DOUBLE-EFFICIENCY QUAD-CELL FOR OPTICAL POSITION SENSING

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ABSTRACT

This paper presents the characteristics of a new approach on the implementation of optical position-sensitive sensor units – Quad-Cells. Linearization and dark-current of quad-cell (QC) structures were experimentally determined and simulation results were also obtained. Comparison between traditional approaches (homogeneous structures) and new design implementation (double-efficiency) is also presented.

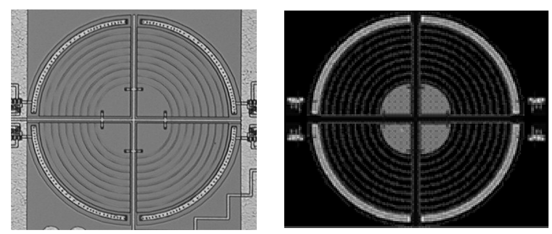
1. INTRODUCTION

Optical position-sensitive detectors (PSDs) have been used in a wide range of applications, including industrial, military, scientific and medical [1].As examples of usage we can cite laser tracking for null sensor, wavefront sensing, solar elevation measurement among others. A light spot impinges on the surface of the sensor that can detect its centroid coordinates. Some features of the sensor basic units (quad-cells) directly change its overall response, specifically influencing the PSD's resolution. The double-efficiency new approach associated with the QC's geometry result in a better response linearization and lower dark-current, thus increasing the sensor's quality in terms of resolution and lower need of post-processing circuitry on chip.

2. LAYOUT

Conventional QC employs four homogeneous photodiode and has been made with either circular or squared geometry. The new layout we propose implements a circular QC featuring a quantum efficiency η_1 in its outer region and a higher quantum efficiency η_2 in its inner region. This property is achieved by stacking a shallower p+-n junction region, confined with radius r_c from the center, on top of the baseline junction. The resulting structure is a p-n in the outer area and p+-n close to the centermost of the QC. This intends to linearize the QC response as it acts like a negative feedback adding more photocurrent in response of the smaller area of the center region. The geometry of each photodiode in the QC is that of a quarter-circle in order to reduce the effect of leakage current, reducing the dark-current proportionally [4].

We fabricated a double-efficiency QC in standard 1.6μm CMOS technology (QC radius R_{QC}= 200μm), where the main baseline junction results from p-epitaxial layer and the n-well; this junction is 2.9μm deep, which increases the photon absorption in silicon for wavelengths above 600nm, as compared to other shallower junctions available in the process. The central region has an additional p+-implant/n-well junction (radius r_c= 65μm). The structure is showed in Figure1.



(a) (b)

Fig. 1. (a) Photograph of the double-efficiency quad-cell (b) Designed quad-cell with ¼-circle pixels.

3. RESULTS

3.1. Simulation results

A numerical model of the QC allows an analysis of the unit response for different conditions such as perimeter geometry (circular or squared), the central radius (r_c), the difference of efficiency (η_1- η_2) and the spot intensity profile. The model considers photodiodes with 200μm lateral size and radially symmetrical spots.

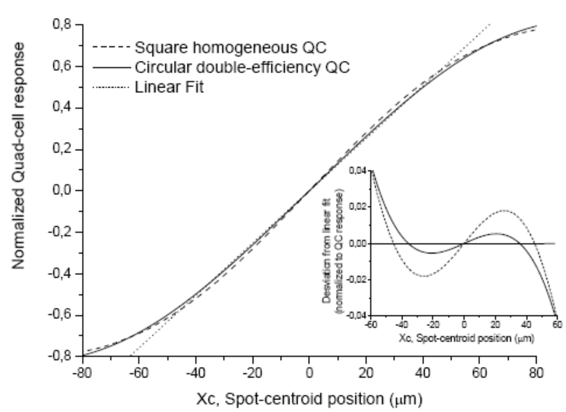


Fig. 2. Response of a square homogeneous and circular double-efficiency quad-cell as a function of the spot position. Inset: fit-error for circular cell (full line) and square cell (dashed line) when a close to sinc-spot scans its surface.

Figure 2 shows a more linearized response due to the increased efficiency of 50% in the central region. For an effective radius sinc^2 spot of 40µm, the sigmoidal response of a squared homogeneous QC is compared to the one of a circular double-efficiency QC. The standard deviation of the circular double-efficiency QC is below 0.4% in the interval [-44µm, 44µm]. This improvement is actually critical in applications where centroid coordinates must be precise. (e.g.: wavefront sensing [2]-[3]).

3.2. Experimental results

3.2.1. Response Linearization

The optical setup was mounted with a HeNe (633nm) non-polarized laser. The beam (ø=10mm) passed through a plane convex lens (f=250mm) and was aimed on the sensor. The beam diameter was estimated to be 55µm in the focal plane using the knife-edge method. The laser-power at this stage was measured 0.44µW. Motorized translation stages guarantees the sensor position. The output signal of the sensor passed through an inverting voltage amplifier (unitary gain, that acts like a buffer) and was acquired by a data acquisition board (NE6023E). A software routine controls the translation stages and processes received data.

The spot sweeps the sensor along the x direction. At the focal plane the spot effective radius is about 35µm and the correspondent double-efficiency QC response can be seen in Figure 3. In the region [-44µm, 44µm] the standard deviation from the linear fit is 0.83%.

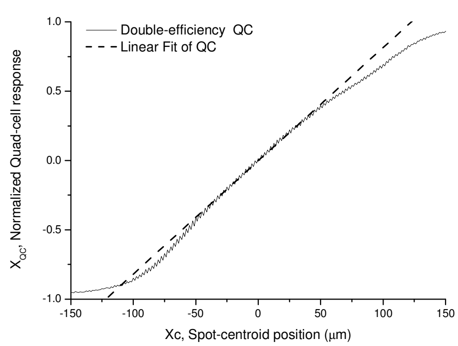


Fig. 3. Response of the active quad-cell when a close to sinc^2-spot scans its surface. SD=0.83%.

3.2.2. Dark-current

The circular QC geometry showed to be a better implementation as it reduces the leakage current, compared to the squared QC, thus reducing the dark-current. The leakage current adds noise in the photodiode response, which reduces the sensor resolution and limits its use in low light application. This noise is proportional to the leakage current square root [5, 6]. Figure 4 shows the leakage current for both circular and square QCs covered with a thin gate oxide (GOX), which contributed to achieve an external quantum efficiency of about 70%.

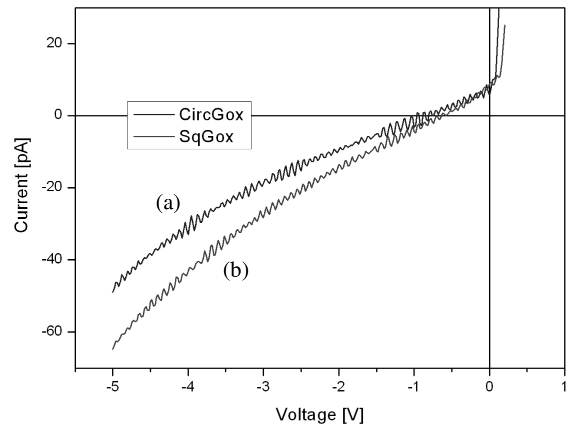


Fig. 4. Leakage current Reduction implemented for circular QC (a) when compared to square QC (b).

3. CONCLUSION

This new double-efficiency design approach showed features that are interesting to implement a good quality optical position-sensitive detector.

It showed good linearization (SD=0.83% for a 35 µm spot effective radius) which reduces the need of complex additional post-processing circuitry embedded on chip and increases position resolution.

The circular geometry was the best candidate among tested structures as its low leakage current is about 38% less than that of its square counterpart.

Therefore, lower output sensor noise is accomplished, leading to good resolution even in low-light applications.

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