Front-Wall Illumination of Spray-Deposited PbS-Si HJ Detector

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ABSTRACT

(n-p) PbS-Si HJ detector has been fabricated by pyrolytic spraying of PbS heterolayer onto p-type silicon wafer. PbS-side of illumination in the wavelength range (450-1150 nm) revealed that the quantum efficiency plateau fairly conforms to that of Si homojunction. Significant specific detectivity of about 8.5 x 10^{11} cm $Hz^{1/2}$ W^{-1} has been obtained at 850 nm wavelength. Signal to noise ratio revealed an optimum operation voltage at 2.5 V.

Keywords: PbS-Si heterojunction, photodetector, spray pyrolysis.

إضاءة كاشف المفرق الهجين PbS-Si المحضر بطريقة الرش من جهة PbS

الخلاصة

تم تصنيع كاشف المفرق الهجين نوع PbS-Si (n-p) بوساطة ترسيب طبقة PbS بطريقة الرش الكيميائي الحراري على شريحة سليكونية قابلة. أظهرت نتائج إضاءة الكاشف من جهة PbS وبالمدى الطيفي 450 – 1150 nm أن له كفاءة كمية طيفية متشابهة مع الكفاءة الكمية للكاشف السليكوني المتجانس. أبدت هذه الكواشف كشفية نوعية عالية نسبياً تصل إلى 8.5 x 10^{11} cm $Hz^{1/2}$ W^{-1} عند الطول الموجي 850 nm. بينت نتائج قياس نسبة الإشارة إلى الضوضاء أن أنسب فولتية انحياز عكسي لعمل الكاشف هي 2.5 V.

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1. Introduction

Silicon semiconductor is greatly used in the visible/ near-infrared applications. The widely used is that of Si diffused p-n junction. Spreading the edge of this junction towards far IR region can be recognized by intimate contact of narrow gap material on the back surface of Si. This material will absorb the transmitted photon; as a result, the detection edge will be extended to the region depending on the bandgap of the narrow gap material. In this mode, silicon is known as a window material. Such a mode is the combination between silicon and the family of narrow bandgap semiconductors such as Ge-Si[1], PbS-Si[2-5]. The latter heterojunction stretches the spectral response up to 3500 nm because lead sulfide operates in the 1000-3500 nm spectral regime. The previous analysis is valid just in the silicon-side illumination. In the case of front-wall illumination (i.e., irradiation is done from PbS side) the principle is completely differed. Since PbS is opaque thus, it will act as an absorber and prevent ideally any photon of energy greater than its direct optical gap to pass through it. Neglecting the reflected light, absorbed light in the PbS heterolayer will create a pair near the surface, this pair will be soon recombined with the high density of traps at the surface. Only the photons (statistically transmitted) will create useful pair. These photons have an energy lies in the region of silicon spectral absorption. Thereupon, the front-wall of illumination leads to spectral region covering the spectrum of silicon homojunction (i.e., 400-1100 nm). The advantage of the front-wall mode is the cost reduction technology, which enables one to fabricate simple HJ detector operates in the spectral range similar to that of diffused p-n junction silicon detector. The simplicity can be realized from the low junction formation temperature and/or the wide variety of the available epitaxy techniques[2, 6-8]. Spray pyrolysis is one of the low-cost techni-ques. This method was utilized previously to produce near-ideal (n-p) PbS-Si heterodiode[9]. This study is a first run up to our knowledge to fabricate spray-deposited PbS-Si photod-etector sensitive in the range of Si absorption region.

2. Experiment

The PbS-Si HJ is formed by growing, at 350 ^oC, a PbS thin film from the aqueous solution of $Pb(NO_3)_2$ and thiourea, this film is sprayed pyrolytically onto a p-type silicon substrate. Ohmic contacts are achieved by vacuum depositing of 200 nm Al electrodes on both sides of the HJ. Monochromator of the range 450 to 1150 nm is used to measure photosensitivity.

Halogen lamp calibrated at different illumination power densities is used to measure short circuit current of the detector. Thickness of PbS layer is estimated by using gravimetric method. In this method, microbalance is used to weighing the Si substrate before and after PbS depos-ition; the weight differ-ence is represented PbS mass (m), thereby, PbS thickness can be obtained by using the conven-tional mass law ($m/\rho A$) where A is the film area and ρ is the film density.

3. Results and Discussion

Figure 1 illustrates the variation of quantum efficiency with wavelength in the span of the operation of silicon (450-1150 nm). The waveform of this plot is similar to that of silicon homojunction. No shift in peak response is observed in samples having different thicknesses of PbS layer. Sine that PbS is a strong absorber and opaque over this span ($\alpha > 10^5\ cm^{-1}$ and reflectivity = 20 % for wavelengths less than 1000 nm), low value of quantum efficiency is expected. Very thin thickness of PbS layer (150 nm) results in a shallow junction where the surface recombination will be dominant and quantum efficiency will be greatly reduced, while thick layer of PbS (250 nm) will prevent photons penetration through the junction. The circumstance can be balanced at 200 nm of PbS thickness and 10 % of quantum efficiency at 800 nm wavelength was obtained.

Specific detectivity (D*) is demonstrated in Figure 2. In spite of low values of spectral responsivity (not appear here), appreciable values of D* have been registered, this is mainly due to low amount of noise current leaked across the junction. Best detection was at 200 nm thick of PbS layer. Same interpretation drawn from quantum efficiency curve can be used to interpret this curve. The maximum value of detectivity in our study is higher than that of PbS/Si prepared by evaporation technique[5].

Linearity has been examined through the variation of short circuit photocurrent density (J_{SC}) versus illumination power density as shown in Figures 3. Generally, linearity is valid up to 100 mW/cm^2 illumination power density, then the curves tend to level off. This behavior is similar to that obtained from other silicon heterojunctions[10].

Non-linearity deviation coefficient (K) was calculated from this figure by applying the formula ($1-R_{\lambda 2}/R_{\lambda 1}$) on the linear part of the curves, where $R_{\lambda 2}$ is the responsivity at higher illumination intensity and $R_{\lambda 1}$ is the resposivity at lower illumination intensity. K-values tabulated in Table I show that the best linear detector is that of 200 nm of PbS thickness.

Signal to noise ratio (S/N) is depicted in Figure 4. It is obviously shown that S/N ratio increases linearly at low bias voltages reaching to a maximum value at 2.5 V bias voltage then falls down. The bias voltage at maximum S/N represents the optimal operation voltage of the detector.

4. Conclusions

Previous results emphasize that PbS-side illumination of n-p PbS-Si HJ photodetector introduces Si homojunction characteristics. The benefit arises from the cost reduction of fabrication where the low-cost spray pyrolysis technique was used in this paper to fabricate this heterostructure.

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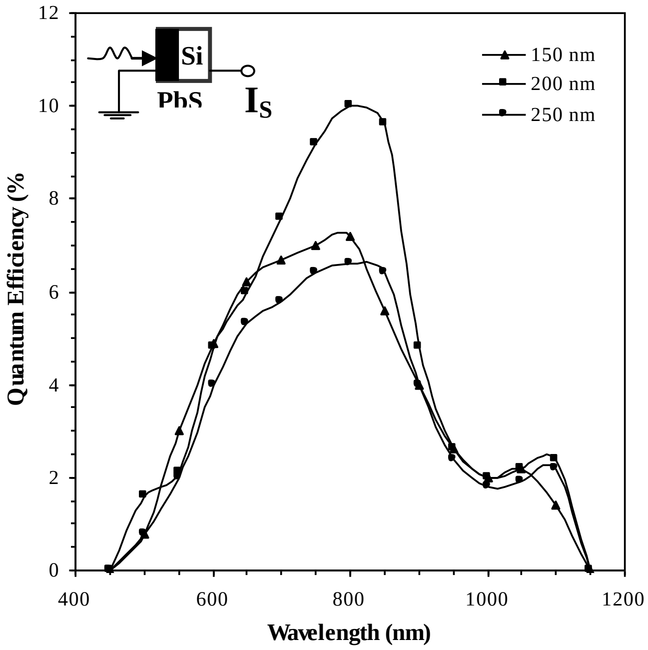

Figure 1. External quantum efficiency variation with wavelength.

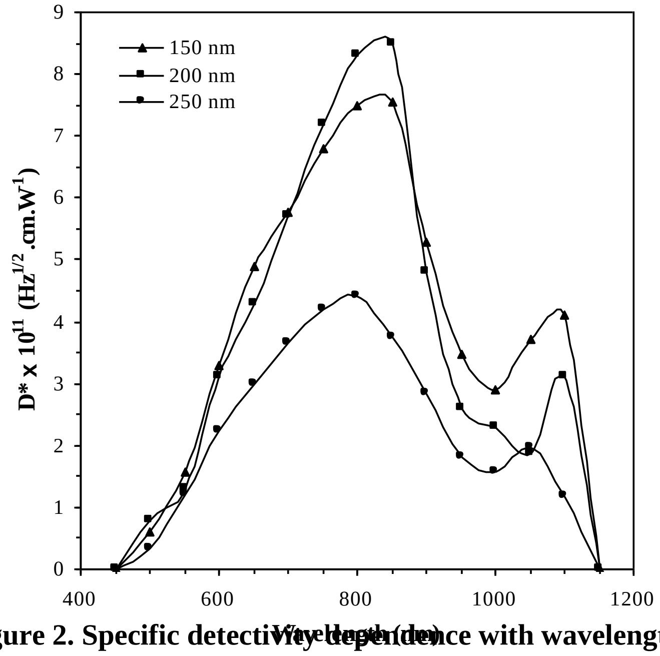

Figure 2. Specific detectivity dependence with wavelength.

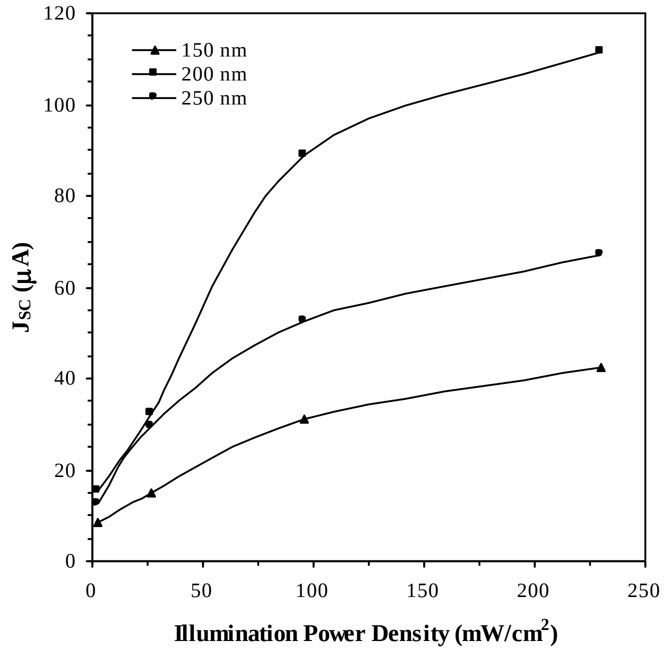

Figure 3. Short circuit current density versus illumination density.

Table I. Non linearity deviation coefficient as a function of PbS thickness.

PbS thickness (nm)	K%
150	96
200	63
250	96

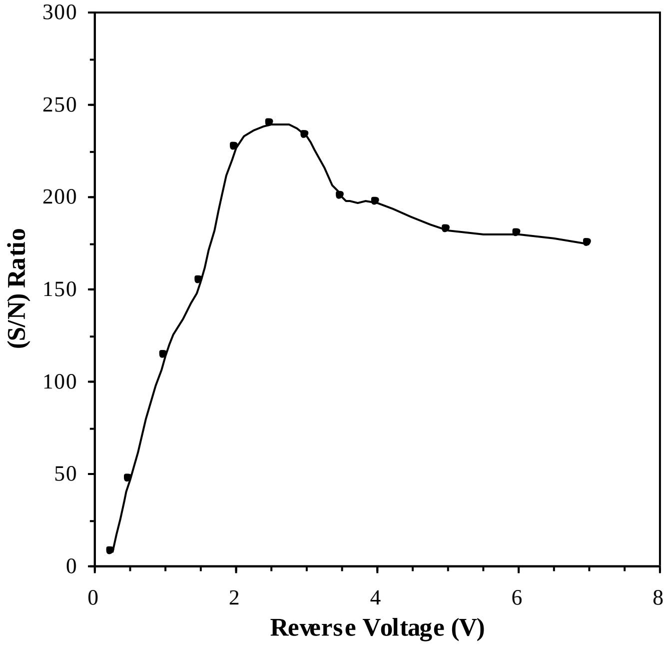

Figure 4. Signal to noise ratio vs reverse bias.