1-1-2010

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10.1109/COMMAD.2010.5699717
This is an Author's Accepted Manuscript of: Jansz, P. V., & Hinckley, S. (2010). Simulation of a Hybrid Polywell and Stacked Gradient Poly-Homojunction CMOS Photodiode. Proceedings of COMMAD 2010. (pp. 161-162). ANU Canberra. IEEE . Available here

Simulation of a Hybrid Polywell and Stacked Gradient Poly-Homojunction CMOS Photodiode

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Abstract: In this paper, we have simulated the performance of a photodiode array that has multiple wells per pixel as well as a stacked-gradient poly-homojunction (StaG) geometry. The pixel response resolution was improved when the first StaG epilayer was within 2 μm of the space charge region (SCR).

1 Introduction: The polywell photodiode development was generated by the need for UV/Blue sensitivity [1]. Frontwall depletion benefits frontwall illumination, but back illumination is not improved, as the photocarriers are generated away from the SCR. Thinning the array wafer is not always possible as the wafer is more fragile. Minimum doping is limited to 10^{14} cm^{-3} which defines the maximum SCR width to be 7 μm at 3 volts.

Using a Stacked gradient poly-homojunction (StaG) in the undepleted substrate may improve the polywell pixel's performance. Backwall illumination has several advantages, including maximum fill factor and ability to tailor PD pixels to a specific wavelength band [2]. Back illuminated imaging arrays with UV/blue sensitivity may have applications for particle physics, plasma spectroscopy, astrophysics, and clinical chemistry [3].

Emulating previous poly-p-well studies [4], recently research has shown the benefit of the poly-p-well-StaG photodiode over the polywell pixel [3]. This was however for a minimum epilayer doping of only 10^{15} cm^{-3} so that the SCR was not at maximum extent; far from the substrate second layer of the StaG geometry.

This research investigates the effect on crosstalk and sensitivity of placement of the StaG with 2, 3, 4 and 6 layers in the 12 μm thick pixel with 3 poly-p-wells. Also, the effect of placement of the StaG 6 layer pixel with 3, 6 and 9 poly-p-wells is considered.

2 Method: Using SEMICAD DEVICE (v 1.2) as previously [3], the simulated array (Fig. 1) was scanned at 5 μm intervals along the front and back of the array with a laser beam of 5 μm width and 0.1 μW power. The first epilayer width was varied from 4 to 11 μm. The other epilayers and substrate were of equal thickness. Table 1 shows Polywell placement using "d" and "w" from Fig. 1. Table 2 shows StaG epilayer/substrate doping.

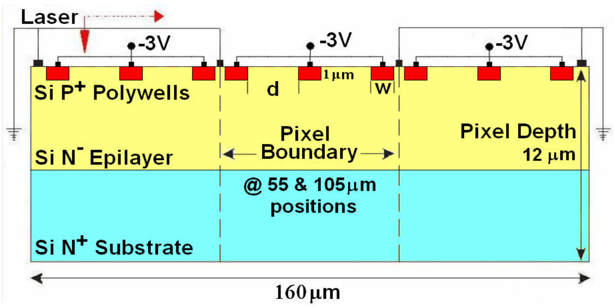

Fig. 1. Polywell 3 – StaG 2 three PD array.

Table 1: Placement of Poly-p-wells.

Number of Polywells	d (Fig. 1) (μm)	w (Fig. 1) (μm)
3	18	4
6	7.8	1.5
9	4.76	1.1

Table 2: Doping of StaG epilayers.

Number of StaG layers	As N-Doping (cm^{-3}) (upper most epilayer first)
2	1e14, 1e17
3	1e14, 3.2e15, 1e17
4	1e14, 1e15, 1e16, 1e17
6	1e14, 4e14, 1.6e15, 6.3e15, 2.5e16, 1e17

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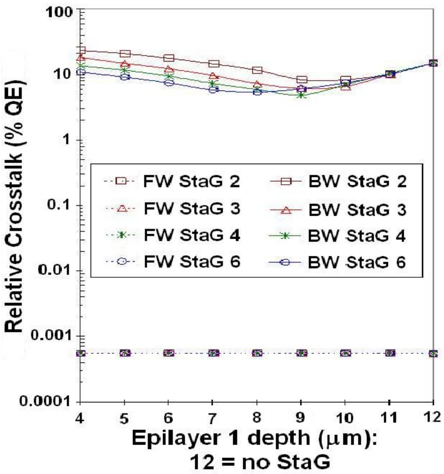

Fig. 2. Relative crosstalk at 400 nm for Back (BW) and Front (FW) illumination of Polywell 3 PD with varying StaG layers.

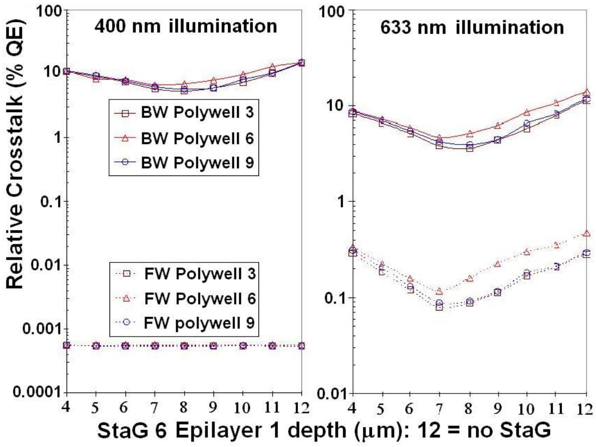

Fig. 4. Relative crosstalk at 400 / 633 nm for Back (BW) and Front (FW) illumination of StaG 6 PD with polywell numbers given.

3 Results and Discussion: Fig. 2 shows the relative crosstalk at 400 nm for various StaG layers in a tri-polywell photodiode. Fig. 3 is similar except at 633 nm.

For front illumination of 400 nm, the polywell photodiode crosstalk is not affected by StaG placement, StaG layer number (Fig. 2), or numbers of polywells with or without a StaG (Fig. 4). The same applies to the 100% maximum QE.

However, back illuminated device crosstalk is dependent on StaG placement and layering (Fig. 2 & 3), and to a lesser extent on the number of polywells (Fig. 4), with up to 70% reduction in crosstalk achievable. Crosstalk is still significantly greater than other StaG photodiode hybrids [5], Guard Junction photodiodes [6] and PIN geometries. Back illuminated sensitivity is only marginally improved by the inclusion of the StaG (0.3%) being nearly at 100% QE.

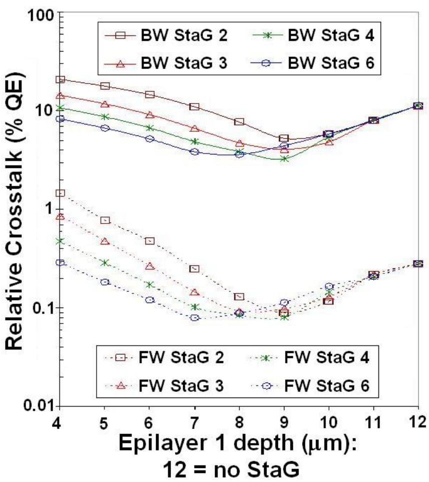

Fig. 3. Relative crosstalk at 633 nm for Back (BW) and Front (FW) illumination of Polywell 3 PD with varying StaG layers.

The StaG geometry is most effective when the second epilayer is within 2 μm of the SCR. Beyond this, the StaG only reflects a minority of carriers (Fig. 2 – 4).

4 Conclusion: For UV application of back illumination to be as effective as front illumination, the SCR needs to be brought to the backwall, dispensing with the need for a StaG. Future UV sensor research will focus on structures that deplete the pixel to the backwall for large and small pixel pitch.

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