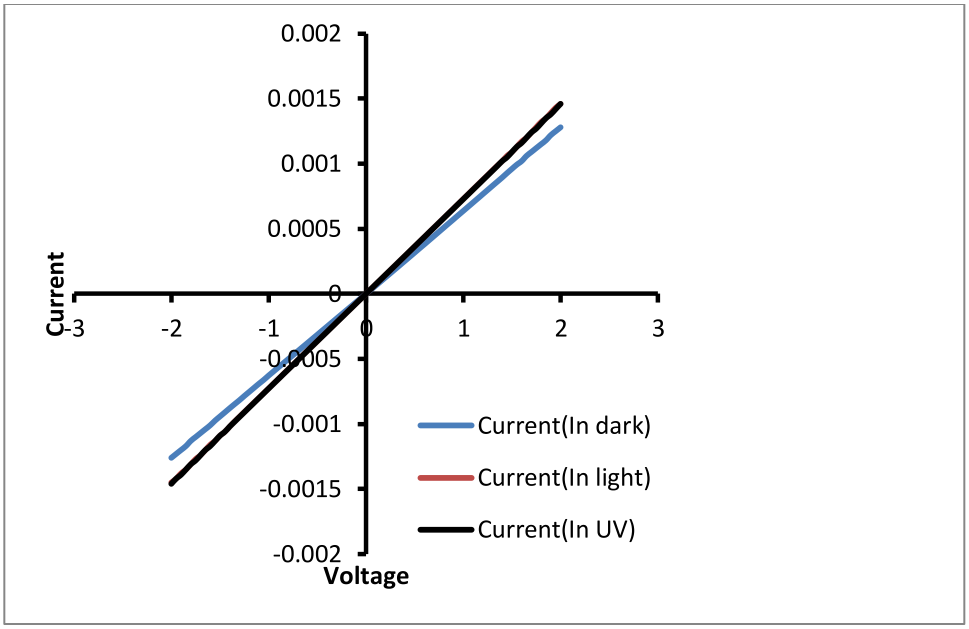


Figure14 : I-V measurements of Metallic SWNTs

Effect of light on Pristine, Metal and Semiconducting SWNTs

Photoconductivity is the phenomenon in which photon absorbed by the semiconductor and electrons excited to conduction band. Photoconductivity of semiconducting decreases with increasing voltage. Whereas in the case of metals and Pristine SWNTs, there is a constant change in photoconductivity.

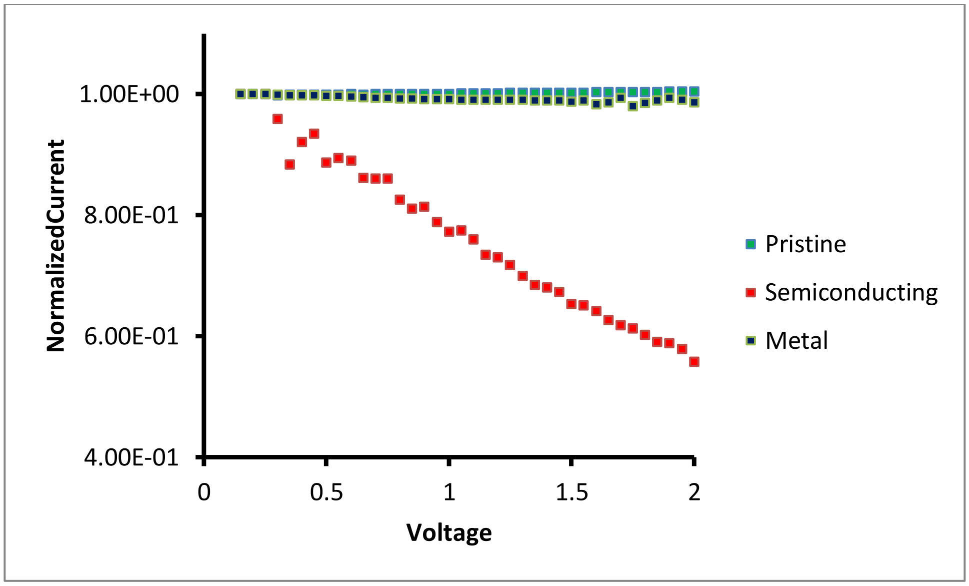


Figure 15 : Normalized current of non functionalized SWNT

Effect of light on OPV functionalized Semiconducting SWNTs

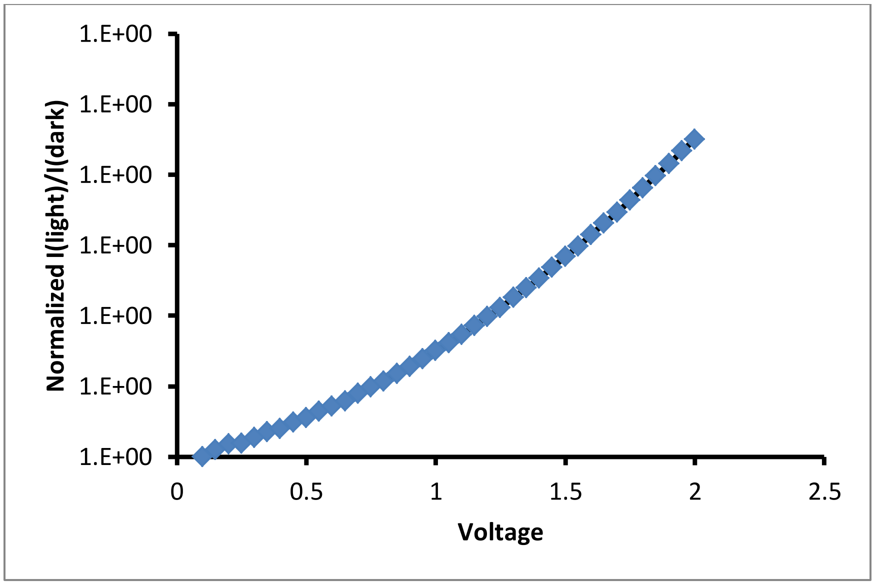


Figure 16: Normalized Photocurrent of OPV functionalized Semiconducting SWNTs

Effect of OPV on Single Walled NanoTubes

OPV functionalized Semiconducting and Pristine SWNTs have more slope than non functionalized Semiconducting and Pristine SWNTs.

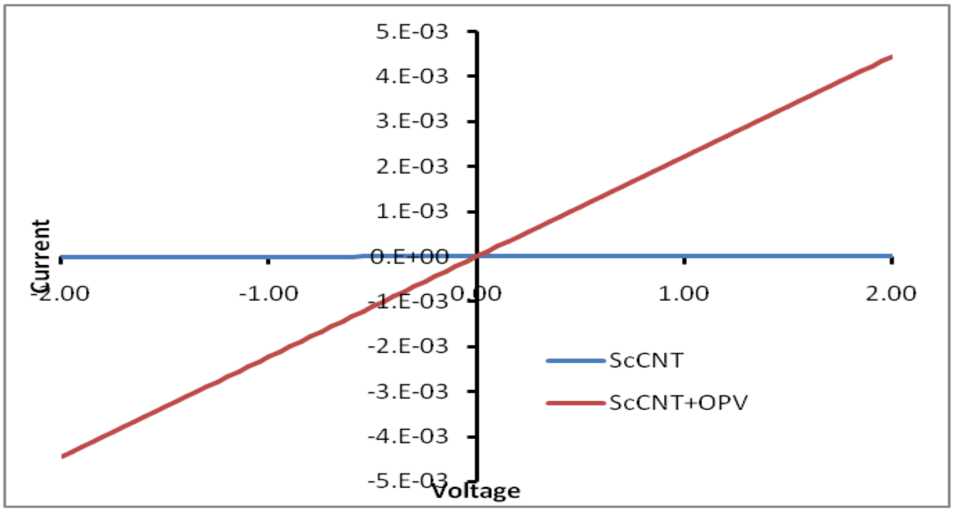


Figure 17: I-V measurement in absence of light

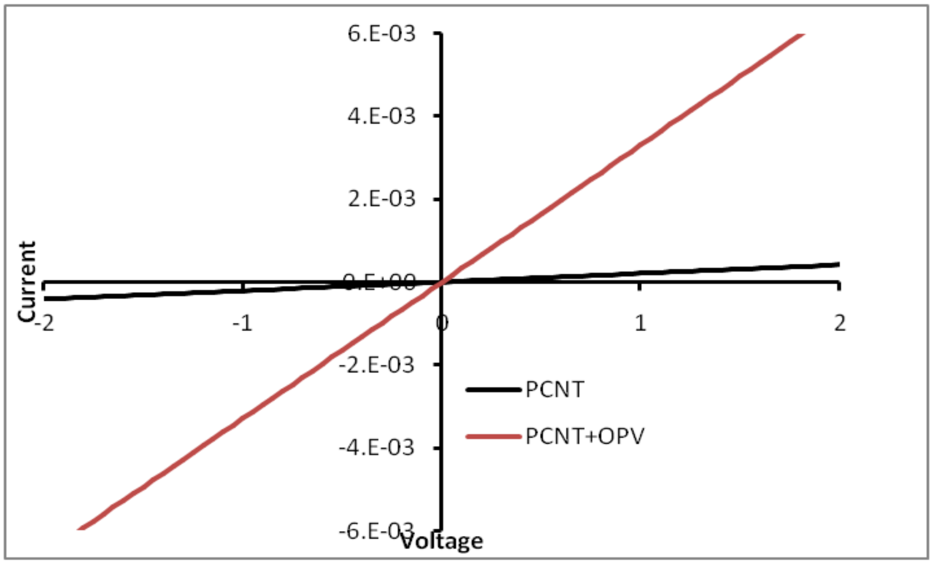


Figure 18: I-V measurement in absence of light

List of Ohmic and diode characteristics of SWNT

Single Walled Nanotubes	**In absence of light**	**In presence of light**	**In presence ofUV light**
Metal	Ohmic Characteristics	Ohmic Characteristics,	Ohmic Characteristics
Semiconducting SWNT	***Diode Characteristics***	Ohmic Characteristics,***decreasing***	Ohmic Characteristics,***decreasing***
Semiconducting SWNT +OPV(conc. e02)	Ohmic Characteristics	Ohmic Characteristics,increasing	Ohmic Characteristics,increasing
Semiconducting SWNT+OPV(conc. e-03)	Ohmic Characteristics	Ohmic Characteristics,increasing	Ohmic Characteristics,increasing
Semiconducting SWNT+OPV(conc. e-04)	Ohmic Characteristics	Ohmic Characteristics,increasing	Ohmic Characteristics,increasing
Semiconducting SWNT+OPV(conc. e-05)	Ohmic Characteristics	Ohmic Characteristics,increasing	Ohmic Characteristics,increasing
Pristine SWNT	Ohmic Characteristics	Ohmic Characteristics,increasing	Ohmic Characteristics,increasing
Pristine SWNT +OPV(conc. e-02)	Ohmic Characteristics	Ohmic Characteristics,increasing	Ohmic Characteristics,increasing
Pristine SWNT+OPV(conc. e-03)	Ohmic Characteristics	Ohmic Characteristics,increasing	Ohmic Characteristics,increasing
Pristine SWNT+OPV(conc. e-04)	Ohmic Characteristics	Ohmic Characteristics,increasing	Ohmic Characteristics,increasing
Pristine SWNT+OPV(conc. e-05)	Ohmic Characteristics	Ohmic Characteristics,increasing	Ohmic Characteristics,increasing

Conclusions

In conclusion, we have shown that the self-assembly of OPV molecules is accelerated through physical interaction with SWNTs in DMF solvents which leads to the formation of hybrid p-conjugated systems and good alignment of OPV with SWNTs. We have shown specific binding of optically active OPV with SWNTs. Absorption and Raman spectroscopy showing the binding of OPV with SWNTs. We have proposed using resonant based optically active molecule that by better binding of OPV with SWNTs except metal SWNTs, increases the conductivity of fabricated devices. Charge transfer from OPV to the SWNTs can be used for fabrication of efficient, flexible and lightweight solar devices. Till now, there are no published data which shows modulity in current by strong binding of OPV and SWNTs blends. This work suggests an exciting pathway for the conductivity of OPV functionalized SWNTs.

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