Preparation of Schottky devices (Al-GaAs &Ni-GaAs) and study of some photoelectronic properties

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تحضير نماذج شوتكي (Al-GaAs &Ni-GaAs) ودراسة بعض الخصائص الكهروبصرية

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Abstract

Four samples of metal (n-type) semiconductor contact had been prepared as a form of Schottky contact where we used (Al & Ni) metals and semiconductor substrate GaAs (donor).The Ohmic contact has been firstly made with thickness (5000 Å) using aluminum for two samples and nickel for other two, four samples were collected, then these samples were annealed under the temperature of (450 K) and pressure (10^{-4} Torr) for (30 min.) to avoid interfacial layers. Then we made a Schottky contact using aluminum twice and nickel twice with (120 Å) thickness and then we annealed the samples under temperature (450 K) and pressure (10^{-4} Torr) , the samples are as follows:(Al-GaAs - Al Ohmic / Al-GaAs - Ni Ohmic / Ni-GaAs - Al Ohmic / Ni-GaAs - Ni Ohmic).Then we calculated the values of the photocurrent as a function of wavelength and we found that the maximum value was for the sample (Al-GaAs-Al ohmic) in the wavelength (800 nm) and the dark current is (1.9×10^{-9} Ampere) then we calculate the Detector coefficients of the samples, the maximum Response was in the wavelength (800 nm) is (0.157 Ampere/ Watt) and maximum Specific Detectivity in the same wavelength is (63.7×10^{11} Hz ^{½} Watt $^{-1}$), the maximum Noise Equivalent Power is (0.157 Watt Hz $^{-½}$) and the maximum Efficiency is (24.4 %) in the same wavelength , the photocurrent and Response values depended on the absorption coefficients of metals and work functions the samples operate within the area under the near-infrared .

الخلاصة

تم تحضير أربع نماذج باتصال معدن شبه موصل (مانح) على شكل تماس شوتكي حيث تم استخدام معدني الألمنيوم والنيكل وأرضية شبه موصل أرسنيد الكاليوم (مانح) , تم أولاً أجراء الاتصال الأومي بسمك (5000 Å) باستخدام معدن الألمنيوم لنموذجين ومعدن النيكل لنموذجين فكانت المحصلة أربع نماذج وتمت عملية التلدين لهذه النماذج تحت درجة حرارة (450 K) وضغط (10^{-4} تور) لمدة نصف ساعة لتفادي حالات السطح البينية ومن ثم أجراء اتصال (شوتكي) باستخدام معدن الألمنيوم مرتين والنيكل مرتين وبسمك (120 Å) ومن ثم أجراء عملية التلدين الحراري للنماذج تحت درجة حرارة (450 K) وضغط (10^{-4} تور) فكانت النماذج كالآتي : (ألمنيوم – أرسنيد الكاليوم وبتماس أومي معدن الألمنيوم/ ألمنيوم – أرسنيد الكاليوم وبتماس أومي معدن النيكل / نيكل – أرسنيد الكاليوم وبتماس أومي معدن الألمنيوم/ نيكل – أرسنيد الكاليوم وبتماس أومي معدن النيكل) . ومن ثم تم حساب قيم التيار الضوئي كدالة للطول ألموجي حيث كانت أعلى قيمة للتيار الضوئي عند الطول الموجي (800 nm) وكانت قيمة تيار الظلام هي (1.9×10^{-9} Ampere) ومن ثم تم حساب معاملات الكاشف للنماذج الأربعة ،حيث تم حساب أعلى قيمة للأستجابة عند الطول الموجي (800 nm) وكانت (0.157 Ampere/ Watt) واعلى قيمة للكشفية النوعية كانت عند نفس الطول الموجي(63.7×10^{11} Hz ^{½} Watt $^{-1}$) في حين كانت أقل قدرة مكافئة للضوضاء (0.157 Watt Hz $^{-½}$) وأعلى كفاءة كمية مسجلة هي (24.4 %)وسجلت قيم التيار الضوئي واللأستجابة أعتماداً على معامل أمتصاص المعدن ودالة شغله وكانت النماذج تعمل ضمن منطقة تحت الحمراء القريبة .

Introduction:

Infrared detectors entering their third generation of development with greater demand on their performance and capabilities, no longer is the goal of just achieving infrared images but now it is required to have greater performance with better uniformity over larger area, lower cost, and multispectral detection (Binh-Minh Nguyen, Darin Hoffman, Edward Kwei-wei Huang, Simeon Bogdanov, Pierre-Yves Delaunay, Manijeh Razeghi, and Meimei Z. Tidrow, (2009), Photodetectors based on different absorption materials are used for a corresponding spectral range, for instance, in the visible wavelength region, Si-based photodetectors are preferred, while in the ultraviolet (UV) wavelengths, the III–V nitrides are the promising materials. It is also well known that the GaAs has superior performance for detection in the 600–900-nm wavelength range. (Meng - Chyi Wu, Yun - Hsun Huang and Chong-Long Ho (2007), in (2000)(Monroy E., Vigue F., Calle F., Izpura J. I. ,Mun˜oz E. and Faurie J.P.) they were reported on the characterization of ZnSe- and ZnMgBeSe - based Schottky barrier photodetectors grown on semi-insulating GaAs by molecular-beam epitaxy. The spectral response of the devices shows Short-wavelength responsivities of 0.10 A/W and detectivities as high as $1.4x10^{12}$ cm $Hz^{1/2}W^{-1}$, in (2004)(Necmi Biyikli ,Ibrahim Kimukin) they were designed, fabricated, and tested Schottky photodiodes with indium–tin–oxide (ITO) Schottky layers ,they were utilized for detection in the ultraviolet (UV) (λ< 400 nm), near-IR (λ ~ 850 nm), and IR (λ ~1550 nm) spectrum, The material properties of thin ITO films were characterized. Using resonant-cavity-enhanced (RCE) detector structures, improved efficiency performance was achieved. Current–voltage, spectral responsivity, in (2009) (Binh-Minh Nguyen, Darin Hoffman, Edward Kwei-wei Huang, Simeon Bogdanov ,Pierre-Yves Delaunay, Manijeh Razeghi and Meimei Z. Tidrow),they were reported the growth and characterization of type-II InAs/GaSb super lattice photodiodes grown on a GaAs substrate, The detector exhibited a differential resistance at zero bias and a quantum efficiency of 36.4% at 77 K, providing a specific detectivity of $6 x10^{11}$ $cm.Hz^{½}.W^{-1}$,in (2009) (Abdollahi Pour S., Nguyen B-M., Bogdanov S. ,Huang E. K. and M. Razeghi) they were reported the growth and characterization of long wavelength infrared type-II InAs/GaSb super lattice photodiodes , The quantum efficiency attains the expected value of 20% at zero bias, resulting in a Johnson limited detectivity of $1.1x\ 10^{11}$ Jones , in (2010) (I. H. Campbell) demonstrate organic photodiodes with a transparency of ~ 80% throughout the visible spectrum and with up to ~ 80% external quantum efficiency (EQE) in the near infrared under reverse bias.

Theoretical Part:

In Figure (1) n-type semiconductor brought into contact with a metal, Due to the positive work function difference between the metal and semiconductor, electrons are able to lower their energy by moving from the semiconductor into the metal, forming a depletion region, a Schottky barrier of height is formed which makes it difficult to inject electrons into the semiconductor, in opposite direction the semiconductor surface potential is Φ_S at zero bias and it changes with the applied bias. Thus, the resistance of the Schottky contact depends on the direction of the current flow. Schottky contacts are difficult to describe mathematically as they involve complicated transport mechanisms like thermionic emission and quantum tunneling, however, in case they are not essential for the device performance, Schottky contacts are often treated in a strongly simplified way, the carrier concentrations at the contact depend on the current densities. (Boer K.W.1990)

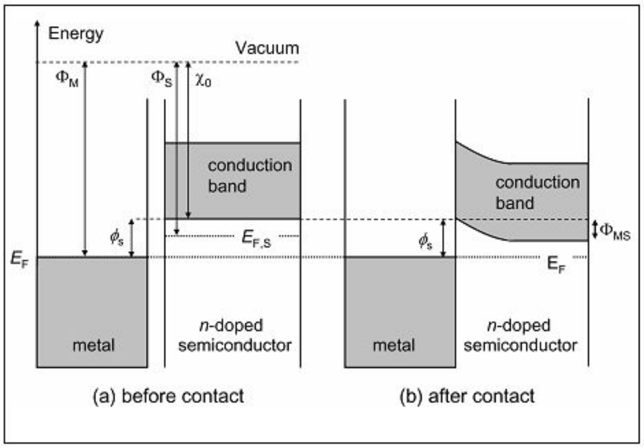

Figure (1) Metal-semiconductor (a) before contact (b) after contact

A photoconductor is a semiconductor device which exhibits a change in conductance (resistance) when photon energy is incident on it, photon energy incident on the detector produces an electron-hole pair which lowers the detector resistance by producing more carriers the change in the photoconductor resistance produces a change in the voltage, as with photo emissive detectors, the photon energy must be greater than the band gap (Eg) at wavelengths less than (Ronald W. Waynant, Marwood N 2000):

$$\lambda_{max} = hc / Eg \text{ ...... (1)}$$

λ_{max} is the critical wavelength, h is Plank constant (6.63 x 10^{-34} J.s) , c is speed of light in vacuum (3 x 10^{10} cm/s) , and when the radiant energy is less than the band gap (Eg) (the band gap energy for the GaAs is (1.42))(Sze S.M. 1990) then the thermionic emission is dominated because it is generated inside the metal only ,this region is inside the(near infrared) wavelengths (Burak Y.K 2001) . The Spectral Response (R) is a function to the Photocurrent density and equal to: (Budde W.1983)

$$R = J_{ph} / P_N \text{ ...... (2)}$$

J_{ph} is Photocurrent density (Ampere / cm^2), P_N is power per unit area (Watt / cm^2) ,the generation of electron–hole pairs requires the interaction with other particles that can be detected as electric signals (Joachim piprek 2003) the signals is the photo current then we calculated the Noise Equivalent Power (NEP) as a function to the Spectral Response: (Jones R.C.1954)

$$NEP = I_n / R \text{ ...... (3)}$$

(I_n) is the noise current and $I_n = (2q\, I_D \Delta F)^{1/2}$, I_D is Dark current (Burak Y.K 2001) ,then the Detectivity (D) is calculated by equation (4): (Budde W.1983)

$$D = 1 / NEP \ \ldots\ldots (4)$$

The number of the electron – hole generated for each fallen photon is known as quantum efficiency (η) and given in the following equation: (Sze S.M.1990, Budde W.1983)

$$\eta = R\, h\, c / \lambda\, q \ \ldots\ldots (5)$$

(λ) is the wavelength in (nm) , (q) is the Elementary charge (1.60218 x 10^{-19} C). (Sze S.M. 1990) For charged particles, ionization may occur along the path of light by many low-recoil collisions with the electrons. Photons have first to undergo an interaction with a target electron or with the semiconductor nucleus, In any case part of the energy absorbed in the semiconductor will be converted into ionization (the creation of electron–hole pairs), the rest into phonons (lattice vibrations), which means finally into thermal energy. The part of energy converted into electron–hole pair creation is a property of the detector material. It is only weakly dependent on the type and energy of the radiation except at very low energies that are comparable with the band gap. (Gerhard Lutz 1999)

Experimental Result and discussion:

The samples had been prepared by using GaAs (n-type) as a semiconductor substrate with resistivity (2x10^{-6} Ohm.cm) and we choose two types of metals (Ni ,Al) as Schottky contact and Ohmic contact for different samples , first we cleaned the GaAs substrate by using NH_4OH:H_2O (1:2) for (2 min) (Gerhard Lutz 1999)and then by water for (5 min) then we made the Ohmic contact with (Al)for two samples and (Ni) for other two with (5000 Å) thickness , then we annealed the samples under a vacuum pressure of the order (10^{-4} Torr) and (450 K) for 30 min. to get good Ohmic contact and small contact resistance,(Chen C.P. 1994) after that we made the Schottky contact with (Ni) for two samples and (Al) for other two with (120 Å) thickness then we annealed the samples under (450 K) temperature and (10^{-4}Torr) pressure in vacuum for 30 min to avoid the interfacial layer effect for the Schottky barrier height (SBH) because we presumed that oxygen play an important role in forming Schottky barrier and the Ohmic contacts. (Otsubo M.2004) The samples are: {Al-GaAs (Al Ohmic) / Al-GaAs (Ni Ohmic) / Ni-GaAs (Al Ohmic) / Ni-GaAs (Ni Ohmic)}. After we made the samples the Photocurrent was measured by using a tungsten light with wavelengths range (400-1100 nm), the figure (2) show the photocurrent as a function to the wavelength, as we can see the sample [Al-GaAs (Al Ohmic)] calculated as the best result of photocurrent we had while the other samples had less than this result especially the samples with (Ni) as Schottky contact , the absorption coefficient depends on the material and also on the wavelength of light which is being absorbed.

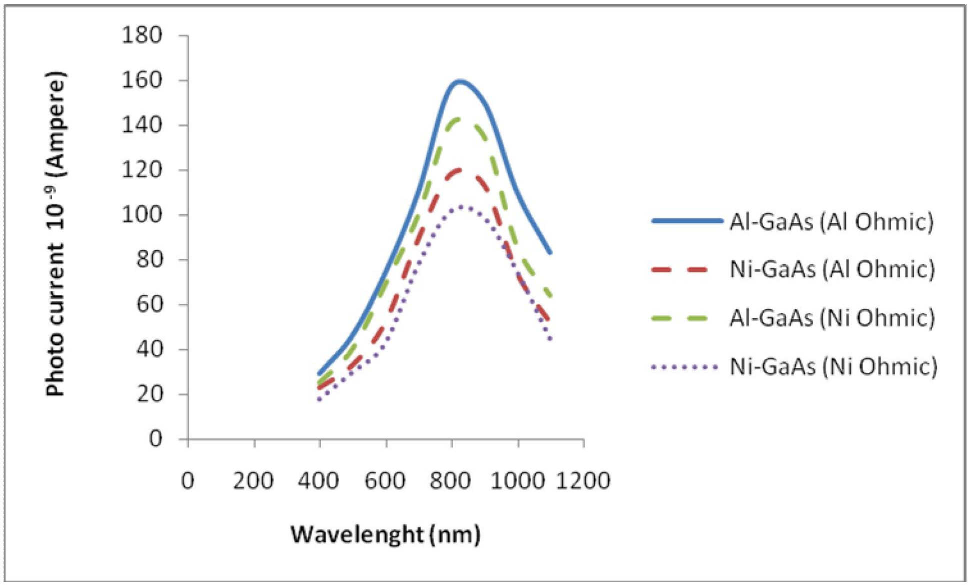

Figure (2) Photocurrent for the four samples as a function to the wavelength

We can divide the plot in figure (2) into three regions as a function to the wavelength (Raheem G.K. 2007):

1. Wavelengths less than (800 nm): The photocurrent increased with wavelength absorption of short wavelengths happened in the region near the surface due to possession of a large absorption coefficient, which means less depth absorption ,this phenomenon is causes a gradual increase in the concentration of carriers generated by recombination at the surface area which makes the increase in the value of the response is a subject to the possibility of collected charge carriers
2. Wavelengths between (800-900 nm): This region has the highest value of the photocurrent where it is assumed for the optical absorption of light within depletion region and this means high efficiency in the separation of electron–hole pairs generated by the electric field and the lack of recombination compare with 1st region
3. Wavelengths more than (900nm): Where there is a decrease in the value of the photo-current can be interpreted that the long wavelength had less absorption because the photon energy does not have enough power to generate the electron –hole pairs then low ratio of generated carriers in the depletion region.

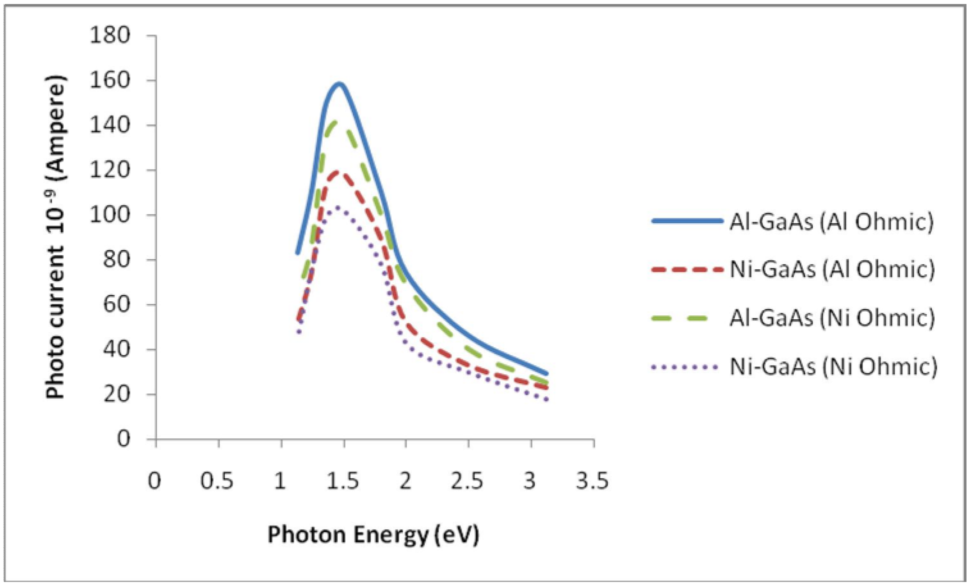

Figure (3) Photocurrent for the four samples as a function to the photon energy

Figure (3) shows the photocurrent as a function of the photon energy, we can devided it into three regions : (Sze S.M.1990)

1. When Photon energy less than the semiconductor band gap energy we can say that the obsorption happened inside the semiconductor band gap because of the energy levels, this levels craeted from the semiconductor impurities, then the electron transition became extrinsic.
2. When the Photon energy more than the semiconductor band gap energy ,there is a different between the two energies and the transition became intrinsic.The obsorption increases when the photon energies increses and then the absorption coefficients (α) increases as in equation (6) and the absorption happened in the surface of the semiconductor :(Martin A. green 1989)

$$\alpha = B^*(h\nu - E_g) \ldots\ldots (6)$$

When B* is constant equal to (2×10^4)

3. When the Photon energy is equal to the semiconductor band gap energy then the obsorption is the maximaum in this energy (due to equation (1) the maximum wavelength we had is 875 nm) and this happened in wavelenghts between (800-900 nm).

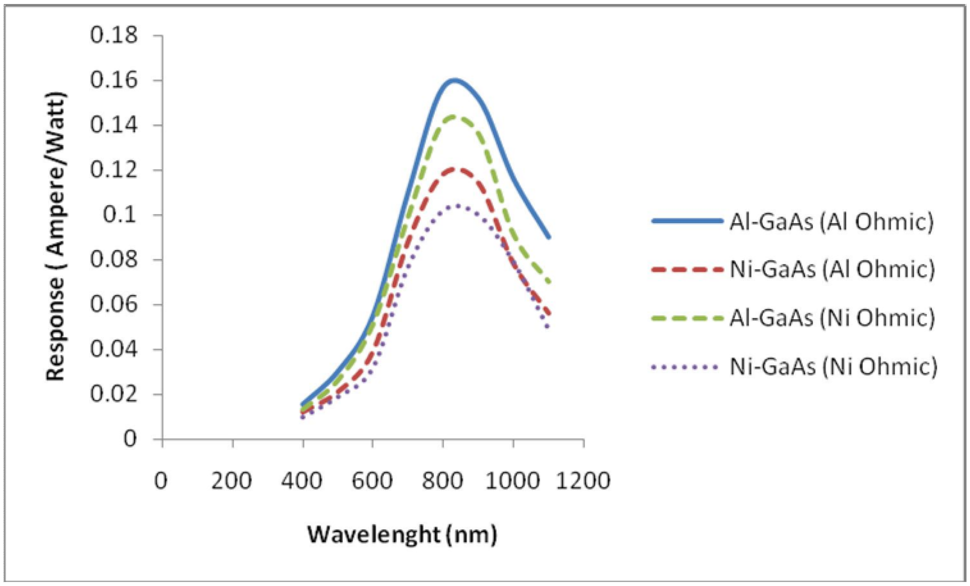

Figure (4) Response for the four samples as a function of the wavelength

From figure (4) we can see the response versus the wavelength, the maximum response that we get was (0.157 Ampere/Watt) for the sample (Al-GaAs/Al Ohmic) in wavelength of (800 nm) the detectors which we made works in the IR region , from figure (5) we have the specific detectivity versus the wavelength, it depended on the wavelength and the samples preparation, the detectivity increased in the sample (Al-GaAs (Al Ohmic) to get the highest value ($63.7\text{x}10^{11}$ Hz ^{½} Watt $^{-1}$) in the wavelength (800 nm) this because it is a function to the response sensitivity as equations (3, 4) and the minimum NEP was ($0.157\text{x}10^{-12}$(Watt Hz $^{-½}$) for the same sample and wavelength, from figure(7) the quantum efficiency versus wavelength ,the highest result we get (24.40 %) at (800 nm) wavelength for the sample (Al-GaAs (Al Ohmic) this because the relation with the response (the response is the number of the generated electron inside the detection for the incident light) thus it is a function to the response as equation (5).

The tables (1, 2) show the results we get for the four samples:

Table (1) shows the results of the currents per wavelengths (800 nm) for the four samples in this work

Samples	**I_{ph} (Ampere)**	**I_n (Ampere)**	**I_D (Ampere)**
Al-GaAs(Al Ohmic)	$157\text{ x}10^{-9}$	$2.47\text{ x}10^{-14}$	$1.9\text{x}10^{-9}$
Ni-GaAs(Al Ohmic)	$118\text{ x}10^{-9}$	$2.50\text{ x}10^{-14}$	$2.0\text{x}10^{-9}$
Al-GaAs(Ni Ohmic)	$141\text{ x}10^{-9}$	$2.50\text{ x}10^{-14}$	$2.0\text{x}10^{-9}$
Ni-GaAs(Ni Ohmic)	$102\text{ x}10^{-9}$	$2.50\text{ x}10^{-14}$	$2.0\text{x}10^{-9}$

Table (2) shows the Detector Parameter per wavelengths (800 nm) for the four samples in this work

Samples	R (Ampere/watt)	D(Hz ^{½} Watt $^{-1}$)	NEP(Watt Hz $^{-½}$)	η %
Al-GaAs(Al Ohmic)	0.157	$63.7x10^{11}$	$0.157x10^{-12}$	24.40
Ni-GaAs(Al Ohmic)	0.118	$47.2x10^{11}$	$0.212x10^{-12}$	18.34
Al-GaAs(Ni Ohmic)	0.141	$56.5x10^{11}$	$0.177x10^{-12}$	21.91
Ni-GaAs(Ni Ohmic)	0.102	$40.8x10^{11}$	$0.245x10^{-12}$	15.90

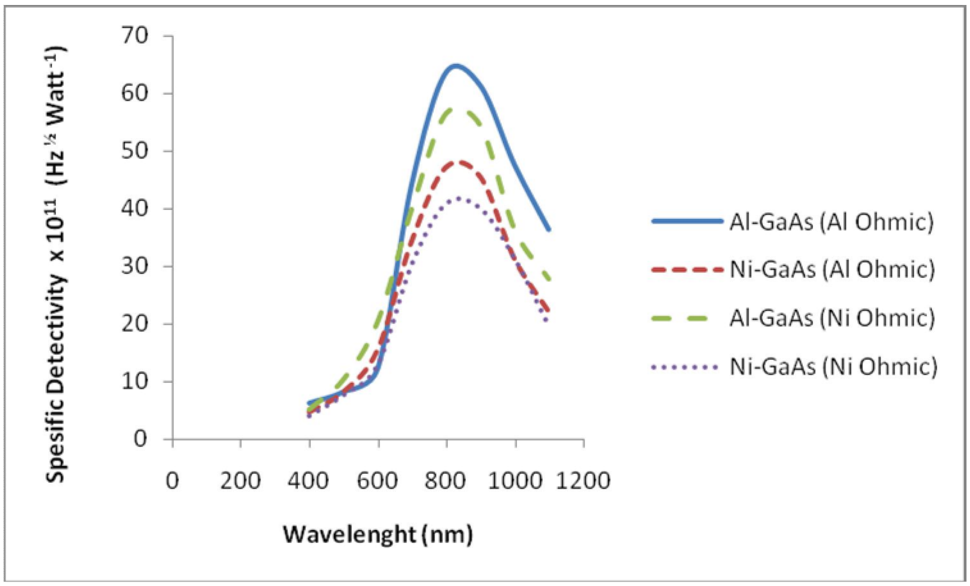

Figure (5) specific detectivity for the four samples as a function to the wavelength

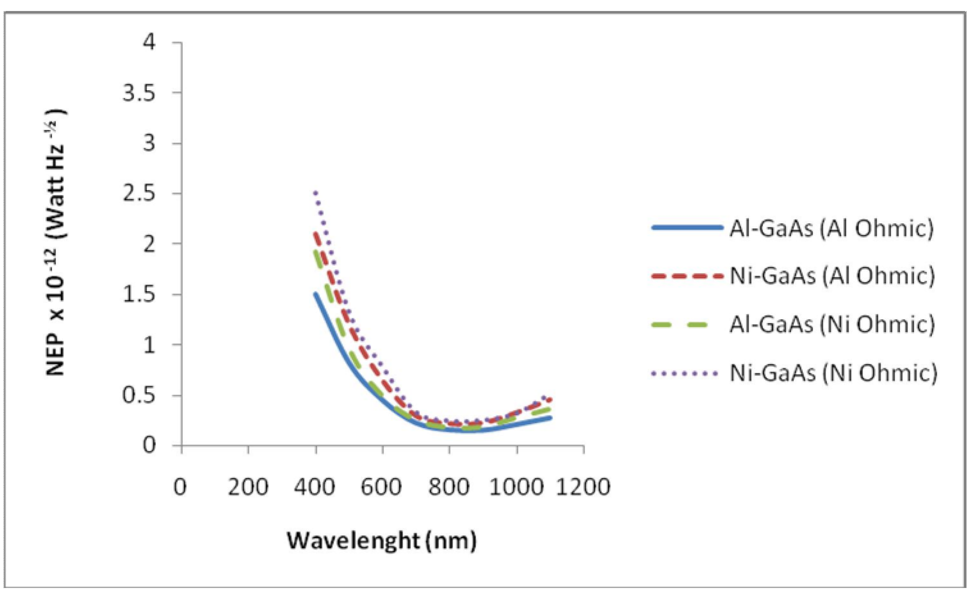

Figure (6) Noise equivalent power for the four samples as a function to the wavelength

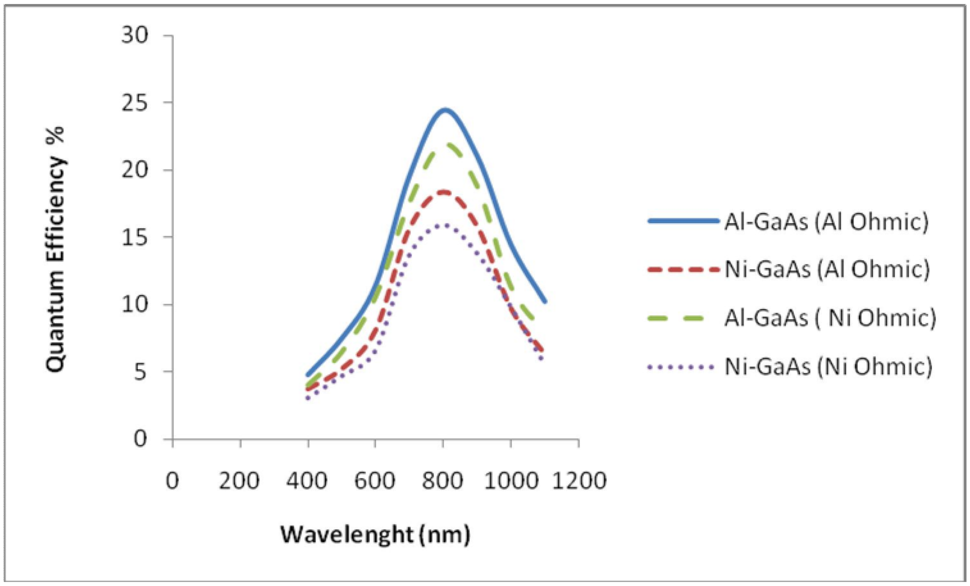

Figure (7) Quantum efficiency for the four samples as a function to the wavelength

Conclusions:

1- Photo current and response depended on the metal type as absorption coefficients and work function then the depletion region that the carrier generation happened inside it.
2- The result depended on the source type (photon energy)
3- An effect of ohmic contact between the samples.
4- The maximum response and efficiency that we get was in wavelength of (800 nm) this means the detectors which we made works in the IR region

Table (3) show some properties for the two metals (Ni & Al) (http://www.matweb.com 2010)

(Al) properties	*Metric*
Work function	*4.13eV*
Density	*2.6989 g/cc*
Atomic Number	*13*
Ionic Radius	*0.510 Å*
Poisson's Ratio	*0.360*
Electrical Resistivity	*0.00000270 ohm-cm*
Thermal Conductivity	*210 W/m-K*
Melting Point	*660.37 °C*

(Ni) properties	*Metric*
Work function	*5.01eV*
Density	*8.88 g/cc*
Atomic Number	*28*
Ionic Radius	*0.690 Å*
Poisson's Ratio	*0.310*
Electrical Resistivity	*0.00000640 ohm-cm*
Thermal Conductivity	*60.7 W/m-K*
Melting Point	*1455 °C*

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