ENHANCED ELECTRON TRANSIT TIME IN PINNED-BURIED PHOTODETECTOR

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Burst image sensors with very high frame rate were developed for studying rapid mechanical motion and transient phenomena [1, 2]. These image sensors are designed to capture images at frame rate 10^6 frames/s or higher. The imager with a large photodetector is required to obtain complete charge readout in much less than 1.0μs. A multi-implant (graded) pinned-buried photodetector can be used to reduce the readout time. To achieve a high-speed detection, with essentially zero frame-to-frame lag, graded potential steps are created in the photodetector by variation of doping concentration of implants. In this work a charge transfer model is developed based on a thermal diffusion model which takes into account the initial charge on each individual implant of an n-implant case and the effective diffusion lengths of all electrons. This model was verified using a three-implant for a pinned-buried (70μm x 45μm) photodetector at 1MHz and 1ns pulse.

The cross-sectional view of a n-N type implant pinned-buried photodetector is shown in Fig. 1. The implant concentration N1 is BCCD implant plus the first photodetector implant, N2 is N1 plus second photodetector implant, N3 is N2 plus the third photodetector implant and so on for Nn implant. These implants result in a graded potential profile along the photodetector as shown in Fig. 1. The potential profile divides the photodetector into n-sections where section-2 acts as a charge sink for section-1, section-3 acts as a charge sink for section-2 and so on. Finally, the potential well under the charge-collecting gate acts as a sink for the charge collected by the photodetector. The image acquisition cycle is the most important cycle of the imager, during this cycle the charge signal is detected by the photodetector, is transferred in series into the registers for detection of successive frames [3]. The layout of a n-N-type-implant pinned-buried photodetector(70μm x 45μm) is considered with n=3. The total area of the photodiode is A and $A_1, A_2, A_3 \ldots A_n$ be the areas of implant regions. The implant area A_1 is divided into p number of small sections with an area of A_{1i} each. Similarly, implant areas $A_2, A_3 \ldots A_n$ are divided into $q,r\ldots m$ number of small sections with an area of $A_{2j}, A_{3k} \ldots A_{nm}$ for each small section. The total charge in the photodetector at any time t can be obtained by the superposition of charges in all small sections at time t. Mathematically it can be expressed as

$$Q(t) = \frac{8}{\pi^2}\frac{Q(0)}{A}\left[\ \sum_{i=1}^{p} A_{1i} e^{-\frac{\pi^2 D_{1n} t}{4L_{1i}^2}} + \sum_{j=1}^{q} A_{2j} e^{-\frac{\pi^2 D_{2n} t}{4L_{2j}^2}} + \sum_{k=1}^{r} A_{3k} e^{-\frac{\pi^2 D_{3n} t}{4L_{3k}^2}} \ldots\ldots \sum_{m=1}^{t} A_{nm} e^{-\frac{\pi^2 D_{nn} t}{4L_{nm}^2}}\ \right]$$

where, $A_{1i} = i^{th}$ area of implant region A_1, $A_{2j} = j^{th}$ area of implant region A_2, $A_{3k} = k^{th}$ area of implant region A_3, and similarly $A_{nm} = m^{th}$ area of implant region A_n. D_{1n}, D_{2n}, D_{3n}, and D_{nn} are the electron diffusion coefficient of implant regions A_1, A_2, A_3, and A_n respectively. L_{1i}, L_{2j}, L_{3k} , and L_{nm} are the effective maximum diffusion lengths of electrons in i^{th}, j^{th}, k^{th} and m^{th} areas of implant regions A_1, A_2, A_3, and A_n respectively.

The number of electrons present in each small section as a function of time after the uniform illumination intensity corresponding to 20,000 electrons incident on the photodetector is turned off at t=0. The electrons are transferred from nearer sections to the collecting gate in smaller time, whereas the electrons are transferred from periphery of the photodetector in longer time. On the average, the electron transfer mechanism from implant region A_1 is slowest and fastest from implant region An. The total number of electrons in the photodetector is obtained by the superposition of the contribution of number of electrons from each small section. The number of electrons present in a photodetector with a three (n=3) implanted regions case as a function of time after the uniform illumination intensity corresponds to 20,000 electrons is turned off at t=0. For the photodetector, for 90% of electron transfer, the readout time is about 500 ns. The charge readout time for three N-type photodetector is much smaller than a single N-type implant photodetector. For 90% electron transfer the readout time for three-implant detector is about 500ns and for single implant detector readout time is more than 1000ns. Charge readout comparison between the experimental results (1 MHz and 100 ns pulse) and the results obtained by using the present model is shown in Fig. 2. It can be seen that for 90% electron transfer the observed readout time is 500 ns and the readout time obtained by the present model is about 500ns.

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References:

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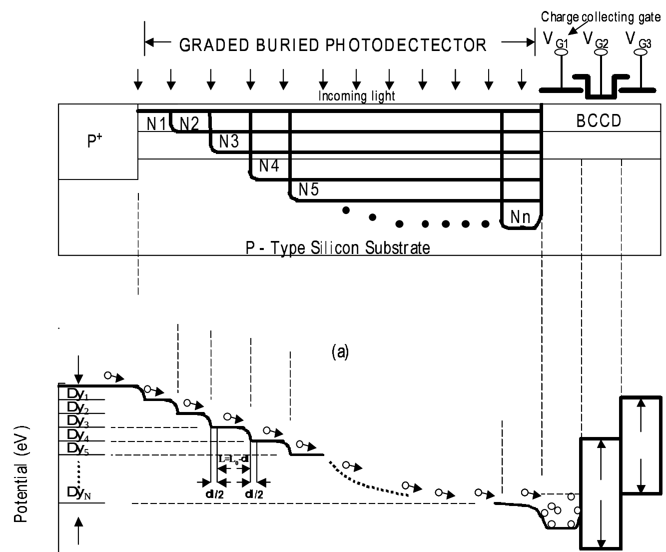

Fig.1 Cross sectional view of the n-N-type photodetector implant (a), graded potential profile and operation (b).

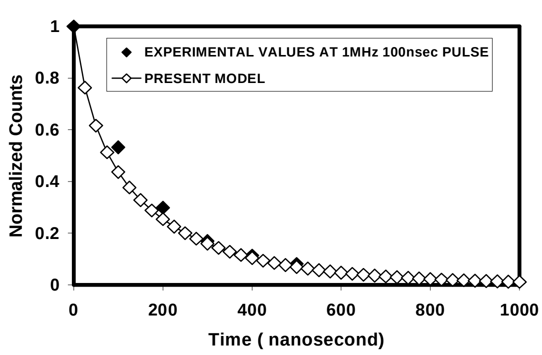

Fig. 2. Comparison between the experimental charge readout values and charge readout values obtained by present model.