Design for MOSIS Educational Program (Research)

BBIC #2 (T3CW-AK):

Project Title

Fully Integrated Bioluminescent Bioreporter Integrated Circuit (BBIC) for Photodetection

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Introduction:

Bioluminescent Bioreporters are bacteria that can be genetically engineered to achieve bioluminescence when in contact with a targeted substance. The bioluminescent bioreporter integrated circuit (BBIC) concept is shown in Figure 1. The bioreporters are placed on a CMOS integrated circuit (IC) that detects bioluminescence and performs signal processing to get the sensor data digitally. The BBIC is housed in a rugged inexpensive package as shown in Figure 1 and can be used in many remote applications in hazardous environment [1,2].

The current design is fully integrated. In this work the photodiode unit is not padded out for field destruction. So there will not be any noise source to distort the detected signal. The concept of System-on-Chip is applicable here. So we get high resolution in the detection process. The proposed work involves analysis, design, fabrication and testing of the microluminometer for use in electronic/biological chemical sensor known as Bioluminescent Bioreporter Integrated Circuit (BBIC).

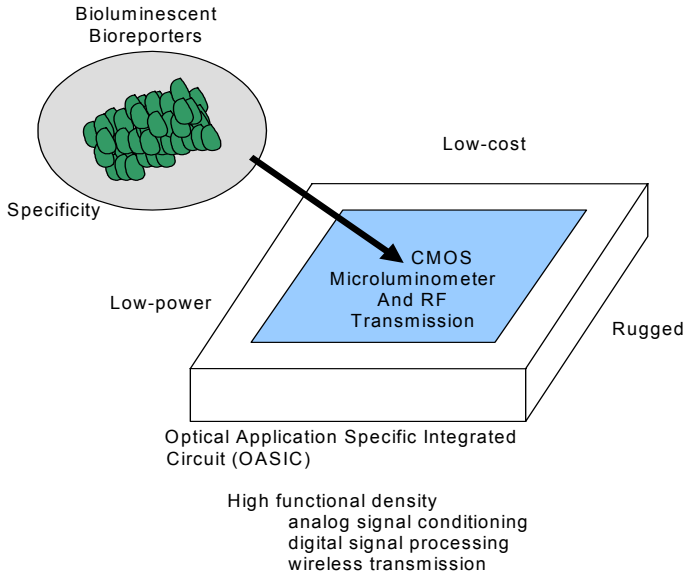

Fig 1: BBIC system shows the integrated circuit with a photodetector

Project Description:

The basic operation of the microluminometer includes photodetection and analog-to-digital transmission. The genetically engineered bioreporters produce bioluminescence when in contact with a targeted substance. The amount of light generated by bioluminescence is proportional to the concentration of the analyte of interest. The light is absorbed by a photodiode array on the device resulting in the generation of photocurrent, which is proportional to the intensity of light. The signal-processing portion of the microluminometer should filter the luminescent signal from photodetection noise, digitize this signal, and prepare it for transmission. The idea is to be able to detect

very small optical signal, which is proportional to the concentration of the targeted substance. Therefore the system should introduce as little error as possible into the measurement to allow for minimum light detection [4]. Incident light on the photodetector produces a current that is collected (integrated) on the feedback capacitor of the integrator. The photo current is converted to a digital signal by an analog-to-frequency converter circuit. The block diagram and simulated results are shown in Figure 1 and Figure 2, respectively. The chip is designed for **TSMC 0.35µm** process and the size of the chip was of the tiny chip format [**2.25 sq mm (1.5mmx1.5mm)].**

Design and Simulation:

The initial design and simulation have been performed using Smart-Spice (Figure 2). After that Cadence Schematic Composer was used to get the Schematic and to run the Simulation in Spectre. The design has also been laid out using Cadence tools. In Cadence Design environment, a Design Rules Check (DRC) and a Layout versus Schematic (LVS) have been performed to ensure that everything is in order. For simulation purpose an ideal current source was used instead of the on-chip photodiode. Post layout simulation was also carried out and the simulation results match the expected results.

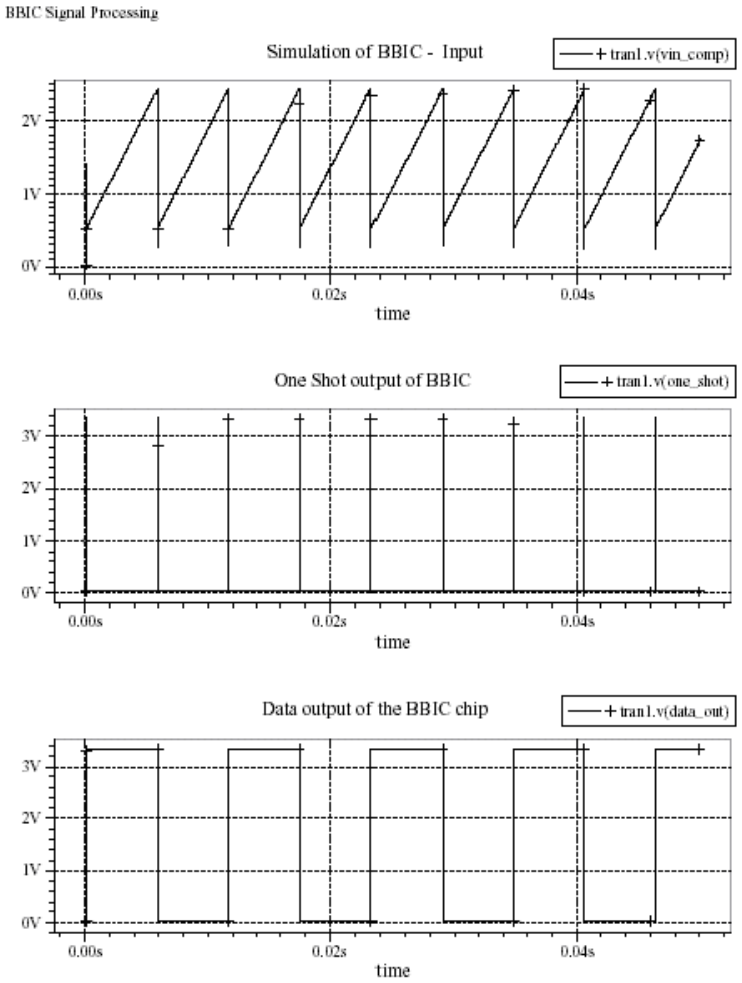

Fig 2: Smart-spice simulation of top level BBIC chip

Test & Characterization:

The chip was tested at the Analog VLSI and Devices Laboratory and the Center for Environmental Biotechnology (CEB) Laboratory at the University of Tennessee. Several test methods have been considered. We used encapsulated bioreporters using a package developed at the UTCEB for optical testing of the chip.

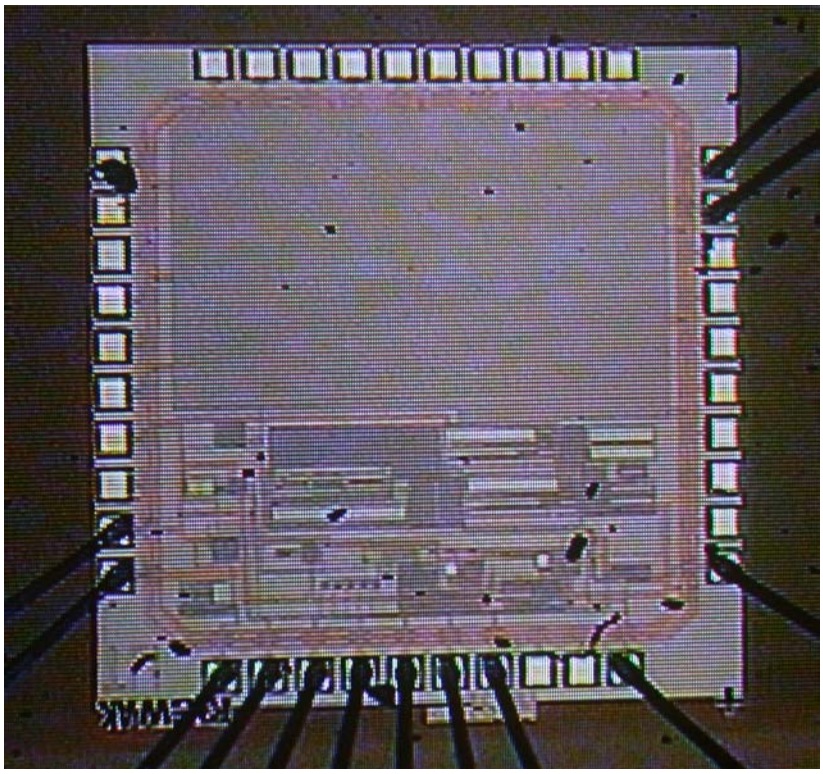

Fig 3: Optical image of fabricated chip (T3CW-AK)

In T3CW-AK (integrated BBIC) chip the integrator's inputs and output are not padded out. So the noise introduced by the capacitors at those ports is eliminated, which makes the integrated version more reliable. Leakage current was measured using this chip by testing the DFF's output period with no incident light. The result was about 50fA, which is shown in Figure 4. Quantum efficiency of photodiode was measured by comparing the BBIC photocurrent with commercial photodiodes, with the same light input. The Q.E. is about 55% with 490nm input light, which is shown in Figure 5.

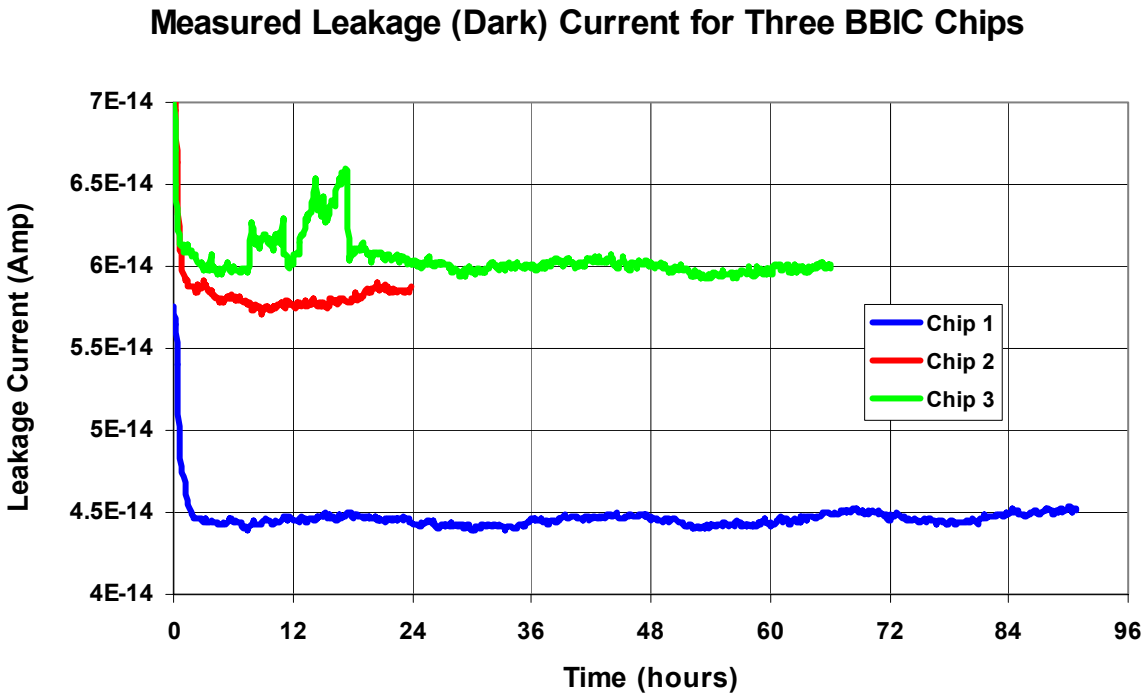

Fig 4: Leakage current measurement of T3CW-AK (integrated) chip

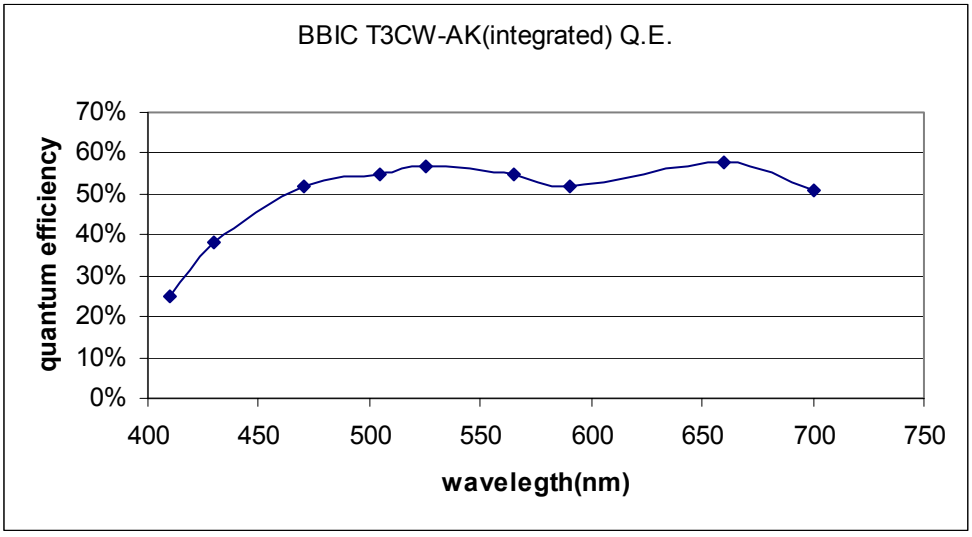

Fig 5: Quantum efficiency measurement of T3CW-AK

References:

[1] M. L. Simpson, G.S. Sayler, S. Ripp, D.E. Nivens, B.M. Applegate, M.J. Paulus, and G.E. Jellison Jr. “Bioluminescent-Bioreporter Integrated Circuits Form Novel Whole-Cell Biosensor”. Trends in Biotechnology, Vol.16, pp. 332-338, August 1998.

[2] Simpson, M. L., G. S. Sayler, J. T. Fleming, and B. A. Applegate. "Whole-cell biocomputing: engineering the information processing functionality of cells". Trends in Biotechnology 19(8), August 2001, 317-323

[3] Mo Zhang, “A Low Power Cmos Microluminometer And Transmitter For Bioluminescent Bioreporter Integrated Circuit (BBIC) ”, Master thesis, April 2003

[4] Simpson, M. L., G. S. Sayler, G. Patterson, D. Nivens, E. K. Bolton, J. M. Rochelle, J. C. Arnott, B. M. Applegate, S. Ripp, and M. A. Guillorn. "An integrated CMOS Microluminometer for low-level luminescence sensing in the bioluminescent bioreporter integrated circuit", Sens. and Act. B 72(2), Jan. 2001, 135-141.