Electrical Characterization of Lateral Photodetector Diode

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ABSTRACT

This work presents a simulated investigation on the performance of lateral thin film SOI PIN photodetector diode working in the short wavelength light spectrum. The lengths of the intrinsic region, the silicon film and the incident wavelength have been varied, in order to verify the influence of these parameters on the photodetector performance. It has shown that lateral thin film SOI PIN diode is suitable for detection of wavelengths ranging between ultraviolet and blue light wavelength.

Categories and Subject Descriptors

I.6 [Simulation and Modeling]

I.6.6 [Simulation Output Analysis]

General Terms

Performance and Verification.

Keywords

PIN; SOI; photodetector; wavelength.

1. INTRODUCTION

Photodetectors are semiconductors devices that can detect optical signals through electronic processes. This device is design to respond to photon absorption [1]. A general photodetector has basically three characteristics. The first characteristic is the carrier generation by incident light. The second feature is the carrier transport and/or multiplication by whatever current-gain mechanism may be present in the circuit. Finally, the third characteristic is the interaction of current with the external circuit in order to provide the output signal [1]. PN junctions can be used as photodetectors, with photons being collected in the depletion region formed in the reverse biased PN junction. The width of the depleted region is a tradeoff between speed and sensitivity. It must be large enough to let a large number of incident photons to be absorbed, but sufficiently short to decrease the photogenerated carriers drift transit time [1][2][3].

PIN diodes can work efficiently as photodetectors, as the length of depletion regions can be controlled by the length of the intrinsic region, squeezed between P and N regions, as schematically shown in Figure 1 [1]. When fabricated in thin film SOI wafers, a good detector for short wavelength light spectrum is achieved [1].

This work aims to analyze the efficiency of SOI PIN lateral photodetector diode from different technical aspects, such as the size of intrinsic region L_i and the Silicon thickness t_{Si}, working in range of short light spectrum.

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2. TECHNICAL BACKGROUND

Electrical current is generated due to drift of minority carriers across a junction. The carriers generated within the depletion region L_i are separated by the junction field, electrons are collected in the n region and holes in the p region. If the junction is uniformly illuminated by photons with hv > Eg, (where is Eg is the band gap energy), a photo generation current is added in the total current [1]. This resulting current due to the optically generated carries by the junction is defined in Eq.1 [1]:

$$I_{op} = qA_{gop}(L_p + L_n + L_i) \tag{1}$$

The current is directed from n to p region. The total reverse current with illumination is Eq.2 [1]:

$$I_{total} = I_{th}(e^{qV/kT} - 1) - I_{op} \tag{2}$$

If there is an open circuit current across the device, I=0, the open circuit voltage V=Voc is equal to Eq.3 [1]:

$$V_{oc} = \frac{kT}{q}\ln[(I_{op}/I_{th}) + 1] \tag{3}$$

The Photovoltaic effect is the voltage across an illuminated junction [1]. In this simulation, the photodiode is operated in the third quarter of its I-V graph. The current is essentially independent of voltage but is proportional to the optical generation rate [2].

3. DEVICE CHARACTERISTICS

The studied of lateral PIN diode has been implemented in SOI technology which refers to the use of a layered silicon-insulator-silicon substrate, based on the previous studies from Professors Souza Michelly, Bulteel Olivier, Flandre Denis, and Pavanelo Marcelo Antonio called Temperature and Silicon Film Thickness Influence on the Operation of Lateral SOI PIN Photodiodes for Detection of Short Wavelengths published in the Journal of Integrated Circuits and Systems in 2011. The fabrication process starts from a P lightly doped silicon substrate ($P_-=1x10^{15}$ cm^{-3}). The interdigitated device area is $0.25mm^2$; it is a square area with 500µm each side. The buried oxide thickness is 400nm t_{oxb}. The anode and cathode regions are 9 µm long, doped with $P_+ = 1x10^{20}$ cm^{-3} and $N_+ = 4x10^{20}cm^{-3}$, separated by a region with natural wafer doping concentration, called (P_-, quasi-intrinsic), whose length is called L_i. The intrinsic region length varies from 1 to 10 µm. A schematic cross-section of this device is shown in the figure 1.

In the two-dimensional device simulation was assumed a single finger PIN diode.

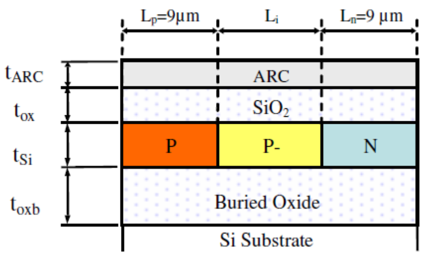

Figure 1: PIN diode cross-section of one finger. $L_p = L_n = 9µm$, t_{ARC}=50nm, t_{ox}=280nm, t_{Si}=40nm, t_{oxb}=400nm [3]

4. EXPERIMENTAL RESULTS AND DISCUSSION

The PIN photodiode simulations were carried out by the Atlas simulation software from *Silvaco International* [5]. The simulation was divided into 3 milestones, in order to analyze the efficiency of PIN photodiode from several perspectives. The simulations parts are:

- 1st milestone: Variation of light wavelength λ from 397 nm to 700 nm for a standard PIN device. The device intrinsic length L_i is 8 µm, Silicon thickness t_{Si} is 80 nm and the oxide thickness layer t_{OX} is 400 nm.

- 2nd milestone: Variation of light wavelength λ from 397 nm to 700 nm and Silicon thickness t_{Si} from 40nm to 100 nm. The device intrinsic length L_i remains the same, 8 µm.

- 3rd milestone: Variation of λ light wavelength from 397 nm to 700 nm and L_i from 1 to 10 µm. The Silicon thickness t_{Si} remains the same as in 1st part.

The Tonyplot snapshot of the device structure is shown in Figure 2 below.

Figure 2: TonyPlot – Atlas Simulation – the orange area is the anode region N_A= 1x10^{20} cm^{-3}, the blue area is the intrinsic region P_-=1x10^{15} cm^{-3}, the red area is the cathode region N_D = 4x10^{20}cm^{-3} and the violet area is the silicion region.

4.1 1st part outcome

4.1.1 |Id| vs λ for tSi = 80 nm

Figure 3 presents the diode reverse current, extracted at Vd= -1V, as a function of the incident wavelength, with power density of 1 W/cm^2. From this figure, it can be noted that for a fixed silicon thickness of 80 nm, the reduction of wavelength stimulates an increase of the photocurrent, which is based on the previous technical studies [1]. Silicon absorbs low wavelength close to its surface, whereas higher wavelengths would be absorbed deeper in the material.

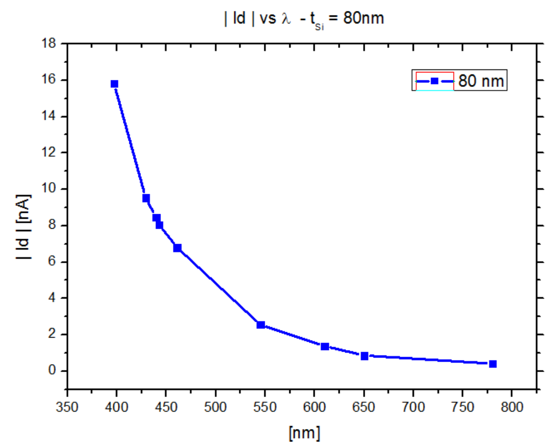

Figure 3: |I_d| vs λ for Vd = -1V

The figure 3, |Id| vs λ is the graph behavior for a standard PIN SOI device with t_{Si} of 80 nm simulated in the short to ultraviolet wavelengths light spectrum. Evidently, the absolute value of current Id is greater in the short wavelength light spectrum.

4.2 2nd part outcome

4.2.1 |Id| vs λ for 40 ≤ tSi ≤ 100 nm

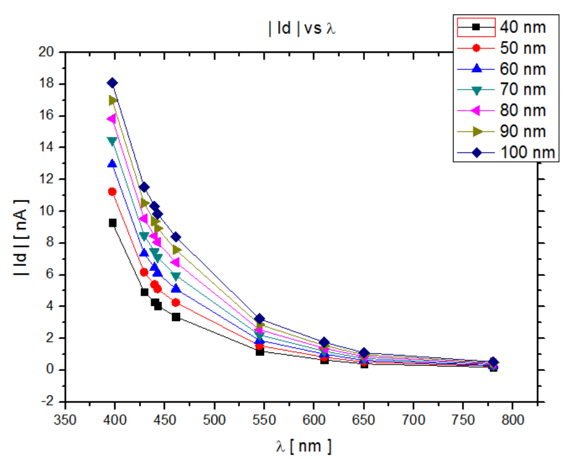

Figure 4: |Id| vs λ for Vd = -1V

The appearance of a forward voltage across an illuminated junction by photon with hv > Eg is known as the photovoltaic effect. The intrinsic region Li is the main design parameter for a PIN photodiode [1]. A small intrinsic length can increase the photon generated electron-hole pairs but greatly increases the dark current [1][2]. The total current which is the sum of the thermally generated current and the optically generated current I_{TOTAL} is greater to short wavelengths, from 397nm to 420nm, ultraviolet to indigo light spectrum. The photons are absorbed in the surface of the device, as shown in figure 4, in the reverse-bias condition for Vd = -1V. Although for long wavelengths the silicon film thickness variation has not affected the photocurrent close to the blue and ultraviolet light spectrum, the reduction of t_{Si} causes the decrease of current Id.

4.2.2 *|Id|/tSi vs λ for 397 ≤ λ ≤ 780 nm*

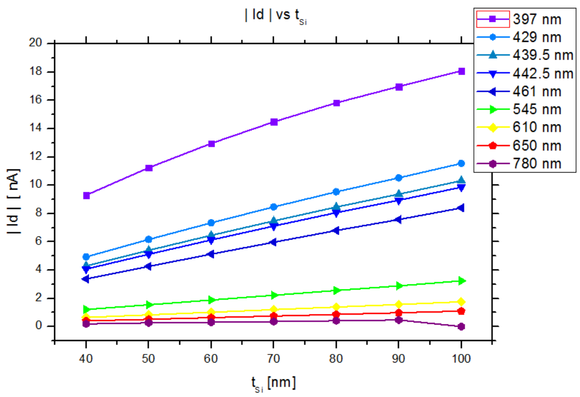

Figure 5: $|I_d|$ vs t_{Si} for Vd = -1V

The figure 5 shows |Id| vs t_{Si} in the reverse-bias condition, considering L_i = 8μm. The absolute value of reverse current is greater for short wavelengths and for larger Silicon thickness. Besides that, the reverse current is also dependent of Silicon thickness t_{Si}.

4.3 3rd part outcome

4.3.1 *|Id| vs Li for 1 ≤ L_i ≤ 10μm*

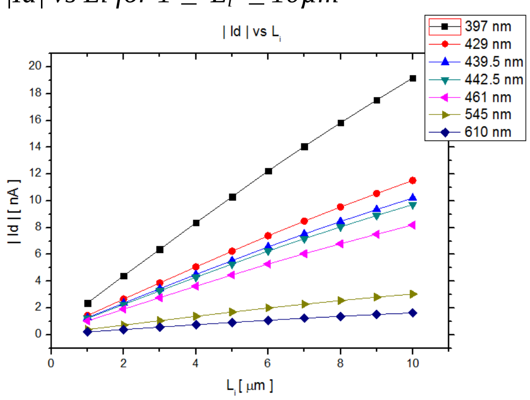

Figure 6: $|I_d|$ vs L_i for Vd = -1V

In the figure 6, |Id| vs L_i, is shown in the reverse-bias condition for Vd = -1V. From these results it can be noted that for a large L_i most of the photons are absorbed in the intrinsic region L_i, then increasing the generated current. The appropriate length for L_i is chosen as a compromise between sensitivity and speed of response. If a L_i is large, most of the incident photons are absorbed in the depletion region. Besides that, a large L_i results in a small junction capacitance. On the other hand, L_i must not be so large that the time required for drifting the photogenerated carriers out of the depletion region is excessive. [2]

4.3.2 *|Id| vs λ for 1≤ Li ≤ 10μm*

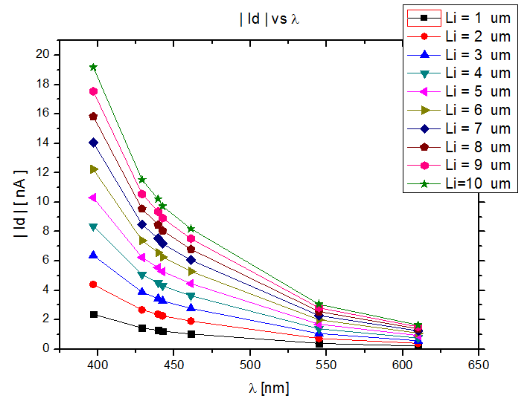

Figure 7: $|I_d|$ vs λ for Vd = -1V

The figure 7 presents |Id| vs λ in the reverse-bias condition. For light wavelengths greater than 425nm, the variation of Silicon thickness t_{Si} does not significantly affects in the optically generation current. The photon generation recombination ratio decreases as the electromagnetic field increases, due to larger Silicon thickness. For example, if the λ is 397nm, the absolute value of reverse current is about $Id_{\lambda=397nm} = 1{,}5832 \cdot 10^{-8}\ A$. Now if λ 461 nm the absolute value of reverse current is $Id_{\lambda=461nm} = 6{,}7992 \cdot 10^{-9}\ A$. Therefore the reverse current has been reduced by 57% compared to these light wavelengths.

4.3.3 *|Id|/Li vs λ for 397 ≤ λ ≤ 610 nm*

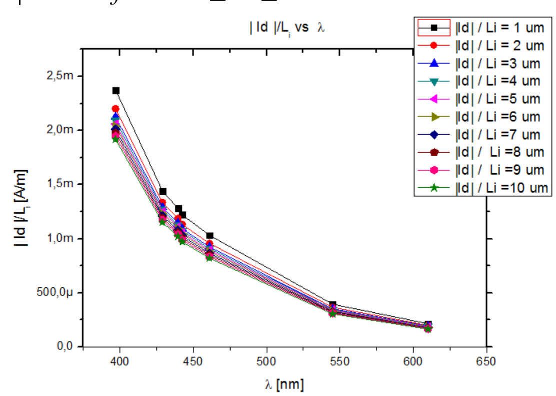

Figure 8: $|I_d|$ vs λ for Vd = -1V

In the Figure 8, $|Id|/L_i$ vs λ in the reverse-bias condition for Vd = -1V, the reverse current is normalized by the intrinsic length L_i in order to show that the carrier lifetime within the intrinsic region L_i is long compared with the drift time, most of the photo generated carries are collected by n and p regions for short wavelength light spectrum and for short intrinsic length L_i.

4.3.4 $|Id|/A_{total}$ for $397 \leq \lambda \leq 610$ nm

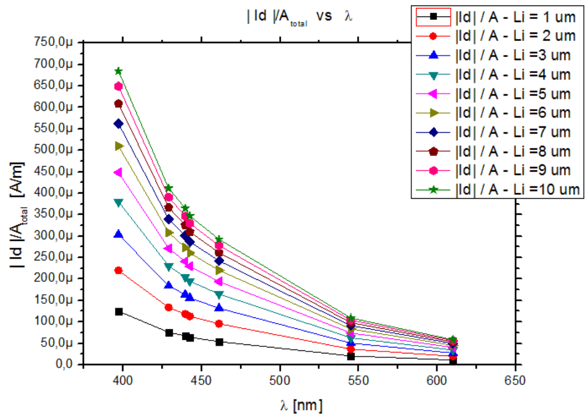

Figure 9: $|Id|/A_{total}$ vs λ for Vd = -1V

In the Figure 9, $|Id|/A_{TOTAL}$ vs λ, in the reversed-bias condition, is considered the amount of reverse current generated by the total area of device, A_t = (Ln + Li+Lp), where Ln is the N-region length (9μm), L_p is the P-region length (9μm) and L_i is the intrinsic region length. The current reverse is also proportional to device area. For instance, if Li=1 μm and λ = 397, the total area is $A_{TOTAL} = Ln + Li + Lp = (9+1+9)\cdot 10^{-6} = 19\cdot 10^{-6}$ and the reverse current normalized is 1.2504x10-4 A/m.

Now if the L_i is increased ten times, the area is $A_{TOTAL} = Ln + Li + Lp = (9+10+9)\cdot 10^{-6} = 28\cdot 10^{-6}$, then the reverse generated current normalized is 6.8485x10-4 A/m for the same wavelength. The reverse generated current normalized by the total area is increased

5. CONCLUSION

In this work, the PIN lateral photodetector diode implemented in thin film SOI technology has been simulated by Atlas from Silvaco International in several technical aspects, such as the intrinsic region length, the silicon film thickness and the incident wavelength. The results showed this PIN diode is designed to work in the short wavelengths light spectrum, in the range of blue and ultra-violet (UV) wavelengths. Besides that, photodiodes fulfilled in thinner silicon films have a high selectivity between UV and blue or violet light wavelengths.

6. ACKNOWLEDGMENTS

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