Illuminated to dark ratio improvement in lateral SOI PIN photodiodes at high temperatures

C Novo¹, R Giacomini¹, R Doria¹, A Afzalian² and D Flandre²

¹ Department of Electrical Engineering, Centro Universitário da FEI, São Bernardo do Campo, Brazil
² ICTEAM Institute, UC Louvain, Louvain-la-Neuve, Belgium

E-mail: carladcpn@fei.edu.br

Received 12 November 2013, revised 12 March 2014
Accepted for publication 31 March 2014
Published 1 May 2014

Abstract
This work presents a study of the illuminated to dark ratio (IDR) of lateral SOI PIN photodiodes. Measurements performed on fabricated devices show a fivefold improvement of the IDR when the devices are biased in accumulation mode and under high temperatures of operation, independently of the anode voltage. The obtained results show that the doping concentration of the intrinsic region has influence on the sensitivity of the diodes: the larger the doping concentration, the smaller the IDR. Furthermore, the photocurrent and dark current present lower values as the silicon film thickness is decreased, resulting in a further increase in the illuminated to dark ratio.

Keywords: photodiode, SOI, temperature

1. Introduction

In semiconductor devices, the incidence of light causes carriers generation, which if not recombined, can contribute to the device current. In this way, PN junctions are widely used as optical devices, since the electric field present in the depletion layer formed between the two regions (P and N) acts to separate the electron–hole pairs and to increase the reverse current of the diode. Moreover, the larger the size of the depletion layer, the greater the amount of light absorption. On the other hand, to have a higher electric field, a smaller depletion layer is needed. Thus, the size of the depletion region is a trade-off between speed of response and sensitivity, because it has to be large enough to allow the largest possible number of photons to be absorbed, and small enough to reduce the transit time of the generated carriers [1, 2].

A special case of the PN junction photodiode is the PIN photodiode, which is one of the most-common photodetectors, because the depletion-region thickness can be adjusted to optimize the quantum efficiency and frequency response. They consist of P and N regions sandwiched by an intrinsic (I) region with length $L_I$, which, in practice, corresponds to either a P-type or N-type region with low doping level ($\sim 1 \times 10^{15} \text{ cm}^{-3}$). These photodiodes are usually reverse-biased with moderate biasing voltages, because this reduces the carrier transit time and lowers the diode capacitance [1]. The reverse voltage is, however, not large enough to cause avalanche multiplication or breakdown. The phenomena that occur within the intrinsic region are very important, since they can change the characteristics of the depletion layer and hence the collected photogenerated carriers. By varying an additional control gate bias, for example, the carriers' concentration in the intrinsic region changes, which can affect the amount of collected electron–hole pairs.

The detection of short wavelengths (λ) in the range of ultraviolet (UV) in the spectral range from 10 to 400 nm is widely used in many applications and is commonly divided into three regions: UV-A (400–320 nm), UV-B (320–280 nm) and UV-C (280–10 nm) [3]. Applications related to UV radiation can be found in medical imaging and the optical
communication market (280–400 nm) [4, 5], protein analysis and DNA sequencing (240–300 nm) [6, 7], forensic analysis (250–300 nm) [8], disinfection and decontamination (240–280 nm) [9] and space observation (vacuum and extreme UV ranges from 200 to 10 nm) [10, 11]. Another important application to be mentioned is the detection and classification of gas, which requires permanent operating temperatures of up to 400 K [12].

Indeed the light penetration depth in semiconductor varies according to the wavelength [1], likewise the smaller the wavelength, the lower the penetration depth. As a result, in lateral PIN photodiodes, carriers generated by light radiation can be collected more efficiently, because the depletion region, in these devices, is formed from the surface to the depth of the junction, unlike vertical ones. For instance, for \( \lambda = 400 \text{ nm} \) the absorption depth is close to 0.1 \( \mu \text{m} \) [1, 13], that is really close to the surface. In such a case, the remaining silicon substrate is not used for photodetection and only contributes to increase the dark current due to thermal generation [14]. In order to overcome this feature, an efficient alternative is to use photodetectors implemented in SOI wafers [15], in which the presence of the buried oxide promotes isolation from the carriers generated in the substrate, making the lateral PIN SOI photodiode suitable for applications that require fast response, low dark current, high quantum efficiency and high sensitivity [15, 16].

Aiming at a better performance, other topologies of photodetectors have been developed. In [17, 18], a trench detector was used to increase the electric field down to a depth of 6 \( \mu \text{m} \), in [19] a metal–semiconductor–metal structure was used and in [20] the authors showed that devices with higher silicon surface roughness could present better responsiveness as well. Also avalanche-gain detectors were reported in [21]. Although increasing the efficiency of the devices, these topologies require additional processing and integration steps while lateral SOI PIN diodes are totally compatible with standard fabrication processes and they should be the first choice for a large area photodiode [14]. In order to investigate the operation of lateral SOI PIN diodes used in medical application and gas detection, this work presents an analysis of these devices with the purpose of examining a way to improve the sensitivity in terms of illuminated to dark ratio (IDR), and, therefore, proposes a study of the impact of variation of different parameters such as substrate bias, operating temperature, anode bias and wavelength. Experimental measurements were performed from 300 to 500 K and a fivefold improvement in the IDR was achieved with a back-gate voltage of \(-20 \text{ V}\) and at the temperature of 500 K. Furthermore, numerical device simulations were used to investigate the diode’s performance in more advanced technologies, following the technological trends where the silicon layer thickness is reduced, as well as the wafer doping concentration.

2. Measured devices

The characterized devices were fabricated in the SOI technology from Université Catholique de Louvain described in [22]. They present a doping profile of P+P-N+ with \( L_t \) of 8 and 9 \( \mu \text{m} \). The intrinsic region is actually a p-type lightly doped one, where the natural wafer doping concentration is kept. Figure 1 shows a schematic cross-section of the studied device, indicating thicknesses and the intrinsic length which are summarized with the doping concentration levels and the total area in table 1. Figure 2 presents an optical microscope image of part of an interdigitated PIN SOI photodiode measured.

3. Experimental results

In order to evaluate the performance of PIN diodes as photodetectors, the devices were measured for temperatures (\( T \)) ranging from 300 to 500 K. The variable temperature
micro probe system from MM Technologies has been used to control the temperature. For the electrical characterization, the measurements were done using an Agilent 4156C semiconductor parameter analyser, both in the absence of light and when illuminated with different wavelengths, ranging from 397 to 460 nm.

The absolute current ($I_D$) as a function of the applied anode voltage ($V_D$) is presented in figure 3 under the incidence of different wavelengths and luminous intensities for both devices. Although the three wavelengths have different luminous intensities, it is clearly seen that the higher the wavelength, the lower the photogenerated current due to the smaller photon energy [1]. Besides, the reverse current has shown to be larger in the diode with $L_I = 9 \mu$m since it has larger photosensitive area, actually 4.28 times larger than the diode with $L_I = 4.65 \mu$m [23].

The influence of back-gate voltage ($V_{BG}$), although not extensively investigated in the past, is very important in the performance of the photodiodes, since it modifies the operation mode (inversion, accumulation or depletion) of the silicon film [24]. In figure 4(A), the photodiode current is presented as a function of the $V_{BG}$ when illuminated by a UV light of $\lambda = 397 \text{ nm}$ and incident optical power ($P_{IN}$) of 0.55 $\mu$W at room temperature. When the film is biased towards accumulation regime ($V_{BG} < -3 \text{ V}$), there is a decrease of the current, related to the decrease of electron mobility and the increase of recombination, due to higher holes concentration. Once the intrinsic area assumes lateral depletion (increasing $V_{BG}$), the current abruptly raises, meaning that carrier’s recombination is smaller. This behaviour which gives rise to a peak in the current level in the depletion mode has been extensively studied for gated diodes in [25]. Moreover, for $V_{BG}$ higher than about 0.5 V, biasing the film towards inversion regime, an effective P+N-N+ like doping profile is created and the minority carriers that dictate the recombination are the holes and not the electrons anymore [26]. The inversion current is lower than the accumulation one, because the hole mobility is smaller than the electron mobility [27]. It is also possible to see in figure 4, that the voltage that produces accumulation in the silicon film is changed as the anode voltage decreases.

Another valid observation is that the fixed charge density at the Si–SiO$_2$ interface is probably the reason for the displacement of the curve from $V_{BG} = 0 \text{ V}$. As mentioned previously, in some applications the photodiodes are exposed to high temperatures, which affect their performance as well as $V_{BG}$. Figure 5 presents the dark current and photocurrent of the diode with $L_I = 8 \mu$m and smaller area. By comparing the dark and photodiode current, one can note that the rise of temperature increases the dark current ($I_{DARK}$) by several orders of magnitude, as a result of increased thermal generation of electrons [27]. On the other hand, apart from presenting higher values, the reverse photodiode current under illumination is not so strongly temperature dependent, and the small $I_D$ increase at higher temperatures is related to the carrier lifetime dependence on temperature, as explained in [15].

Figure 3. Photocurrent ($I_P$) as a function $V_D$ for two different $L_I$ and three wavelengths, for $T = 300 \text{ K}$.

Figure 4. (A) Photocurrent with $\lambda = 397 \text{ nm}$ and (B) dark current as a function $V_{BG}$ for different $V_D$ at $T = 300 \text{ K}$ and $L_I = 8 \mu$m.
The diffusion component is composed of majority carriers, which, in inversion, are electrons, which have higher mobility, resulting in a higher current. Moreover, the diffusion current will have a strong influence, since there is a great increase of the intrinsic concentration ($n_i$). However for higher temperatures ($T > 460$ K), the diffusion current becomes larger than the accumulation one. This fact is explained as follows: the total reverse photocurrent can be approximated by the sum of the diffusion current and the generation current (drift current) [29]. At sufficiently high temperatures ($T > 460$ K for the studied device), the diffusion current will have a strong influence, since there is a great increase of the intrinsic concentration ($n_i$). Moreover, the diffusion component is composed of majority carriers, which, in inversion, are electrons, which have higher mobility, resulting in a higher current.

From the results shown in figure 7, it can be seen that as the temperature is lowered, the dark current becomes less sensitive to temperature, mainly below 400 K, due to the smaller thermal generation, which results in an increase of generation carriers’ lifetime [28]. In addition, thermal generation is more pronounced in the depletion layer, where there is a smaller carrier recombination owing to the presence of fixed charges [26]. As a result, the dark current has its maximum value for $V_{BG} = -3$ V, when the silicon film is pushed into vertical depletion. For $T = 500$ K, the diffusion current strongly influences the generation current, as already mentioned. In addition to featuring higher values, it is clearly seen that, in comparison to the dark current, the reverse photodiode current under illumination is not so strongly temperature dependent.

An important figure of merit for evaluating the performance of a photodetector is the IDR that is obtained dividing the photogenerated current by the dark current [29]. Figure 8 presents the light-to-noise-ratio as a function of temperature for different $V_{BG}$ values and it can be observed that the higher IDR is obtained for lower temperatures, mainly due to the decrease of dark current with the smaller thermal generation of carriers. In addition, concerning the back-gate bias, the IDR increases as the $V_{BG}$ is more negative, such that the film is in accumulation. However, the photodiode shows a lower IDR with $V_{BG}$ of $-3$ V, in depletion mode of operation. In inversion (positive $V_{BG}$), the IDR barely varies with $V_{BG}$.

The improvement of the IDR is very important for the photodiodes, since it increases its sensitivity to the incident optical signal, so that the photogenerated current is clearly distinguishable from dark current. In order to improve the observation of this figure of merit, figure 9 shows the normalized IDR by its value with $V_{BG} = 0$ V. Remarkably, the IDR increases when the device is biased in accumulation.
mode, especially at higher temperatures. However, for lower temperatures, the normalized IDR tends to one, meaning that its variation is smaller.

Figure 10 shows the illuminated to dark ratio, normalized by its value with \( V_{BG} = 0 \) V as a function of temperature for three different temperatures and anode voltages, for \( L_i = 8 \) \( \mu \)m. The IDR is increased as the back-gate bias is reduced, and this fact is related to the decrease of the relative dark current. Finally, it is important to see that we can achieve the highest normalized IDR for \( T = 480 \) K with \( V_D = -0.5 \) V in accumulation mode.

The total quantum efficiency (\( QET \)) as a function of the temperature is plotted in figure 11 for different \( V_{BG} \) for \( L_i = 8 \) \( \mu \)m, \( V_D = -1.5 \) V, \( \lambda = 397 \) nm and \( P_{IN} = 0.55 \) \( \mu \)W. The \( QET \) is defined as the ratio between the photogenerated current (that is the total diode current minus the dark current) and the maximum current that would be generated if there was no kind of loss, like the recombination photogenerated carriers before reaching the anode of the device, the non-photosensitive area (metal covered and interconnections) and reflection [2]. The \( QET \) was calculated based on the responsivity [13] as demonstrated in (1)

\[
QET = \frac{hcR}{\lambda q}
\]

where \( R \) is the responsivity defined as the relationship between the photocurrent and the incident optical power, \( h \) is the Planck constant, \( c \) is the light velocity in the vacuum and \( q \), the elementary charge of electron.
As can be seen in figure 11, the total quantum efficiency increases as the temperature is higher, for all $V_{BG}$ values. Indeed, the higher $QE_T$ of 86% was achieved in depletion mode of operation ($V_{BG} = -2$ V) and for $T = 500$ K. This is due to the increase of generated photocurrent at higher temperatures apart from $V_{BG}$ bias. This behaviour suggests that there is an increase in the amount of absorbed incident optical power that could be related either to a reduction of the absorption length, or to a kind of avalanche or charge multiplication effect related to the increase of carriers’ thermal energy at high temperatures as explained in [13].

In order to make this issue more clear and quantitative, table 2 brings the comparative values of photocurrent, dark current, IDR and quantum efficiency normalized by its value with $T = 300$ K for $P_{IN}$ of 0.55 $\mu$W. It can be seen that the raise in $QE_T$ ratio in inversion mode ($V_{BG} = +20$ V) is related especially to the increase in photocurrent. On the other hand, the raise in IDR ratio in accumulation mode ($V_{BG} = -20$ V) is related mostly to the decrease in dark current.

### Table 2. Ratio of (IDR$_{500}$ K/IDR $300$ K); ($QE_{T}$ $500$ K/$QE_{T}$ $300$ K); ($I_{PH}$ $500$ K/$I_{PH}$ $300$ K); ($I_{DARK}$ $500$ K/$I_{DARK}$ $300$ K), for $L_1 = 8$ $\mu$m, $V_D = -1.5$ V, $\lambda = 397$ nm and $P_{IN} = 0.55 \mu$W.

| Parameter | $V_{BG} = -20$ V | $V_{BG} = 0$ V | $V_{BG} = +2$ V | $V_{BG} = +20$ V |
|-----------|-----------------|----------------|----------------|----------------|
| IDR$_{300}$ K/IDR $500$ K | $12 \times 10^{-3}$ | $0.1 \times 10^{-3}$ | $0.074 \times 10^{-3}$ | $0.27 \times 10^{-3}$ |
| $QE_{T}$ $500$ K/$QE_{T}$ $300$ K | 1.6 | 1.81 | 1.43 | 3.64 |
| $I_{PH}$ $500$ K/$I_{PH}$ $300$ K | 2.11 | 3.55 | 1.7 | 5.18 |
| $I_{DARK}$ $500$ K/$I_{DARK}$ $300$ K | 145 | 17410 | 18050 | 13371 |

4. Numerical simulation analysis

Aiming to investigate the physical phenomena related to the observed experimental results and extend the analysis for more advanced technologies, with reduced silicon film thickness, numerical simulations of thin-film SOI PIN photodiodes were performed with Atlas software [30].

All devices were simulated considering a sharp transition of the doping concentration at the boundary of P, intrinsic and N regions and using the same technological parameters as the experimental samples. Physical models accounting for mobility ($\mu$) dependence on doping concentration ($N$), temperature and electric field, bandgap narrowing, Auger and SRH recombination, doping and temperature-dependent lifetime were included in the simulation files. It is worthwhile noting that no optimization of model parameters has been made and no oxide or silicon traps were considered, which is beyond the scope of this analysis and may affect the quantitative results but does not affect the qualitative analysis. An illumination source with UV ($\lambda = 400$ nm) wavelength was considered, with power density of optical beam of 0.1 mW cm$^{-2}$.

Figure 12 shows the changes in the electron and hole concentrations produced by the different $V_{BG}$. In this figure it is shown a cut in the diode structure in the thickness direction (silicon depth) exactly in the middle of the intrinsic region. In this cut is found first of all the passivation oxide, then the intrinsic region, after the BOX and then the silicon substrate forming a capacitor. When the back-gate bias is such that there is an accumulation of holes in the silicon film, a hole concentration higher than the original value of $1 \times 10^{15}$ cm$^{-3}$ can be observed. In the same way, in the flat band condition, the holes and the electrons concentration are equal to their original values and constant along the thickness of the film. Finally, in weak and strong inversion with higher values of $V_{BG}$, the electron concentration becomes higher than the hole one [31]. These changes in the concentrations are responsible for the different behaviours of the device, depending on $V_{BG}$.

The curves of current as a function of the back-gate bias, similar to those presented in figure 4 were simulated for two different $N_I$ and different anode voltages (figure 13). It is possible to see that for $V_{BG}$ smaller than the flat band voltage ($V_{FB}$), the current falls, and this point depends on $N_I$ and $V_D$ values. For higher $N_I$, the silicon film Fermi potential ($\phi_F$) is higher as well, which explains the reduction in the $V_{FB}$. Furthermore $V_{FB}$ is changed by the anode voltage because it alters the potential applied to the intrinsic region.

However, the threshold voltage of the inherent capacitor structure (that can be observed when the device begins to operate in the inversion mode) does not change much with $V_D$ due to the decrease of the depletion charge when increasing $V_D$, which compensates the $V_{FB}$ raise [1].

The IDR is strongly influenced by temperature as can be noted by figure 14 where the IDR as a function of $V_{BG}$ is shown for three different temperatures. As the temperature is increased, the IDR decreases and this behaviour is repeated...
for the three values of $N_i$. This plot also allows the observation of the different modes of operation (accumulation, depletion and inversion), and in depletion it shows the lowest IDR due to the higher thermal generation since p.n $\ll n_i^2$ (p: holes concentration, n: electron concentration and $n_i$: intrinsic concentration) [1]. Regarding the doping concentration of the intrinsic region, $N_i$, the larger this value, the lower is the IDR, due to the increase in the dark current, and decrease of the generated photocurrent, which is the result of the higher recombination rate and shorter carriers lifetime [32].

This trend can be observed in figure 15 as well, where the IDR is presented as a function of the temperature. When $V_{BG} = 0$ V, the lower values of IDR are presented, whereas for $V_{BG} = -20$ V (accumulation mode), the IDR have the higher values especially for smaller values of $N_i$.

As the use of lateral SOI PIN diodes allows for implementing photodetectors integrated with CMOS circuits, it is important to know the behaviour of these devices for the implementation of photodetectors in more advanced technologies, where the silicon film thickness is reduced. With this purpose, two sets of technological parameters were also used to simulate the photodiodes. The first one features $t_{Si} = 40$ nm, as in the 150 nm technology from Oki Semiconductors [33] and the second one, $t_{Si} = 15$ nm, following the 65 nm technology from IMEC [34]. The lengths, doping concentrations for $P$, $N$ and intrinsic regions and the other thicknesses were kept as in the previous simulations.

Figures 16(a) and (b) present the photocurrent and dark current as a function of back-gate bias, obtained for the three different silicon film thicknesses. Due to numerical precision limitations of the simulator, very low current levels are subjected to significant numerical noise [30]. For this reason, it was not possible to accurately estimate the dark current of these devices for room temperatures, as can be seen in the figure 16(a). However, figure 16(b) allows for noting that there is a reduction of $I_{DARK}$ for very thin silicon film devices in comparison to thicker ones. The simulated results also show that by thinning the silicon film down, the photogenerated current decreases, as a consequence of the reduction of the amount of absorbed photons.

From the results in figure 12 and with the aim at verifying the influence of the silicon film thickness in the sensitivity of the photodetector, the IDR has been obtained and is presented in figure 17. The simulated results showed that the IDR increases with silicon film thickness reduction for all the simulated temperatures. The IDR rise is more pronounced in accumulation mode ($V_{BG} = -10$ V) followed by the inversion mode ($V_{BG} = +10$ V), while in depletion ($V_{BG} = 0$ V) the signal to noise ratio becomes less sensitive to $t_{si}$ reduction.
5. Conclusions

In this work the influence of back-gate bias on the performance of lateral SOI PIN photodiodes at high temperatures was presented. Experimental results demonstrated that the operation mode of the photodiodes was affected by back-gate bias, modifying the photogenerated current, which presents its maximum value when the silicon film is laterally depleted, indicating minimal carriers recombination. It was also shown that when the photodiode is operating in strong accumulation regime (negative $V_{BG}$), a higher illuminated to dark ratio (IDR) is obtained. In fact, IDR in accumulation ($V_{BG} = -20$ V) can be almost five times higher than that for $V_{BG} = 0$ V for temperature of 480 K. The total quantum efficiency of the device increases as the temperature is higher and can achieve 86% in depletion mode of operation ($V_{BG} = -2$ V) for $T = 500$ K. Although the technology of the experimental samples is suitable for imaging applications, the analysis was extended to more advanced technologies through numerical simulations, which showed that a higher IDR is reached for thinner silicon films and smaller substrate doping concentrations in the range of ultraviolet.

Acknowledgments

C Novo, R Giacomini and R Doria acknowledge the Brazilian research-funding agencies CNPq and FAPESP for the financial support to this work and M Souza and M Pavanello for intellectual support and access to UCL partnership.

References

[1] Sze S M 1981 Physics of Semiconductor Devices vol 3 (New York: Wiley) pp 743–60
[2] Streeman B G and Banerjee S 2000 Solid State Electronic Devices (New York: Prentice-Hall) pp 384–5
[3] Monroy E, Omnès F and Calle F 2003 Wide-bandgap semiconductor ultraviolet photodetectors Semicond. Sci. Technol. 18 R33–51
[4] Grundfest W 1999 Overview of medical applications and cardiovascular intervention QELS’99: Proc. Quantum Electronics and Laser Science Conf. pp 23–28
[5] Ingles M and Steyaert M 2004 Integrated CMOS Circuits for Optical Communications (Berlin: Springer)
[6] Karczemsk A and Sokolowska A 2001 Materials for DNA sequencing chip Proc. Int. Conf. on Novel Applications of Wide Bandgap Layers (Zakopane, Poland) vol 3 p 176
[7] Bulrecht O and Flandre D 2009 Optimization of blue/UV sensors using PIN photodiodes in thin-film SOI technology ECS Trans. 19 175–80
[8] Smith W A and Lam K P 2010 Exploratory analysis of UV-vis absorption spectra CISP’10: 3rd Int. Congress on Image and Signal Processing pp 3359–63
[9] Knight G 2004 Monitoring of ultraviolet light sources for water disinfection Proc. 39th IEEE Industry Applications Conf. vol 2 pp 1016–8
[10] Malinowski P E et al 2010 10 μm pixel-to-pixel pitch hybrid backside illuminated AlGaNp- Si imagers for solar blind EUV radiation detection Proc. IEEE Int. Electron Devices Meeting (San Francisco, CA) pp 348–51
[11] 2008 ITRS International Technology Roadmap for Semiconductors: Lithography www.itrs.net
[12] Braga M S, Ramirez F J and Salcedo W J 2010 Image Sensor for Detection of Gases (Muller: VDM Verlag) pp 90–108
[13] Afzalian A and Flandre D 2005 Physical modelling and design of thin-film SOI lateral p-i-n photodiodes IEEE Trans. Electron Device 52 1116–22
[14] Zimmermann H, Muller B, Hammer A, Herzog K and Seegebrecht P 2002 Large-area lateral p-i-n photodiode on SOI IEEE Trans. Electron Devices 49 334–6
[15] Souza M, Bulteel O, Flandre D and Pavanello M 2011 Temperature and silicon film thickness influence on the operation of lateral SOI PIN photodiodes for detection of short wavelengths JCS 6 107–13
[16] Shi L and Nihtianov S 2012 Comparative study of silicon-based ultraviolet photodetectors IEEE Sensors J. 12 2453–9
[17] Ghioni M, Zappa F, Kesan V P and Warnock J 1996 A VLSI-compatible high-speed silicon photodetector for optical data link applications IEEE Trans. Electron Device 43 1054–60
[18] Ho J Y L and Wong K S 1996 High speed and high-sensitivity silicon-on-insulator metal-semiconductor-metal photodetector with trench structure Appl. Phys. Lett. 69 16–18
[19] Liu M Y, Chen E and Chou S Y 1994 140 GHz metal-semiconductor-metal photodetectors on silicon-on-insulator substrates with a scaled active layer Appl. Phys. Lett. 65 887–8
[20] Levine B F, Wynn J D, Klemens F P and Sarusi G 1995 1Gh/s Si high quantum efficiency monolithically integrable $\lambda = 0.88 \mu m$ detector Appl Phys. Lett. 66 2984–6
[21] Yoshida T, Ohtomo Y and Shimaya M 1998 A novel p-i-n photodetector fabricated on SIMOX for 1 GHz 2 V CMOS OEICs Technical Digest of IEDM pp 29–32
[22] Flandre et al 2001 Fully depleted SOI CMOS technology for heterogeneous micropower, high-temperature or RF-Microsystems Solid-State Electron. 45 541–9
[23] Souza M, Bulteel O, Flandre D and Pavanello M 2010 Analysis of lateral SOI PIN diodes for the detection of blue and UV wavelengths in a wide temperature range ECS Trans. 31 199–206
[24] Afzalian A 2006 Optical detectors in SOI CMOS technologies for blue DVD and short distance optical communication Doctoral Thesis Université catholique de Louvain, Belgium 52–55
[25] Rudenko T, Rudenko A, Kilchytska V, Cristoloveanu S, Ernst T, Colinge J P, Dessard V and Flandre D 2004 Determination of film and surface recombination in thin-film SOI devices using gated-diode technique Solid-State Electron. 48 389–99
[26] Afzalian A and Flandre D 2007 Characterization of quantum efficiency, effective lifetime and mobility in thin ungated SOI lateral PIN Photodiodes Solid-State Electron. 51 337–42
[27] Colinge J P and Colinge C A Physics of Semiconductor Devices (New York: Kluwer) pp 73–89
[28] Galeti M, Martino J A, Simoen E and Claeys C 2008 Improved generation lifetime model for the electrical characterization of single and double-gate SOI nMOSFETs Semicond. Sci. Technol. 23 125011
[29] Li G, Zeng Y, Hu W and Xia Y 2014 Analysis and simulation for current-voltage models of thin-film gated SOI lateral PIN photodetectors Optik 125 540–4
[30] SILVACO 2010 ATLAS user’s manual
[31] Novo C, Giacomini R, Doria R, Afzalian A and Flandre D 2013 Back-gate bias influence on the operation of lateral SOI PIN photodiodes at high temperatures EUROSOI’13: Proc. 9th Workshop of Thematic on SOI Technology, Devices and Circuits (Paris)
[32] Novo C, Giacomini R, Afzalian A and Flandre D 2013 Operation of lateral SOI PIN photodiodes with back-gate bias and intrinsic length variation ECS Trans. 53 pp 121–6
[33] Domae Y et al 2008 Improvement of the tolerance to total ionizing dose in SOI CMOS Proc. IEEE Int. SOI Conf. pp 135–6
[34] Augendre E et al 2005 On the scalability of source/drain current enhancement in thin film SOI Proc. ESSDERC pp 301–4