RESEARCH PAPER | Physics | Volume : 3 | Issue : 3 | March 2013 | ISSN - 2249-555X

Fabrication of Silicon PIN Photodiode for Nd^{+3}-YAG Laser Detection

KEYWORDS: Silicon, PIN photodiode, Nd-YAG laser, detection, responsivity

Baha'a A M Al-Hilli, Al Mustansiriyah Univ., College of Education, Physics Dept.

Mohammed K Khalaf Ministry of Science and Technology, Applied Physics center

Kadhim A. Aadim University of Baghdad, College of Science, Department of Physics

Ghuson H.Mohammed University of Baghdad, College of Science, Department of Physics

ABSTRACT *Fabrication of Si PIN photodiode has been carried out, and optimized for optical wavelength of 1.06 μm. It is found that the photodiode has three layers (n+-π-p+) structure with deep junction fabricated on large diameter wafer of 1 mm thick, and high resistivity (ρ≥600 Ω.cm) as a starting material using a thermal diffusion method. Details of the fabrication processes have been presented and the performance parameters were given. It has been found that the peak spectral response of about 1.5 A/W occurred at wavelength of 1.06 μm and the photodiode was operated at a high reverse bias range 170-180 volt. Also, the response time was measured and found that the photodiode has a short response time equal to τ =85 ns.*

1- Introduction

Photodiode is a reverse biased p-n junction when a radiation incident on the photodiode, the depletion layer separate the generated electron-hole pair and a photocurrent flow in the external circuit. The operation in a high frequency require a narrow depletion region width in order to reduce the drift time, in other hand to raise the quantum efficiency needs to enlarge the depletion region width that allow absorb a large ratio of the incident light, so that there is a compromise between the speed of response and spectral responsivity.[1]

A structure that results in a good long wavelength response with only relatively modest bias levels is so called pin or (PIN) structure, illustrated in Fig.(1).The PIN diodes consist of a P-region and an n-region separated by an intrinsic region. The intrinsic region width W is much larger than the space charge width of a normal p-n junction. If a reverse bias is applied to the PIN diode, the space charge region extends completely through the intrinsic region.

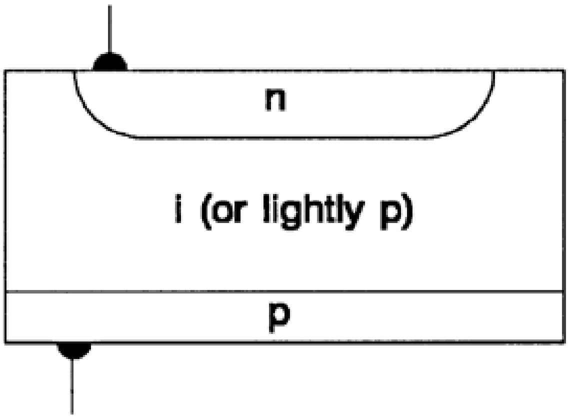
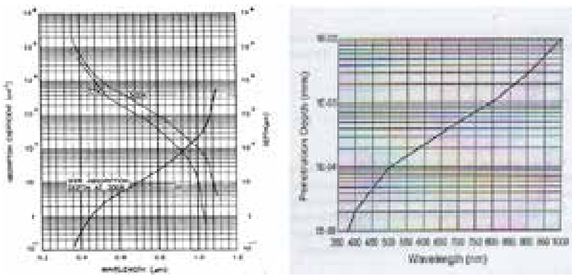


Fig. (1) Schematic structure of the fabricated PIN detector

Silicon is the most commonly used semiconductor in microelectronics and optoelectronic devices. Because the bandgap of ordinary bulk silicon is 1.07 eV, the absorption and the photo-response decrease precipitously for wavelengths longer than 1100nm. Consequently, silicon photo-detector are insensitive to Nd^{+3}-YAG and Nd^{+3}-Glass laser wavelengths (1060 & 1064 nm) respectively. To detect these wavelengths, other semiconductor materials such as germanium or indium gallium arsenide are typically used, but these materials are more expensive and difficult to integrate into silicon- based microelectronics. Extending the sensitivity of silicon- based and silicon compatible photo-detectors is therefore an active area of research.[2]

In a number of materials, silicon in particular, the absorption length for a range of wavelengths is small. Thus, a significant fraction of the light in this wavelength range will not be absorbed before passing through the device. A partial solution to this problem has been to place a reflector on the surface opposed to the entry surface thus reflecting the light back through the sensitivity region and doubling the path length for the light absorption.[3]

The current generated is proportional to the incident light or radiation power. The light is absorbed exponentially with distance and is proportional to the absorption coefficient. The absorption coefficient is very high for shorter wavelengths in the UV region and is small for longer wavelengths Fig.(2). Hence, short wavelength photons such as UV, are absorbed in a thin top surface layer while silicon becomes transparent to light wavelengths longer than 1000nm.moreover, photons with energies smaller than the band-gap are not absorbed at all.



(a) (b)

Fig. (2) (a) absorption coefficient and (b) penetration depth of light into silicon substrate for various wavelengths

2- Experimental Part

A: Detector calculations and design consideration

In order to construct a detector, it is need to prepare a starting material wafer with high purity, high resistivity and high thickness because it will be considered as a large part of the absorption region W, and the width of this region depends

Volume : 3 | Issue : 3 | March 2013 | ISSN - 2249-555X

on the depth at which photons of a specific wavelength would be absorbed, as given by: $W=\frac{1}{\alpha}$, for Si PIN photodiode, the absorption coefficient equal to: αo=10 cm^{-1} at λ=1.06 μm thus the width of the absorption region has the value: W=1mm, we know that the depletion region must be within the absorption region which is depending on the reverse bias and the junction capacitance[4].

The upper surface of the detector coated with SiO_2 or Si_2N_3 antireflection coating in order to achieve a high transition by which all the incident photons on the detector surface will pass through it when the refraction index of the film verify the condition: $n_1=(n_o n_2)^{\frac{1}{2}}$ and the film thickness may be the quarter of the incident wavelength: $d_1=\frac{\lambda}{4n_1}$ then for SO_2N_3 n_1=1.8973, n_2=3.6, d_1=0.13966 μm.

B-Fabrication

A high resistivity p-type Si wafer (ρ≥600 Ω.cm) and 1 mm thick was used as a starting material. The structure of the Si PIN photodiode which is used for detector fabrication is shown in Fig. (1). The first layer p^+-type is formed by diffusing boron to the back surface of the wafer with approximately 50 μm thick, then diffusing a shallow n^+-type to the front surface layer in the center to form the junction and the guard ring with selected mask. This contact is rather thin (~0.5 μm) in order to minimize the loss of photo carriers due to recombination process. The diffusion time of the n^+-contact is adjusted to control the reverse breakdown voltage.

The ohmic contact from Al & Au are deposited with selected mask to the front and back surface respectively, using evaporation technique. Finally an assembly processes were performed which include the cutting, packaging with suitable (TO-5) base and then wire bond and shelling.

3-Results and Discussion

1-Responsivity and Quantum Efficiency

The responsivity is the ratio of the output photocurrent expressed in amperes to the radiant power expressed in Watt . $R_\lambda=\frac{I_{ph}}{p}(A/W)$This parameter was measured using Optronic (DSR-500) system with Halogen-Tungsten light source and standard Si photodiode type (730-5c) as a reference detector. The quantum Efficiency which is the number of electron-hole pairs produced per incident photons is given as a fuunction of responsivity: $\eta=R*\frac{1.24}{\lambda}\%$

Where R is the responsivity in (A/W) and λ is the wavelength in (μm).

Fig.(3) show the variation between the responsivity as a function of wavelength for Si PIN photodiode in the range of (400-1200) nm. It is clear from this figure that maximum peak response of the detector of about 1.5 A/W is occurred at λ=1.06μm which is correspond to a quantum efficiency of 30% Fig.(4), and then it is rapid dropped beyond of 1.1μm because of the radiation is penetrated deeply into the P+ layer Also, noise equivalent power and then detectivity and specific detectivity can be calculated too, using the following relations and measured values of the detector:

$$NEP=\frac{noise\quad current\left(A/Hz^{\frac{1}{2}}\right)}{responsivity\quad at\quad peak\ (A/W)}\left(Watt/Hz^{\frac{1}{2}}\right)$$

$$D=\frac{1}{NEP}\left(\frac{Hz^{\frac{1}{2}}}{Watt}\right)$$

$$D^*=\frac{\left[effective\quad sensitive\quad area\left(cm^2\right)\right]^{\frac{1}{2}}}{NEP}\left(\frac{cm.Hz^{\frac{1}{2}}}{Watt}\right)$$

Where:

A: is the detector area = 9×10^{-2} cm^{-2},

I_o: is the dark current = 9×10^{-7} Amp.

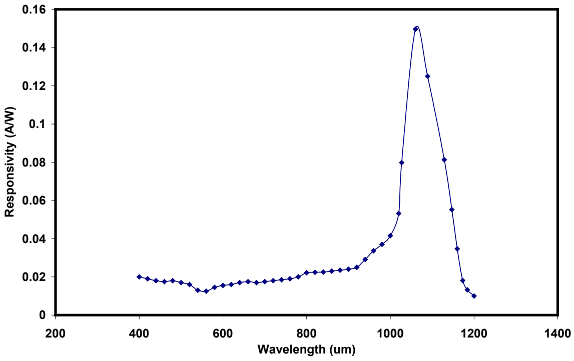


Fig.(3) responsivity vs. wavelength of the PIN detector

The antireflection coating keeps the surface reflection to less than ~3 percent at 1.06 μm. recombination at the thin n^+ contact and at the surface becomes substantial for wavelengths less than 600 nm. The response drops rapidly beyond 1.1 μm as the radiation penetrates deeply into the p^+-substrate.

1- Response Time

The response time of the output current pulses was investigated as a function of bias voltage by excitation with short laser pulses of 200 ns duration from GaAlAs laser at λ=904 nm. As depicted in Fig.(4), at a reverse bias of 10 volt and load resistance of 470 Ω, the response time of the output signal is approximately (τ~80 ns)with a slow tails of the long fall time (t_f~350 ns) due to the presence of the trapping centers which delays the relaxation of the excited carriers. It is well known that the ultimate limit to the speed of response of the PIN diode is the transit time of the carriers across the wide depletion region. In devices with low absorption coefficient, response time of several tens of nanosecond is expected and in fact observed.

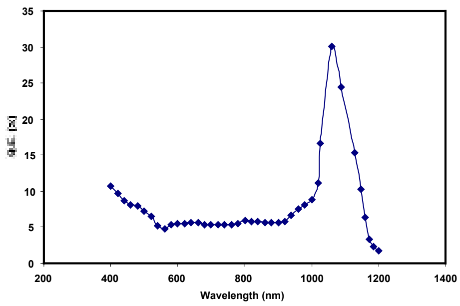


Fig.(4): Quantum Efficiency vs. Wavelength of the PIN detector

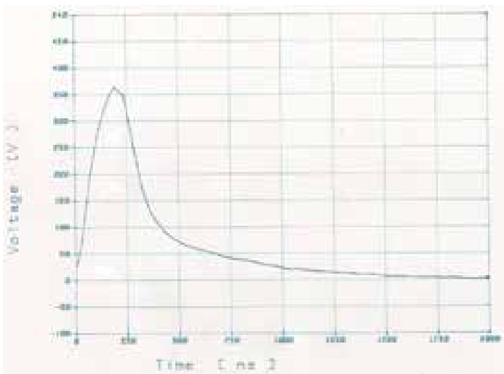


Fig. (4) Response time of the PIN detector

In the case of silicon, where drift region needs to be ~1 mm for high quantum efficiency at λ=1.06 μm, the typical response time is < 50 ns, faster response require a compromise in quantum efficiency.

A second possible limitation on the speed of response is the R-C time constant, however, detectors are generally designed to have low capacitance of < 20 pF when fully depleted, therefore, RC time constant are not usually a problem.

Table (1) conclude the most detector figure of merit values at wavelength λ=1.06 μm.

R (A/W)	η (%)	I_n (A)	NEP (W/ $z^{1/2}$)	D ($Hz^{1/2}$/W)	D*(cm. $Hz^{1/2}$/W)	t_R(sec)
1.5	30	9×10^{-12}	3.31×10^{-12}	30.2×10^{10}	9×10^{10}	125×10^{-9}

4-Conclusions

The front illuminated, planar Si PIN photodiode having n^+-π-p^+ structure with high resistive p-type substrate and high thickness wafer give excellent performance for (1.06 μm) detection. The high quantum efficiency and responsivity obtained from the presence of guard ring and passivation technique with suitable antireflection coating. At this wavelength were absorption is more uniform throughout the entire width of the diode, the hole/electron distinction is lost. Then the p-types higher reverse bias dominates and allows it to have the faster transit time.

The fabricated PIN photodiode can be used for Nd^{+3}-YAG laser detection with excellent reliability.

Acknowledgment

We are greatly indebt to Mr. Dhia'a Jasim and Mr. Nazar Wadi'i of Al Mansour Company. Also I wish to thank Dr. Naseer Karim for his helpful discussions are also acknowledged.

REFERENCE 1- S. M.Sze, "Semiconductor devices, Physics and Technology", John Wiley &Sons, NewYork, CH.7, CH.10, (1985). | 2- James E. Carey, Catherine H. Crouch, Mengyan Shen and Eric Mazur, "visible and near infrared responsivity of femtosecond laser microstructured silicon photodiode", Submitted to Opt. Lett.(2004) | 3- Paul P. Webb, "photodiode having enhanced Long wavelength response", US patent, "4,277,793", Jul.7, (1981). | 4- Baha'a A.M.Al-Hilli, "Fabrication of Silicon Avalanche Photodiode", M.Sc. thesis, p.40, (1999). |