Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 586-587

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Active Pixel Sensor Using an SOI MOSFET Photodetector with a Quantum Wire

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1. Introduction

Recently there has been a great interest in CMOS image sensors in the field of digital imagers. The main reason for this is an increased customer demand for miniaturized, low-powered, and cost-effective imaging systems [1]. But CMOS image sensors have some disadvantages and representative one is non-optimized photodetectors. By this reason, there are many on-going researches to improve the performance of photodetectors [2], [3], [5]. Meanwhile, to overcome restrictions of the conventional devices, the low-dimensional devices that utilize quantum phenomena such as quantized conductance have been studied widely [4]. These quantum devices can be used not only in VLSI systems, but also as optical devices [5], [6].

In this research, an SOI NMOSFET with a quantum wire as a photodetector is proposed and its optical responses were measured. In addition, this photodetector is applied to a voltage-gained CMOS active pixel sensor (APS) which is designed and fabricated using a standard 1.5μm CMOS process.

2. Experiments

A. SOI NMOSFET photodetector with a quantum wire

The proposed photodetector, SOI NMOSFET with nano-scaled channel width, was fabricated on p-type SOI (100) wafer. The silicon nano-wire is patterned by mix-and-match method which used both conventional optical lithography and electron beam lithography, and then thermal oxidation was performed at 900℃ in order to obtain narrower wire. Most processes, except above steps, are similar to a standard NMOS technologies. As a result, 30nm wide silicon wires could be obtained. A photograph of the fabricated SOI NMOSFET and a SEM image of the finally obtained silicon wire are shown in Fig. 1.

B. CMOS active pixel sensor

A schematic and a layout of the designed unit pixel are shown in Fig. 2. Generally, an APS has a source follower output stage. But, in this work, an APS with a common source output stage was designed to obtain a proper voltage gain. The designed unit pixel consists of 4 NMOSFETs.

3. Results and Discussion

An I_{DS}-V_{DS} curve of the proposed photodetector which is measured under the common drain mode with different illumination level instead of the gate voltage, fixed on –100mV, is shown in Fig. 3. A light source used in this experiment was a halogen lamp and the optical power in a legend was measured at 600nm of wavelength. As shown in the figure, incident light power acts as a gate bias. The operational principle of the photodetector is as follows [3]. A built-in field induced by the n^+-poly-silicon gate and the p-silicon substrate separates photo-generated electron-hole pairs. The electrons drift toward the channel and are swept to the drain. The holes, on the other hand, effectively accumulate in the body because of higher potential barrier than the electrons [3]. This is similar to a hetero-junction transistor [5]. As light power which is equivalent to gate bias varies, a conductance quantization is expected at low temperature [4]. If a narrower wire was fabricated, the conductance quantization effect could be observed at room temperature.

A transient response of the photodetector was measured with an external 1MΩ resistor for a He-Ne laser (λ=633nm). This is related to the hole accumulation and removal in the body. As shown in Fig. 4, the rise time is about 80μs and the falling time is about 90μs. It is enough to apply to image acquisition systems with television resolution at 30 frames per second [1].

The proposed APS is completed by wire connection of the designed unit pixel which has a voltage gain of 1.3 and the new photodetector. A measured waveform at the integration node of the designed APS, according to incident light power, is shown in Fig. 5. A light source used in this experiment was halogen lamp and the optical power was measured at λ=600nm. It could be confirmed that the stronger light is illuminated, the more charge-up is occurred. Thus, it is possible that the output in proportional to the light power is obtained.

4. Conclusions

A new photodetector using an SOI NMOSFET with a quantum wire has been presented. The photodetector has good optical characteristics with photocurrent of several nano- amperes and optical transition time about 80μs. Also, a CMOS APS wire-connected with the photodetector has been studied. The sensor exhibits well-defined and highly sensitive characteristics as the incident light power varies. Consequently, it might be possible for this sensor to be applied to digital imager operating at several-ten frames per second.

Acknowledgements

This research was supported by Korea Electronics Technology Institute(KETI).

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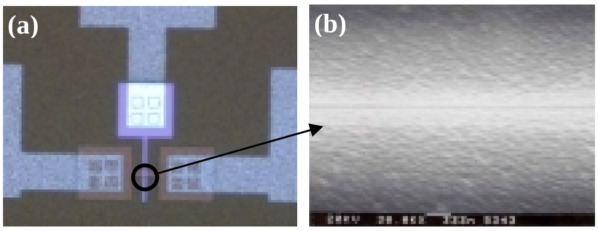

Fig. 1 (a) Photograph of the SOI NMOSFET and (b) SEM image of the silicon nano wire.

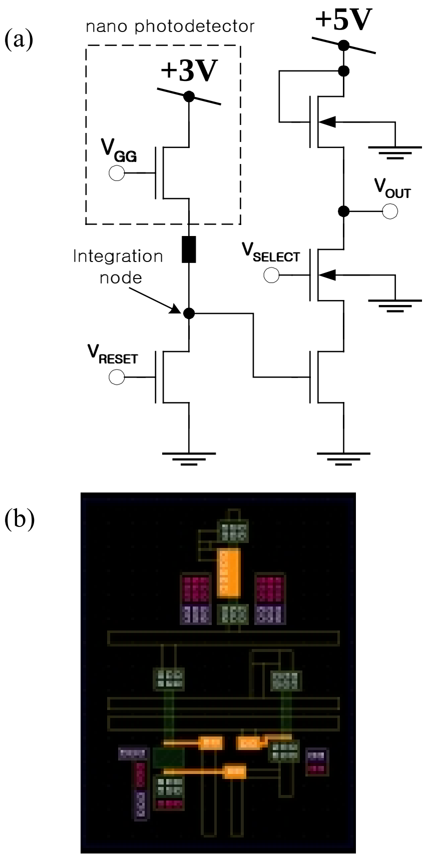

Fig. 2. (a) Schematic and (b) layout of the designed unit pixel.

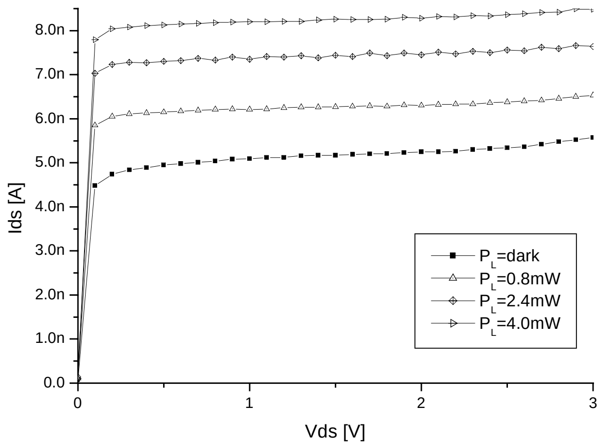

Fig. 3. I_{DS}-V_{DS} curve of the photodetector as a function of the incident light power instead of the gate voltage.

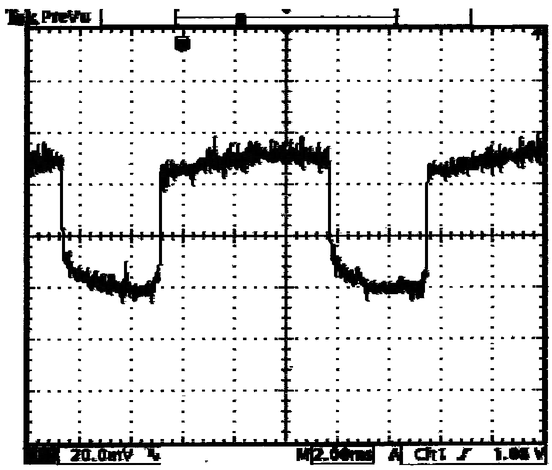

Fig. 4. Transient response of the photodetector for λ=633nm.

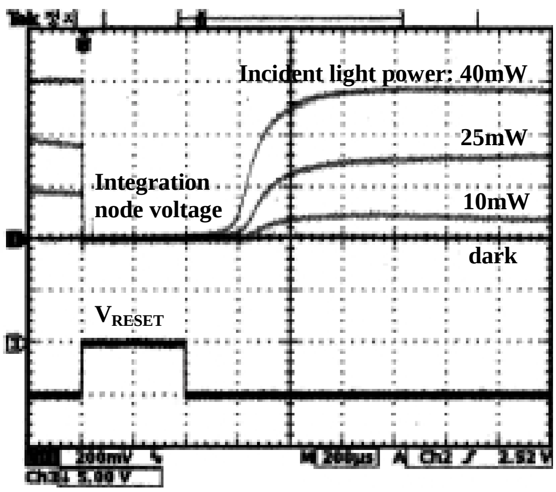

Fig. 5. Waveform at the integration node of the completed active pixel sensor as the incident light power varies.