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A Proof of Principle Study of a Novel Silicon based Retina Sensor for Patients with Macula Degeneration

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Abstract - Recent advances in semiconductor technology have made it possible to achieve imaging devices that can serve as bionic retinas when implanted within the human eye. Traditional concepts for bionic retina prosthesis involve implantation of a CMOS CCD array in place of the dysfunctional retina of the patient [Ref. 2]. This concept suffers from a limitation of a finite battery life, which leads to frequent replacement of batteries. Secondly, the need to bias each pixel makes the number of electrodes large enough to occupy a large portion of active area on the chip. Moreover, more number of electrodes means greater data bandwidth required for restoring vision. It is proposed to use passive devices like solid state photo-voltaic Cells, which instead of consuming external power would in fact generate signals to stimulate the nerve fibers of the optic nerve. The need for digital data processing can be circumvented as the visual information (photo-generated analog signal) is directly coupled to the ganglion fibers of the macula region. The use of silicon as sensor material makes the device sensitive to infrared wavelengths making it possible for the recipient to have good visibility even at night.

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This paper presents a detailed illustrated summary on the design aspects of the sensor, which is essentially an array of p-n junctions. It also presents a detailed overview on the device physics aspects of the proposed Solid-State (Silicon) retinal sensor. The design of this sensor was evaluated analytically through extensive physics based device simulations using a commercial Technology computer aided design (TCAD) tool.

The mask layout consisting many variants of this sensor has been designed for fabrication in BiCMOS technology. The device physics and biological compatibility aspects of the individual pixel of the sensory array have been addressed with possible solutions to be implemented in future.

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PACS: 85.60.-q , 42.66.-p

I. Introduction

Restoration of sight in the human eye is the subject of cutting-edge research worldwide. The most prevalent concept of restoration of sight for patients with corneal damage is a corneal replacement. But corneal damage is not the only malaise, which inhibits vision in patients throughout the world. Retinal dysfunction or retinopathy accounts for vision loss a significant percentage of patients. The only artificial method to help patients with retinal damage is by way of implanting a sensor in place of the retina and hard wiring the sensor to various points in the cerebral cortex. The problem with implants of electrical nature lays with the life of the power source in this case a battery. This makes it highly impractical to use when considering the implant would be sitting in the eye. The extremely delicate nature of tissue in the human eye makes the job of realizing a viable semiconductor device a very big challenge. To avoid these problems, it is proposed to use a pixilated solid state (silicon) photo-voltaic cell array [Fig. 2] having a pixel size of the order of 100 μm x 100 μm (minimum resolution of the human eye). The concept is such that the image will be focused upon the sensor array and the subsequently the individual pixels would be activated and a potential difference would be generated at the electrodes of these individual pixels and which will in turn be coupled to the ganglion fibers in the Macula Fovea region of the eye cavity. Thus establishing an electrical communication between the optic nerve and the artificial retina.

II. Sensor Design

Starting with a p-type, low resistivity (100 Ohm-cm), <111>, 300 μm thick Silicon wafer, a phosphorus implant on the front side formed the n+ field shaping electrodes (anodes/strips) whose widths in this design were 40 μm with a 30 μm interstrip gap between adjacent n+ strips (Pitch = Strip Width + Gap = 70μm) [Refer Fig. 1 (a)]. The peak phosphorus concentration in n+ anode region was approximated around 1 x 10^{20} cm^{-3} with a Gaussian distribution along depth. Next, a boron implant on the backside formed the p+ cathode region (substrate contact) having a 40μm width. The next step was to open contact windows for both n+ and p+ regions on front and backsides respectively. The last step being metal deposition and patterning for creation of electrode regions over n+ and p+ regions of the p-n junction. The complete two dimensional layout of the sensor consists of 900 pixels with a total active area of (2mm x 2mm).

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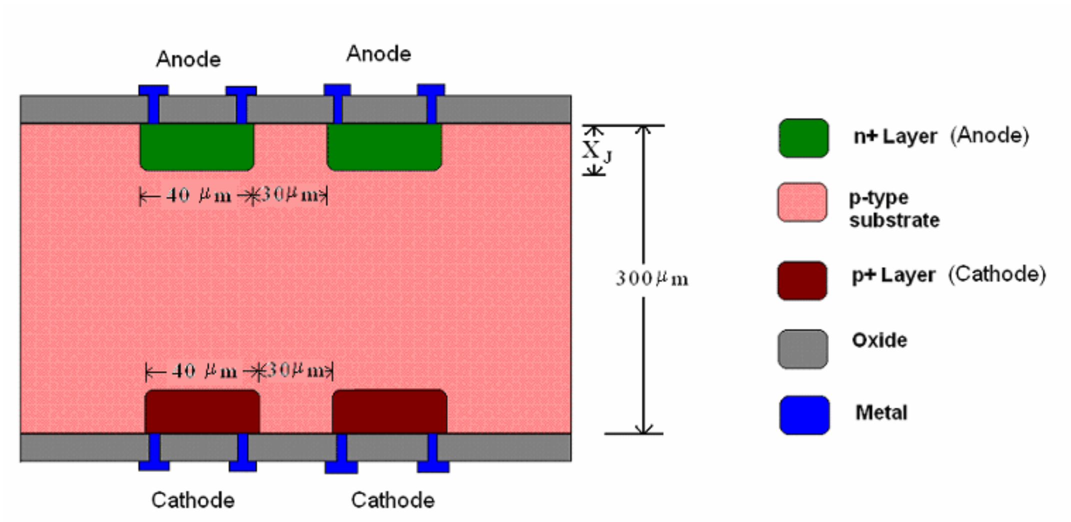

Figure 1 (a) : 2-Dimensional cross section of individual pixels of the photo-voltaic device.

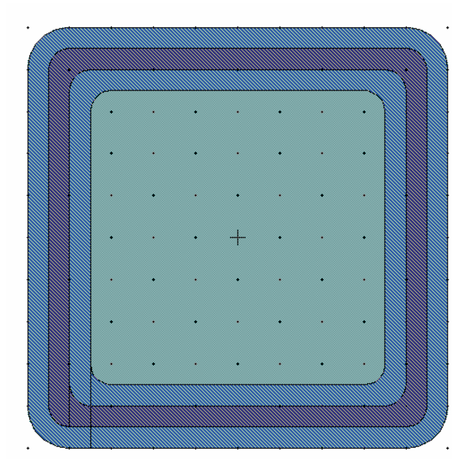

Figure 1 (b) : Composite layout of a single pixel of the retinal sensor.

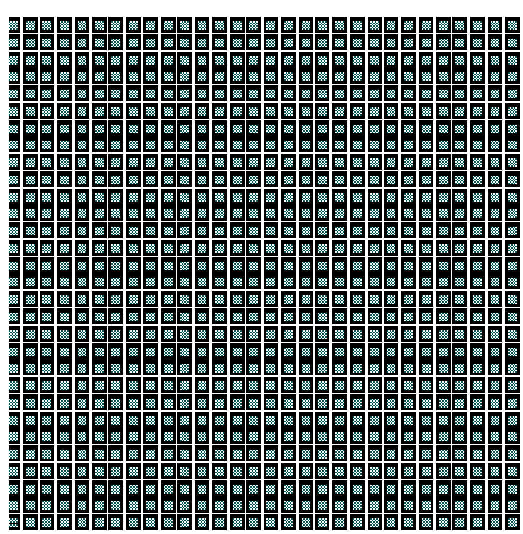

Figure 2 : Layout of the silicon photovoltaic array consisting of 900 pixels.

III. Physics Based Device Simulations

a) *Objectives and Methodology*

The hypothetical 2-dimensional cross-section was then exposed to an incident optical photon flux and wavelength was varied from 400 nm to 1.5 microns. The optical beam intensity was kept at a level equivalent to the incident normal photon intensity (10 micro-Watts) on a human eye for co-relation. Moreover, the simulation was done only for normal incidence of photons on the sensor. The simulation was performed to derive the relation between the terminal anode current (amperes / micron) with the optical photon wavelength [Fig. 3]. Additionally, the Quantum efficiency (extrinsic & Intrinsic) was also extracted for the simulated 2-D cross-section of the device.

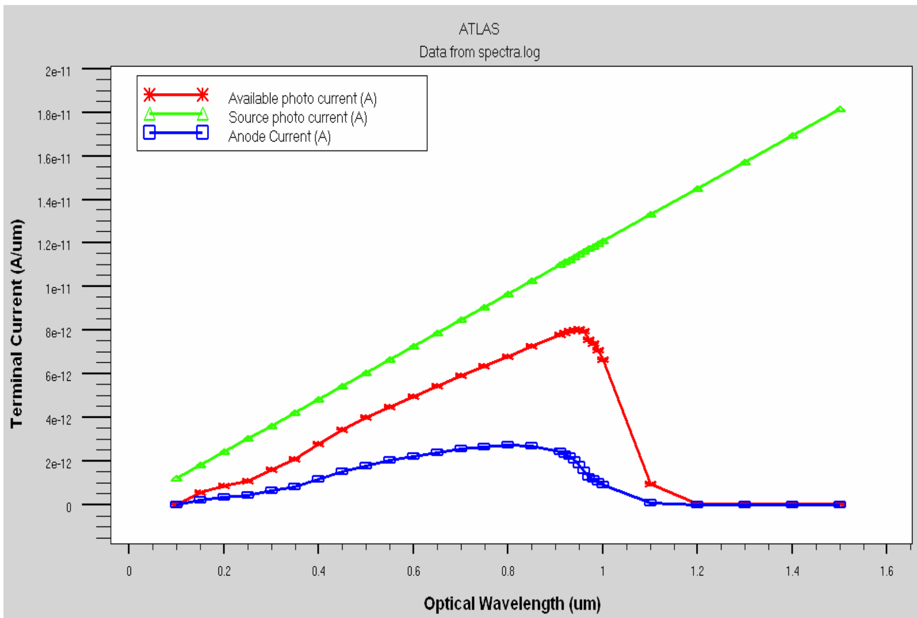

Figure 3 : Anode current versus Optical Photon wavelength.

b) *Results and Discussions*

As seen from the plot of Terminal current versus optical wavelength, the terminal current shows maxima at an optical wavelength of 900 nm. This is typical of property of the substrate material used, in this case silicon. The source photo-current which is a linear function of the wavelength increases with increase in wavelength. The available photo-current is a measure of the amount of current that would result if all the incident photons were converted to photo generated carriers in the device. The optical photonic radiation was made incident at the closest approach to the top surface of the device. Inspite of that, a significant portion photon flux was lost due to reflection from the specular silicon surface and the metal contacts. Hence this shows in the vast difference in maximum values of available photo current and the terminal current appearing at the device. The plot of quantum efficiency versus wavelength also shows a maximum at 900 nm thereby verifying the earlier results [Fig. 4]. The difference in between the extrinsic and intrinsic quantum efficiency also shows evidence of certain amount of reflection losses. These losses can be substantially minimized using Anti-Reflection Coating over the front surface of the sensor.

Alternatively, the simulation for the effect of a variation in optical beam intensity on the terminal voltage (Open circuit voltage) shows a linear increase in voltage with an increase in beam intensity [Fig. 5]. This is analogous to a similar effect of incident light on the human eye.

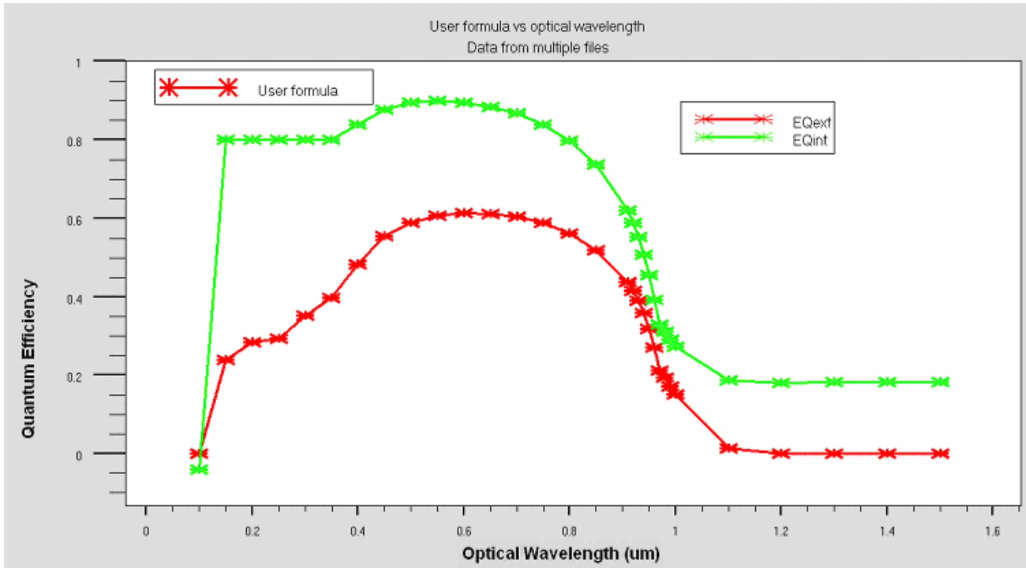

Figure 4 : Quantum Efficiency (External & Internal) versus Optical Photon wavelength.

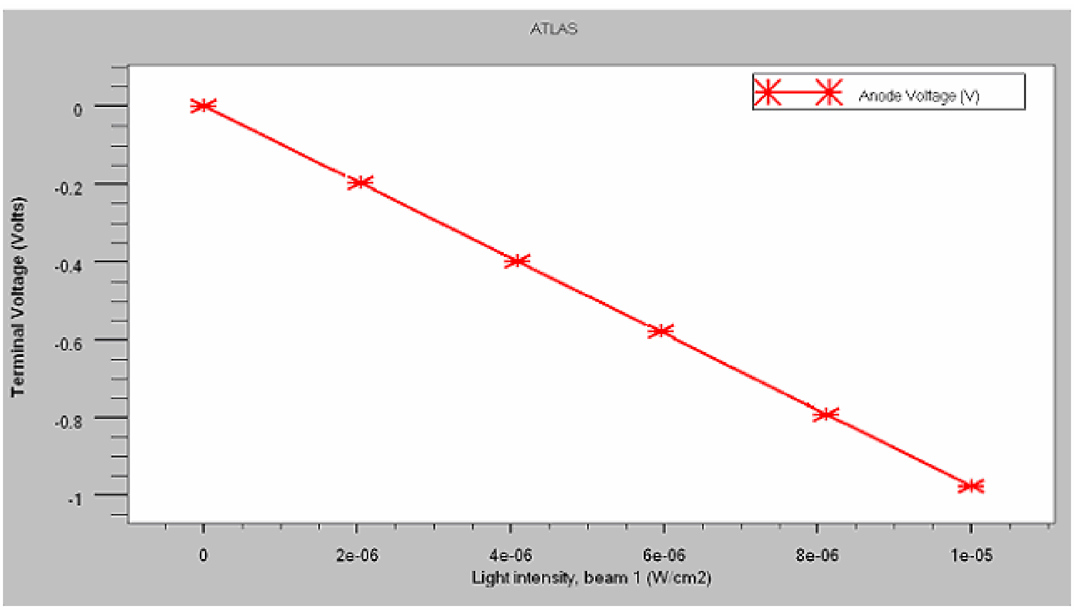

Figure 5 : Anode Voltage versus Light Beam Intensity (Watt/cm^2).

IV. Bio-Compatibility Issues

A bio-compatible conducting glue will be used to attach the sensor over the damaged retina in the Macula Fovea region (Fig. 6). The glue layer will be patterned by photo lithography such that the glue only remains in the region over the electrode surface and nowhere else. Before attachment of the sensor certain bio-compatibility issues need to be addressed. Firstly, the problem of damage to the inner walls of the eye caused by sharp edges of the scribed sensor die needs utmost attention. This problem can be subverted by introduction of a bio-compatible polymer over the side-wall regions along the thickness region of the sensor die. Secondly, the problem of dead volume occurring due to the curved nature of inner wall of the eye and planar nature of the silicon die. This problem may lead to improper electrical contact between the ganglion fibers in the macula and the sensor. This problem can only be subverted by designing solar cell based sensors over polymer substrates employing an organic electronics regime.

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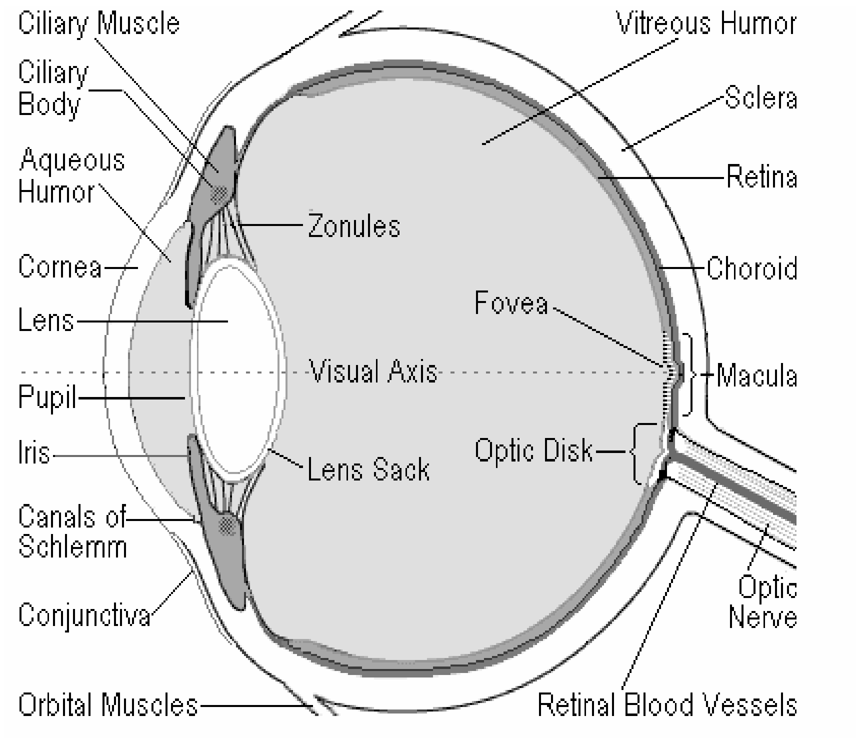

Figure 6 : Lateral cross-section of the human eye.

V. Conclusions

The retinal sensor array has been designed for fabrication in BiCMOS technology. A thorough device physics based analytical study has been carried out to extract terminal electrical parameters of the individual pixel in the array. Biological compatibility issues relating to the implantation of the silicon sensor in the human have also been addressed. The forthcoming stages are the actual fabrication and electrical (dc & optical) characterization of the sensor array.

VI. Acknowledgements

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