[ME02] Model of coherent photon detection in a lateral pin photodetector structure

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Introduction

Several types of photodetector for use with the microwave modulated optical signals have been developed over the last few years. Of all the materials, silicon PIN photodiodes are able to generate at moderately high response speed semiconductor devices since it has low capacitance, which come from the intrinsic characteristic of the silicon material. Furthermore, silicon photodiodes absorption wavelength responded at the wavelength of just below 1000ηm.

Most of the p-i-n photodetector devices are based on the vertical p-i-n photodetector structure, which can combine speed with moderate responsivity [1]. The drawback with the conventional p-i-n structure is that the thickness of the intrinsic absorbing layer of the p-i-n photodetector is the fundamental constraint due to a compromised on either the speed of response or the responsivity in the design [1-3]. This is due to a thin intrinsic region which is required for a short carrier transit time and therefore for high speed; where else a thick intrinsic region is required for high responsivity [5]. This limitation can be overcome by precise understanding the movement of electron in the device.

In the past, the erratic movement of a photon principally those captured in a high speed detector was found to play an important role in the efficiencies of the device. Studies were performed to understand and summarize the relevant result in both macroscopic and microscopic level [2-4]. The objective of this work is to model an environment that can simulate the random absorption of coherent photons that generate holes and electrons in the device and the organized movement of the charges in the presence of an electric field.

Materials and methods

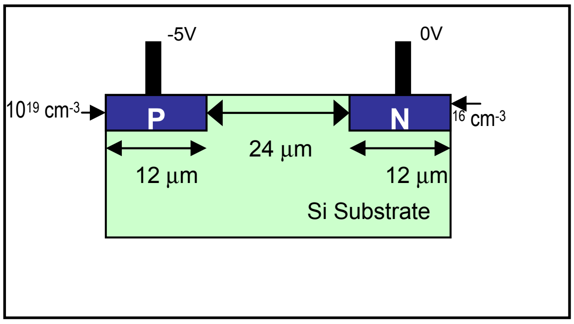

FIGURE 1 A rough model of a single cell sliced plane of an interdigitated PIN silicon photodetector.

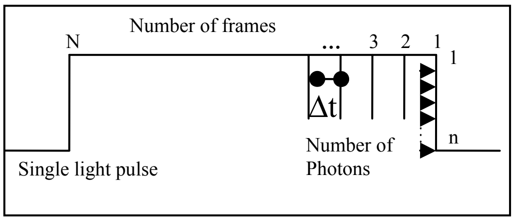

FIGURE 2 Model of a light pulse. With n number of photons per frames for N frames.

The model of the light pulse is as shown in **Figure 2**, whereupon a single light pulse assumedly from a very coherent laser source is modeled and systematically sliced into N sections or frames with n number of photons per frame. The light source is assumed to be originated from a stabilized highly coherent laser, with the detector having unity quantum efficiency and the receiver circuit is noise-free. The receiver as also assumed to be operating at 1µm wavelength. Since the coherent light frequency is about 300THz and each group of photons at a frame occupies in one harmonic time Δt as in eq(1) and the whole pulse width t can then be written as eq(2). Therefore if f =300THz, then Δt ≈ 3fs. If the pulse width is 2.4ps, then the total frame number is 800. However, if the pulse width is

2.4ns, then the total number of frames is 800,000.

$$\Delta t = \frac{1}{f} \qquad (1)$$

$$t = N \times \Delta t \qquad (2)$$

The modeled light pulse is then bombarded into a cross section plane of the p-i-n structure (**Figure 1**).

The light pulse is spitted into N frames, where each of them contains n photons. Results presented here was to observe the characteristics of the electrons below the noise level. The result obtained can be used to study the detailed development of analytical models of light propagations in detectors.

Results

User required data are keyed into a GUI interface**.** The random discrete properties of the light were replicated by a process of random light particles were bombardment into the device with the physical properties of donor density of 10^{16} cm^{-3} and acceptor density of 10^{19}cm^{-3}, size of the absorption region at a varying length and a bias voltage of =5 V was used for this research, at the interval of 3 fs. From these conditions, device response was predicted. A flux plot was generated (**Figure 3**) and it acts as a guide to the flow of the electrons and holes through the device. Each electron that travels on their subsequent flux lines and have their own velocity and lenght upon their position in the device. Therefore, a precise set of data based on each random positioning of the electrons, as shown in **Figure 4**, were generated. Then a rough calculation of each of the electrons,**Figure 5 (a)**, were listed based on the transit time of each electrons. From the rough approximation of the electron, a revised summation, **Figure 5 (b)** , current was generated from all 10 of the electrons per frame for the continuation of 800 frames. The process was repeated for the subsequent gap size; 20µm, 30µm, 40µm, 50µm, 60µm, 70µm, 80µm, 90µm and 100µm. Figure 6 illustrated the sum of electrons captured at an interval of 3fs. **Figure 7**, was used to sumarized and compare the current response from the devices.

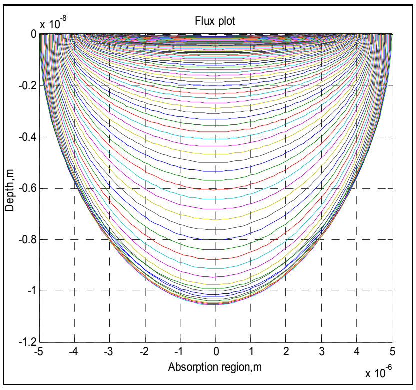

FIGURE 3 The flux plot for the gap size of 10µm.

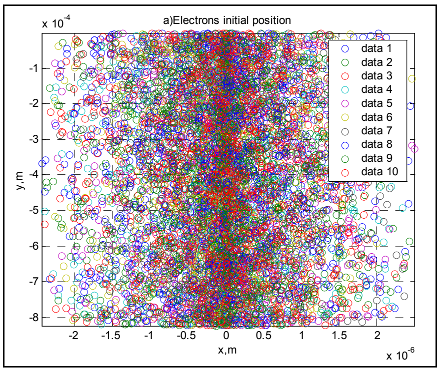

FIGURE 4 The random positioning of 10 electrons per frame for 800 frames

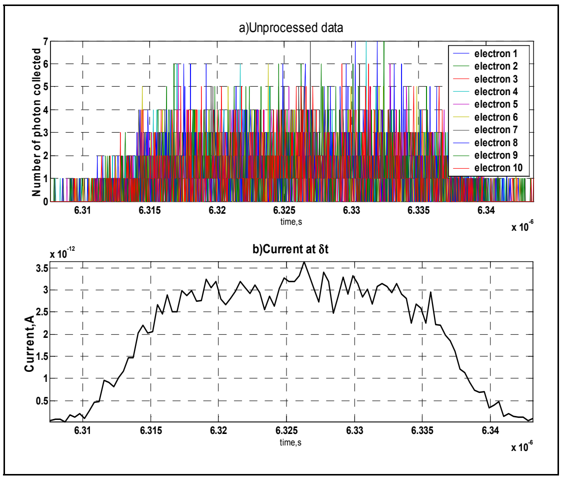

FIGURE 5 (A) The unprocessed data accumulated from 10 electrons per frame from 800 frames. (B) The summation of all the electrons and calculation of current according to the transit time regardless of the frames.

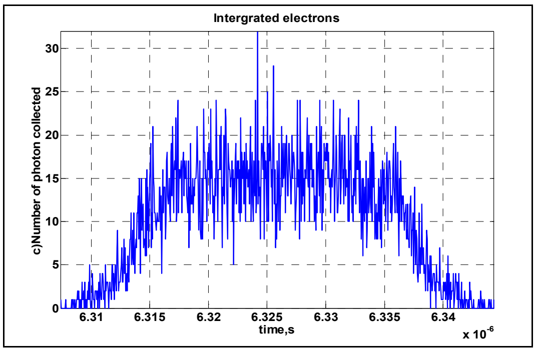

FIGURE 6 Summation of the electrons at an interval of 3fs for the intrinsic region of 10µm.

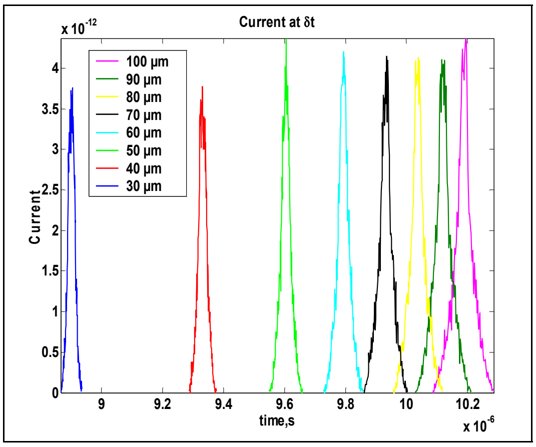

FIGURE 7 Current comparison for intrinsic region from the size of 30µm until 100µm

Discussion

Replicated environment by means of computational methods are important as a form of analysis before the construction of the exact device. Simulation played a major role in this as the result for each subsequent flux lines were prearranged with its own set of drift velocities and mobilities. Therefore the research was based on an assumption that it is space dependent with time independency.

From **Figure 7**, it was shown that the thicker the intrinsic region, the slower the response speed while the thinner the intrinsic region, the faster the transit time. However an overlapping of pulses can be seen for current generated around the intrinsic region of 70µm until 100µm. This was contributed from the fact that the wider the absorption region, the more efficient the capture of electron through the device. Therefore a larger amount of electron were captured at a time.

It is also noted that as the gap size increased, the current will also increased at a notable state. This further justify the fact that the wider the region, the higher current can be generated.

In actual environment, noise factors will hold a critical role especially during very low light environment. Therefore, this study will prove useful in determining the characteristics of electrons in microscopic sense without any interference from noises.

Chiefly these models were used to simulate the movement of an electron in conjunction with the electric field and the whole field of radiosity is related with quickly integrating the light transfer function for all of the surfaces in the scene.

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