P6

Buried double junction pixel using green and magenta filters

K.M.Findlater[a], P.B.Denyer[b], R.K.Henderson[b], J.E.D.Hurwitz[b], J.M.Raynor[b], D.Renshaw[a]

[a] *Department of Electronics and Electrical Engineering, The University of Edinburgh, The King's Buildings, Edinburgh, EH9 3JL , Scotland, UK, Email: Keith.Findlater@ee.ed.ac.uk*

[b] *VLSI Vision Ltd., Aviation House, 31 Pinkhill, Edinburgh, EH12 7BF, Scotland, UK*

Abstract

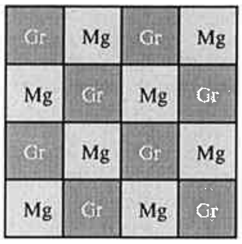
This work investigates the suitability of a buried double junction structure for colour imaging. Four spectral responses suitable for colour imaging are presented; these are obtained by the combination of the BDJ structure with two suitable colour filters. A transistor active pixel circuit is also given which allows this structure to be operated in an integrating mode. Operational amplifier and direct measurement structures are also used.

1.0 Introduction

Conventional CMOS colour image sensors employ a standard n^+/p diode as the photosensing element in an integrating active pixel combined with an array of 3 colour filters, often RBG filters arranged in a Bayer pattern. Usually the final colour image is reconstructed using image processing techniques on chip or in a co-processor.

Many photodiode structures have been proposed for colour measurement, e.g. [1]-[3]. These avoid using colour filters. They use multi-level photodiode structures, or exploit the voltage dependence of the spectral response of photodiodes, to obtain at least two responses from which the colour information can be determined.

Two linearly independent signals are sufficient to resolve a single narrowband colour (i.e. a single wavelength). For colour imaging, tri-chromatic colour theory states that a minimum of 3 linearly independent responses is required [4]. To our knowledge, the BDJ structure has never been used in an imaging application with colour filters or in an integrating mode. The work reported here investigates the use of this structure with green and magenta filters. Figure 1 illustrates how such pixels could be used in an array. This results in four colour responses from two pixels, which can then be reconstructed into a colour image.



Gr	Mg	Gr	Mg
Mg	Gr	Mg	Gr
Gr	Mg	Gr	Mg
Mg	Gr	Mg	Gr

Figure 1: A small section of a pixel array using BDJ photodiodes and green and magenta pixels.

2.0 Structure

The structure investigated is shown in Figure 2. In normal CMOS sensors only a single junction is used. This structure has been previously used for photometry with a linear array of logarithmic pixels for narrowband colour measurement [5].

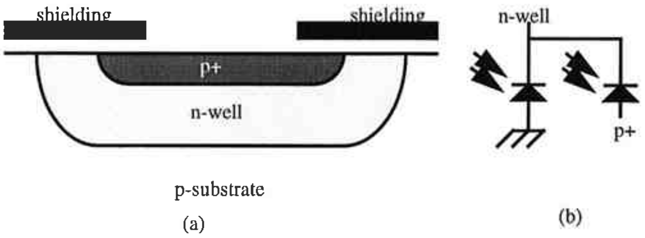


Figure 2: Double junction structure cross section (a) and equivalent circuit model (b).

The absortion of photons in silicon is given by the equation:

$$I_{opt}(\lambda, x) = I_{opt_o} e^{-\alpha_{opt}(\lambda)x} \qquad (1)$$

where I_{opt} is the photon flux of wavelength λ at a depth x, I_{opt0} is the incident photon flux, and α_{opt} is the absorbtion co-efficient. As the absorbtion length of incident photons in silicon is wavelength dependent, the top junction of the structure is more sensitive to the blue end of the spectrum and the lower junction to red - a property that can be exploited to optain spectral information.

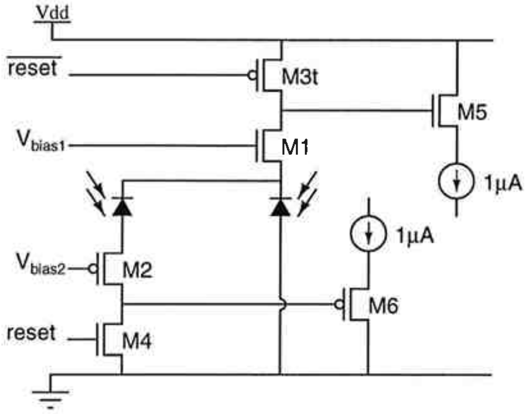


Figure 3: Active pixel circuit.

The cathodes of the two diodes share the same node which presents some challenges to the designer of an integrating active pixel. Figure 3 shows a 3 transistor active pixel configuration suitable for use with the BDJ structure. For comparison, charge integrating operational amplifier readout and direct measurement structures were also fabricated, all using the same 0.5 μm CMOS technology (large photodiodes were used in all cases). As can be seen in Figure 3, both NMOS and PMOS transistors are required in the pixel. Transistors M1 and M2 hold the photodiodes at a constant voltage, while M3 and M4 reset the gates of M5 and M6, which are then charged by the photocurrent. The operational amplifier integrating circuit is shown in Figure 4. Its principle of operation is the same as the transistor pixel - the voltage present on the positive terminal of each amplifier biases the diode terminal, and the photocurrent is integrated on the polysilicon capacitor.

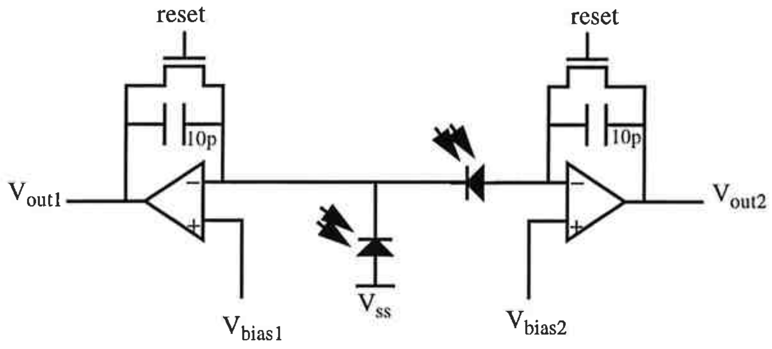


Figure 4: Integrating circuit using operational amplifiers.

3.0 Results

3.1 Spectral results

The photocurrent of the BDJ direct measurement structure was measured from 350-1050 nm in 10nm steps. Figure 5 shows the responses obtained from the two junctions. It can be seen that the quantum efficiency of the N-well/P-substrate diode is much higher than that of the P+/N-well. Additionally, the N-well junction was found to collect photogenerated charge from the surrounding silicon. This was eliminated during the direct measuments by optically masking the surrounding area. After normalisation (Figure 5b) the spectral selectivity of the two junctions is clearly apparent. This result is in general agreement with previously published curves and device simulation predictions, though of course some difference between the spectral response of different technologies is to be expected due to the different junction depths.

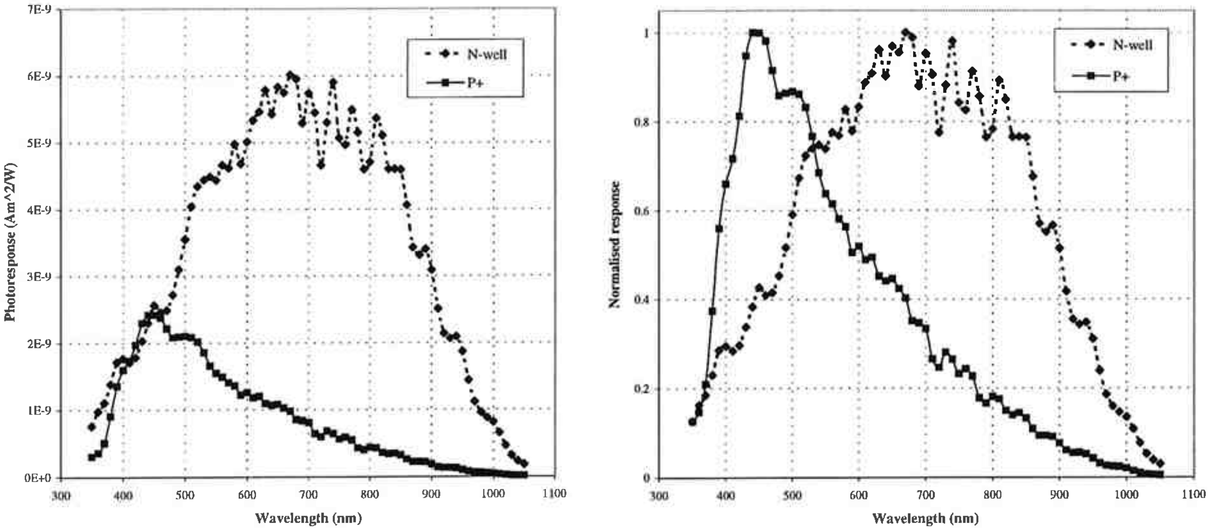
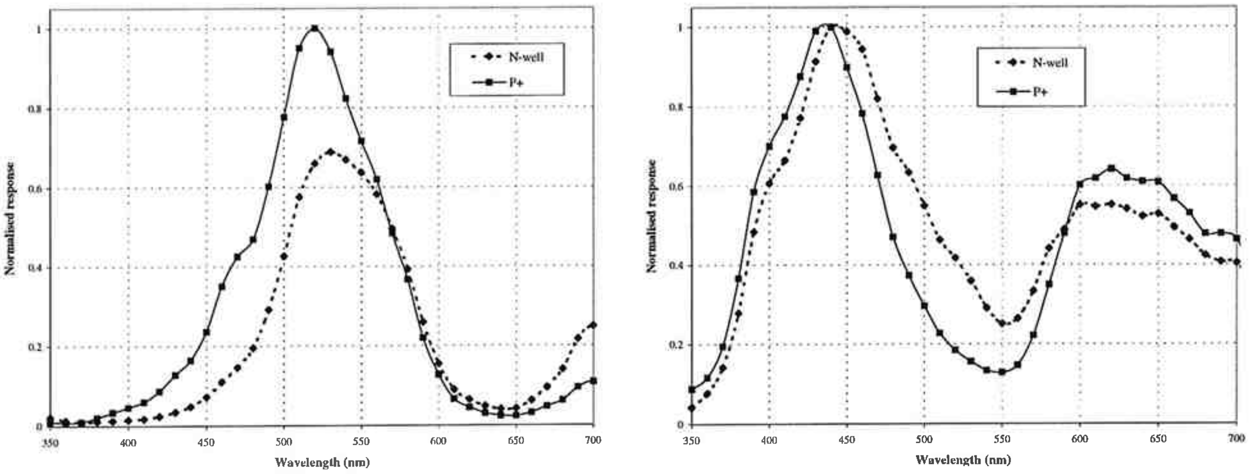
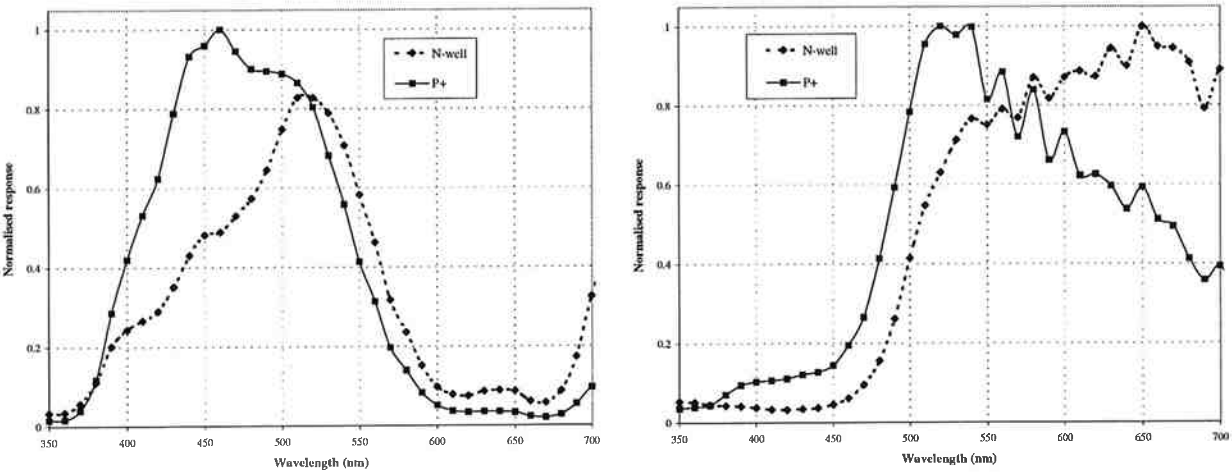


Figure 5: Spectral response of the P+/N-well and Nwell/P-substrate junctions.



(a) (b)

Figure 6: Normalised spectral response of the BDJ structure with (a) green and (b) magenta filters.



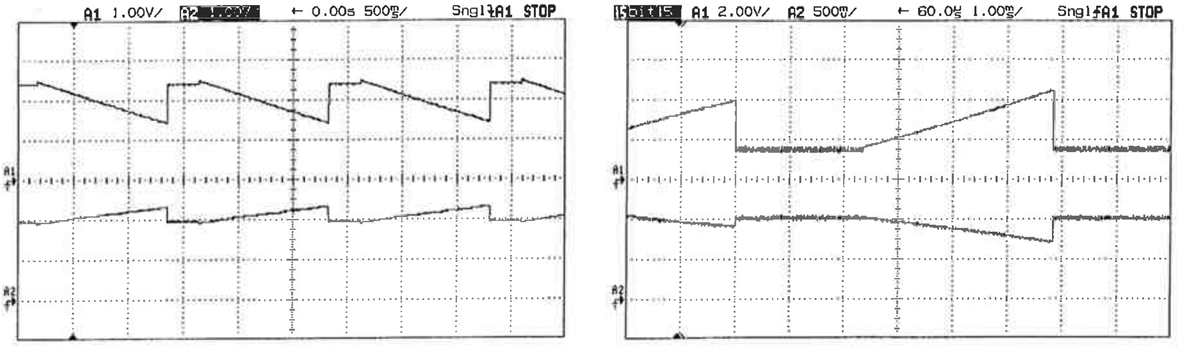
(a) (b)

Figure 7: Normalised spectral response of the BDJ structure with (a) cyan and (b) yellow filters.

The pixel response was then measured with green and magenta filters in place as is shown in Figure 6. As no infra-red blocking filter was used there is a large IR response irrespective of the filter type. As can be seen from the figure, four different spectral responses are obtained from two pixels which would allow this structure to be used in a colour imager. Due to the nature of this structure, it is also possible to use a magenta/cyan or a cyan/yellow filter pair as an alternative to the magenta and green approach. The curves obtained with cyan and magenta are given in Figure 7. It is intended, as further work, to determine and compare the colorimetric accuracy that can be obtained with the different combinations.

3.2 Pixel measurements

Due to the unequal quantum efficiency of the two BDJ junctions, normalisation of the two responses was required. This can be easily achieved in the pixel by correctly setting the ratio of the two integrating capacitances. The present data suggests that the capacitance on which the N-well current is integrated should be 3-4 times that of the P+ one.



(a) N-well (top waveform) 1V/div, P+ (bottom waveform) 1V/div. Timebase: 500ms/div.

(b) N-well (top waveform) 2V/div. P+ (bottom waveform) 500mV/div. Timebase: 1 ms/div.

Figure 8: Pixel waveforms: (a) transistor active pixel in the dark and (b) op-amp pixel in unfiltered light.

Figure 8 above shows the waveforms obtained from the transistor and op-amp pixel structures. Due to the problems with the N-well sensitivity to photogeneration in the surrounding silicon the active pixel was measured in the dark. It can be inferred from the waveform in Figure 8a above, that the dark current of the N-well is higher than of the P+, assuming that both integrating capacitances are equal.

4.0 Conclusion

The combination of a double junction photodiode structure with various colour filters has been investigated. The spectral selectivity of this structure produces four spectral responses from two pixels. An active pixel structure has been presented which allows the BDJ to be operated in an integrating mode. Optimal perfomance would be achieved by setting the integrating capacitance according to the sensitivity of the two junctions.

5.0 Acknowledgements

The authors would like to thank the Test and Characterisation group of VLSI Vision for their help with the spectral measurements. Also thanks to Neil Rankin of the Edinburgh Microfabrication Facility for assistance with measurement equipment and Keithley Instruments Ltd for equipment loan. This project is supported by EPSRC Award Number 98318217 and is CASE sponsored by VLSI Vision Ltd.

References

[1] G.N.Lu, M.B.Chouikha, G.Sou and M.Sedjil, "Colour detection using a buried double *p-n* junction structure implemented in the CMOS process", *Electronics Letters*, 1996, Vol. 32 , No. 6, pp. 594-596

[2] R.F.Wolfenbuttel, "Operation of the silicon colour filtering element", *Sensors and Actuators,* 1989, Vol. 16, pp. 13-23

[3] M.Bartek, P.T.J Gennissen, P. Sarro, P.J.French and R.F.Wolfenbuttel, "An integrated silicon colour sensor using selective epitaxial growth", *Sensors and Actuators A,* 1994, Vol. 41-42, pp. 123-128

[4] R.W.G.Hunt, "The reproduction of colour", Fountain press, Kingston-upon-Thames, 5th edition, 1995

[5] M.B. Choikha, G.N.Lu, M. Sedjil and G.Sou, "A CMOS linear array of BDJ color detectors", *Proc. of SPIE*, 1998, Vol. 3410, pp.46-53