Fabrication and Study Se/Sb on Silicon Detector Heterojunction

Khalid Z. Yahiya
Received on : 25/4/2007
Accepted on : 5/8/2007

Abstract

The optical response characteristics of Se/Sb thin film heterojunction deposited on a p-type silicon substrate were studied. Results indicated that the obtained isotype heterojunction is linearly graded and has 0.8V built-in potential. Also, the maximum spectral responsivity and maximum quantum efficiency were obtained at the region of (600-650) nm and the detectivity was about $7.77x10^{10}$ cm.Hz $^{1/2}$.W^{-1}. Response time of the manufactured detector was about 225ns. This work is a good attempt to manufacture the heterojunction detector from V and VI elements.
KEYWORDS: Isotype heterojunction, Si-based devices, Sbx-1Sex devices, Optical response

تصنيع ودراسة كاشف سيلينيوم/انتيمون سليكون من نوع مفرق هجين

الخلاصة

في هذا البحث، جرى دراسة خصائص الاستجابية البصرية لكاشف المفرق الهجين المصنع مـن أغشـية سيلينيوم/انتمون الرقيقة المرسبة على قاعدة من السيليكون القابل .أظهرت النتائج المستحصلة أن المفرق الهجين المتماثل هو من النوع المتدرج خطياً ويمتلك جهد بناء داخلي(0.8V) تم الحصول على أقصى استجابية طيفية وكفاءة كمية في منطقة الأطوال nm (600-650) وبلغت القيمة الكشفية ($7.77*10^{10}$cm.Hz$^{1/2}$ W^{-1}) جـرى قياس زمن الاستجابة للكاشف المصنع وكان بحدود 225ns يعد هذا العمل محاولة جيـدة لتصـنيع كاشـف المفرق الهجين من عناصر المجموعتين الخامسة والسادسة من الجدول الدوري.

Introduction:

There are many available techniques for the fabrication of heterojunctions those are the base of most photoelectric devices such as detectors, solar cells and semiconductor lasers. Such heterojunctions are prepared by growing epitaxially one semiconductor material onto a different semiconductor material. The most common preparation techniques are chemical -vapor deposition (CVD), solution growth, alloying, sputtering and vacuum evaporation [1-7].

In vacuum evaporation, direct evaporation of the semiconductor or co-vaporation of the constituent elements of the compound semiconductors are the main employed processes and subsequent condensation on single crystal substrates in high vacuum can be used principally for growing hetero-epitaxial layers of any semiconductor material. Usually, the films grown by this technique are polycrystalline [1, 8-10].

The most common compounds formed from II-VI, IV-VI or III-V groups are important semiconductors. The main necessary requirements of such structures are parity and equivalence. Due to previous works, structures made of V-group elements (As, Sb and Bi) combined with VI-group elements (Se, Te and Po) are not common to form compound semiconductors. Extensively studied in order to achieve good semiconducting properties, the chalcogenides of antimony (Sb) are interested. They have rather complex lattices and prepared by direct reaction of elements at 500-900°C. Both n-type and p-type materials can be obtained

https://doi.org/10.30684/ etj.29.6.3
University of Technology-Iraq, Baghdad, Iraq/2412-0758

by appropriate doping [1, 11-12].

Experiment

A 150 nm-thickness thin film of antimony was deposited on a 1x1cm^2 p-type (111) silicon substrate using 10^{-6}torr vacuum evaporation system. The substrate was kept inside the chamber and a 150 nm thin film of selenium was deposited over the Sb film by the same system. Hence, a 300 nm-thickness region of n-n isotype Selenium-Antimony (Se/Sb) heterojunction was formed. The deposition rate was ~30 nm/min and the tolerance of such process is <3%. The aluminum top contacts were deposited on the selenium layer while nickel contact was deposited on the silicon backside. Fig. (1) explains the structure of the heterojunction detector manufactured in this work.

Measurements included transmission spectrum, reverse and forward I -V characteristics, C-V characteristics and I-V characteristics in dark and under illumination by a halogen lamp, wavelength-dependent responsivity, quantum efficiency, specific detectivity and response time constant Se/Sb-on-Si structure. In order to carry out the electrical measurements, a 10k: resistor was connected in series with the detector.

Results And Discussion

As shown in Fig. (2), the Se/Sb structure formed on glass slide has transmittance lower than that of Se or Sb films individually. This is definitely a result of increasing thickness. This structure changes its transmittance 3 times as the wavelength of incident radiation changes over the range 400-1100 nm which may be considered reasonable tends to be more transparent at long-wavelength region. Wavelength range of the used spectrophotometer does not allow to measure at longer than 1100 nm.

The structure of Se/Sb formed on silicon substrate was found sensitive to the incident light as shown in Fig. (3). The photogenerated current increases by a factor of 10 as the incident light intensity increases by 2.33 times only. That assigns good photo-conductive effect and no saturation was observed.

The I-V characteristics shown in Fig. (4) explain good rectifying behavior for the n-n isotype heterojunction formed. Within the applied voltages used in measurements, no breakdown was observed under reverse biasing condition.We have used two lasers (He-Ne and diode) to examine the dark and light current characteristics, as illustrated in Fig. (5). The dark current is less than 0.1mA and the device is more sensitive to the 632.8 nm radiation than to 570 nm. So, this may encourage studying the optical response characteristics at this region of wavelengths (red).

In order to determine the type of the heterojunction formed, C-V measurements were performed under reverse biasing condition as shown in Fig. (6). The heterojunction was found linearly graded and the built-in potential (Vbi) is about (0.8V).

Fig. (7) shows the wavelength-dependent spectral responsivity (R_λ) and it is clear that maximum responsivity appears at the red wavelengths and its peak is at about 630 nm. Also, the device has another peak at about 850 nm but lower than that at 630 nm. Such results may stimulate to manufacture detectors and sensors to both peaks. The shape of responsivity function at low wavelengths depends on the surface conditions.[5] Photons of such wavelengths (<550 nm) are absorbed at the vicinity of the surface where they generate electron -hole pairs. Such effect caused these pairs to recombine before reaching the junction.[12] Hence, the availability of charge carriers will be reduced due to recombination and the responsivity decreases.

External quantum efficiency (EQE) was determined as a function of wavelength, as shown in Fig. (8), and a19.6% maximum EQE was achieved at 630 nm. Such value could be acceptable in designing and manufacturing of solar cells and photonic detectors. Though, this value of EQE is lower than that of silicon photodiodes as the latter have taken too much interest by researchers and engineers.

There are two interpretations for the introduced characteristics of the Se -Sb structure. The first one proposes formation of $Sb_{x-1}Se_x$ intermediate layer. The enhanced characteristics are attributed to the new properties of Sbx-1Sex layer (much probable Sb_2Se_3). The structure of Sb_2Se_3 is already a compound semiconductor of 1.3eV band-gap [10] that reveals the peak response is ranging about 950 nm±20 nm whereas peak response in this work was observed at 630 nm±15 nm. This may be attributed to the formation of $Sb_{x-1}Se_x$ and partial amounts of both elements (Se and Sb) [6].

The second interpretation is the contribution of Sb/Si and Se/Si layers, individually, to the characteristics of the heterojunction structure. In this case, the characteristics of the upper layer (Se) support those of the lower layer (Sb) producing more sensitive and less transparent structure. As the thin-film structure is formed on a semiconductor substrate (in this work it is silicon), two effective regions are formed. The first region is formed between the substrate (silicon) and the lower layer (Antimony) while the second one is formed between the two deposited thin films themselves, which in turn includes two probabilities as mentioned above. Most elements of V group demonstrate responsivity at 500-650 nm region when diffusing in silicon [1].

The specific detectivity (D^*) of the Se/Sb-on-Si heterojunction was measured at room temperature as a function of incident light wavelength. Results of D* are illustrated in Fig. (9) and the maximum value is about $7.77x10^{10}$cm.Hz $^{1/2}$.W^{-1}, which may be considered low as compared with the obtained results from III-V and IV-VI structures. Attempts to increase the external quantum efficiency (EQE) are required for consecutive increasing in D^* levels.

A rise time of 0.5Ps was measured and the response time being about 227ns. Despite that this time is rather long for some applications, some other applications require photonic devices with good stability in operation. The Se/Sb-on-Si heterojunction detector of this work explained good stability as the temperature was raised over room temperature (~45°C).

Conclusions

With a preview of the obtained results in this work, an isotype Se/Sb heterojunction was formed on a p-type silicon substrate. The achieved characteristics can be interpreted by to two probabilities. The formation of a semiconducting Sbx-1Sex intermediate layer is possible and this layer possesses properties better than both elements individually. Also, the formation of two heterojunction regions (Sb/Si and Se/Si) contributing to the overall characteristics of the structure is also possible. The results indicated that the obtained heterojunction is linearly graded with 0.8V built-in potential, the maximum of both spectral responsivity and quantum efficiency were obtained at 630 nm, and the maximum detectivity was about $7.77x10^{10}$cm.Hz$^{1/2}$.W^{-1}. Response time of the manufactured detector was 227ns. This work is a good attempt to manufacture the heterojunction detector from V and VI elements.

References

[1] Sze, S. M., "Semiconductor Devices: Physics and Technology", John Wiley & Sons (New York) (1986).

[2] Sharma, B. L. and Purohit, R. K., "Semiconductor Heterojunctions", Pergamon Press (Oxford) (1974).

[3] Dal Corso, A. and Resta, R., "Density-functional theory of macroscopic stress for crystalline Se", Phys. Rev. B, Vol.50, No.7 (1994) pp.4327-4331.

[4] Stein, B. L. et al., "Electronic properties of Si/Si1-x-yGexCy heterojunctions", J. Vac. Sci. Technol. B, Vol.16, No.3 (1998) pp.1639-1643.

[5] Kim, J. D. & Lee, S.H. & Hwang, J. D. & Noh,T. W. and Yun,S. I. "Sb-based infrared materials and photodetectors for the near-room-temperature applications", Infrared Technol., Vol.11 (1998) pp.2999-3007.

[6] Zogg,H.& Masek,J.& Fach,A. & John, J.& Buttler,W. "Pb1-xSnxSe-on-Si LWIR thermal imaging system", Vol.11 (1998) p.2552.

[7]Jin,N.P.&Berger,S.L.&Thompson,P.E. &Hobart,K.D., "pnp Si resonant interband tunnel diode with symmetrical NDR", Electron. Lett., Vol.37, No.23 (2001) pp.1412-1414.

[8] Ismail, R. A. and Hadi, A. A., "Electrical characteristics of Si doped with Sb by laser annealing", Turk. J. Phys., Vol.27 (2003) pp.1-8.

[9] Sean L. Rommel,& Niu Jin, T. E. Dillon,& Sandro J. Di Giacomo, & Joel Banyai,& Bryan M. Cord, & Imperio, D. J. Hancock,& N.Kirpalani, V. Emanuele,& Paul R. Berger,& Phillip E. Thompson,& Karl D. Hobart,& Roger Lakeb "Development of B/Si/Sb and B/Si/Sb/Si/B resonant interband tunnel diodes", on-line article (2004).

[10] Farag, E. S. M., "Disersive optical constants of a-Se100-xSbx films", Opt. Laser Technol., Vol.36 (2004) pp.35-38.

[11] Greenwood, N. N. and Earnshaw, A., "Chemistry of the Elements", Pergamon Press (Oxford) (1989) pp.637-697, pp.882-917.

[12] Yahiya, K. Z., "Dark and Light Characteristics of Sb-Se Heterojunction Formed on Silicon Substrate", accepted for publication in J. Eng. Technol., November 2004.

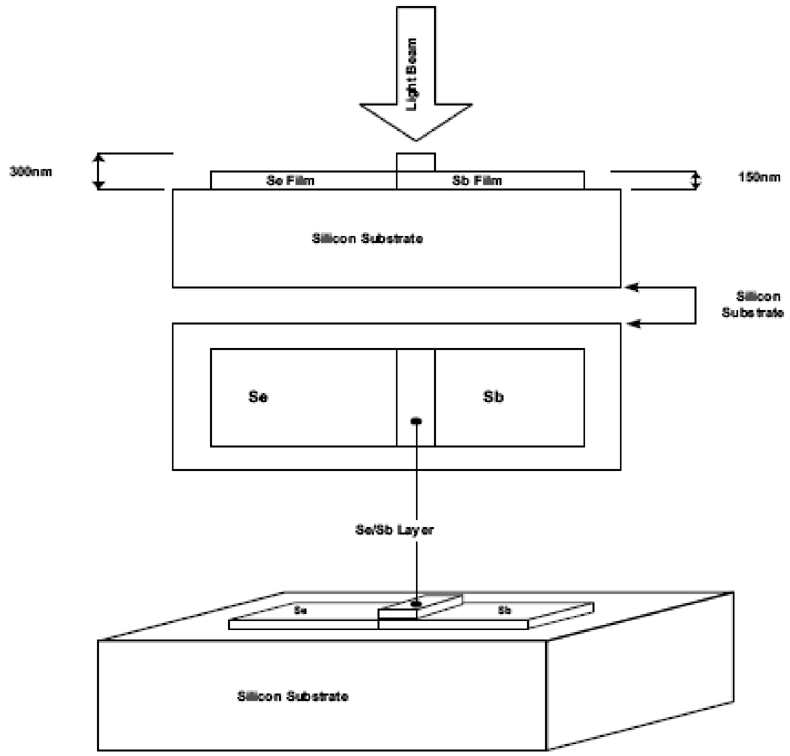

Fig. (1) The Se/Sb-on-Si structure formed in this work

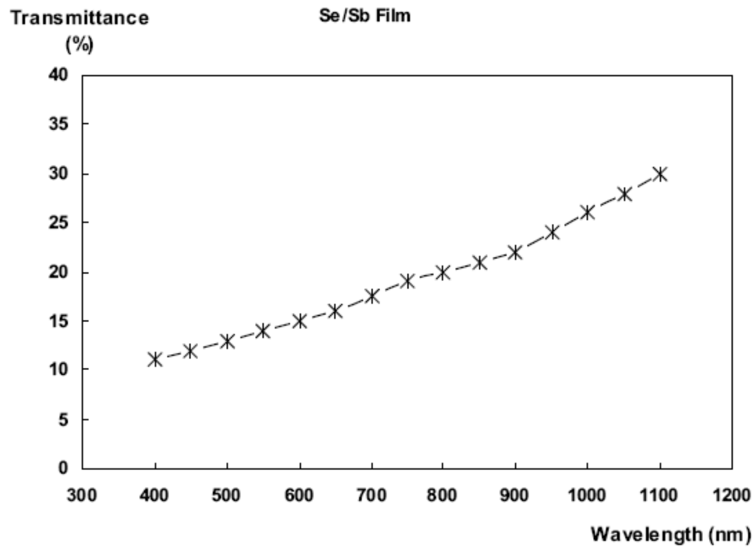

Fig. (2) Transmission spectrum of the Se/Sb structure in the range (400-1100) nm

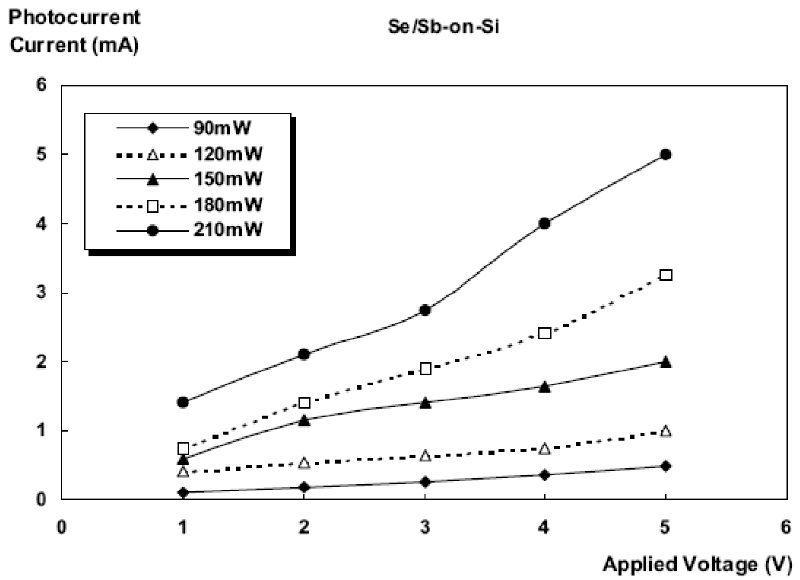

Fig. (3) I-V characteristics of Se/Sb-on-Si structure at different incident light Intensities

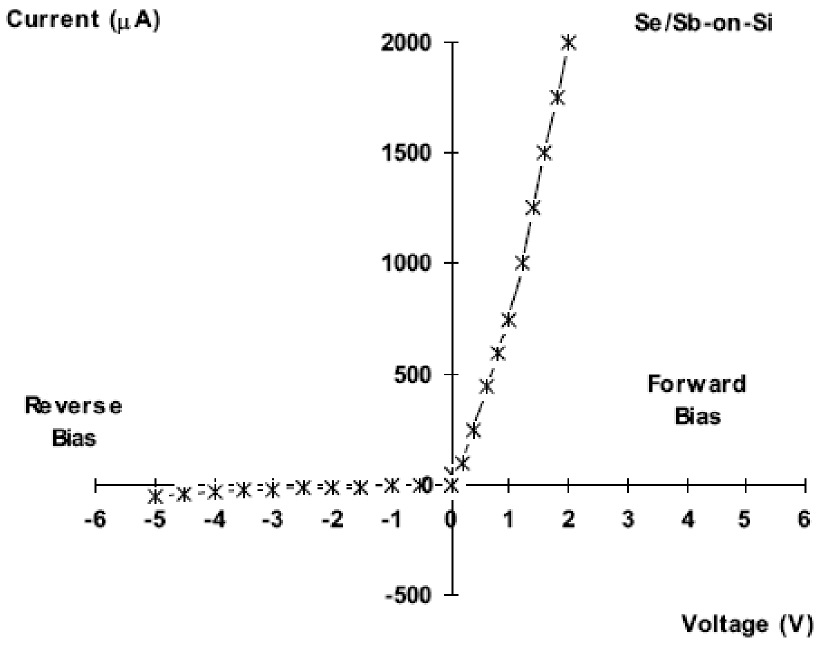

Fig. (4) I-V characteristics of Se/Sb-on-Si heterojunction in forward and reverse biasing

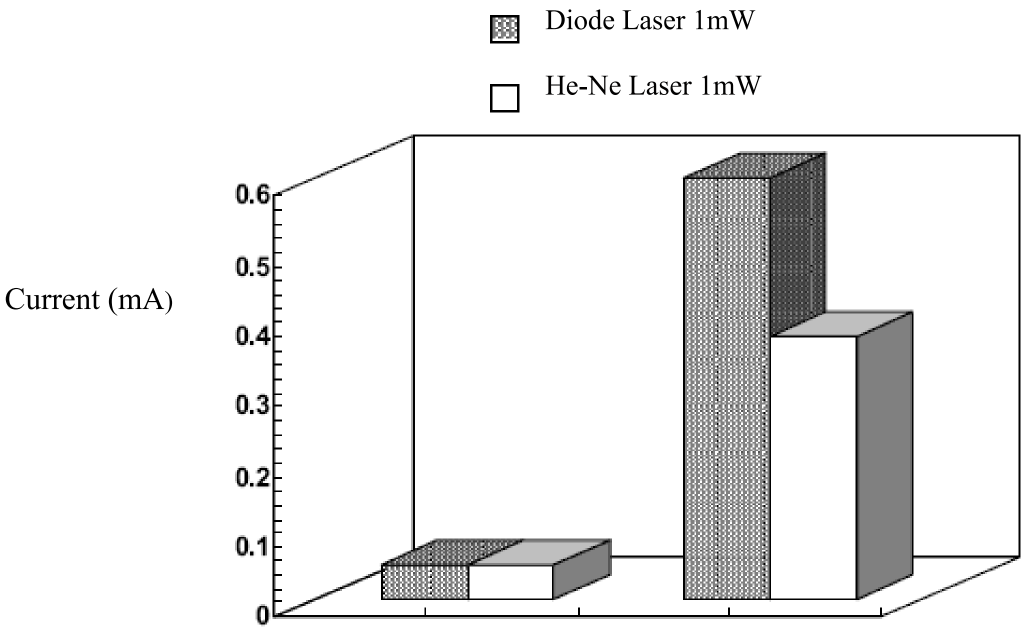

Fig. (5) measured dark and light characteristics of Se/Sb-on-Si heterojunction using 1mW He-Ne laser and 0.8mW diode laser.

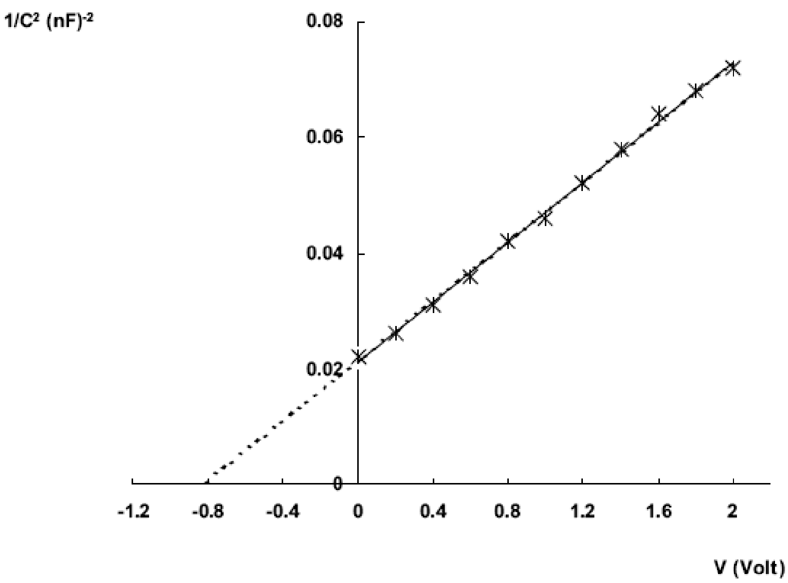

Fig. (6) C^{-2}-V characteristics of the heterojunction in reverse biasing. V bi~0.8V

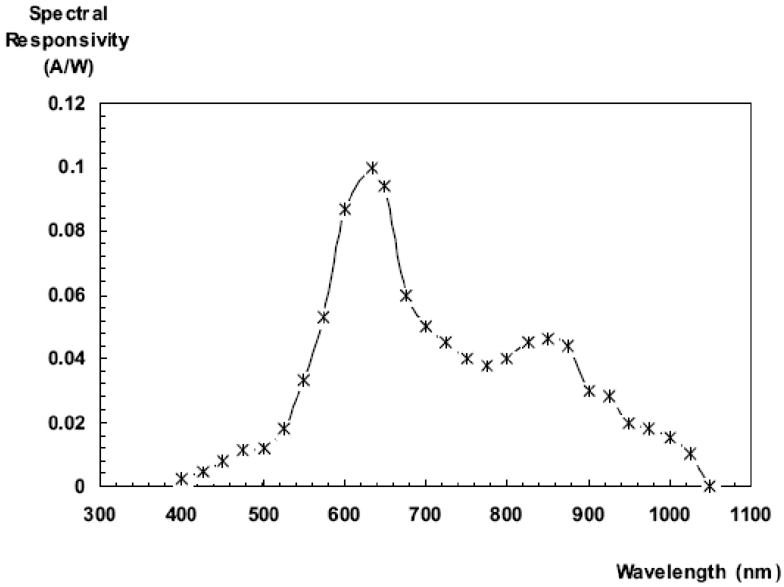

Fig. (7) Wavelength-dependent spectral responsivity of the Se/Sb-on-Si heterojunction detector

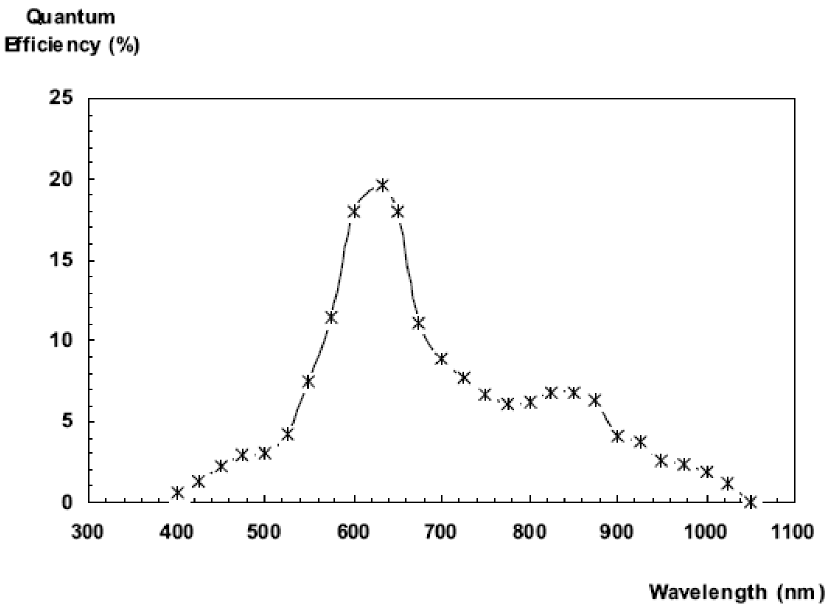

Fig. (8) Quantum efficiency of the Se/Sb-on-Si heterojunction detector versus wavelength of incident light. The maximum efficency is about 19.6%

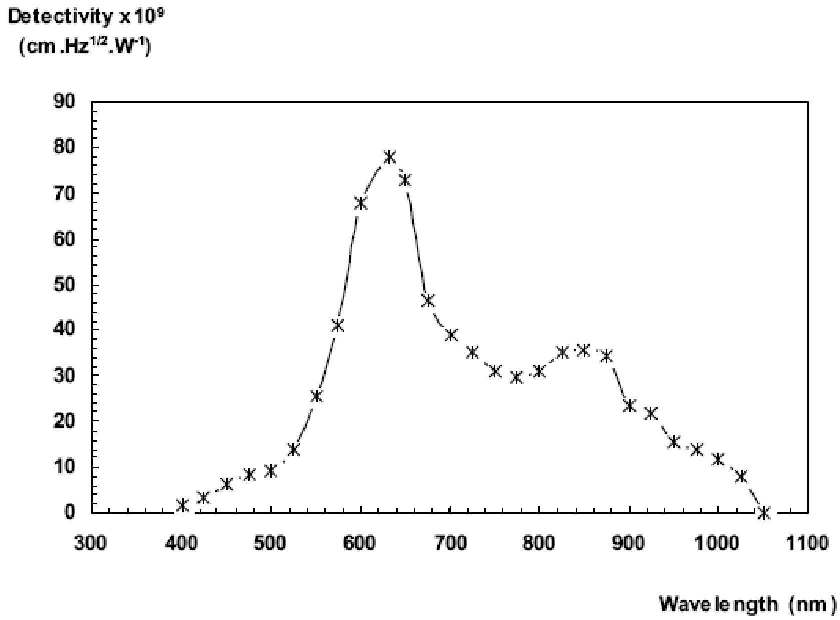

Fig. (9) Measured detectivity of the Se/Sb-on-Si detector versus wavelength of incident light. The maximum detectivity is about $7.77x10^{10}cm.Hz^{1/2}.W^{-1}$