A Design of CMOS On-Chip Photovoltaic Device and Regulated DC-DC Converter for Micro System

Haruki ONO
Electronics and Electoronical Engineering
Keio University
Yokohama City, JP 223-8522
haruki@nak.elec.keio.ac.jp

Kazuki Nomura
Electronics and Electoronical Engineering
Keio University
Yokohama City, JP 223-8522
nomura@nak.elec.keio.ac.jp

Nobuhiko NAKANO
Electronics and Electoronical Engineering
Keio University
Yokohama City, JP 223-8522
nak@elec.keio.ac.jp

Abstract - In this paper, we propose an electric power system for a stand-alone micro system. The micro system consists of photovoltaic device, voltage boost, ring oscillator, and regulator on a single silicon chip. We designed and measured several types of photovoltaic devices. The maximum output voltage of photovoltaic device is 550mV. The bootstrap charge pump circuit and regulator are designed for this power supply. This power supply outputs more than 1V. It is enough voltage for standard CMOS circuit.

I. Introduction

Recently wireless sensor system has been developed [1]. A stand-alone micro system which behaves without external power supply is needed by the sensor system and the implantable medical device. Hence the stand-alone system fulfills power supply, voltage conversion and application to execute on a chip, it does not need to be connected to discrete components and even leave the possibility of saving the packaging[2]. The standard CMOS process involves pn junction that is able to work as photovoltaic device. The combination of on chip photovoltaic device and circuits has a great potential for stand-alone micro system.

We proposed an electric power supply for the stand-alone system. A photovoltaic device which can be constructed by standard 0.18 μm CMOS technology are chosen for power generation of the micro system. The output voltage is typically 400mV to 550mV per single cell and the output current is determined by the area and amount of light. Under sunlight, 1 mm^2 photovoltaic device generates several tens of μW typically [3]. However, the several hundreds of mV output is not enough to operate standard CMOS circuit. Therefore, boost voltage DC-DC converter is required. The photovoltaic devices output power is boosted by DC-DC and regulated for general CMOS circuit.

II. On chip power system

As noted previously, this power supply is consisted by photovoltaic device, DC-DC convertor and regulator. Fig.1 shows the block diagram of the photovoltaic power supply that we propose. The solar cell develops little power in series

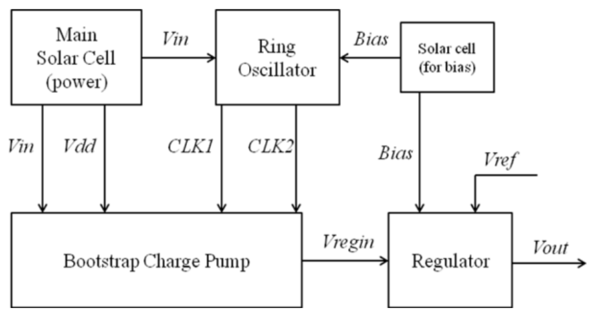

Fig. 1 Whole block diagram

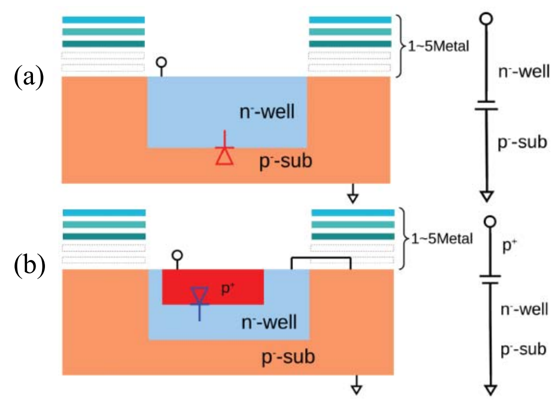

Fig. 2 Cross view of $n^- p^-$ structure (a) and p^+n^- structure (b) on-chip photovoltaic device

to get high voltage. In our whole block diagram, there are two solar cells. The main solar cell is for the power supply and the four series-connected solar cells are used to improve the voltage conversion ratio by regulating the oscillation frequency. A bootstrap charge pump to boost up the input voltage from main cell are involved. A Regulator to regulate output voltage from bootstrap charge pump is also designed.

A. Photovoltaic devices

We designed several types of on chip photovoltaic devices. Here we introduce the two single type of structure of photovoltaic devices. Those structures are n^-p^- single cell structure and p^+n^- single cell structure. Fig.2 shows cross-section views of each structure photovoltaic cell [3].

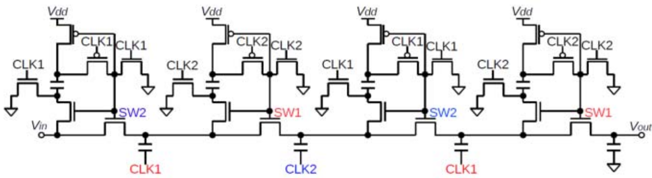

Fig.3 3 stages bootstrap charge pump circuit

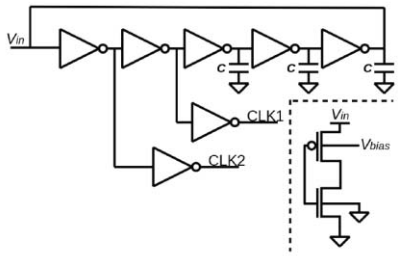

Fig.4 Ring oscillator circuit

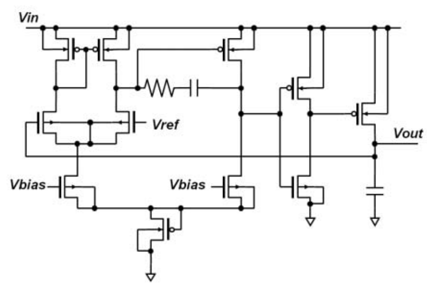

Fig.5 Regulator circuit

N^-p^- structure (Fig.2-a), the n-well is formed upon a silicon substrate. It is the simplest way to design pn junction. However, p terminal connected to the ground, output from n terminal turns to negative potential. P^+n^- structure (Fig.2-b), the n-well is formed upon the p^- silicon substrate and p^+ area is formed on the n-well. This structure causes the positive voltage to the p^+ substrate. That is suitable for normal CMOS circuit operation.

B. Circuit Design

For boosting output voltage of photovoltaic device, we designed DC-DC boosting converter. This converter is consisted by bootstrap charge pump, ring oscillator and regulator circuit. Fig.3 shows circuit schematic of the 3 stages bootstrap charge pump [4]. The ideal output voltage of the n stage bootstrap charge pump could be calculated as follows.

$$V_{out} = V_{in} + V_{clk} \times (n-1) \quad (1)$$

where V_{clk} is the peak voltage of the clock waveform. To get the appropriate conversion ratio, 3 stages bootstrap charge pump were designed. Fig.4 shows schematic of the ring oscillator (RO) circuit. The RO block is ingenerate clock signal for charge pumps. Fig.5 shows schematic of circuit the regulator. The output voltage of photovoltaic device would be variable by solar light to cell. Hence boosted output power is regulated by regulator. A comparator operates the pmos switch, the output (V_{refin}) is adjusted to reference voltage.

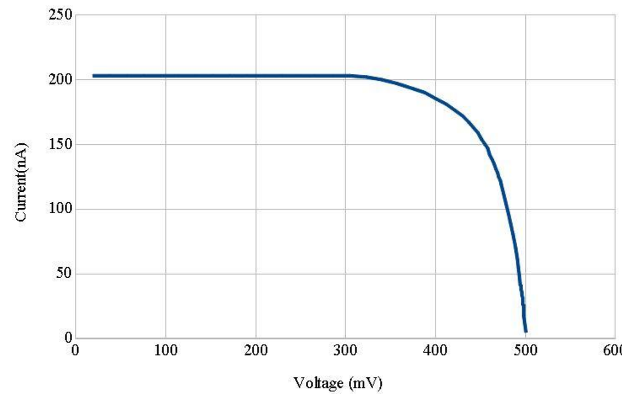

Fig.6 Voltage-current current characteristics model of the on-chip solar cell reflecting the experimental result at 100 μm × 100 μm, 7600lux

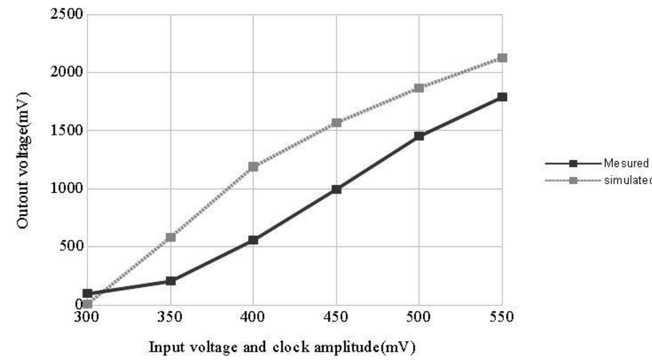

Fig.7 Measured and Assumed input output characteristics of the 3 stages bootstrap charge pump at 100kHz frequency clock signal, 60MΩ load

III. Experimental results

We measured the voltage n^-p^- photovoltaic device to model the equivalent circuit. Fig.6 is the comparison between the experimental results and the behavior of the simulation model. The output current was constant in between 0 to 320 mV output voltage. During this region, the solar cell behaves likes a current source.

Next, we discuss about each circuit elements in the supply circuit. The operation of the bootstrap charge pump was verified by external clock signal. The 3 stage bootstrap charge pump supplied clock signal of 100 kHz frequency pulse wave equipment demonstrated and assumed the output as Fig.7. At the input voltage of 500mV, it outputted the voltage above 1V. The gap between simulated and measured output voltage is caused by the difference of V_{th} and I_{ds} at subthreshold region between spice model and practical device.

IV. Conclusion

We proposed a photovoltaic power supply for a stand-alone micro system. This power supply circuit consists of solar cell, bootstrap charge pump, oscillator and regulator. All of them are designed in 0.18 μm standard CMOS technology. Several

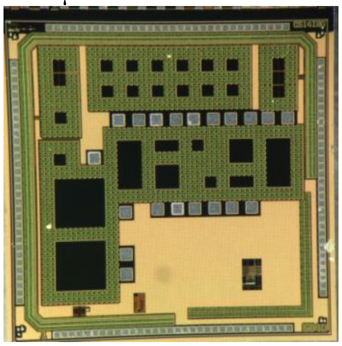

Fig.8 Designed different structures of on-chip photovoltaic device

structures of on-chip photovoltaic device have been designed and measured (Fig.8). The operation of 3 stage bootstrap charge pump was verified by external clock signal. In this study, we have greatly approached to develop stand-alone micro system.

Acknowledgements

The VLSI chip in this study has been fabricated in the chip fabrication program of VLSI Design and Education Center (VDEC), the University of Tokyo in collaboration with Rohm Corporation and Toppan Printing Corporation.

References

[1] Shunfeng Cheng, "A Wireless Sensor System for Prognostics and Health Management", IEEE SENSORS JOURNAL, VOL. 10, NO. 4, APRIL 2010, pp.856-862

[2] Jay Taneja, "Design, Modeling, and Capacity Planning for Micro-Solar Power Sensor Networks", International Conference on Information Processing in Sensor Networks, April 22-24, 2008, pp. 407-418.

[3] H, Yongtai, "Design of solar photovoltaic micropower supply for application of wireless sensor nodes in complex illumination environments", Wireless Sensor Systems, Vol. 2, Issue. 1, March, 2012, pp. 16-21.

[4] Wenming Yang, "Design, Fabrication, and Testing of a Prototype Microthermophotovoltaic System", Microelectromechanical Systems, VOL. 13, Issue. 5, Oct, 2004, pp. 851-856.

[5] Anna Richelli, "A 0.2-1.2 V DC/DC Boost Converter for Power Harvesting Applications" IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 24, NO. 6, JUNE 2009, pp.1541-1545.