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Operation of Lateral SOI PIN Photodiodes with Back-Gate Bias and Intrinsic Length Variation

Carla Novo[1], Renato Giacomini[1], Aryan Afzalian[2], and Denis Flandre[2]
[1]Electrical Engineering Department , Centro Universitário da FEI, São Bernardo do Campo, Brazil
[2]ICTEAM Institute, UC Louvain, Louvain-la-Neuve, Belgium
e-mail: carladcpn@fei.edu.br

Abstract: This paper presents an analysis of the operation of lateral thin-film SOI PIN photodiodes for the detection of short wavelengths. Experimental measurements were done varying the back-gate bias in order to point out the behaviour of the device. In addition, by using two-dimensional numerical simulations, the intrinsic length (L_I) was changed, with the purpose of predicting the performance of this photodetector in more advanced technologies.

Introduction: Optical detection at short wavelengths close to blue and UV (λ<480nm) have many applications in biomedical and environmental fields [1] and in data storage applications [2]. These applications require the use of efficient photodetectors such as PIN Photodiodes, which consist of a PN junction separated by an intrinsic region with length Li [3], which in practice corresponds to a weakly doped P or N region. In such devices, carriers generated by light radiation can be collected more efficiently; because the depletion region is formed from the surface to the end of silicon film, and silicon devices absorb light as a function of their thickness [3]. Furthermore, the hole-electron pairs must not recombine, and have to be quickly separated by the action of the electric field present in the depletion region that corresponds approximately to the intrinsic length. Therefore, the intrinsic length must be large enough to allow for the absorption of a significant number of photons, but sufficiently short to reduce the transit time for drift of photogenerated carriers [4]. The characterized devices follow the 2µm technology from UCL described in [5]. They have 8 and 9µm of Li, consisting of a doping profile of P+P-N+. Figure 1 shows a schematic cross-section of the studied device.

Experimental Measurements: The normalized photocurrent as a function of the applied voltage (V_D) is presented in Figure 2 under the incidence of three different wavelengths for both devices. It is clearly seen that the higher the wavelength, the lower the photogenerated current due to the decreased photon energy [3]. Besides, the current has shown to be larger in the diode with L_I=9µm since it has larger photosensitive area [6]. The variation of back-gate voltage (V_{BG}) modifies the operation mode (inversion, accumulation or depletion) of the silicon film [7]. In Figure 3 is presented the photodiode current as a function of the V_{BG} when illuminated with 397nm. When the film is biased towards accumulation regime (V_{BG}<-5V), 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 carriers recombination is smaller. Moreover, for V_{BG} higher than about 0.5V, 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 [8]. The inversion current is lower than the accumulation one, as the hole mobility is smaller than the electron mobility. It is also possible to see in Figures 3 and 4, that the decrease of V_D alters the accumulation, requiring a more negative V_{BG}. Besides, the more negative V_D, the higher the photocurrent, due to the larger depletion layer and higher electric field. The same behaviour is observed in Figure 4, where the higher photocurrent is obtained for λ=397nm, due to the already mentioned higher photon energy.

Numerical Simulation Analysis: Two-dimensional numerical simulations were performed in Atlas Software [9], and no ARC (anti-reflection coating) has been included. It is worthwhile noting that no optimization of model parameters has been made, which is beyond the scope of this analysis and may affect the quantitative but not the qualitative analysis. Simulations with L_I varying from 1.1µm to 72.3µm were performed. As L_I is changed, the total number of fingers is changed as well, since the diode total area was kept constant. Figure 5 shows the normalized photocurrent as a function of L_I for two different intrinsic doping concentrations. It is possible to see that for L_I< 6µm, the photocurrent increases as L_I is increased, due to larger photosensitive area., while both doping concentration present the same values of photocurrent, because they have the same length of depletion region. As L_I becomes higher than 6µm, the device with N_I=1x10^{15}cm^{-3} presents a reduction of the photocurrent, because it becomes not fully depleted and the action of the recombination phenomena takes place [2]. In a PN junction, the depletion region stretches over the less doped region, that is, the intrinsic region. Thus, as L_I decreases, the effect of back-gate bias is less pronounced, because the device becomes fully depleted, reducing the carriers recombination. On the other hand, the influence of P^+ and N^+ regions becomes more effective, as they are closer to each other. This behaviour is similar to the short-channel effects in MOS transistors [10], if we make an analogy taking the backgate of the PIN diode as the MOS gate. Figure 6 presents the normalized photocurrent as a function of V_{BG}. For higher L_I, the observed curve is similar to that of experimental data, however, as L_I decreases, the accumulation photocurrent becomes smaller than the inversion one, thanks to the higher recombination rate in accumulation and the N_D change is more pronounced.

Conclusions: In this work the influence of back-gate bias and the intrinsic length variation on the performance of lateral SOI PIN photodiodes was presented. Experimental results demonstrated that the operation mode of the photodiodes was affected by backgate bias, modifying the photogenerated current, which presents its maximum value when the silicon film is laterally depleted, indicating minimal carriers recombination. Two-dimensional numerical simulations were used to reproduce the experimental data and showed that the choice of the intrinsic length (L_I) and consequently the number of fingers is crucial for the responsivity of the photodetector. The results showed that the higher photocurrent was obtained for L_I around 6mm, indicating minimum recombination effect in this condition.

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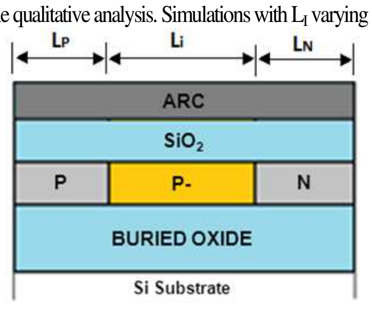

Figure 1: Cross-Section of PIN SOI Photodiode

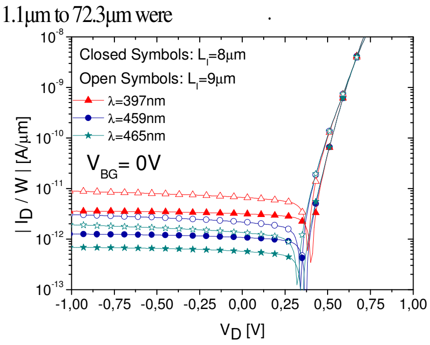

Figure 2: Normalized photocurrent as a function V_D

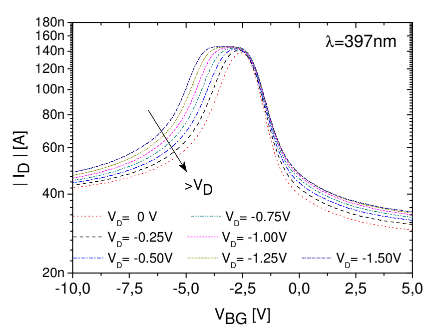

Figure 3:Photocurrent as a function V_{BG} for different V_D

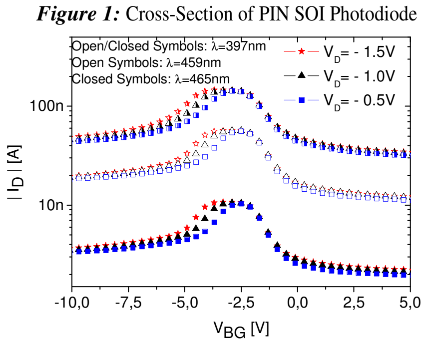

Figure 4:Photocurrent as a function V_{BG} for different λ

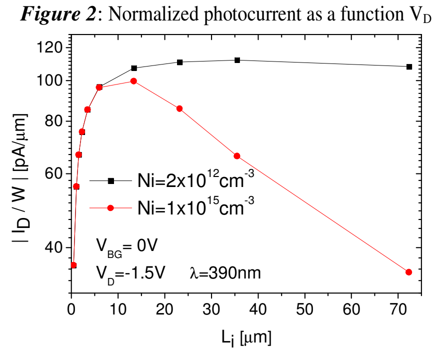

Figure 5:Photocurrent as a function L_I for different N_I

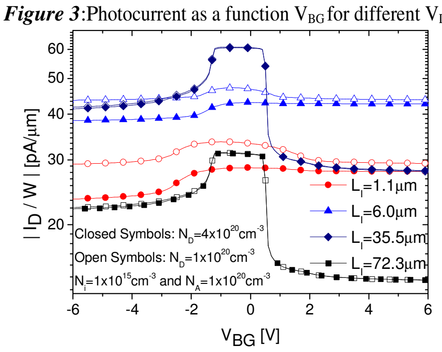

Figure 6:Photocurrent as a function V_{BG} for different L_I