INVESTIGATION OF PHOTODETECTOR PERFORMANCE BASED ON $MAPBI_3$/RGO HETEROSTRUCTURE

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ABSTRACT

M. Sc. Thesis

INVESTIGATION OF PHOTODETECTOR PERFORMANCE BASED ON $MAPBI_3$/RGO HETEROSTRUCTURE

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The remarkable achievements in perovskites led to the development of photodetectors, which have a significant place in optoelectronic applications. Heterostructured perovskite-based photodetectors achieve higher performances than pure perovskite photodetectors. The current study demonstrates an rGO/MAPbI3 heterostructured photodetector produced by spin coating. The structure was characterized by XRD, SEM (vertical-sectional), EDX, and FTIR analyses. I-V and C-V measurements in the dark and under different lighting intensities showed that the current and the capacitance increase with the lighting intensity. Moreover, frequency-dependent measurements showed that the capacitance decreases as the frequency increases. As the light intensity increased, the n value increased up to 60 mW/cm2. ΦBo values vary between 0.45 and 0.68 eV for dark and different light intensities. n values higher than one indicate the presence of potential barrier inhomogeneities. The photosensitivity S(%) values of the Al/Gra/p-Si device were

calculated at the reverse bias of -2 V. The device's rectification ratio (RR) was 162 at 2 V.

Key Words : Photodetector, perovskite, reduced graphene oxide, heterostructure.
Science Code : 90532

ÖZET

Yüksek Lisans Tezi

$MAPBI_3$/RGO HETEROYAPILI FORODEDEKTÖR PERFORMANSININ İNCELENMESİ

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Perovskitlerdeki dikkat çekici başarılar, optoelektronik uygulamalarda önemli bir yere sahip olan fotodetektörlerin geliştirilmesini sağlamıştır. Heteroyapılı perovskite tabanlı fotodetektörler, saf perovskite fotodetektörlerden daha yüksek performans sağlar. Mevcut çalışma, döndürerek kaplama ile üretilen bir rGO/MAPbI3 heteroyapılı fotodetektörü göstermektedir. Yapı, XRD, SEM (dikey-kesitsel), EDX ve FTIR analizleri ile karakterize edilmiştir. Karanlıkta ve farklı aydınlatma yoğunluklarında yapılan I-V ve C-V ölçümleri, akımın ve kapasitansın aydınlatma yoğunluğu ile arttığını göstermiştir. Ayrıca, frekansa bağlı ölçümler, frekans arttıkça kapasitansın azaldığını göstermiştir. Işık şiddeti arttıkça n değeri 60 mW/cm2'ye kadar çıkmıştır. ΦBo değerleri, karanlık ve farklı ışık yoğunlukları için 0,45 ile 0,68 eV arasında değişmektedir. Birden yüksek n değerleri potansiyel bariyer homojensizliklerinin varlığını gösterir. Al/Gra/p-Si cihazının fotosensitivite S(%)

değerleri -2 V ters polarizasyonda hesaplanmıştır. Cihazın rektifikasyon oranı (RR) 2 V'ta 162 olarak belirlenmiştir.

Anahtar Kelimeler : Fotodedektör, perovskit, indirgenmiş grafen oksit, heteroyapı.
Bilim Kodu : 90532

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SYMBOLS AND ABBREVITIONS INDEX

SYMBOLS

η : Quantum Efficiency

S : photo sensitivity

I_L : photocurrent

I_{dark} : dark current

ABBREVITIONS

GQD : graphene quantum dots

UV : Ultraviolet

CVD : chemical vapor deposition

PVD : physical vapor deposition

GO : graphene oxide

rGO : reduced graphene oxide

MAPBI3 : Methyl amine Iodide

R : Responsivity

SNR : signal –to – noise ratio

G-R : Generation-Recombination

NEP : Noise Equivalent power

D : Detectivity

PEC : photo electro chemical

TEM : Transmission Electron Microscopy

SEM : Scanning Electron Microscopy

XRD : X-Ray diffraction

EDX : energy- dispersive X-Ray spectroscopy

NMR : nuclear magnetic resonance spectroscopy

FTIR : Fourier transform infrared spectroscopy

DMF : dimethyl formamide

Pbl2 : methyl amine iodide

RR : rectification ratio

PART 1

INTRODUCTION

With the increasing use of photodetectors, which convert light signals into electrical signals through the photoelectric effect, in fields such as spectroscopy, optical communication, environmental monitoring, healthcare, guided missile technology, self-driving cars, chemical and biological sensing, research on the development of existing photodetectors is increasing [1,2]. The basic requirements of photodetectors, which have become more common with the development of smart systems, are fast and high response and low noise [3]. For this reason, material selection is important as it will significantly affect performance. Direct bandgap organometal halide perovskites have demonstrated high performance in optoelectronic devices such as solar cells, light emitting diodes, lasers, field-effect transistors, and photodetectors. Since perovskite structures with different properties can be formed with different elements, each perovskite structure can exhibit different electrical, optical and physical properties. Thanks to these features, perovskite structures have become the focus of attention of researchers. It has been widely used and applied in the manufacture of photovoltaic devices, especially thanks to its high efficiency and low-cost features.

Graphene, on the other hand, is a promising material for new electronic devices due to its high electron mobility, atomic layer thickness, and unique mechanical flexibility. Broadband absorption has made graphene an attractive candidate for solar cells, ultrafast photodetectors and terahertz modulators. For graphene and GOs, the photoresponse states in p−n junction devices have been widely investigated, extensively studied in optoelectronic fields, especially photodetectors, thanks to their wavelength-independent light absorption and wide band gap, but they are the only one in optoelectronics due to their low absorption cross section and fast

recombination rate. limited its use. Thanks to the integration of graphene and perovskite nanostructures, these problems can be solved effectively.

Since the composite structures of perovskites formed with other materials to create heterostructures are an effective method to increase the performance of photodetectors, many inorganic semiconductor materials such as graphene and quantum dots or organic-inorganic composite structures have been investigated in these hybrid devices [4]. Despite the superior performance and technological production processes of inorganic photodetectors, complex and costly production methods pose a problem. The preferred flexibility, cost-effectiveness and simple fabrication methods for photodetectors can be met with organic and nanomaterials, but more studies are needed for expected performance outputs. It is possible to develop high performance photodetectors by combining the advantages of inorganic semiconductors with their easy processability and high charge carrier mobility with the effective light absorption of perovskites. In 1999, Mitzi et al. Organic-inorganic hybrid halide perovskites as active materials in field-effect transistors, and Kojima et al. used hybrid perovskites in photovoltaic cells [5,6]. Thanks to its superior optical and electrical properties, it has attracted great attention in the last 6 years, especially in the field of solar cells [7]. Of the organic inorganic hybrid lead perovskites, methylammonium lead halide perovskites (MAPbX3) (X=I, Br, Cl) are remarkable for their large absorption coefficients in a wide spectral range, high charge carrier mobility and small exciton binding energies. Thanks to the integration of graphene and perovskite nanostructures, the researchers were able to effectively improve the performance of photodetectors. In the results obtained for the rGO and CH3NH3PbI3-based photodetector produced by He et al., in situ synthesis method, more efficient charge transfer occurred compared to pure perovskite, and it was reported that the hybrid system showed 6 times more response speed with higher photoluminescence intensity [8]. Wang et al. obtained a wider band gap in their photodetector based on graphene/perovskite structure compared to pure perovskite. The structure exhibited higher sensitivity and higher photoconductive resistance compared to perovskite [9]. Spina et al. reported for the first time a CH3NH3PbI3 nanowire/graphene heterostructured photodetector [10]. It has been reported that the photosensitivity of the device is increased by producing electron-hole pairs in

nanowires under illumination, by separating the work-function difference between graphene and perovskite by the internal electric field. On the other hand, Dong et al., for a photodetector based on perovskite graphene structure produced on flexible substrate, under illumination, electron-hole pairs were produced in perovskites and transferred to graphene due to its low energy level, the device showed a wide band range from near UV to NIR [11].

In this study, the structural, surface and chemical characterizations of the heterostructure formed by coating SiO2, reduced graphene oxide (rGO) and MAPbI3 on Si wafer were investigated by XRD, SEM, EDX and FTIR. In order to determine the photodetector performance, current-voltage and capacitance-voltage measurements and frequency-dependent capacitance-voltage measurements were performed at different lighting levels and under darkness.

1.1. LITERATURE REVIEW

V.A. Nebol'sin, V. Galstyan, Y.E. Silina, in 2020 they made a discussion about how oxidation works for graphene and graphite, and at the same time all the pros and cons of graphene oxide were considered to be an independent substance, and this work was done by many analyzes and advanced environmental security systems have been carried out to answer many questions regarding the composition and independence of graphene oxide, finding that there are many attempts in the chemistry and physics of graphene and its development, and there are also many disappointments they are exposed to, but continuous attempts and continuous research on this substance and how to develop it and benefit from it in all ways [12].

Due to the good chemical and physical properties of graphene researchers and its derivatives, have become interested in using graphene and its derivatives more widely in many fields, including to create a composite coating that has high advantages, and for this reason in 2021 Many experiments and research have been conducted on how to benefit from it, in a paint way, and try to change the properties of the produced paint and achieve the required level. Arash Fattah-alhosseini * Maryam Molaei, Meisam Nouri, Kazem Babaei made a thorough comparison and

reading of all the research conducted on this subject and showed them graphene and its derivatives can be used in coatings to enhance hardness, corrosion and wear resistance, resulting in superior optical activities [13].

In 2018, Xingguang Wang, Mingming Li, Biao Zhang, Huan Wang∗, Yang Zhao∗∗, Baohui Wang did extensive research on halide perovskite photodetectors and their properties and review all the advantages and disadvantages due to the great interest they received due to their performance in a photoelectric device, and they focused largely on its work in the field of operating devices and for harvesting the light. And their focus was largely on conductive optical detectors and optical detectors with a vertical structure, in terms of their response and operation, and how they performed compared to their quality. And it was shown to them that it is possible to enhance the capacity and increase the efficiency of these devices by adding materials such as TiO2 or graphene. However, the instability of perovskite photodetectors remains a challenge and must be addressed, so the researchers tried to mix them with certain materials to increase their stability [14].

H. Ferhati, F. Djeffal, in 2019 proposed a new p-Si-MSM-UV-photodetector (PD) based on interdigitated graphene electrodes. This is to obtain higher performance and great response speed, and they proved in their studies that all of these can be improved with the presence of graphene, and this is due to its speed and superior transparency, and this is what makes this device significantly superior to traditional devices, as it has a response time of 3 micros per second. These good properties make it a very suitable device for high sensing applications, especially using 2D materials [15].

Al-Shammari A, B, M. Halim, F. Yam a, N.H.M. Kaus in 2020 presented an easy way to create PDS modules to give high-performance UV photodetectors, showing that a thin layer of tio2 or tio2/Go can be added to glass. With the increase of rGo, the graphene layers can become more compact and affect the conductivity. The results showed that the presence of tio2/Go in UV photodetectors could become one of the great filters in this field [16].

Due to the emergence of various types of ultraviolet detectors, researchers are constantly trying to make new and more developed types that can benefit more from them. In 2019, Changsong Chena , Shaoda Zhanga , Baofa Hua , Haisheng Sana, b,∗ Werner Hofmanna, Zhengdong Chengc, and Werner Hofmanna made a kind of carbon nanowire which is thermoplastic and is successively combined with rGO and SWcnT to detect ultraviolet rays. And they also made a full comparison between a light detector based on RGo / ZNWS with a second device that is also for light detection, but based on SWCNTs / ZNWs, so it was found for them that the first type has a high optical response, which is higher than the second type and by negating When its efficiency is very high, the second type is characterized by its ability to turn on and off, and the response time over the first type, and its cost is also appropriate [17].

Because of the continuous need for energy continuously, there has become a need to store and retain the energy that is produced, and for this reason in January, 2022 Eyyüp Can DOLUEL made a complete thesis to try to increase the efficiency in the anode and how to produce graphene and how to benefit from it and use it in the anode. And through the experiments that he conducted, it became clear to him in the results that the batteries that are used on a daily basis and which are made of lithium can be produced from the graphene anode and in several ways [18].

Lin and others attempted to find and demonstrate an organic halide perovskite photodiode equivalent to commercially available silicon isotopes, which in turn made four types of devices: the first one that had a thin layer of vinyl with a layer of methyl butyric acid methyl ester) PC6oBM) with a thickness of 10 nm, the second device consists of a layer of (PC6oBM) with a thickness of 50 nm, the third device consists of a layer consisting of C6o thicker and reaches approximately 130 nm, and the last device was exposed to the lowest dark current. It was found that the fourth type can provide the ability to detect light above 1012 johns through UV - visible light [19].

Fang and others made a device with advantages that could solve the problem of weak light for picopods, where the device is a photodetector consisting of a hybrid

perovskite. Which is low noise by electron transfer by adding a layer of double fullerene, which reduces clicking noise and shot noise. Various types of ELT and HLT were used because of their ability to reduce noise, and they also made three new devices: the first device, which is HLT and PCM/C6o 20/20 nm ELT, and the second device is also HLT PCM/C6o 20/20 nm ELT, the third device which is crosslinked like HLT and PCM/ C6o 20/20 nm ELT [19].

For the first time, Sutherland et al. modified the photodiodes based on spiro-omeTAD Tio2/perovskite, and these modifications were made by applying a thin, toothless AL2O3 layer over the Tio2 material, which features a nanostructure to enhance the extraction efficiency. The carrier, as it was found that the results given by the finder device have a very high sensitivity in areas near infrared as well. After their discovery, a perovskite-type light detector was discovered and manufactured, which has the ability to work with self-energy and has a basis of Tio2 nanorods/CH3NH3PbI3, which is heterogeneous, and has the ability to respond to ultraviolet rays also because of its dependence on Tio2 [19].

Lee and others have constructed a photodetector from perovskite and reduced graphene and at the same time compared it with a second device in which graphene is virgin. It was found that the light current in the new device is higher and at the same time the wavelengths are shorter. Many other attempts have been made to produce highly responsive and high-performance optical transistors, as the first optical transistor made of CH3NH3PbI3/graphene nanowires was demonstrated by Spina et al. After doing many experiments, the light response and the rise and fall time of the device were improved [19].

Many optical transistors have been produced and discovered by many researchers such as Dong, Zhang, Teng, Wing and many others. They reported on devices they produced or developed, but among the devices that had the highest performance compared to most other light detectors were The ones made by Zhang et al. It was created by steam deposition and was working on both organic and inorganic light. After that, the researchers found that the hybrid devices have a response to light that is eight times higher than the pure CH3NH3PbI3 photodetector. At some point, Su

and others reported that they had developed a photodetector that does not need external energy, that is, it is self-operating, and it showed very good results and a quick response, and its detection includes ultraviolet rays and visible light as well [19].

Because of the special properties that are present in graphene such as its carrier movement and its various chemical and physical properties, it is very suitable for use in solar cell devices and light detectors as well. At the same time, it is possible to benefit from graphene derivatives such as graphene oxide, as it is considered one of the materials that have a major role in the stability of solar cell devices [20]. Reduced graphene oxide, which is largely produced by a certain process in which a part of the oxygen is taken on the surface of graphene oxide, and this process is done by many methods such as chemical or thermal reduction. This material derived from graphene can be used in many light detectors because of its low price and the possibility of using it in organic and inorganic materials as well. In several recent studies, it was shown that if reduced graphene oxide, which is specifically p-type, is used in semiconductor devices, a high response is provided [21]. The presence of TiO2 in solar cell devices with rGO is considered an advantage to increase the efficiency of the device and increase its performance, and because of this feature, the use of TiO2/rGO has become one of the most widely used structures to detect light and is constantly compared with pure TiO2.

The presence of reduced graphene oxide in different quantities in light detectors (TiO2 /rGO) gives different results in performance. It is possible to reduce the gaps of the thin films as the amount of rGO increases, and this directly affects the electrical conductivity of the device. This gives the possibility of a promising and advanced future for light-detection devices. After that, researchers' interest goes to a second direction, which is the possibility of making devices that do not require external energies. Any self-powered devices that produce electrical energy directly from photovoltaic energy, the configuration of these devices is p-n junction, Schottky junction and photoelectric .[22]. Self-powered devices, especially those of the PEC type, are characterized by their ease of manufacture and stability .[23].

Autonomous PEC type devices (SPPD) can be easily produced by using metal oxide with semi-continuous materials such as ZnO and TiO2. The use of TiO2 has become popular due to its cheap price, chemical stability and many other advantages. But like all other materials with advantages, it also has disadvantages, because when used alone, this material cannot absorb all radiation [24]. That is why researchers are trying to combine it with other substances to activate it and help it expand the extent of its absorption.

Graphene can be utilized to help increase electron transport and thus reduce electron-hole recombination, and this is what [25]. attempted to demonstrate in an autonomous device that is based on graphene, TiO2 nanorods and ZIS. The results showed that a device has a high response to visible light, unlike other devices. It is shown in Figure (2.1) how to install and operate the TNRs / G / ZIS device, which works without any external energy. Where it was found that the presence of TNR has a benefit in electron transfer and the presence of ZIS improves the response of TNR in front of all kinds of light, and the presence of graphene has a benefit in separating carrier waves and transmitting them quickly.

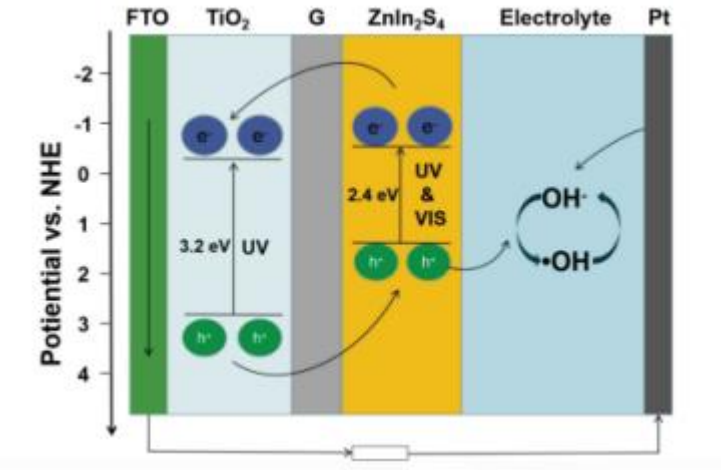

Figure1.1. Install and operate the TNRs / G / ZIS [25].

Semiconductors such as Zno are important materials for light detection devices, which are often inexpensive and easy to manufacture .[26]. The use and emergence of materials that are semiconducting (CdS) and combined with Zno helps to isolate the electron-hole pairs, and when graphene is present and combined with them, they

can form a heterogeneous structure of graphene / Zno / CdS, which has a high response to most rays From violet to visible. Graphene, in its presence in the device, added a greater conductivity and high sensitivity as well.

In light detectors when TiO2 NTs is used in their structure, their response is good, but while using TiO2 NT nanotubes, the performance is much better with a significant increase in response [27]., and the presence of graphene can increase these properties, and for this reason its use with TiO2 has become very popular in light detectors. Because there is a difference in the energy level between TiO2 and graphene, this helps to transfer an electron, and this prevents recombination of charges. One of the most well-known and used methods for making TiO2 NTs is electrochemical synthesis. Researcher oothongkaew et al made a light detector consisting of TiO2 NTs with several layers of graphene covered in it [28].

ZnO is also considered one of the materials that have received great interest by researchers in regards to its use in light detection devices, as it is characterized by its low price and large surface area, and it is also good in detecting ultraviolet rays. Like any other semiconductor, this material can also be combined with other materials to increase its properties and improve its performance. When adding materials such as DZnO nanowires (ZNWS) to it, its properties increase, but it has other drawbacks such as the photoelectric efficiency that is low. Benefiting from graphene in these cases is one of the most appropriate solutions to improve the sensitivity of these devices. But so far, not many studies have been done regarding this type of combination of graphene and ZNW. In general, two types of compounds have been prepared in which ZNW is used with graphene CNT only .[29]. Where they used rGO with carbohydrate ZNWS and SWCNTs, the experiments conducted on this device show that its properties and response in terms of results that gave it better than pure ZNWS.

Various physical mechanisms of the chemical effect of oxygen were studied in the study. The device is characterized by a high sensitivity to detect light and a much higher on/off ratio. InGaZnO (a-IGZO) is the most common AoS, which is used for gas detection. But because of the very few studies on AoS that are specifically in

improving performance, the few of the studies that have been conducted on it have become more widespread, as Huang et al made an attempt to develop a UV and O3 detector that helps to sense By gas fractions (Huang, Yan & Lou, 2022). As shown in Figure (2.2) and it appears in the results that the device shows that the response is quick to the sensitivity, and at the same time the response of the device to the gas is high, which can reach 12.8, and this proves that the device is a gas sensor as well and not only a photodetector.

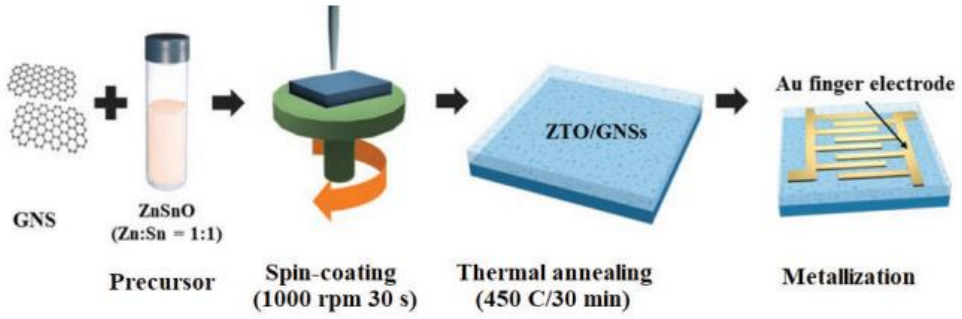

Figure 1.2. Produce a dual-function a-ZTO/GNS device [30].

A portion of one or more layers in graphene are defined by graphene quantum dots (GQD), whose properties are distinct such as that they have a fast electron transfer rate and a large surface area. And while its particles were less than 100 nanometers in diameter, they are highly sensitive to ultraviolet (UV) and visible light as well. It is possible to obtain a high photoelectric current with a low dark current when making the structure of ZnO / GQD, because of the structure in ZnO which contains nanoflower, which increases the absorption of weak rays and at the same time the presence of GQD helps the transmission, the results of the work of this device showed that the current Low is 40nA and visible light is 2.1μA. Recently, it has been shown that materials such as diamond and Sic may be promising materials in light detection devices .[31]. When Sic is thermally analyzed at a very high temperature, graphene/Sic form is obtained, and this is the most appropriate method to obtain graphene/WBGc junctions, which is one of the most correct ways to improve light detection devices .[32]. When we get graphene/Sic, researcher Li et al proved that the performance of the device is affected, it can directly see an electron when it is transferred from Sic to graphene, and this increases the Fermi energy, and when we

reduce the number of graphene layers to one layer, sensitivity and efficiency increases with it. It is affected well, in general the performance of the device is improving. The outstanding performance of some materials such as (4H-SiC) due to its wide bandgap and high heat conductivity has become a source of interest for researchers such as Bencherif et al .[33]. After the many experiments that are conducted continuously to improve the performance of optical sensors, it was found that metals such as Au, Ag, and Pt. can increase the absorption properties, without forgetting that graphene remains one of the basic materials to increase the performance of the devices .[34]. Bencherif et al demonstrated a graphene/4H-SiC MSM device, whose goal is to improve the device with Au particles. The results showed that Au has the ability to increase SiC adsorption capacity and improve graphene sensitivity and response time by up to 60%.

On the other hand, researchers are trying to work on improving the elasticity of the devices. As the elasticity decreases and the flatness increases, the device works better. For this reason, Liu et al created the ZiO / graphene device, but this is enough to weaken the device in one way or another .[35]. This can be improved by placing a layer of perovskite between the ZnO and the graphene, because in a way CSPbBr3 inorganic halide perovskite, especially the P-type, has superior properties. For this reason, various strategies have been developed and implemented to incorporate CSPbBr3 into ZnO NW/graphene light detectors .[36]. A lot of research and studies have been conducted regarding the development of light detection devices that depend on nanoelectronics to increase the quality of the device [37]., but in some of the studies they showed that the response time of the device could be reduced due to Electrodes that are interconnected .[38]. This proves that there is a great need for further studies on this topic to improve the response time of these Si-MSM devices. The researcher Ferhati et al showed a device that detects violet-P light of the type Si-MSM, which is based on GrIE, and its use is due to its rapid response to ultraviolet rays, and its low optical loss .[37]. The results showed that the photoresponse of GrIE/P-Si is significantly better than that of Au/P-Si photodetectors. Also due to the ability of graphene to bond with materials that are semiconducting which could improve the performance of the devices, researcher Bei et al. followed the electrochemical deposition method to create a structure of

ZnO(NAs)/graphene/CuO2 compounds for the light-detector that is from PEC type, the results showed that the UV and visible rays were 21.2 mAW-1 and 17.1 mA W-1. Because of graphene, electrons can be transferred from CuO2 layer to ZnO, and CuO2 gives high conductivity due to its current density, and the presence of graphene increases the device's ability to carry charges. PEC type.

PART 2

PHOTODETECTOR MATERIALS

2.1. CARBON BASED MATERIALS

From the very beginning, the presence of carbon has greatly affected the daily life of man. For the first time when a fire was detected, they discovered the smoke from which carbon was produced. When this smoke hits a certain place, a black spot is produced, which can be considered as unburned carbon. In the eighteenth century, scientists recognized it as an element, specifically in 1789, the element carbon was officially named after the old Latin name for coal, which was named by the scientist A.L Lavoisier, and then French chemists wrote a special book on this subject [39].

The element of carbon, or what is called the element of life, because it is included in most of the structures of the human body, it is the second element available in the body, especially in the mind, where it forms its basis. Carbon is one of the fourth materials available in the universe, as it consists of six protons and six electrons, and the presence of six electrons in its formation helps it and allows it to bond with four other carbon atoms or any of the hydrogen atoms or any other atom in order to achieve stability in its outer shell, and this is due to the presence of Four electrons are in its outer shell and it needs four more electrons to stabilize its shell, so that it bonds with other carbon atoms or other atoms to achieve stability. The structure of the carbon element is shown in Figure (2.1) The element carbon can bond to each other and create long chains of carbon atoms, which can extend to millions of atoms [40].

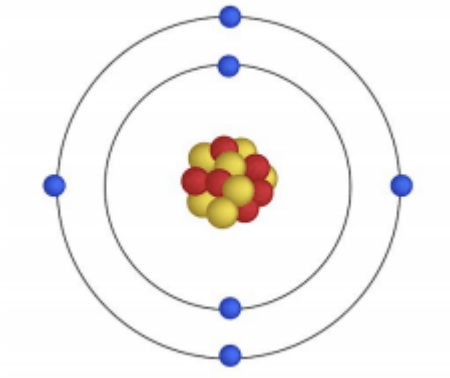

Figure 2.1. Structure of carbon.

Carbon is one of the most known elements on earth, and it is included in all areas of life. Because of the carbon scope and importance in many fields, there is a complete science related to this substance, which is called the science of organic chemistry. Carbon is used in the manufacture of plastics, glass, and medicines, as well as in the food industry. The bonding of carbon with itself has many forms, and most of them are very strongly bound, but it can be break and link them with other elements. Figure (2.2) shows the shape of the element carbon.

Figure 2.2. Carbon [httpsimages.easytechjunkie.comcarbon-rock.jpg].

Allotrope is a term given to substances that have one or more forms in chemical elements, but have the same physical state, meaning that a particular element bonds to its atoms differently and each time a different substance is created. Of the most allotropes that can be created from the element carbon are diamond and graphite, as shown in the figure (2.3) Which shows the types of allotropes made of carbon.

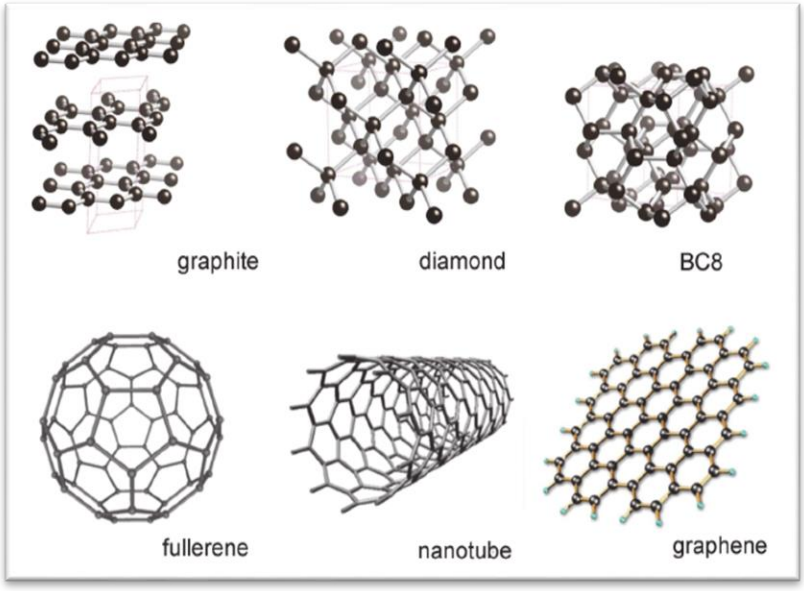

Figure 2.3. allotropes of carbon [41].

Diamonds are materials made entirely of carbon. Each carbon atom is covalently bonded to another similar atom. The reason for the existence of different sizes of diamonds is because there is no limits in the connection between atoms, the more atoms there are, the larger the diamond with it. Because of the strong covalent bond present in diamonds, they have many distinctive properties. They are very strong, a good conductor of heat, have a high density, and have a very high melting and boiling point. On the other hand, they are a poor conductor of electricity and do not melt easily. When three of the electrons in a carbon atom are associated with three other electrons from another carbon close to it, where one of the electrons remains in a layer that can move freely, this entire process is to obtain a three-dimensional graphite material. The bonding of atoms in graphite is stronger than that found in diamond, and this is due to the free electron that works on additional bonding in the layers. Graphite has a high melting point and is fairly soft and is widely used in pencils. It is an excellent conductor of electricity and heat, but it is insoluble in water or solvents. To obtain single layers of this material, all layers that are molten must be broken in its structure.

Since carbon is present in most of the materials around us, it has many properties, whether it affects positively or negatively on its surroundings. Pure carbon can exist in more than one form with different colors and crystallization, and also from

possible abundance of carbon in the form of allotropes, which are also carbon, but due to the bonding of their atoms, their physical and chemical properties also change. In the earth's crust there is the presence of the element carbon, even if it is a secondary role, but its presence is important, and with regard to photosynthesis, carbon is an important element. and in terms of the chemical properties of this element, the atomic number of carbon is 6 and it has an atomic density of 2.2 - 3 cm, and in terms of boiling point, it is 3652 degrees Celsius. Carbon has a high ability to bond with each other and form long, stable and strong chains at the same time, and there are no limits to determining the number of atoms that can be attached to each other. Although carbon is an important part of our life, when compared with other elements, it does not have many chemical properties. Because carbon is resistant to oxidation, it cannot interact with many metals and materials such as chlorine, hydrochloric acid, and others [42].

The interest and studies of researchers about carbon is largely due to its presence and use in most of human daily activities. They constitute 18% of the body and are considered an important source of carbohydrates in most foods such as proteins and sugars, and diamonds, which are considered carbon, although it is considered one of the most beautiful and most expensive stones in existence, but it has many other useful uses, it can be used for cutting glass and polishing as well. It is possible to use carbon in paints as well, and from other forms of carbon such as graphite, which is more widely used in pencils. One of the most important areas in which this element is used knows the age of bones and fossils, which researchers call carbon 14.

2.1.1. Graphite

The presence of graphite in nature is not new, but it was present in more than one form. around the year 1565, some people who lived in the areas of Seathwaite Fell, especially near Borrowdale in England, found strange deposition of a dark-colored substance close to black, and they began to use it extensively in It was placed on sheep and animals to separate them from each other, and after that it became clear to them that this deposition is graphite. But scientifically, graphite was known when the scientist Edward J. Acheson was working on certain experiments on carborundum at

a very high temperature, which reaches 7500 degrees Fahrenheit. What was later called graphite. Where Edward took on this achievement the patent, after which everyone was trying to make it commercially, especially after 1897.

Graphite or we can also say plumbago is an abundant natural mineral that consists of several layers of one carbon atom. Graphite comes in many ways, including when carbon compounds are reduced and turned into carbonaceous materials, and is also found in abundance in meteorites and igneous rocks. It is very similar to other carbon groups and its color is opaque between gray and black and also its shape in the form of flexible sheets or large lumps, sometimes it is earthy or can also be compacted. The presence of this substance in highly metamorphic rocks and in many places and large cities [42]. Figure (2.4) shows the Structure of Graphite.

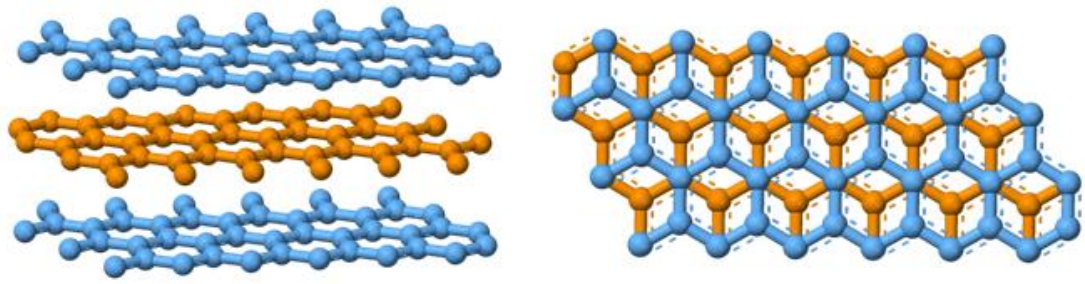

Figure 2.4. Structure of Graphite.

Often, if we look at natural graphite, we find that it is not pure, and its availability in large sizes is very rare. So a lot of research has been done on the possibility of making industrial graphite by extrusion or pressing of coke, and crystals of different sizes can be produced due to the temperature in the graphite material. According to the research that was conducted, it was found that this graphite may also be heterogeneous, and also its resistance may differ between one graphite and another, due to the size of the crystal and sometimes to changes in the thermal path. The crystal form of graphite is shown in Figure (2.5).

Figure 2.5. Graphite.

After conducting a lot of research and experiments in the past years, amazing features and qualities were found about graphite. Graphite is very strong and has the ability to work at high temperatures, and it can interact in many chemical reactions and at the same time graphite conducts electricity with high efficiency, as it displays In Figure (2.6) because of the presence of free electrons in its layers, it can move within layers, and this helps it conduct, and it has different acoustic and thermal properties. Graphite is characterized by its optical properties where the contrast of its properties reaches the maximum, and also characterized by its strong multi-color; it can largely be used on materials that are subject to corrosion, as graphite is considered a rust-resistant material. It is also uniaxial and has severe refraction as well. The layers of graphene are bound together by a force called the van der Waals force .[43]. The use of graphite in its pure form is little, and this is due to its poor mechanical properties and fragility, so it can be used with minerals or other materials and to make chemical compounds.

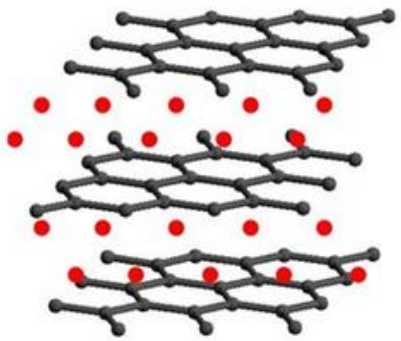

Figure 2.6. Free electrons between the graphite layers.

There are many applications where graphite has been used because of its special properties. Because of the strong bonding between the atoms in graphene, it makes it a very strong material, which makes it suitable for use in making armor and rocket engines. Despite the strength of graphite, it has a high ability to extend, as it is very flexible. It is used in plastic pipes and is placed in places where there is fire. When graphite is stretched, it acts as a resistance material against the spread of fire. It can also be used in nuclear reactors, and when mixed with rubber materials such as Sumpf, it can be used as a radar-absorbing material. And it can be used in batteries and the manufacture of steel materials and lubricants as well. In the past years, the use of graphite in batteries has become more widespread. In some of the batteries in cars, more than 40 kilograms of graphite is used. The use of industrial graphite has also become widespread, as it has been widely used in bicycle frames, golf clubs, and the body of sports cars as well.

2.1.2. Graphene

To identify graphene, we must look at the things and living organisms around us with a second look, or rather, we must look at the new dimensions that are found only in graphene. Although in recent years the name of graphene has become frequently repeated and interest in it has become clear both in research or scientific experiments conducted by researchers. But the existence of graphene itself is not new. In fact, researcher Benjamin Collins showed in 1859 the layers of reduced graphene oxide, which are high, after which the experiments taking place in this regard became more and more scientists' interest in graphite and an attempt to isolate its layers, as did Bohm and his colleagues in 1962, when they isolated layers of graphite by electron migration. Where they used the term graphene to describe a single layer of graphite for the first time in 1987. And around 2004, Dr. Andrei Gaim and Konstantin Novoselov in America and Russia, specifically the University of Manchester and the Institute of Technology, used mechanical peeling on graphite layers to obtain a single layer of graphite. It is possible that there are about 3 million layers of graphene in 0.3 mm of graphite, which they transfer onto a silicon substrate. For their experience, they were awarded the Nobel Prize. In a figure (2.7) Showing the graphite and its layers, it shows that one of these layers represents graphene. There are many

methods for producing graphene including chemical vapor deposition which is one of the most common and widely used types of graphene production. [44].

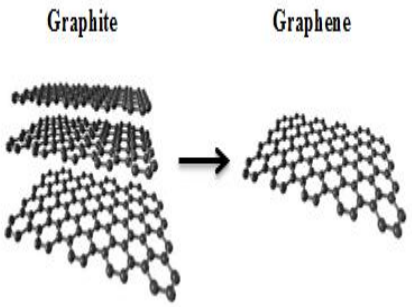

Figure 2.7. Graphite and Graphene.

Graphene is an atom made entirely of carbon that has a single, two-dimensional layer, and is shaped like a honeycomb. The thickness of the graphene disc is in the range of 0.35 nm, which is 1/200,000 times smaller than the diameter of a human hair. Figure (2.8) shows the shape of single-layer graphene discs. Each disk of graphene has three stable and strongly conductive bonds with each other and is completely stable, as this stability in the graphene structure is due to the orbital hybridization of atoms and the strong bonding between these atoms. It is possible to find graphene in the form of a nano ribbon, which can act as an energy barrier, the smaller the width of the tape, the greater the energy barrier. This property of graphene can be considered a promising future for graphene-based electronic devices . [45].

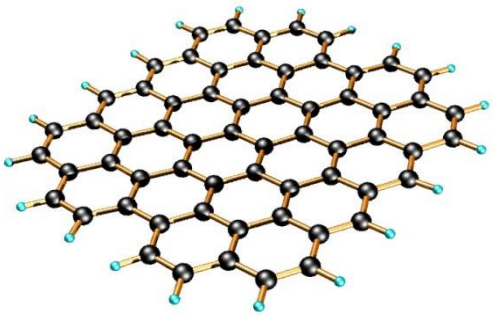

Figure 2.8. Graphene Structure.

Graphene is one of the materials with great properties, as it has attracted a huge amount of properties and made most researchers interested in it and trying to make

use of it as much as possible [46,47].Graphene has a very high mechanical strength, about 1600 GPa, and is considered a superconducting material without the need for high temperature. The reason for the good conduction of electricity is due to the electric current density, which is hundreds of times better than that of copper, and the mobility of charge carriers is very high, when electrons move through graphene they have no resistance. Its thermal conductivity is fantastic, and graphene is an incredibly flexible material that can make a computer screen fold into the size you want, stretching to 25% of its length. Graphene also has a very large and wide surface area, and is light in weight despite its high tensile strength. In terms of light, graphene produces an optical current by forming two electrons by absorbing photons, and if they are separated from an external location, light is produced. Graphene can change and make life easier, as it makes it easier for people and gives them access to fuel directly from the air, it has the ability to make salt water drinkable, it can also protect metals from rust, and it can even detect cancer cells in the human body. But graphene is incompatible with water and quickly agglomerates because it contains water-resistant solutions [48].

By looking at free-form graphene from powerful microscopes, it was found that the surface of graphene is not completely flat, but rather rough and has ripples and bends, and these bends are usually naturally present in graphene, which are nanometers in size. Where it was found through microscopy that these ripples are caused by changes in temperature, and the freedom of electrons can cause asymmetry in the lattice. It is important to know that the changes that occur due to the change in temperature may change again over time, and there will also be ripples on the edges of graphene where its density is higher than in other places, as shown in Figure (2.9) Wrinkled, Wavy and Crumbled Graphene: Overview of Formation mechanism, electronic properties and applications. [49]. Many researchers have tried to create and make developments to reduce these floats that exist on the surface of graphene by predicting its surface composition and identifying its defects, and these ripples can also be used in chemical reactions towards hydrogenation, and annealing is the reason. ripples can form in graphene and heating it can sometimes return the plates to their normal state [50].

Figure 2.9. Graphene ripple.

Many methods have been used to produce graphene and the most successful and developed methods are chemical synthesis, chemical peeling, mechanical peeling, microwave synthesis and chemical vapor deposition (CVD). The CVD technique is one of the fastest and most widely used methods to support the growth of the membrane, and due to the selected substrate and the different temperature, its composition and multi-layers may also differ. To perform this process, the method must pass through two stages. In the first stage, an attempt is made to activate the gaseous reactants, and then comes the second stage, which, due to the chemical reaction that occurs, forms a stable layer, and then carbon accumulates when it reaches a high temperature, and this is how the graphene meets on Surface The figure (2.10) shows the process of producing graphene by this method (30).

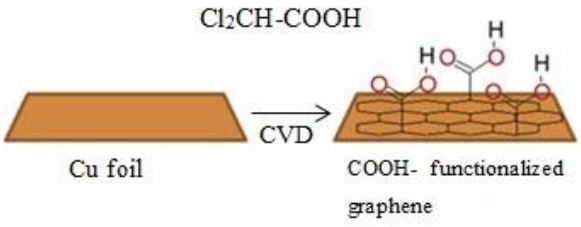

Figure 2.10. CVD graphene growth.

The second method by which graphene can be produced is mechanical exfoliation, which is by means of an adhesive tape that is pasted on the surface of the graphite material, but when removing graphite from the adhesive material, there is more than one layer on the adhesive surface, so by repeating the process more than once it can be obtained one layer which is graphene. It is considered one of the easiest ways to produce graphene, but it is not suitable for large quantities.

The many properties that characterize graphene give it the ability to be used at least in most applications and fields. Because of the strength that graphene is characterized by, it can be used to increase the strength of materials, so it is possible to add it to metals and plastics to add strength to them, even if the added amount of graphene is little. And its conduction of heat gives it the ability to use it in heat dissipation, this property makes it useful to increase the light in the LED and make its life longer, and graphene has also been used in mobile phones, where the thermal films added to the phone are based on graphene. The small size of graphene makes it very suitable for use in storage applications, especially in batteries and capacitors, as it is stored and charged more quickly compared to other materials. It can also be used to paint materials and protect them from corrosion. And because of its high flexibility, it can be used in screens and solar panels as well. Another use of graphene in our daily life is in the blades that are on the oar, in order to help it withstand shocks and resistance. And in medical applications, it has recently become used in sensors to help detect particles of materials.

2.1.3. Graphene Oxide

It is possible that the history of the appearance of graphene oxide is older than graphene itself, after the discovery of graphite when the researcher Benjamin Brody oxidized and exfoliated graphite around 1859 and produced graphene oxide when he showed it in the form of a single layer, but at that time because graphene is not known And there is no background on it so the discovery of this material did not get the attention it needed. Then, when graphene was discovered, they found that this method for creating graphene oxide was effective, inexpensive, and could benefit from it in the long run. Many have tried to prove that the term graphene oxide is incorrect and cannot be used for this material, but it has been scientifically proven and it is not necessary to give a literal meaning. Researchers such as Hirsch have tried to find an appropriate nomenclature for graphene derivatives such as graphene oxide, but no result has been reached [51].

The use of the word graphene oxide has become a greater place in research and scientific literature, although this word has not been officially recognized, but is used

by researchers to describe a network of carbon, which is one atom intertwined with groups of oxygen or molecules Oxygenated on its edge, the structure of graphene oxide is illustrated in Figure (2.11) and it is possible to define graphene oxide as formed through a chemical reaction between two-dimensional graphene with oxygen, hydroxyl or carboxylate. It is known that the thickness of this material is 1.1 and 0.2 nanometers, but its dimensions can reach approximately a few nanometers or hundreds of micrometers. Although graphene has deformations on its surface and sometimes affects it, its presence is not very large, the distortions and wrinkles on the surface of graphene oxide are very large and often affect it, and the chemical composition and changing amount of oxygen can affect the graphene oxide quality or method. Its production and the final product. After many attempts and experiments about graphene oxide, at the end, a model was proposed that was acceptably perfected [52].

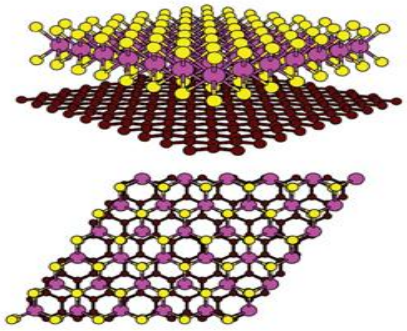

Figure 2.11. Structure of graphene oxide.

Graphene oxide is another material with graphene-like properties because its structure is oxygen-dependent and chemically shifting. And when the oxygen separates from it, it can turn into graphene. In fact, graphene oxide is formed by the oxidation of graphite, whereby we can increase the tensile strength by increasing the oxidation in terms of the materials used in the oxidation. Potassium chlorate is one of the most prominent and widely used. This material has outstanding mechanical and electrical properties, including that we can use it in polymeric nanocomposites due to its tensile strength. But graphene oxide is a non-conductive material, so we can use it as an insulator and any electrical resistance materials, and it has a low thermal conductivity, as it can be used as a heat insulator for clothing and can be used to

improve heat transfer efficiency [54]. When comparing graphene oxide with graphene, the chemical and physical properties of graphene oxide are very unique and should receive more attention in experiments and discoveries. More than 40% of its surface is oxygen and this is what gives importance in its field. It is possible to install systems based on emulsions [51]. It is also dispersed in solutions, it is a hydrophilic material due to the presence of oxygen on its surface, but there are areas on the surface of graphene oxide that do not contain oxygen, and this is what makes these areas hydrophobic. But due to the presence of oxygen on the surfaces of graphene oxide, the mechanical properties of graphene oxide are very poor compared to graphene. These weak mechanical properties of graphene oxide are due to its structural defects.[51]. The presence of oxygen on its surface makes it work as an insulating material, so if the percentage of oxygen is more than 25%, it is an insulator, and if it is less than this percentage, it acts as an electrical material. conductive, and also if oxygen is removed, this material restores conductivity, so in most articles and research it is shown that to improve the mechanical and electrical properties of graphene, the graphene oxide on its surface must be significantly reduced, and this process is performed by annealing or chemical reduction.[51].

Since the beginning of the emergence of graphene oxide and its spread, there are many methods and strategies that have been followed to make this material in the easiest and best way, and from the methods that were followed such as Brodie, Offeman and Hummers. In making graphene oxide, researchers follow the method of combining graphite oxide with types of citrus or oxidants. Each method of manufacturing graphene oxide differs in the type of acid and the degree of oxidation, and this depends on the properties of the graphene used. One of the most used methods for making graphene oxide is the Hummers method. In this method, a type of gas that is toxic is initially placed, where the presence of this gas is essential during the production process. The graphite is oxidized by substances such as potassium or a certain concentration of sulfuric acid. After obtaining the graphite that came from graphite oxide, it is derived, and when the oxidation process completes, the hydroxide on the surface of the graphite is stabilized and then water and oxygen enter between the layers and react strongly and produce graphene oxide.

Researchers N. Ünlü1,C. Aksu Canbay1,a oxidized graphite and produced graphene oxide by Hammers method completely and successfully, where they mixed the materials they need for the process such as graphite and sodium nitrate that are present in a certain percentage of sulfuric acid and left it for an hour. Then they gradually add potassium permanganate and mix the mixture well in ice water for an hour and a half, and in the next step, water free of ions is added while continuing to mix, and hydrogen peroxide is added with a high temperature close to boiling. In the last steps, ion-free water is added to the mixture and placed in the oven. Where the material obtained after 24 hours in the oven is graphene oxide in the form of a powder structure.[54].

Graphene oxide can be used with many applications and with many materials and is one of the most promising materials in the next generation, it can be used in the automotive industry and also in biosensors and gas sensors, GO is widely used to develop effective absorbent materials New technologies and solar cells have shown And hydrogen storage, materials for ultra-thin paper and many other fields, and according to the studies that have been conducted, graphene oxide has a very good water-dispersion ability, so we can benefit from it in many ways, but this does not prevent that graphene oxide at present is not a stable material and it takes It takes a lot of study then to understand how to treat this valuable substance. In the new studies, new methods and techniques for making this substance were shown, and this makes it one of the most promising materials in the storage and use of nuclear waste.

2.1.4. Reduced Graphene Oxide

Graphene is one of the most important and most developed materials in the past years, as it has received great attention to be used in applications and to show its properties more, but its use in most applications and in this form is difficult, and this is due to its high cost. After many experiments and methods that were followed, the researchers found a new way to make a material very similar to graphene, which is reduced graphene oxide, which is produced by reducing graphene oxide and its cost is mostly lower. It is possible that this material is similar to graphene in many respects, but it may not give the same efficiency as graphene produced in a

traditional way, such as the method of chemical peeling, but in general experiments and research on this subject and attempts to develop the material are continuing, and who can develop and use it more broadly in the future.

In terms of structure, which graphene oxide reduced has, it is very similar to the structure of graphene, and because it is produced by reducing graphene oxide, the quality of the product and its structure, which should be similar to graphene, depends on the method in which the graphene oxide is reduced. The figure (2.12) Shows a difference between graphene oxide and reduced graphene oxide, in which the functional groups, which are carboxyl, hydroxyl and epoxy groups, were reduced. Where the functional groups present in reduced graphene oxide are very few, i.e. they are absent as in the case of graphene.

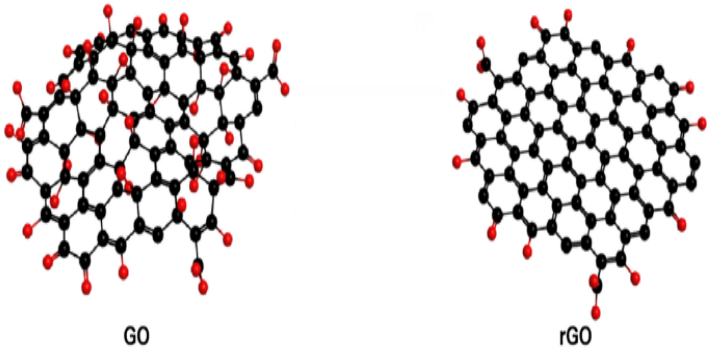

Figure 2.12. Difference between structure of GO and rGO.

The reduced graphene oxide is characterized by its black color and powdery texture, which is completely odorless, and has different paper dimensions. It is known that it is insoluble neither in water nor in solvents as well, and in terms of its density, it is in the range of 1.91 g / cm3. Its approximate surface area is BET: 422.69 - 499.85 m 2 / g, and it can be dispersed in solutions of high concentrations few. In terms of electricity, it is a good conductor of electricity. And from these properties, it shows us that it is very close to graphene and it is possible to benefit from it and use it in applications in which graphene is used.

Chemical deposition was performed directly and for the first time by Chen et al in 2010, in which a colloidal dispersion with specific measurements is formed after

placing graphene oxide into a specific powder. Reduced graphene oxide prepared in this way is very strong and insensitive, but if the dispersion concentration of graphene oxide is low, it causes precipitation. At the same time, graphene oxide has been reduced by the coating reduction method for the first time by Ramsha and Young et al. in 2009. In this method, graphene oxide is covered with coating to form a compressed film, and then this electrochemical oxide is reduced. The film is produced, and this leads to the reduction. Graphene oxide is coated by pinning the electrode and capping it with electrodes, and there are many methods for this process, including spin coating. There are many ways to reduce graphene oxide, which have been followed by many researchers, for example, some researchers added urea to hot graphene oxide to improve its reduction, and others put graphene oxide in a furnace at very high temperatures to reduce it, others treated graphene oxide with hydrazine hydrate at boiling temperature for a whole day. Or exposure to hydrogen plasma or other methods. But in general, reduced graphene oxide made by these methods has a poor electrical conductivity. And also, another method for producing reduced graphene oxide is by means of materials such as hydriodic acid and sodium borohydride, but sometimes this is considered a difficult process because most of the materials from which this material is made do not disperse. This negatively affects the desired result. We can evaluate the atomic amount of oxygen on the reduced graphene oxide by means of an X-ray machine. Place it for a long time at room temperature, but significantly as the temperature increases, the speed of graphene oxide reduction increases, and at the same time it is almost impossible for graphene oxide to be completely reduced even if the temperature reaches 1200. But we must also beware of this substance, as sometimes the production of this substance is a cause for the production of pollution.[55]. Despite many of the wonderful advantages that reduce graphene oxide has, except because it was produced due to dispersal oxidation, so its crystal is weak, so researchers tried to produce more effective methods for reducing graphene oxide. It was found that the most effective method is the reduction of graphene oxide by electrochemical reduction, which has many advantages, one of which is the absence of chemical residues.[56].

Many devices have been manufactured in which graphene oxide has been used to reduce, and one of these devices are field-effect transistors, and reduced graphene

oxide is used in the form of chemical and biological sensors. In applications such as solar cells the use of reduced graphene oxide is a powerful alternative to ITO as it can be used as a transparent electrode. It can also be used in batteries, due to its high storage capacity. In the most recent studies, it was used in lithium batteries, and researchers tried to increase the device's performance by absorbing metal oxide nanoparticles, which are electrically isolated. On the other hand, it can also be used in systems dedicated to the detection of biological molecules.

2.2. PEROVSKITE

Although perovskite was all the time there, it was from unknown and unnoticed materials, while it was discovered for the first time in 1839 in the form of a crystal structure, where interests became increasing around it to reveal what this material is and how it can be used. They are one of the most abundant minerals not only on Earth, but also on other planets such as Mars. The color of perovskite is between brown and black, as it was named after its first discoverer, Lev Perovsky in 1792, he discovered his first crystal of perovskite around 1945. But the transitional movement of this material after its introduction in the form of CH3NH3PbBr3 by kojima et al in 2009 [57].

The usual and widespread perovskite has the formula of salts (AX, BX2). A and B form cations in the structure, which is in the form of clumps, and there are certain ions surrounding Xis and B, which bind them together, which is called C. The pure perovskite consists of oxygen, calcium and titanium (CaTiO3), where the oxygen atoms meet In the edge and the calcium is in the center of the structure, while the presence of titanium is more in the corners In the figure (2.13) the structure of the perovskite was clearly shown. Perovskite are deposited in three forms, whether solid, liquid or gaseous, and for proper deposition, there are two methods that researchers follow. The first method is by mixing the salts in one solvent and after their precipitation, the solvent is extracted to obtain a solid perovskite. This method is easier to use and also faster, but it is possible that the salt will not dissolve in the solvent because its polarity is low and at the same time not all solvents can be easily removed from the salts. One of the methods that researchers use to tackle the

problem of solubility is to follow the second method to obtain perovskite. In this method, each salt is dissolved individually and in different substances, and then the solvent is removed. Production of perovskite as a solid. There is a way to produce perovskite without the need to mix and then dissolve solutions, it uses solid materials directly, and it is possible to grind and mix the materials to produce perovskite in the form of fine powder. Cheng et al. The perovskite was made using mechanically synthesized CsPbBr3 that was dispersed, recycled, and evaporated, resulting in a plastic film. It can also be said that it is possible to obtain perovskite by gas, that is, vapor deposition by physical methods (PVD) or chemical methods (CVD). In the past few years, many researchers have become interested in this method of producing perovskite because this method is considered easy because it does not need a substance to dissolve it. Only when the precursors are mixed and then precipitated from it is the perovskite produced [57].

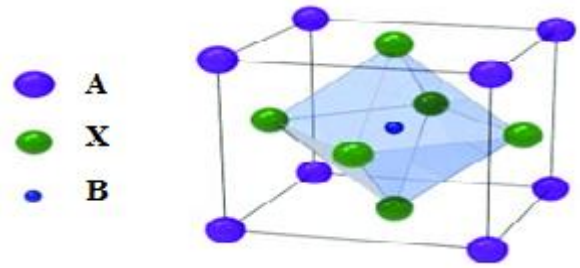

Figure 2.13. Structure of perovskite.

Perovskite is one of the materials with many properties and advantages; it is an excellent conductor of electricity as shown by the results in Ba2YCu3O7. But although perovskite has the property of conducting electricity, it can be used as an insulating material as well. For example, in BaTiO3, although it is usually considered a conductor of electricity, but when exposed to high temperature and converting its tendency to cube, it can act as an insulator and does not have any from properties to conduct electricity. In materials such as micro electrons, perovskite can be used as an anti-magnetic material. It is possible to say that the presence of perovskite is an important material for physicists, because they can change its properties according to changes in its structure.

Perovskite can be benefited from and used in many applications due to its unique characteristics and advantages. It can be used in sensors, solar cells, lasers, memory preservation and other applications. When used in solar cells in the form of thin films, it is one of the cheapest options with very high results and efficiency. It gives solar cell devices high flexibility with low weight and high transparency as well. Using it to change light into electricity is better and more efficient than silicon. It is expected that the sales of this substance will increase and reach 214 million dollars by the year 2025. Another uses of this substance is when some of the researchers used nano perovskite in electrochemical sensors, specifically for alcohol, acetone and glucose. It can be used in anodic catalytic materials in fuel cells. With regard to gas sensors, perovskite is one of the most widely used materials, for example, perovskite oxides are a thermally stable material and a wonderful gas sensor, especially for the detection of carbon dioxide and nitrogen dioxide.

2.2.1. Methylamine Lead Iodide ($MAPbI_3$)

MAPbI3 has a typical perovskite structure as shown in Figure 2.14, where MA+ is located at the vertex position, Pb2+ stands at the body center position, and Iis located at the corners of octahedral environments surrounding the central Pb2+ ion.

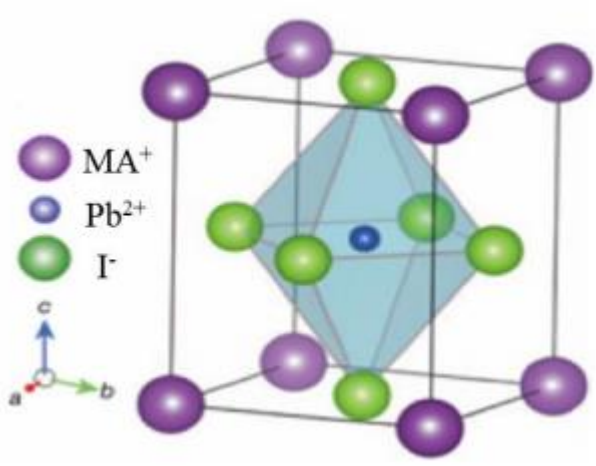

Figure 2.14. The crystal structure of MAPbI3

At room temperature, the structure of MAPbI3 is a tetragonal phase with the space group I4/mcm and the lattice parameter a=8.743 Å, c=12.6708 Å [22]. Above 300 K, the structure is a cubic phase with the space group Pm-3m and the lattice parameter

c=6.391 Å. Below 160 K, the structure became orthorhombic phase with the lattice parameters a=8.8363 Å, b=12.5804 Å, c=8.5551 Å [23].

Since MA+ has a dipole moment with a symmetry of C3v, the orientation of MA+ will have an influence on the crystal structure. The relationship between the orientation of MA+ and the structure at different temperatures is shown in Figure 1.2. According to the results of neutron diffraction, it is impossible for MA+ with a low symmetry to be placed in an octahedron with m-3m (Oh) high symmetry without introducing disorder. Therefore, the MA+ will have six equivalent orientations in the cubic phase. The C-N bond is along direction. Since MA+ has three-fold axes, the octahedron has four-fold axes. Therefore, MA+ will exhibit four-fold disordered rotation along these axes at high temperature, and it will have 24 possible orientations with a complete disorder. For the tetragonal phase structure, the low symmetry of C3v also cannot meet the requirement of $\bar{4}$2/m (D2d). In this case, the MA+ has eight possible orientations with a partial disorder. For the orthorhombic phase, since the symmetry of the crystal structure is further reduced, the MA+ does not need to be disordered to satisfy the symmetry and shows the anti-parallel arrangement [24-25].

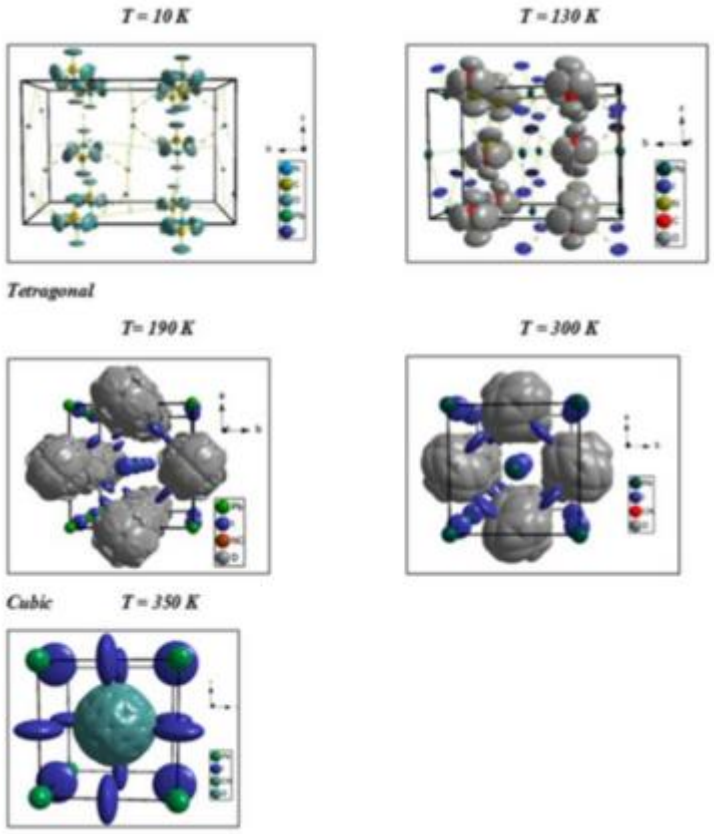

Figure 2.15. Structures of MAPbI3 at five temperatures based upon refinement of neutron powder diffraction data[24].

PART 3

PHOTODETECTOR

Si, Diamond and other materials are based on the work of a traditional UV photodetector, but most of the time the results are incorrect and not 100% or there is a poor response, which is due to a problem due to network mismatch and other reasons and at the same time these devices are high cost It is difficult to manufacture.[58]. Therefore, it was necessary for researchers and scientists to find a solution to these problems facing them. After many experiments and attempts, they were able to create a 2D UV detector. But this achievement was short-lived because 2D materials cannot be used directly to absorb light, and from there new experiments began trying to take advantage of 2D materials in detecting light. Researchers have become very interested in detection devices whose membranes are thin and work on ultraviolet rays, and this interest is due to the great advantages that characterize it, such as its uses in monitoring and optical communications and many other applications, so that this material has a practical application, it must be few The price, with an easy structure, and the condition that it can be operated at medium temperatures or room temperature [59]. ZnO is of great interest due to its unique properties and its uses in light detection devices. However, materials such as zinc oxide and graphene, despite their advantages, need to be studied more extensively, due to the lack of sufficient research and reports on these materials. Many researchers tried to improve the performance of ZnO-based UV PDs, but the introduction of MgO as an insulating layer for the response of UV films, which was done by Kim et al., had the highest response among others at 27 A/W, many researchers tried to reach High responses to this degree, but in all cases the results are less than expected. In one of the experiments, ZnO NWs grown on SiO2/Si were combined, which gave much higher structural results than ZnO, as its response was 188 A/W. And the researches showed that ZnO has the ability to give impressive properties and results if graphene flakes are introduced into its structure.

3.1. STRUCTURE AND WORKING PRINCIPLE

Increasing speed, efficiency, high sensitivity, and a quick response time are among the important characteristics of the ideal photodetector devices. Because of the continuous development witnessed by the devices responsible for making electrical signals from the optical signal, the characteristics that must be characterized by these devices increase. Many studies and researches are conducted on a daily basis in this regard, but it is considered difficult to reach a device that is free of defects and distinguished by its elaborate performance. Electromagnetic rays with a wavelength between 100 nanometers and 400 nanometers, which lie between visible light and X-rays, are called ultraviolet rays. These rays can be the cause of many problems in human health when exposed to them on a continuous basis. Often the presence of an ozone layer protects the entry of these rays to the earth, but if the wavelength of these rays is long, it can pass through the ozone layer. That is why the presence of special devices for ultraviolet rays is important to detect these types of harmful rays and convert them [60].

3.1.1. Vertical Structure

In general, a typical p-i-n device consists of a transparent, highly doped p-type contact layer, printed with an n-type contact layer that is also high-temperature doped. Whose structure is of the glass substrate/indium tin oxide/HLT/perovskite/ELT/metal electrode. This type of device is widely used in many applications such as biological detection, optical communication, and many others. The most widely used (p-i-n) perovskite (phenyI-C61-butyric acid methyl ester) device, where perovskite is added as an insulating layer between the anode/hole transporting layer and electron transporting layer/cathode. But this device suffers from coverage problems as its coverage is low, and for this reason researchers are conducting many experiments and studies on it to solve the problems facing this type of device. Researcher Du and others conducted a complete study about the inverted-configuration photodiode and its composition, especially the type of diodes that are formed based on the organic halide perovskite, where they made three different devices of type: PD1, which is not free of insulating layers, and PD2 which

is with (BcP)), PD3, which is also with (poly) and also (PFN) as cathode insulating material. After these devices that were made, it was found that the material (PFN) present in the type of PD3 can act as a material to prevent the existing holes that form in the interface of the PcBM. Lin and others also attempted to find and demonstrate an organic halide perovskite photodiode equivalent to commercially available silicon isotopes, which in turn made four types of devices: the first one that had a thin layer of vinyl with a layer of methyl butyric acid methyl ester) PC6oBM) with a thickness of 10 nm, the second device consists of a layer of (PC6oBM) with a thickness of 50 nm, the third device consists of a layer consisting of C6o thicker and reaches approximately 130 nm, and the last device was exposed to the lowest dark current. It was found that the fourth type can provide the ability to detect light above 1012 johns through UV - visible light.

This device is constructed of a transparent n-type layer on a p-type contact layer, the structure N of which is the glass substrate/indium tin oxides/ELT/perovskite/HLT/metal electrode. Like any other device, these devices face problems and weaknesses in their work. The researchers' role is to conduct the necessary studies to solve these problems. Fang and others made a device with advantages that could solve the problem of weak light for picopods, where the device is a photodetector consisting of a hybrid perovskite. This is low noise by electron transfer by adding a layer of double fullerene, which reduces clicking noise and shot noise. Various types of ELT and HLT were used because of their ability to reduce noise, and they also made three new devices: the first device, which is HLT and PCM/C6o 20/20 nm ELT, and the second device is also HLT PCM/C6o 20/20 nm ELT, the third device which is cross linked like HLT and PCM/ C6o 20/20 nm ELT. According to the experiments that were conducted, the results show that the dark current has a reverse bias, and also that the presence of additional insulators was not a reason for the extraction of photo generated carriers. For the first time, Sutherland et al. modified the photodiodes based on spiro-omeTAD Tio2/perovskite, and these modifications were made by applying a thin, toothless AL2O3 layer over the Tio2 material, which features a nanostructure to enhance the extraction efficiency. The carrier, as it was found that the results given by the finder device have a very high sensitivity in areas near infrared as well. After their discovery, a perovskite-type light

detector was discovered and manufactured, which has the ability to work with self-energy and has a basis of Tio2 Nano rods/CH3NH3PbI3, which is heterogeneous, and has the ability to respond to ultraviolet rays also because of its dependence on Tio2. After that, many researches were conducted regarding the discoveries that occur in this field, so many other devices with new features were discovered, and a number of other devices were also improved at the same time in order to modify the interface layers and electrodes, which can be used to connect carriers. The charge generated by the photons. Mixed halide perovskite can be considered one of the ideal devices for detecting light from ultraviolet to infrared, especially a kind of perovskite that has been discovered and developed to be suitable for lasers, solar cells and light detectors. Many methods have been followed by many researchers to find the best way to detect light within a narrow range. Fang and others revealed optical detectors with a single crystal and mixed halide, as the results showed that this device can change its response to colors according to the halogen atoms.

3.1.2. Lateral Structure Photodetector

This type of electronic device that is used for more than one function, in terms of detecting light and amplifying the signal as well. It is possible to consider these devices to have more advantages than photodiodes, and this is due to the fact that these devices have lower noise and higher sensitivity. And in terms of types, they are divided into two types. It consists of a single layer of photo-activated film, then by deposition of the electrodes the potential can transfer the carriers generated by the light. Optical transistors are generally formed in the same way as an ordinary transistor, but its area is exposed to illumination with three electrodes, and it can be treated as a device between a photodiode and an ordinary transistor.

For photodetectors to be useful and can be used in multiple applications, they must have certain characteristics. Ideal photodetectors have high sensitivity in multiple areas of the spectrum. In terms of response, its response is at least very specific or stable, such as photodetectors whose work is based on the energy of the sun, and their sensitivity becomes very high against ultraviolet rays. Another important characteristic is the efficiency and transparency of the device, as well as its high

performance. And the fact that the price is appropriate, or rather low, is also important. The photodetector that works on ultraviolet rays for semiconductor materials is characterized by its unique characteristics in terms of high response, speed, and low energy consumption, and at the same time, its cheap price made it widely used in communications and medicine applications. Characteristics change from one device to another, and the presence of all the characteristics in one device is not a requirement, for example, photodetectors that have high sensitivity often do not have a high frequency range.[61].

3.2. PARAMETERS OF PHOTODETECTOR

3.2.1. Responsivity (R)

To obtain accurate results in the output signal, the responsivity (R) must be taken into account, which is the ratio between the optical signal that enters and the electrical signal that goes out. The higher the optical response, the more accurate the output signals.

3.2.2. Quantum Efficiency (η)

The ratio of the electrons that were generated to the ratio of the photons that were projected is considered quantum efficiency; it can also be defined as the electrical sensitivity present in the irradiator. Where it is in the form of a percentage of the photons that are in the form of the hole pairs in the photodetector relative to the photons that come from the detector. In other words, the quantum efficiency increases as the optical current increases.

3.2.3. Signal-to-Noise Ratio (SNR)

Some of the signals that come out of the output are unnecessary and annoying and are expressed as noise. Maintaining a high signal-to-noise ratio is the most suitable way to get rid of noise, while the presence of these signals is a must, they are mainly caused by the structure of the photodetector device, the more fluctuation in the

arrival of the photon or an unexpected movement of electrons increases with it the noise. In research such as ohnson, Generation-Recombination (G-R), and Beat Noise, it was widely tried to explain this noise and try to find solutions to get rid of it, it was found that it works inversely with frequency, as the frequency increases, the noise energy density decreases. And sometimes it is possible to get noise when using the devices continuously.

3.2.4. Noise Equivalent Power (NEP)

Noise Equivalent Power which can be obtained when a voltage is applied to a noise or current, and through which a specific signal is generated that is equal to the amount of noise present on the detector. But because the ratio of the signal to the noise changes with the change of the input energy, it cannot determine the sensitivity of the detector.

3.2.5. Detectivity (D)

Detectivity which can be defined as the opposite of NEP, the more detectivity increases with it the performance of the detector increases, when detectivity is different, but the photodetectors of the same quality can be compared with each other.

3.3. APPLICATION

The uses of photodetector devices are very wide and are found in many diverse applications, so they have been used very widely in devices dedicated to measuring light and radiation, and applications for spectrometry are not free of these devices, as they were used in this type of applications to measure optical forces. In data storage, microscopes and interferometry are also found, when the photodetector is highly sensitive, the chance of its use in applications for laser identification and night vision devices increases. And in optical communications and noise in laser and optics experiments, a photodetector is notably used, which has a fast response. Because of

the many properties that characterize this material, the application in which it is used is constantly increasing with the developments that occur in technology.

One of the most widespread devices with typical results in the field of light conversion are potodetectors, and it is one of the most common setups that convert an optical signal into an electrical signal, as it depends on electromagnetic radiation, and these devices are used in environmental monitoring and X-ray detection applications Infrared light and optical communications. And in the past few years, a lot of research was conducted on the use of other materials to detect light that emitted from ultraviolet rays, such as ZnO and GaN, where these devices are organic, so they have advantages such as lightness in weight and flexibility. There are devices that are semiconductor such as a phototransistor or a photoconductor that helps light detectors in many ways, they improve their performance and help in building an optoelectronic system to form excellent quality light detectors.[62].

3.4. GRAPHENE BASED UV PHOTO DETECTORS

There has been a great and wide interest in electronic devices that are based on CMOS and it turns out that there is a promising future for this type, due to the possibility of being small in size and this was shown according to Moore's Law, and a computer with a single chip was introduced for the first time in 2015 Also, many people have tried MSM PD for the purpose of improving its optical response, and this happens by improving its quality or reducing its output resistance. However, there remains a lack of response speed and response performance, and at the present time, solving these problems is of great importance, especially in optical communications, and also because of the presence of many properties and advantages found in two-dimensional materials such as graphene that can be used in optical applications. Studies have shown that the presence of graphene in UV-PD has a promising future and high performance. This is because of the many and wonderful features that characterize graphene in terms of its ability to design a new optical electronic devices, making the space less and many other advantages, but so far the devices that work on graphene are not perfect, but suffer from a high time response , and this makes it need to improve its accuracy and work to reduce losses in optical

detection devices .[67]. In general, most ultraviolet photodetectors are based on Cr / Pd, but these materials often have a low transmittance, which can be less than 80 percent, but this is something on the contrary in graphene, which has a very high transmittance because its gap is zero. Devices that detect light can be checked by comparing them under the ozone layer and with infrared radiation, and sometimes during this process someone may suffer from less noise than what is in the ground when they detect the light. Many analyzes and research are carried out on the use of sensitive materials in light detection devices, including GaN, Diamond and SiC, where SiC is one of the most widely used and common materials and works at high temperature, at the same time binary materials have become very popular for such devices. But graphene needs effort to transport, and this increases its cost .[68]. There is a possibility to combine SiC with graphene flakes to make high-performance light detection devices by analyzing them at a high temperature, and each material has its advantages in its work in the device, so the graphene is in the form of a thin layer and SiC is a sensitive. There are already attempts to produce such a device, where these two materials were combined with it, which was produced by Li et al. It had a very high response, but when applied in a practical way, it turned out to be difficult because the time of its decay is in seconds and its response was less than expected. In some studies, devices that detect light, which depend on graphene and are on the 4HeSiC axis, were produced, but they are considered isolated, and after making several modifications to them, it was found that there is the possibility of producing a device with high characteristics if the number of waves carrying graphene is reduced .[68]. Through many experiments conducted on how EG / SiC UV light detectors respond and how graphene affects them, it was found that the number of carriers present in graphene has a significant impact on the response of the device. In the figure (3.1) show the first strategy and how graphene can improve performance.

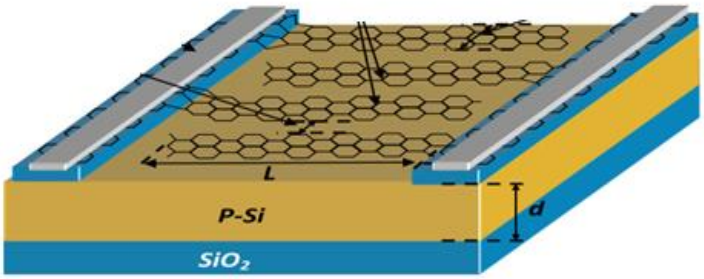

Figure 3.1. The first strategy and how graphene can improve performance.

3.4.1. Strategies For Using Graphene

Many strategies have been followed, including the use of graphene instead of metal, and this reduces the reflection of light. In one of the experiments conducted in this regard, it showed that after using graphene, the advantages increased. The scope of incorporation into graphene and this is also a very good feature as it helps to improve performance.

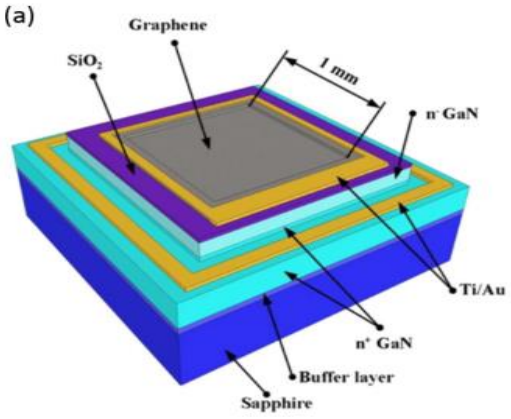

Figure 3.2. First strategy.

Also, in another strategy, optical detection devices were manufactured by integrating graphene with semiconductors, and in this strategy, it was also found that the use of graphene gives advantages and higher sensitivity than traditional devices. And one of the most successful strategies was when the gap on the graphene was modified to be suitable for the light that comes from ultraviolet rays, where the size of the graphene in this case is so small that its dimensions are 0 .

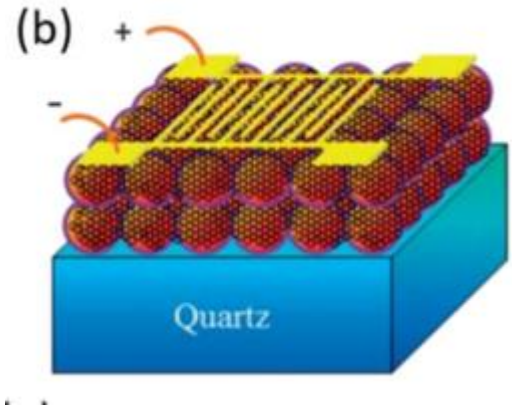

Figure 3.3. Second Strategy.

After all, the use of graphene has become very popular in devices that detect light under ultraviolet rays, due to its properties and giving it great results in this field. Graphene has metallic electrodes, so its performance is higher, and this is what Thomas Müller has proven. The light absorption in devices that are manufactured to detect light and are based on graphene can be improved by combining them with gratings or wave guides, and this makes the interaction between graphene and light increases and the performance of the device increases with it, and through this loss one of the researchers called Macro Furchi et al stated that when FabryPerot flour is combined with graphene, it can increase the effectiveness by 60% or more, and other researchers also said that it can increase the effectiveness by 70 percent when combined with NIR. At the same time, to increase performance, it was found that graphene can be combined with materials that have a higher ability to absorb light. Their performance is approximately 107 A/W under illumination, as shown in the figure (3.4) below.

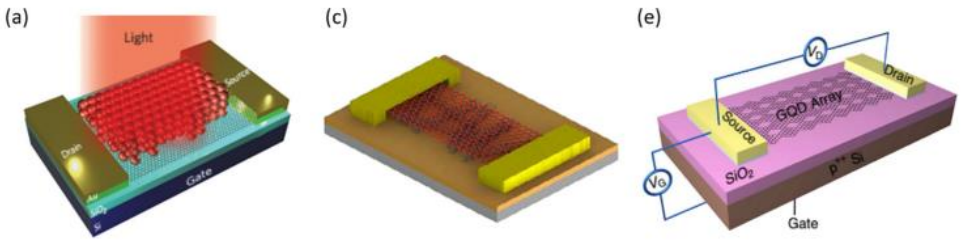

Figure 3.4. Broadband High Photoresponse from Pure Monolayer Graphene Photodetector.

Many researchers have become interested in light detectors with a TiO2 nanostructure due to the presence of a large surface, although in many cases the performance of these devices is good and acceptable, but attempts are continuing to improve them and bring them to perfection. Because of the structure and the many distinctive properties that exist in graphene, researchers became interested in how to combine the two materials and their interaction with each other. In one of the research projects conducted on this subject, it was reported that a light detector was made based on TiO2 NTs, to which a thin and transparent layer of graphene was added. Sheets composed of TiO2 NT change while inserting graphene on them and are affected, and the presence of graphene can increase the absorption of nucleus particles, and also it can increase the percentage of current gained ten times when compared with a device that has not been added with graphene

3.5. SELF-POWERED PHOTODETECTOR

Since photodetectors have been shown to have a key role in many areas of daily life, researchers are looking for ways to develop them into traditional optical detectors. Despite their high power and effectiveness, demonstrating these properties requires external energy. It turns out that it is possible to manufacture self-powered light detectors that are capable of converting an optical signal. In most cases, these types of devices have a high response speed and the ability to keep them running continuously. Self-operating optical detectors are generally divided into three types: p-n junction type, Schottky junction type, photoelectrochemical (PEC) type, but the most interested and researched types are the photoelectrochemical (PEC) type, because it is not complicated to manufacture and its response is often very fast. The introduction of graphene to these devices can have a benefit by reducing the re-installation of heterogeneous optical carriers, but not all cadmium molecules stick to the graphene, so it can be said that its effect is not strong, and also during the research, it was found in the results that the presence of graphene can The nanoparticles increase the density of the image carriers, and this reduces the interface barrier, and with it the sensitivity increases.

3.6. HALIDE PEROVSKITE PHOTODETECTOR

The halide perovskite organic mineral is one of the many materials that have received attention and research has been conducted on their use in many fields, such as optical detectors in lasers or transistors, as well as in solar cells. Its importance and performance in the field of optical detection devices. Inorganic light detection devices are among the devices that have great popularity and confidence in ensuring their work, but at the same time they are considered complex and very expensive, but after the discovery of halide perovskite, it was found that they are characterized by processing capacity and also have the ability to transport shipments, meaning that they have Advantages of organic and inorganic materials as well. This material was used for the first time in 2009. It was found to have a very high efficiency in the field of solar energy conversion at very high rates, and the first film that contained halide perovskite was manufactured in 2014 (M.A. Green, A. Ho-Baillie, H.J. Snaith, 2014). Since PD-type optical detectors are considered important materials in the discovery of missiles or optical sensors, there has been great interest in them and an attempt to conduct research on them. Photodetectors of the type (PD) are a flexible material that can be found in the form of fibers such as a photodetector fabric, and the large metals they contain, which are the reason for limiting their flexibility, and this is what made researchers try to find a solution to it. An attempt was made to insert the perovskite layers between zinc and graphene, but there remain problems in these layers due to their incompatibility with each other. Touch and they are better conduction and they are collected by pressure filtration method. A photodiode is a type of vertical structure in photo detectors. It is characterized by its typical vertical structure, quick response and low effort. But for light detectors such as phototransistors, whose structure is lateral, where their response is slow and not good, and this is due to the spacing of the electrodes, but at the same time, these devices can be characterized by being easy to produce and can increase the gains due to the injection of side charge. In general, there are many types of organic halide perovskite photodetectors. Over time, researchers are seeking to discover new features about this device. One of these researches was about a planar heterojunction structure photodetector. As it responds quickly and does not require much effort, but

at the same time it has disadvantages such as that its ability to detect light is weak to a certain percentage.

PART 4

CHARACTERIZATION METHODS

4.1. STRUCTURAL AND MORPHOLOGICAL

4.1.1. Transmission Electron Microscopy (TEM)

The accuracy of the optical microscope is close to 300 nanometers, which is considered not good and is mainly caused by the wavelength of light, and this makes more interest in the use and development of electron microscopes, as they work using electron beams instead of light. The presence of electrons is what makes the advantages of these devices more, as the wavelength of the electron is 100,000 times less than what is found in visible light, and its accuracy reaches 0.05 nanometers. In terms of types, electron microscopy is divided into two main types, transmission electron microscopy (TEM) and scanning electron microscope (SEM) [63]. The first electron microscope was manufactured in 1931, which operates in the same way as light transmission microscopes, but differs from not using light and altering it using an electron beam; this device was of the type (TEM) and was made by Ernst Ruska and Max Knoll. The TEM device consists of many components to complete the magnification process in a professional manner.

Electron gun: This is what is considered the beginning of the process with it, as it works on using electrons to produce a certain current, which is concentrated in the form of a beam of electron and this, helps the lenses in the capacitor to perform its work. This prepared sample is directed and focused through an objective lens, which helps to create the image. After that, the preparation process ends and the work is at the bottom of the column through a device that displays the image and enlarges it. The more the force is adjusted, the magnification process changes more. A device such as the 400 kV TEM can give a resolution of less than 0.2 nanometers, even if

the samples are sometimes thick. There is also a STEM device that has the capabilities to give very good accuracy, which can reach up to 0.5 nanometers.[63]. After completing all the steps for enlarging the TEM image, it is displayed on films or sometimes in advanced equipment, displayed on TEM cameras. This device and this technique can be considered a specific method that complements the well-known crystallization methods such as those found in the X-ray cooler, but the TEM device is distinguished over the traditional device that it can combine many properties together in one developed device. Because of the advantages of TEM such as that it is considered a very powerful tool for the quantitative characterization of the structure of nanomaterials and chemicals. It is possible to develop and extend TEM and create a STEM, which works on taking the sample from an image taken from TEM and trying to make a three-dimensional image of it. In the figure (4.1) show the component of TEM.

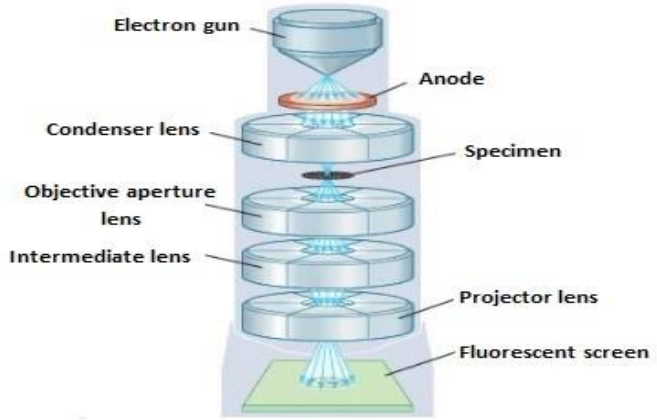

Figure4.1. TEM.

The sample that is used in the device and is enlarged must be of high quality, because it directly affects the results. Being a thin sample is one of the most important things, and this is to be easy to see by the electron beam, where the thickness should be between 100-500 nanometers and not exceed this thickness. But in general, we can say that each sample when we use it differs in terms of its preparation method, the type, size and crystallization of the sample greatly affect [63].

- Powder samples: If the samples are in the form of a powder, then it is most likely present in a specific solvent, then an attempt is made to separate the ethanol and put it on an amorphous substance. The sample is present when the solvent is evaporated from it.
- Solid samples: In order to be able to directly handle and transfer samples that are solid and at the same time the samples have an electron scattering, a kind of ultra-scattering should be used, with a glass or diamond knife on it to cut the sample.
- Focused ion beam: This technique is considered one of the most advanced techniques in which TEM is prepared. It uses a specific Ga beam to try to make the sample ideally thin, and it is possible to control how the sample is cut directly.

4.1.2. Scanning Electron Microscopy (SEM)

The SEM device is considered one of the pioneering devices for enlarging images by means of electrons. There are many opinions about the first device that was made. In this regard, it can be said that Manfred von Ardenne was one of the first researchers to show such a device in 1937. A few years later, researchers in New Jersey With the establishment of the first SEM in the year 1942, and at the time, its capabilities were considered very high, as it could magnify 8000 times. But commercially and for the first time, SEM was made by Cambridge University in 1965, and after that it became a lot of frequent appearances, as ZEISS made a full digital scanning device SEM in 1985, and after many of its rehearsals on this subject, he was able to In 1993 he created a FE-SEM with a precision of about 10 nanometers, and all of this was done using electronic optics such as Gemini. In recent years, 61-beam SEM was introduced, which is much faster than the normal device, which was produced by ZEISS MULTISEM 505. Nowadays, SEMs are considered to have a low stretching force that reaches 1 nanometer, and they can compress images 400,000 once.

SEM device is generally made up:

- Electron column: This column is a place from which certain electron beams are produced, in which a focus is placed on a small diameter of the sample. In deflection, there is a part at the end of the column called the sample chamber, in which samples are kept.
- Electronic gun: This gun is equipped with a fuse consisting of a cathode, to give it the ability to emit a thermal electronic beam. Then the thermal electrons are collected in the form of an electron beam, and a positive voltage is applied to them so that electrons flow through it to a metal plate (anode). It is possible to adjust the current in the electronic tube while we put the electrode between the cathode and the anode and the voltage was negative.
- Condenser lenses: These lenses determine the strength of the electron rays when they hit the specific sample. While the beam passes through the anode, the sample beam passes through a focal point and is greatly affected by the condenser lenses and they get closer to each other.
- Apertures: Mostly in the lenses there is the presence of extraneous electrons. The silhouette of these openings is mainly dependent on the removal of these electrons, and at the end of the lens there is a certain aperture that scans the diameter or can show the size of the sample. This size builds on many of the results like accuracy, the smaller the size, the greater the accuracy and depth of field.
- Scaning coil after that, work is done to twist the beam with a point that is considered a point. This process is done after the sample beam is focused in the previous step.
- Speciman chamber the final part located in the column has many control elements, there are certain tools that are manually controlled to move them in (x, y, z) directions.
- Electron detector: When the sample interacts with the beam, the role of the electronic detector comes in, which converts the signals and makes them in the form of digital images.
- Vacumm system: One of the most important conditions that must be present in the column is that the column is in a complete vacuum, and this is because the presence of gases can cause electrons to collide with gaseous molecules, and this is what can make the final image unclear. There are many ways to

empty the column, including the use of an oil diffusion pump, which pushes the air into the column to be then informed from the system by mechanical pumps. The figure (4.2) shows the components of SEM.

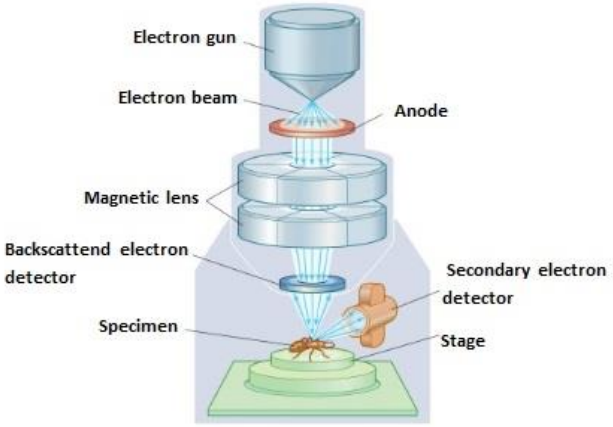

Figure 4.2. SEM.

Many criteria must be included in the sample that is used in SEM.

It must have high durability, to be discharged, and be a good conductor of electricity

- The fact that the sample surface is vertical is one of the basic criteria that must be met due to concentration problems in the examination surface.
- In the event that the sample is not conducting electricity, it can be covered with pieces of conductive material such as metals or carbonates, and then a spray coating method is used, to increase the production of electrons.
- To carry out the unloading process smoothly, the sample must be fixed well on the existing holder and glued with an electrically conductive adhesive.
- Sometimes a specific type of treatment, such as chemical etching, is needed to show the details of the sample's structure.

4.1.3. X-Ray Diffraction

The existence and discovery of X-rays is nothing new. In the years close to 1895, the researcher William Conrad discovered it, and then the use of these rays became very

wide in many applications such as medical sciences and physics. Including Max Thunder Felix, who received the Nobel Prize for his research on this topic in 1915. He worked to create a special equation that relates the distance of atoms to the wavelength of X - sheets of a given crystal.[64]. Also, researcher PP Ewald developed these rays by creating a specific matrix consisting of scattered atoms, in order to give an appropriate character to the light waves that hit the sample.

The materials used in such experiments are mostly in the form of very small crystals, and each of these materials has a very regular atomic arrangement, meaning that it consists of a nucleus and electrons around it. Since every atom has a regular shape, X-rays can be widely used to measure the distance between atoms by means of the diffraction effect. Where a basic requirement for these rays is that crystals are arranged and not scattered. And X-rays in their work depend mainly on the overlap of the structure between the X-rays of the color and the sample being processed. The Bragg equation is the basic equation on which the work of the rays depends, as it appears in Figure (4.3) the ray beam spreads on the surface of the sample taken at different levels, and this is what makes the X-rays produced with a different path length and be highly dependent on the distance between the crystal plane and the specific angle that Rays fall on it. The equation will generally be in the following form:

$$n\lambda = 2\, d \sin\theta \qquad (4.1)$$

This equation determines a distance in the reticular planes of the sample.

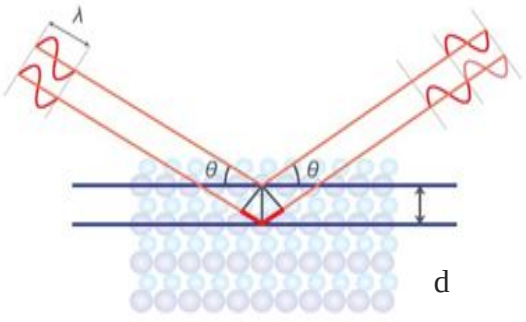

Figure4.3. Bragg’s law.

In the equation, it must be known that only if the path difference is doubled, can structural interference occur.

X-ray diffraction (XRD) can be used in many applications such as determining crystal structures and performing quantitative analyzes of certain minerals, and also it is possible to perform some structural measurements, it has many strengths. The sample used in this type does not need many settings, it works on interpreting the data well, as it can know the presence of defects in a particular crystal, and everything related to the structure of the crystal taken as a sample.

- It is used in the composition of medicinal materials; it is possible to use these rays to analyze the structure of the crystal and also determine the components of the pharmacy.
- The use of X-ray diffraction is one of the best and most appropriate operations in forensic medicine, because this application is very sensitive and non-destructive methods must be used in it to conduct chemical analyzes.
- It is possible to use these rays to identify minerals and the quantities present in them in samples and different materials. That is why the presence of XRD is considered a must in geological applications.
- It is also widely used for the manufacture of glass.
- It can be used as an insulating coating against corrosion in steel materials.

4.1.4. Energy-Dispersive X-Ray Spectroscopy (EDX)

Energy-dispersive X-ray spectroscopy (EDX) is a specific material that is added with SEM or TEM to increase the imaging ability of the microscope, also works on chemical characterization and is a preliminary analysis of certain materials. And the data that is produced by this technique has peaks equal to the actual results of the sample, where the existing energy works to eject electrons from the central shell, to take its place other electrons with higher energies and is located in the outer shell and this is what happens by X-rays. The primary work of EDX is to measure the energy at which X-rays are emitted by means of an energy dispersal spectrometer. In order to get quick results free of false peaks, it is necessary to rely on the signal-to-noise

ratio and the cleaner the spectrum, the fewer false peaks. By placing sensitive to low concentrations, the effort used to prepare the sample is greatly reduced. In some cases, the preparation takes less than a minute to prepare, even if it is complex. In some of the techniques, the use of EDX alone is not sufficient, but complementary techniques must be introduced with it, such as the techniques of Raman microscopy, nuclear magnetic resonance spectroscopy (NMR) or surface analysis, and many others Figure (4.4) shows a model of EDX, showing the movement of electrons and how the electrons take their place from the outer shell, and also shows the energy of the X-Ray.

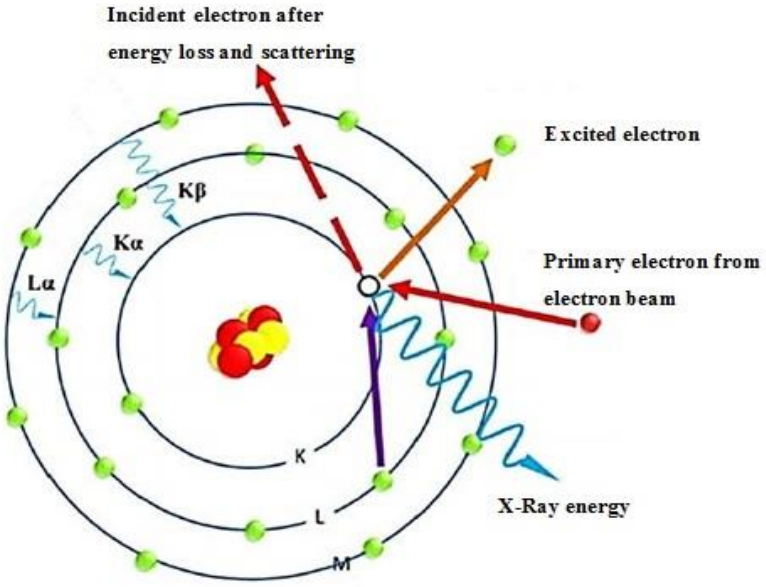

Figure4.4. EDX spectroscopy model.

The use of the EDX technique is one of the best methods because it does not negatively affect the sample used, and it can be used in percentage analyzes and qualitative analyzes as well. In SEMs devices, systems are used that help determine the percentage of samples used and at the same time identify the peaks, that is, EDX technology is widely used in this type of devices.

Because EDX analysis is not harmful to the materials and the applications it enters and does not require many changes in the sample, it can be used to monitor the quality of materials and dyes and detect impurities, and presents the problems that

appear in the external form and the mist that covers on the sample, and it works to show the eyewitness in the product clearly. The use of this analysis has many benefits, as it identifies a problem and its exact location, improves speed, increases production, and controls an environmental factor as well.

4.1.5. Fourier Transform Infrared Spectroscopy

Fourier transform infrared spectroscopy (FTIR) is one of the techniques used to identify some organic materials, and some types of inorganic materials as well, and in infrared radiation, and in recent years the interest of researchers in this topic has increased, especially in the areas of detection of tumors and cancer. This analysis monitors the chemical properties of materials by scanning samples from them. Having a FTIR analysis is of great importance for understanding the products. She worked to identify chemical compounds such as coatings, pharmaceuticals, and many other consumables. In general, it serves to detect certain guest groups. This technique is considered one of the easiest techniques in terms of application, and the best in terms of vibration. This analysis can be presented with many other techniques to increase efficiency and uses, for example infrared spectroscopy along with thermo gravimetric analysis and many others. The FTIR device works by sending infrared radiation over certain distances that change from 10,000 to 100 cm from the sample until it absorbs the radiation to convert it into a kind of vibrational energies that are in the form of a spectrum.

- It is widely used to identify new materials, especially solids and liquids.
- It can be used to determine the percentage of spoilage present in materials, especially liquids.
- It can also be used to find out what materials are added to materials after they have been extracted into polymeric matrices.

4.2. PHOTOELECTRIC EFFECT

In the years around 1887, wihlem luding demonstrated the first photoelectric effect, after which he and Heinrich conducted an experimental investigation to find out

more about it. After conducting this experiment, they found that most surfaces, when exposed to electromagnetic radiation, absorb the radiation and emit electrons. When an electron is ejected from a specific surface by a photoelectric effect called a photoelectron, and the current that is produced in this process is known as a photocurrent. The amount of emission of electrons and their energy changes with the change in the frequency of the light that is falling on the surface of the material. Because the electrons and nuclei are highly interconnected, this force is not easily broken, it needs that the photons that hit the surface have a very high energy to perform this process and for the photoelectric effect to take place correctly. Sometimes photons hit the surface and work on electronic emission, but their energy is not enough to move the photons from their place. Meaning the energy of the light that hits the surface and its frequency directly affects the emission of electrons. The figure (4.5) shows how energy can affect the emission of electrons.

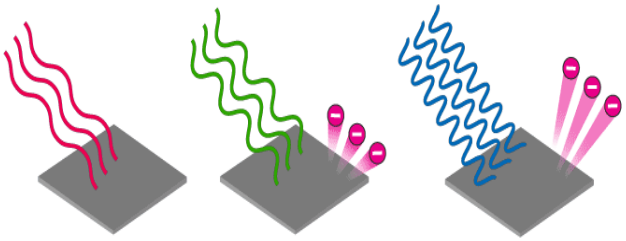

Figure 4.5. The effect of energy on the emission of electrons.

Figure (4.5) the figure shows that when the energy of the light is not enough, no electrons are emitted as shown in the red light, and when the light has good energy, as in the green light, the electrons can move, but when the light energy is very high, the electrons can be emitted and moved from Their place is very noticeable as it exists with a blue light. Photon properties;

- Photons in general have no mass and do not have an electric field reflection.
- The quantum ratio of the photons is zero.
- The photon is one of the fastest objects, as it can reach the speed of light in empty spaces.
- Photons have no charges.

Photoelectric effect characteristics;

- The relationship between photoelectric current and light intensity on a surface is direct.
- As the frequency of light increases, the movement of electrons increases with it.
- The frequency that characterizes the surface can change from one material to another.

Because of the good properties of this method, it is frequently used in many applications:

- The photoelectric effect can be benefited from by using it in alarm devices that are used for theft.
- Because of its light effect, there is a great need for its use in night vision devices.
- It is widely used in solar cell devices.
- In nuclear devices, there are some attempts to introduce the photoelectric effect on them.
- In digital cameras, these sensors are widely used, because of their need to see different colors of light.

4.2.1. Photoluminance Spectroscopy

In general, when light hits a specific sample, and the surface absorbs the light exposed to it, a certain process takes place called photoexcitation, which causes electrons to move and jump, and when this process occurs, there is an emission of a certain light, and this is called Photoluminance PL. The forms of photoluminance can somehow be divided into: phosphorous fluorescence and chemical fluorescence. The luminance period and degree can be changed based on the amount of excitation to which the material is exposed. This method is widely used to know the levels of the sample interface, its roughness, and the impurities on it. This method is generally considered harmless because it is not affected by the environment and there are no changes in the sample. When the material is inefficient in terms of radiation, the use

of this method is considered unsuitable and this is due to the dependence of PL mainly on radiological events. And it can be very suitable for use in semiconductors because it is not affected by pressure.

Although PL is considered one of the analyzes with many advantages such as simplicity and at the same time its high ability to find electronic properties, but like any other analysis it has disadvantages and who can affect it, because it depends on optical techniques, it may face many problems, including that The PL does not have a high efficiency, and at the same time, if the surface quality is not good, the results in PL are affected. And also, its ability to determine the density is very weak.

4.2.2. UV-Visible Spectroscopy

UV-visible spectroscopy is an interaction of light and matter to measure its wavelength, as it is highly dependent on the amount of radiation that can be absorbed, and that is reflected by atomic materials. Light absorption in visible and ultraviolet rays with a wavelength between 180 and 800 nanometers. Materials generally differ in their ability to absorb radiation, some materials absorb UV rays and others do not, which is why this issue has been taken advantage of for quantitative analyses. At the same time, the energy in visible light works inversely with the wavelength, that is, the higher the wavelength, the lower the energy present, and in each substance or sample its electrons need a certain energy to be upgraded, and this is what makes the light absorb materials in different ways. Recently, researchers have worked to create a type of device that operates with specific waves, i.e., a special device for each type of radiation, for example, when the work of the device is limited to radiation in the range of 200-250 nanometers, then it is called the ultraviolet visible region, and if it is Between 2500 and 25,000 nanometers is called an infrared spectrophotometer. The main components used in any UV visible spectrum is shown in detail in the Figure (4.6).

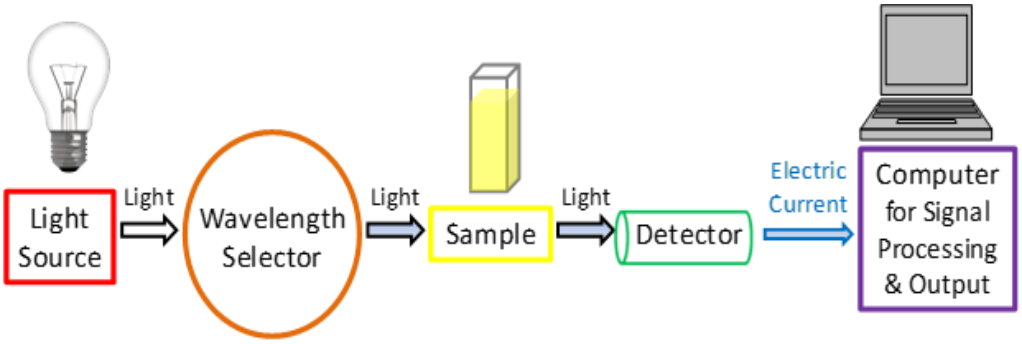

Figure 4.6. Components of UV visible spectrum (Credit: Dr. Justin Tom).

Ultraviolet visible spectroscopy is widely used in many diverse areas of our lives, as it can be used in medicines, bacteria cultivation, DNA determination and many other fields. In the identification of DNA, the use of UV-visible has spread greatly due to its speed in investigation, taking into account the percentage of absorption and contamination in the DNA. And in the pharmaceutical industry, this analysis has shown a great development, and this is because it can be used to identify pharmaceutical compounds such as local anesthetics or antibiotics that can be challenged in compounds of veterinary materials. This analysis can determine the level of caffeine in the drinks, and at the same time it has the ability to know the percentage of coloring matter in grapes or cherries, to know their quality in wine. In terms of safety, it can be used in transformers to monitor the existing oil so that electricity is delivered safely and quickly.

PART 5

THIN FILM PHOTODETECTOR

5.1. THIN FILM

Electronic devices used in optoelectronic applications, optical devices, and energy storage devices are becoming increasingly popular to make them flexible, thin and lightweight. Several methods are used to obtain thin films that consist of a very thin layer, the thickness of which ranges between nanometers or micrometers. Membranes can be deposited chemically or physically. In the chemical method, the substrate must be exposed to a volatile substance and then reacted on a substrate to produce a thin film. On the other hand, precipitation is formed in the physical substance by changing the substance from condensate to vapor and then back again to a thinner phase, this is called PVD method. These methods are considered unsuitable and expensive due to their need for a very high temperature. When comparing this method with another newly discovered method called sol-gel, this method is much better than other deposition methods, as it contains three technologies (spraying, paint recycling, and dip coating). To make a thin film in the best way, at an affordable cost and with high quality, spin coating can be considered as the most suitable method for this process. It is possible that the membranes may not be in the form of a single layer. Sometimes the membranes are in the form of more than one layer, as is found in solar cells and also in electrical cells.[65]. In general, it can be said that the use of thin films in applications dates back to 1838, when the first thin film was discovered, as it was produced by the method of electrolysis, and after a few years many other methods were carried out to produce thin films such as chemical reaction and evaporation in inert gas and other ways. But it was not developed or spread as expected until the development of vacuum devices.

5.2. THIN FILM PRODUCTION METHODS

Obtaining a thin and uniform thickness in the thin films is something that everyone is trying to reach, as reaching this matter depends on three parameters: Speed, which has an inverse relationship with the thickness of the film, the higher the speed of rotation, the less the film thickness. The second parameter is the viscosity of the solution. An increase in the viscosity may affect the thickness uniformity throughout the film. The last parameter is the evaporation rate. The faster the solution evaporates; the more viscosity is maintained in the solution [65].

5.2.1. Vacuum Thermal Evaporation Technique

It is considered one of the most used deposition techniques in physical techniques. In evaporation techniques, the focus is on changing the phase of the material from solid to vapor, and then returning it back to its solid state to obtain thin films. To perform this process, the material must be placed in the vacuum.

This technique can be performed depending on two basic parameters, first a material that is thermally evaporated and focused on the potential difference on the substrate at a high vacuum level, which is between 5-10 to 9-10 mbar. Figure (5.1) shows the method of convection evaporation.

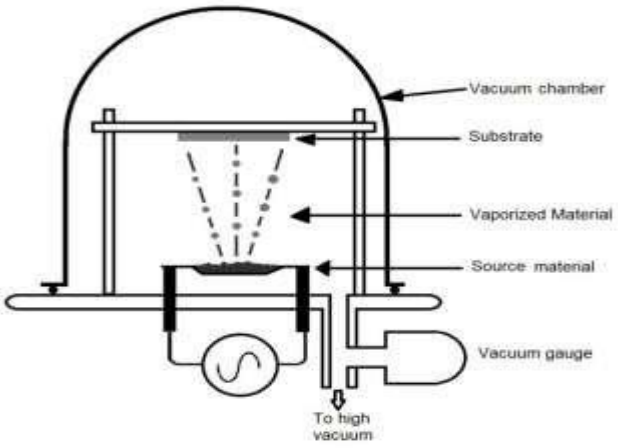

Figure 5.1. Vacuum Thermal Evaporation Technique.

This method is considered one of the easiest and proven methods for preparing thin films, especially chalcogenide films, for example Mns and Cdsse. They can be used in many applications such as solar energy and memory switching.

5.2.2 Electron Beam Evaporation

Vaporization can be carried out in this way for many materials, including metals and oxides. Vaporization in this method is by collecting many electron filaments and then hitting them on the target material by two electric fields, and this process is performed in a vacuum. Figure (5.2) shows the mechanism of action of this method for making a thin film.

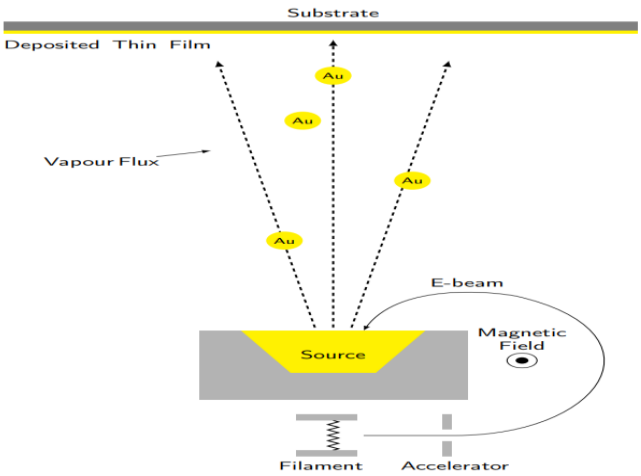

Figure 5.2. Electron beam evaporation.

5.2.3. Pulsed-Laser Deposition

Which is considered one of the most distinctive types of physical deposition, because it gives quick results and is highly compatible with most types of inert gases. Evaporation in this method is carried out by using a laser to extirpate the material in a complete vacuum environment. To produce a column that is deposited on many types of substrates, the quality of the thin film mostly depends on the wavelength of the laser, the distance at which the substrate is targeted, and the duration of the pulse. As shown in Figure (5.3) Many types of lasers can be used in this process and the most common are XeCl and KrF.

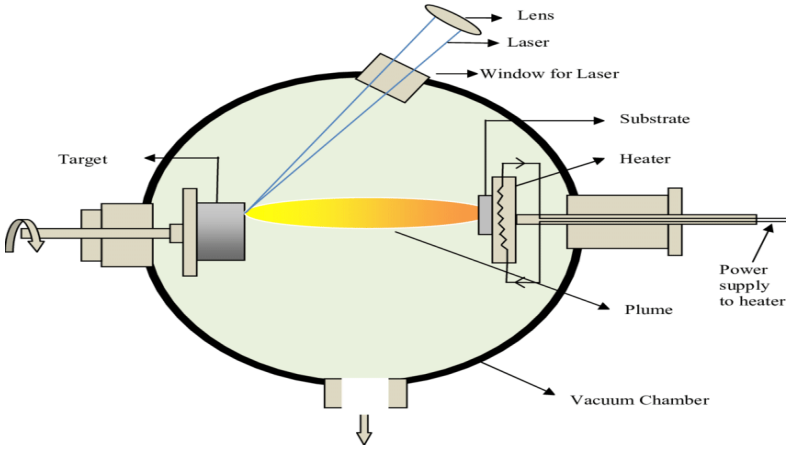

Figure 5.3. Pulsed-Laser Deposition.

5.2.4. Sputtering Technique

In order to obtain materials that have been deposited and their composition remains the same and has not changed, the use of a Sputtering system is the most appropriate way to obtain these results. In general, there are many types of Sputtering evaporation, but the presence of direct current and radio frequency method covers the rest of the other methods. In the first type, it is used with materials that are electrically conductive and have a low price, and this method depends largely on DC current. And the use of the second method is for insulating materials only, and one of the most used materials in this method and in which films are produced is aluminum nitride films. It is possible to say that the Sputtering technique is widely used in metals and oxides.

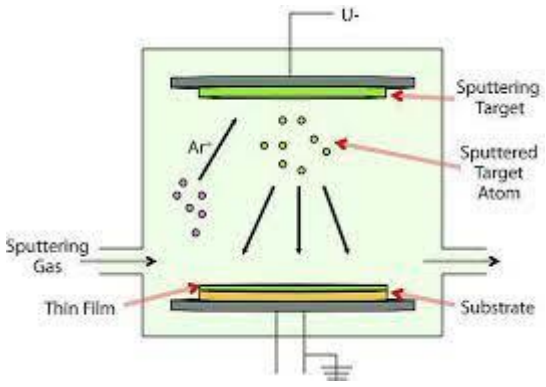

Figure 5.4. Sputtering technique.

5.2.5. Sol-Gel Technique

It is a compound word; sol comes in the sense of forming a colloidal suspension and gel in the sense of changing a sol into a gel or solid. For the preparation of transition metal oxides. Which is a chemical process that occurs to make new materials such as ceramics, there are two ways to perform this process, firstly the preparation of inorganic precursors by inorganic salts in an exclusive aqueous solution. In the second method, metal alkoxide precursors are prepared in non-aqueous solutions by metal alkoxides [66].

The dependence of the sol-gel technique is on the polycondensation of metal oxides, where the R is an alkyl group and the Z is considered a state of oxidation of the metal atom MZ +, which can be obtained by certain processes, and then a hydrolysis is done, which aims to form groups M-OH and then the condensation process, in which the water is removed.

5.2.6. Dip-Coating Technique

In general, the dip coating process can be carried out using five basic steps, immersion, starting, sedimentation, draining and finally evaporation. From them, transparent layers of oxides are produced, with a thickness of the specified film reaching 1 micrometer. The figure (5.5) shows the method of making a dip coating.

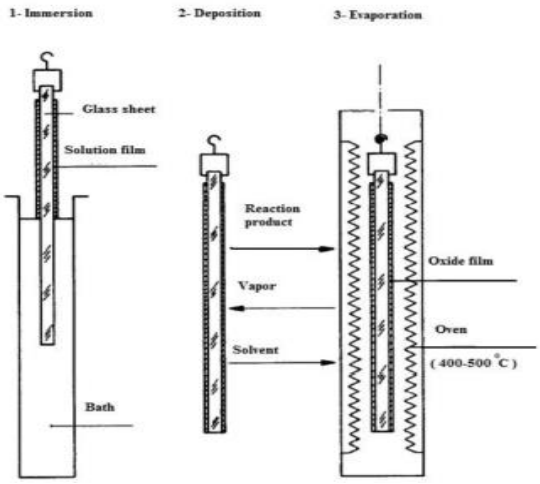

Figure 5.5. Dip-coating technique.

5.2.7. Spin-Coating Technique

Emslie et al, who is considered the first to manufacture the Spin coater device, which was around 1958. However, due to some deficiencies in the device, the researcher Meyerhofer et al modified it as he gave many proposals and solutions to reduce the thickness in the thin film, which can change Because of the rotation speed, evaporation rate and viscosity in the solution, he did this work in 1978. And after them, M. MeftahulFerdaus et al, Mohor Ferdowsi and others made spin coating machines with certain speeds of 3000 revolutions in just one minute, an increase in speed It makes the cost less, but because the device made by Mohor Paradise is manually controlled, the control was inaccurate and the film produced was irregular in some places. This is what made researchers like Z.Kaddchi make a system that controls the speed and makes it uniform between 2000-3000 which is called ATM 320. Then many researchers made devices to control the speed and at the same time produce a uniform thin film, and this is what Manikandan et al By making them for LPC 11024.

The technology of spin coating to create a thin film with a small and uniform thickness is carried out through four specific stages shown in Figure (5.6) In the first stage, a small amount of solution is deposited in the substrate, then the second stage begins, which is by the rotation of the substrate, after which work is done to maintain on regular rotation until a thin film is created, at the last stage the added solvent evaporates. For a consistent film the proper temperature must be maintained until the solvent evaporates properly [66].

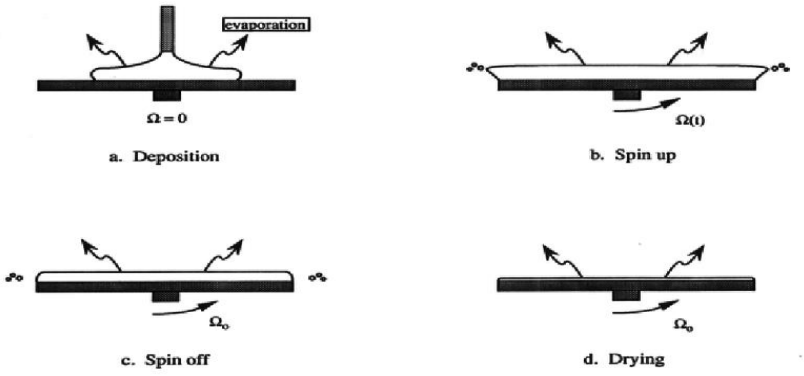

Figure 5.6. Spin Coating Process

5.2.8. Chemical Bath Deposition Technique

This technique is considered one of the oldest techniques used to produce films on a substrate, in this method to make chalcogenide films or metal films a certain technique is used which is called solution growth. Where in this technique the solution is complicated by bonding to ions and then by using ammonia or diamine, a complex solution is obtained. Then the anions produced from thiourea or sodium sulfide solutions are added, as final steps, the substrates are made in a horizontal or vertical shape inside the solution to obtain a specific film from them. But in the oxide film method, the process is different. After the complexing step, the substrate is placed in a specific solution with an appropriate temperature between 60-100, and this is to deposit the metal hydroxide films.

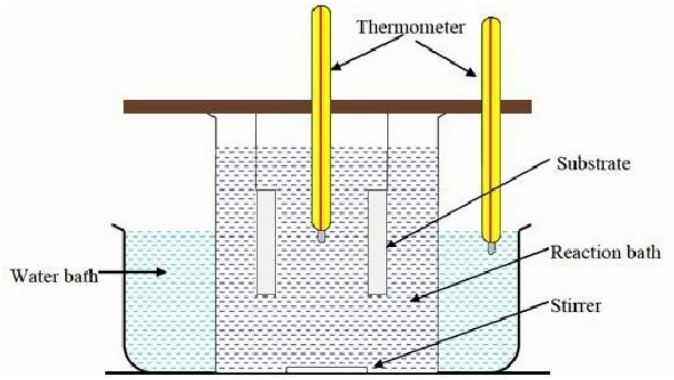

Figure 5.7. Chemical bath deposition technique.

PART 6

METHODOLOGY

6.1. PRODUCTION OF PHOTODETECTOR

For the production of rGO/MAPbI3 composite, SiO2 was coated on Si wafer by thermal oxidation method in the first step. The oxidation process was carried out in a temperature-controlled environment with O2-N2 gas flow in the tube furnace. In the second step, 0.4 g of rGO was dissolved in 100 mL of water in an ultrasonic bath. This solution was first coated on Si/SiO2 surface by spin coating at 500 rpm for 10 seconds, then at 3000 rpm for 20 seconds and dried at 100 degrees. In the third step, a 1:1 mixture of methyl amine iodide and PbI2 was prepared in 20% dimethylformamide (DMF) and heated at 70℃ until the solution turned yellow. This solution was coated on Si/SiO2 by spin coating on the CNT coated surface at 2000 rpm for 40 seconds. Finally, it was dried at 100℃ for 10 minutes. Figure 1. shows the schematic structure.

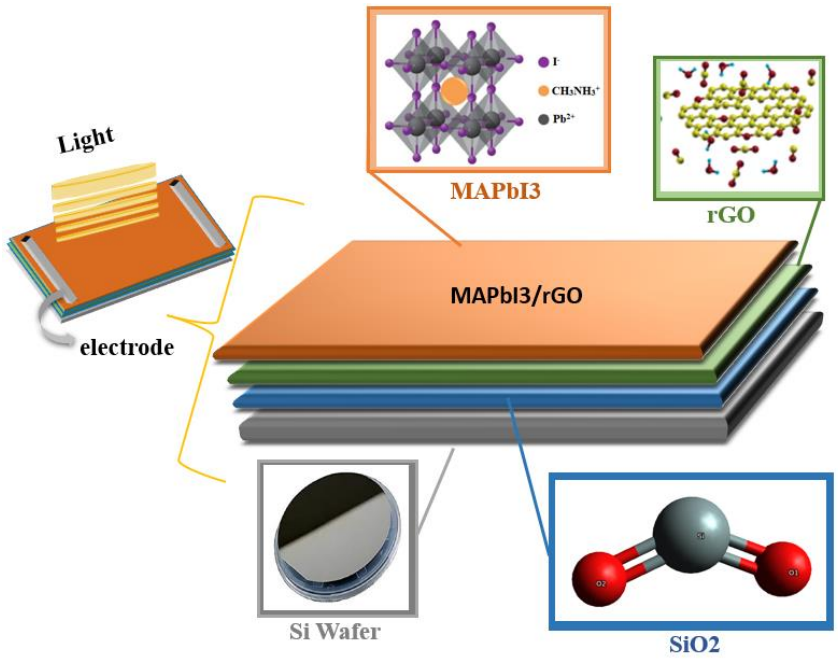

Figure 6.1. Schematic illustration of MAPbI3/rGO heterostructure.

X-ray patterns were obtained by X-ray diffraction (XRD) with a CuKα1 radiation source (Rigaku Ultima IV model, λ=1.5406 Å) over the range of 10°<2θ<90° at a speed of 3° min-1 with a step size of 0.02°. The samples' 2D surface morphology was determined by FESEM (Carl Zeiss Ultra Plus Gemini FESEM). FTIR device (BRUKER ALPHA, having a resolution of 4 cm x 1; equipped with a DTGS detector. The forward and reverse bias I-V and C-V measurements were performed by using the Keithley 4200 semiconductor parametric analyzer system at room temperature. Solar simulator, Sciencetech (SF300-B) small collimated beam, 300 W, Class ABA was used for measurements under illumination.

6.2. CHARACTERIZATION

6.2.1. Structural and Surface Characterizations

In Figure 6.2., the XRD diffraction peaks obtained at 2θ=10°-90° of XRD analyzes performed to confirm the formation of MAPbI3/rGO are given. The tetragonal growth planes of (110), (220) and (310) MAPbI3, the diffraction peaks of 14.08º, 28.5° and 32° at 2θ, respectively, in Figure 6.2. confirm the full formation of the MAPbI3 perovskite film prepared using the two-step method [12,13]. For rGO, a small peak at 25.4° and a broad peak at 43.6° were detected, which is consistent with the literature, corresponding to the (002) and (111) planes, respectively [14]. The incorporation of rGO nanolayers into perovskite systems reduced crystallinity, which was confirmed by a decrease in peak detection intensity in XRD models of MAPbI3/rGO films compared to pure perovskite [15].

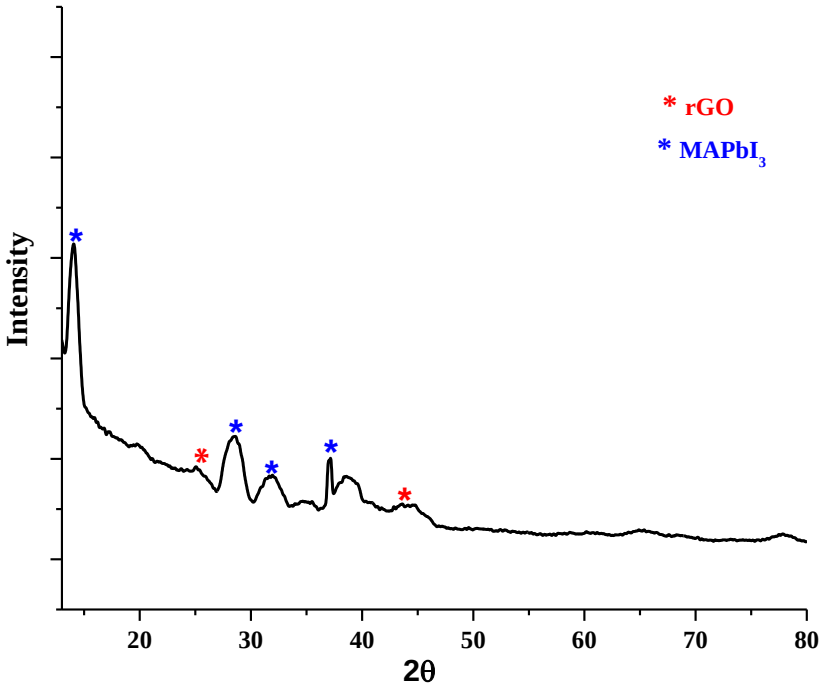

Figure 6.2. XRD diffraction pattern of MAPbI3/rGO heterostructure.

Figure 6.3. shows vertical section SEM images of the MAPbI3/rGO composite structure. Considering the morphology of the electrode, it was determined that almost all of the rGO structure of the spin coating method, which is the production method, was filled by MAPbI3 small perovskite crystals. The structure, which is denser with high persistence and allows effective charge formation and separation in perovskite films, was also beneficial for the transport of carriers throughout the film. The structure represents a weaker crystal morphology with small perovskite crystal grains. Although voids are present in the MAPbI3/rGO interface, the interface layer does not form in such structures. In addition, the EDX results of the MAPbI3/rGO electrode in Figure 4 confirm the compositions in the structure.

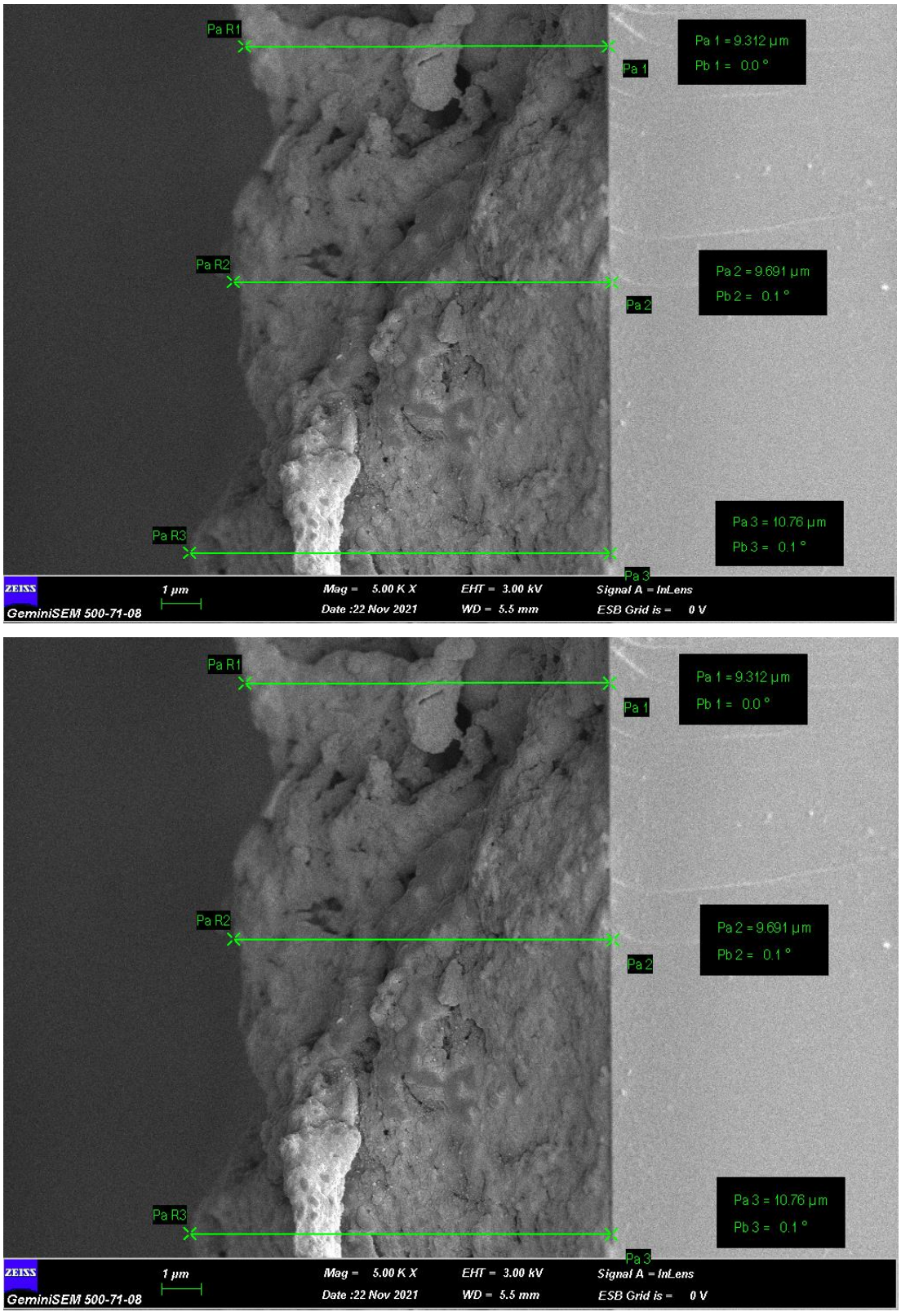

Figure 6.3. SEM Image (Vertical Section) of MAPbI3/rGO heterostructure.

Element	Weight %	Atomic	Net Int.
C K	24.61	64.73	610.98
O K	6.68	13.19	254.82
Si K	6.94	7.8	711.74
Pb M	11.42	1.74	469.26
I L	50.36	12.54	1616.28

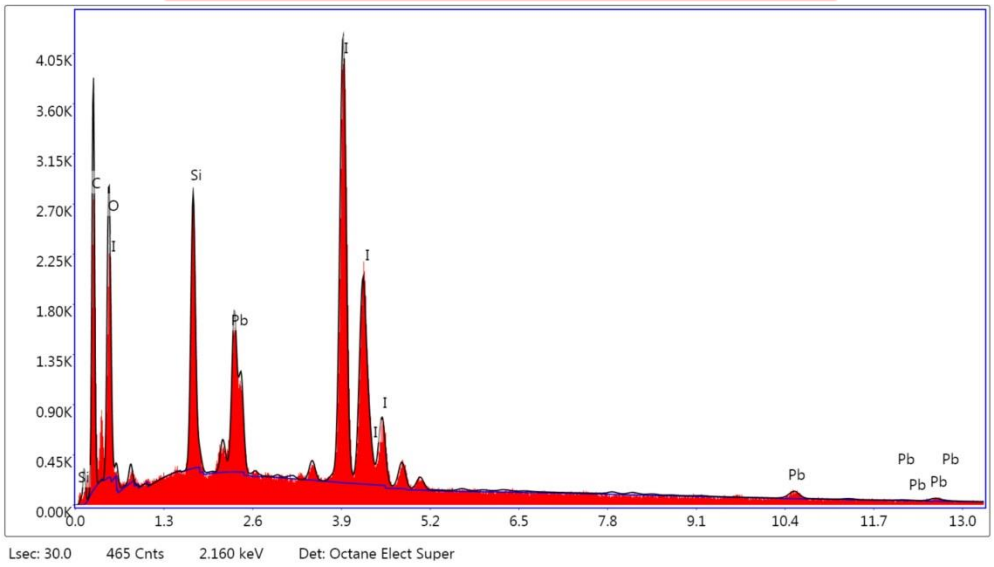

Figure 6.4. EDX Analysis of MAPbI3/rGO heterostructure.

FTIR analyzes to determine the chemical bonds of the MAPbI3/rGO composite structure were performed at wavelengths between 600 and 4000 cm^{-1}. Strong bands at 1093 of SiO2 are associated with asymmetric and symmetrical Si-O-Si stretching vibration bonds [16]. Peaks with peaks of 2374, 1717 correspond to C-H and C = O of rGO, respectively [17]. It showed broad absorption peak observed at ~3414 cm-1, corresponding to the O-H stretching vibration, which may indicate the presence of adsorbed water molecules in addition to carboxy and hydroxy O-H groups in rGO. 1398 cm-1 corresponds to C-OH [18]. FTIR vibrations of $MAPbI_3$ at 660 and 860 cm1 show characteristic features of C–O stretching and C–N stretching. The 1250 peak belongs to the C–H bending of the vibration frequency [19]. At MAPbI3, the characteristic peaks are for N–H stretching vibration at 1571 cm-1 and for C–H stretching vibration at 1463 cm-1 [20,21].

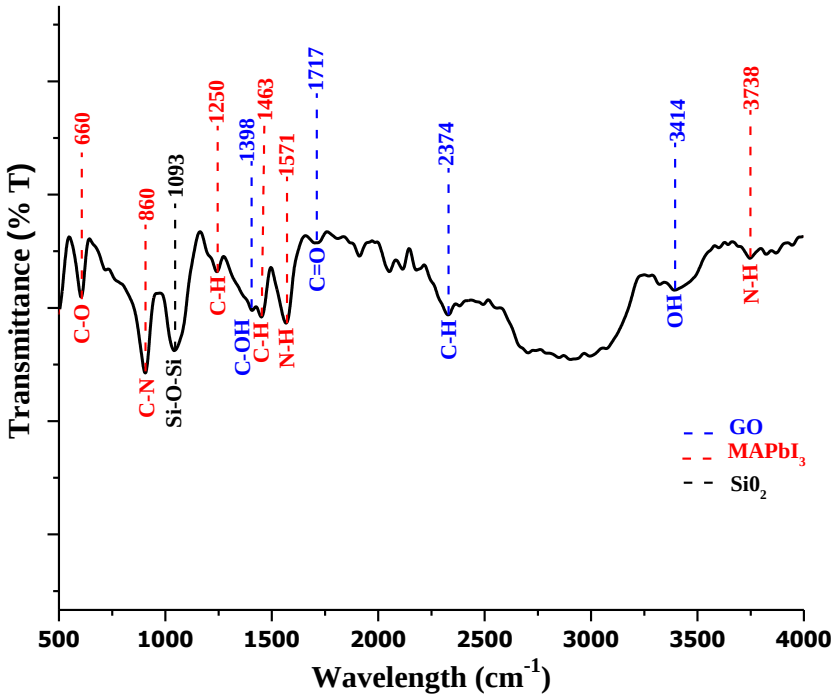

Figure 6.5. FTIR analysis of $MAPbI_3$/rGO heterostructure.

6.2.2. Characteristics of Photodetector

For the produced MAPbI3/rGO heterostructure photodetectors, the series resistance and parallel resistance values are calculated according to the single diode model and given in Table 6.1. The Table 6.2. gives V_{bi} values versus illumination intensity.

Table 6.1. Series resistance (Rs) and parallel resistance (Rp) values calculated according to the single diode model.

Illumination intensity (mW/cm^2)	R_s (kΩ)	R_p (MΩ)
Dark	528,7	2,578
20	502,8	3,850
40	452,8	3,186
60	417,5	3,763
80	415,3	7,200
100	377,2	8,410

Table 6.2. Vbi values versus illumination intensity.

Illumination intensity (mW/cm^2)	V_{bi} (V)
Dark	0.52
20	1.4
40	1.4
60	1.14
80	1.3
100	1.12

Methods such as thermionic emission (TE) theory, Ohm's law, Cheung and Cheung's method are used to calculate parameters such as series resistance, ideality factor, and potential barrier height of optoelectronic structures [20,21]. Figure 6.6. shows the current-voltage properties of MAPbI3/rGO PD structures examined in forward and reverse bias and the effect under dark and visible UV light intensities.

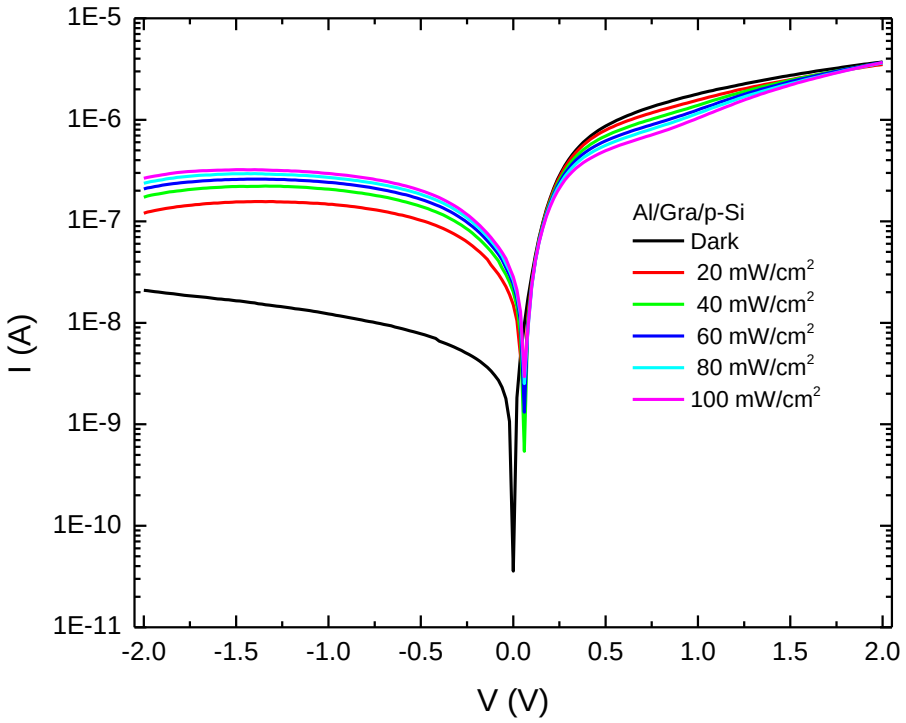

Figure 6.6. I-V graphs of Al/MAPbI3/rGO /p-Si device under dark and different illumination levels

The increase in reverse voltage current and illumination levels shows that the produced PD structure exhibits photodiode behavior. The increase in the forward and reverse current values at ± 2 V according to the visible UV light intensities of the photodiode behavior can be shown as evidence. However, there is a need to calculate

electronic parameters using thermionic emission (TE) theory and Cheung and Cheung's method. According to TE theory, the metal-semiconductor junction with the interface layer and series resistance Rs is expressed by the following equations [20,21].:

$$I = I_0 \left[exp\left(\frac{q(V-IR_S)}{nkT}\right) - 1 \right] \quad (6.1)$$

were,

$$I_0 = AA^*.T^2 exp\left(-\frac{q\Phi_{Bo}}{kT}\right) \quad (6.2)$$

where q is the electron charge (C), T is the absolute temperature (K), V is the applied voltage, IRs is the voltage drop across Rs, k is Boltzmann's constant, A is the rectifier contact area, A* is Richardson's constant, n is the ideality factor deduced by Equation 1, and ΦB0 is Equation 2 is the potential barrier height subtracted by [20,21].

$$\Phi Bo = \frac{kT}{q} ln\left(\frac{AA^*T^2}{I_0}\right) \quad (6.3)$$

$$n = \frac{q}{kT} \frac{d(V-IR_S)}{d(\ln(I))} \quad (6.4)$$

Table 6.3. Electronic parameters of MAPbI3/rGO PD produced at visible-UV light intensities.

Visible-UV light intensity (mW/cm²)	**Cheung's**		**TE**	
	Rs (kΩ)	Rs (kΩ)	n	ΦBo (eV)
Karanlık	492	491	2,97	0,64
20 mW/cm²	393	388	11,97	0,64
40 mW/cm²	311	320	12,02	0,65
60 mW/cm²	297	338	9,88	0,45
80 mW/cm²	265	265	11,78	0,67
100 mW/cm²	244	245	10,96	0,68

Experimentally calculated values are given in Table 6.3. As the light intensity increased, the n value increased up to 60 mW/cm2. ΦBo values vary between 0.45

and 0.68 eV for dark and different light intensities. n values higher than one indicate the presence of potential barrier inhomogeneities. Figure 6.8 is expressed to compare the x, n and ΦBo values. The voltage dependent resistances of PD were calculated using the Cheung method and plotted in Table 6.3 and Figure 6.7 to compare Rs with Cheung 1 and Cheung 2'. As the loads in the valence band are excited to the conduction band with increasing illumination intensity, the Rs values for the sample decrease.

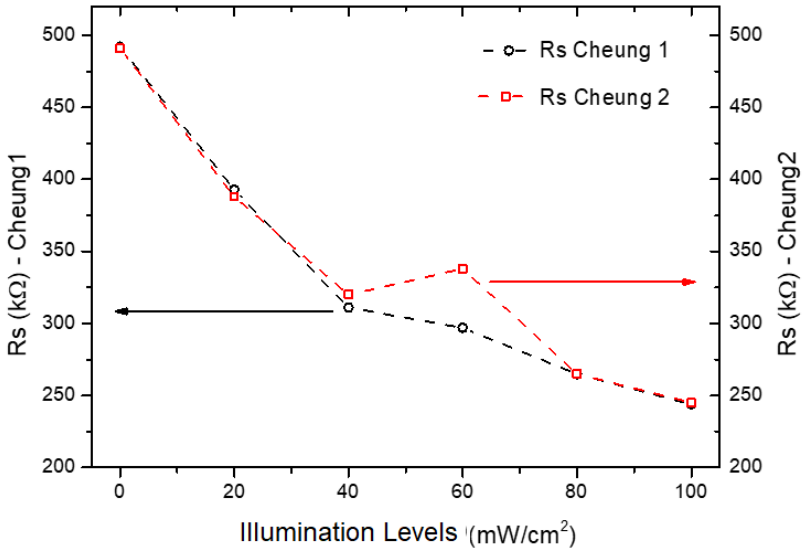

Figure 6.7. Compare Rs with Cheung and Cheung's method.

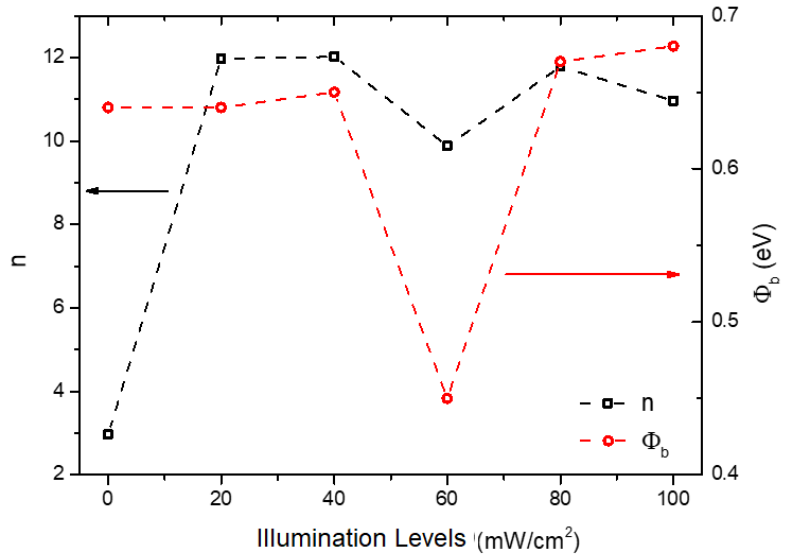

Figure 6.8. Φ_{Bo} ve n values of MAPbI3/rGO PD produced under dark.

Fig. 6.9 shows the dark and the illuminated C-V characteristics of the Al/Gra/p-Si device. According to Fig. 6.9, the values of C increase as a function of the light intensity especially in accumulation and depletion regions. In studies on similar devices, the increase in charge density in the junction area and interface due to the charge carriers created under the light has been shown as the cause of the additional photo-capacitance under the light. [3, 4]. In addition, the increase in charge carrier concentration under illumination also leads to an improvement in the space charge layer [24-26].

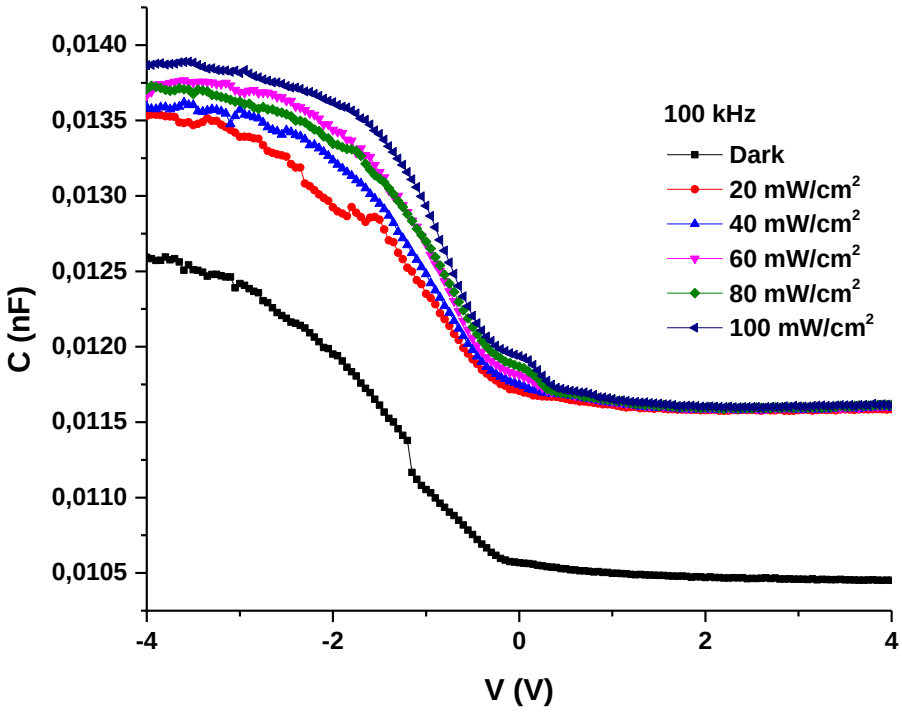

Figure 6.9. C-V graphs of MAPbI3/Rgo device under dark and different illumination levels (f=100 kHz)

Figure 6.10 shows the results of C-V measurements between -4 V and + 4V for an MAPbI3/rGO device at different frequencies in the dark. Accumulation, depletion, and inversion regions can be clearly seen from the graphs. It is seen that the measured capacitance values decrease with increasing frequency for all voltage regions. This phenomenon observed for most semiconductor junction devices is explained by the fact that the interface states, which contribute significantly to the measured capacitance, cannot follow the applied ac signal at high frequencies [27,28].

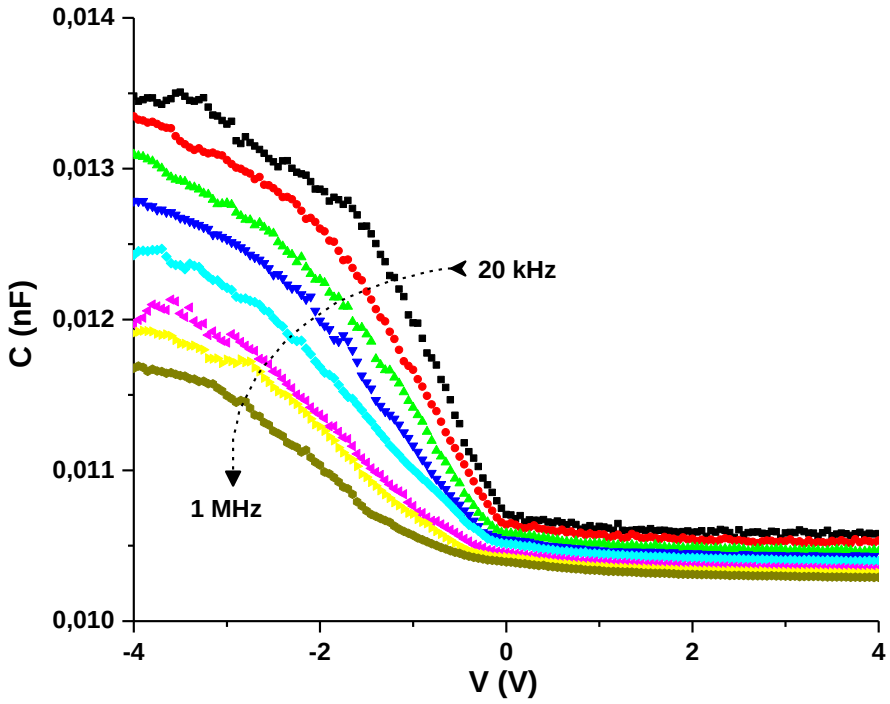

Figure 6.10. C-V graphs of Al/MAPbI3/rGO /p-Si device at various frequencies

The photosensitivity (S) is given as;

$$S\ (\%) = \frac{I_L - I_{dark}}{I_{dark}} x100 \qquad (6.4)$$

where I_L and I_{dark} are photocurrent and dark current, respectively. The photosensitivity S (%) values of MAPbI3/rGO device were calculated and plotted as a function of illumination intensity in Figure6.9. at the reverse bias of -2 V. According to the graph, as a result of the photo-generated charges due to the applied electric field, S values increase with rising illumination intensity [22,29].

In the metal-semiconductor junction, the internal electric field formed due to the charges on the depletion region edges allows the photo-generated charge carriers formed under the light to separate from each other and reach the contacts and the photocurrent is formed. The insulator or oxide layer used at the interface in MIS, MOS, and similar structures widens the depletion region and increases the intensity of the mentioned electric field. It can be argued that for the MAPbI3/rGO device, the graphene interface layer also increases the internal electric field strength with a similar effect, and a distinct photocurrent is formed [22,23].

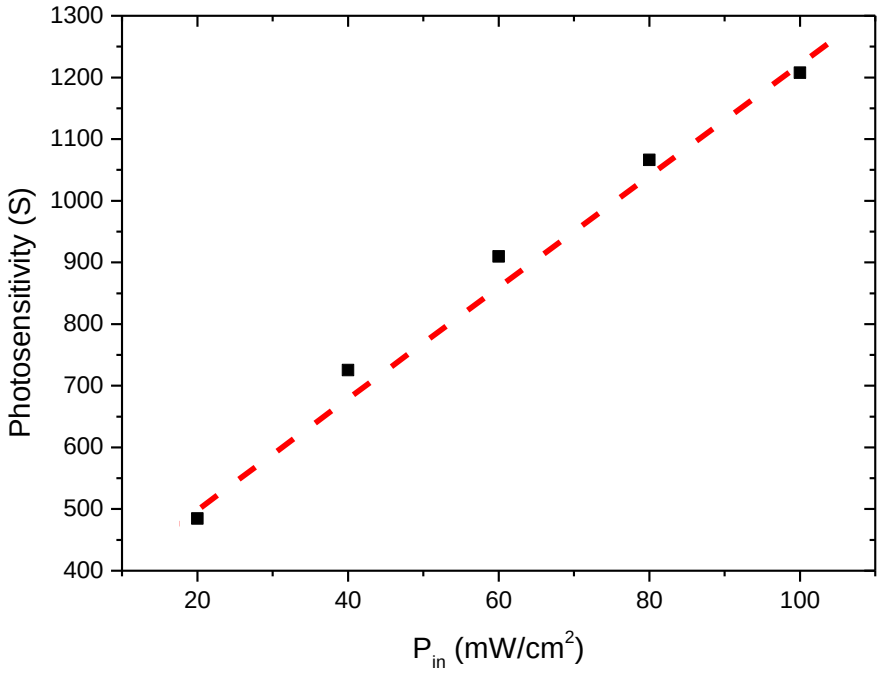

Figure 6.11. Photosensitivity S(%) versus illumination intensity of MAPbI3/rGO device.

Table 6.4. Photosensitivity values versus illumination intensity.

Illumination Intensity (mW/cm^2)	**Photosensitivity (%)**
20	42033
40	56255
60	66613
80	73416
100	79351

In the metal-semiconductor junction, the internal electric field formed due to the charges on the depletion region edges allows the photo-generated charge carriers formed under the light to separate from each other and reach the contacts, where the photocurrent is formed. The insulator or oxide layer used at the interface in MIS, MOS, and similar structures widens the depletion region and increases the intensity of the mentioned electric field. It can be argued that for the MAPbI3/rGO device, the graphen interface layer also increases the internal electric field strength with a similar effect, and a distinct photocurrent is formed [22, 23]. It is seen that the photosensitivity increases with increasing illumination intensity. Compared with the literature, it was determined that the photosensitivity results were high [68].

PART 7

CONCLUSION

- In this study, the performance of photodetector based on rGO/MAPbI3 heterostructure produced by spin coating method in three stages in a controlled manner on Si wafer substrate was investigated.
- The increase in the reverse bias current proportional to the illumination intensity confirms that the device exhibits photodetector behavior.
- In addition, it was observed that the capacitance values increased as a function of the light intensity and the charge carrier concentration increased.
- The decrease in capacitance values with increasing frequency is explained by the inability to follow the AC signal applied at high frequencies.
- The findings of this study will encourage further optoelectronic applications based on perovskite hybrid material.
- Moreover, frequency-dependent measurements showed that the capacitance decreases as the frequency increases.
- As the light intensity increased, the n value increased up to 60 mW/cm2. ΦBo values vary between 0.45 and 0.68 eV for dark and different light intensities. N values higher than one indicate the presence of potential barrier inhomogeneities.
- The photosensitivity S (%) values of the Al/Gra/p-Si device was calculated at the reverse bias of -2 V. The device's rectification ratio (RR) was 162 at 2 V.

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RESUME

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