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An Optical/Potential/Voltammetric Multifunctional CMOS Image Sensor for On-chip Biomolecular/Neural Sensing Applications

T. Tokuda, I. Kadowaki, K. Kagawa, M. Nunoshita, and J. Ohta
Graduate School of Materials Science, Nara Institute of Science and Technology
Takayama 8916-5, Ikoma, Nara, 630-0101, Japan.
Phone: +81-743-72-6054 E-mail: tokuda@ms.naist.jp

1. Introduction

In the last decade, on-chip bio-sensing and bio-assay technologies using LSI-based intelligent sensors have been attracting a lot of interests and expectations. Measuring bioscientific targets (DNAs, proteins, neural cells, etc.) with on-chip configurations, there are three major approaches to take. One is optical sensing (imaging) [1], another is potential sensing with capacitively coupled electrodes [2], and the other is voltammetric analysis with conductive electrodes [3]. In the present work, we designed a novel image sensor with all the three sensing functions. We designed an optical/electric dual-sensing pixel and columnar circuitry to achieve the optical/potential/voltammetric triple imaging functions.

2. Design of optical/potential/voltammetric multifunctional CMOS image sensor

We designed the sensor with 0.35μm 2-poly, 4-metals standard CMOS technology. Fig. 1 shows schematic and layout of the optical/electric dual-sensing pixel designed for the multifunctional CMOS image sensor. The size of the pixel was 7.5μm x 7.5μm, and the pixel number was 320 x 240 (QVGA). The pixel consists of a photodiode (PD), a sensing electrode and reset (M_1, M_4), amplifier (M_2, M_5), and select (M_3, M_6) transistors for PD and electrode, respectively. Since the pixel was designed with parallel output configuration, the optical and electric sensing functions can be simultaneously operated.

The PD with a size of 10.8μm^2 was formed with N-well/P-sub structure. The circuitry of the optical sensing part of the pixel is a standard 3-Transistor active pixel sensor (APS) [4].

In the electric sensing part of the pixel, the sensing node (cathode) of the PD in APS was replaced with the sensing electrode. The sensing electrode with a size of 38μm^2 was formed with the top metal layer. As fabricated, the sensing electrode is covered with passivation layers of the standard LSI structure. The sensor is used as a capacitively-coupled on-chip potential image sensor.

The sensing electrode has a reset transistor (M_4). Without the reset transistor for the electrode, the potential sensing function suffers from residual charge in the electrodes as large offset in pixel characteristic [5]. The reset line for the electrode is also used to establish a current path in voltammetric imaging function.

Fig. 2 shows schematic of columnar circuitry of the sensor. The columnar circuitry consists of two sets of a columnar load unit and a pmos source follower for optical and electric columnar signal lines, respectively. Each load unit has both nmos and pmos loads. Switching the applied voltage on pixel (**PixelPower** in Fig. 1(a)), and biasing pmos and nmos loads appropriately, the pixel amplifier transistor (M_2, M_5) can be operated in both source follower and common source mode.

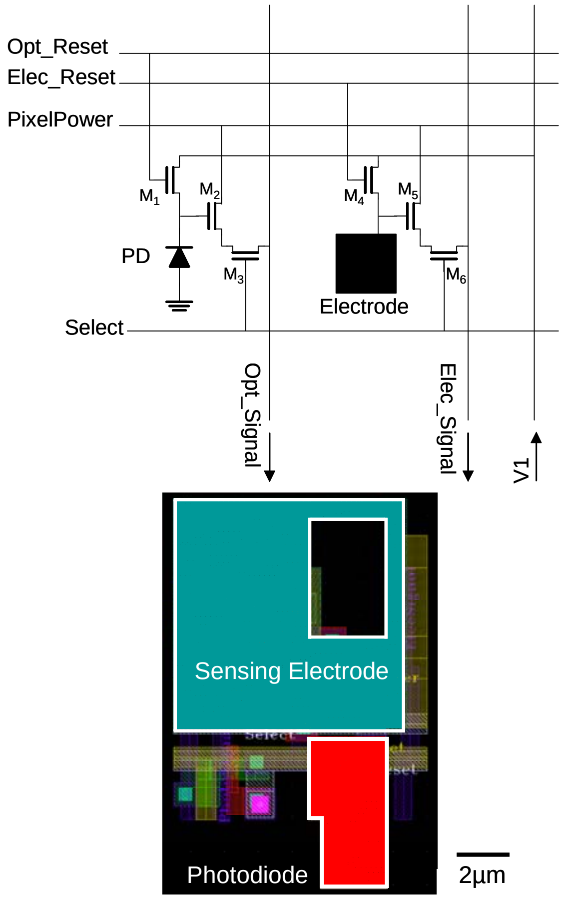

Fig. 1 (a)Schematic, and (b) layout of the optical/electric dual-sensing functions

To implement the voltammetric function on the sensor, not only voltage sensing path, but also a current supply path and current sensing circuitry are necessary. As noticed previously, the current path between the columnar circuitry and pixel is established with the reset line. In order to use the sensing electrode for voltammetric measurement, a voltage follower with resistance feedback is configured in each column. The current injected through the sensing electrode into measured object is estimated from a difference between input and output voltages of the sensing amplifier.

As shown in Fig.2, the sensor has four output channels for (1) PD level, (2) electrode potential, (3) input monitor

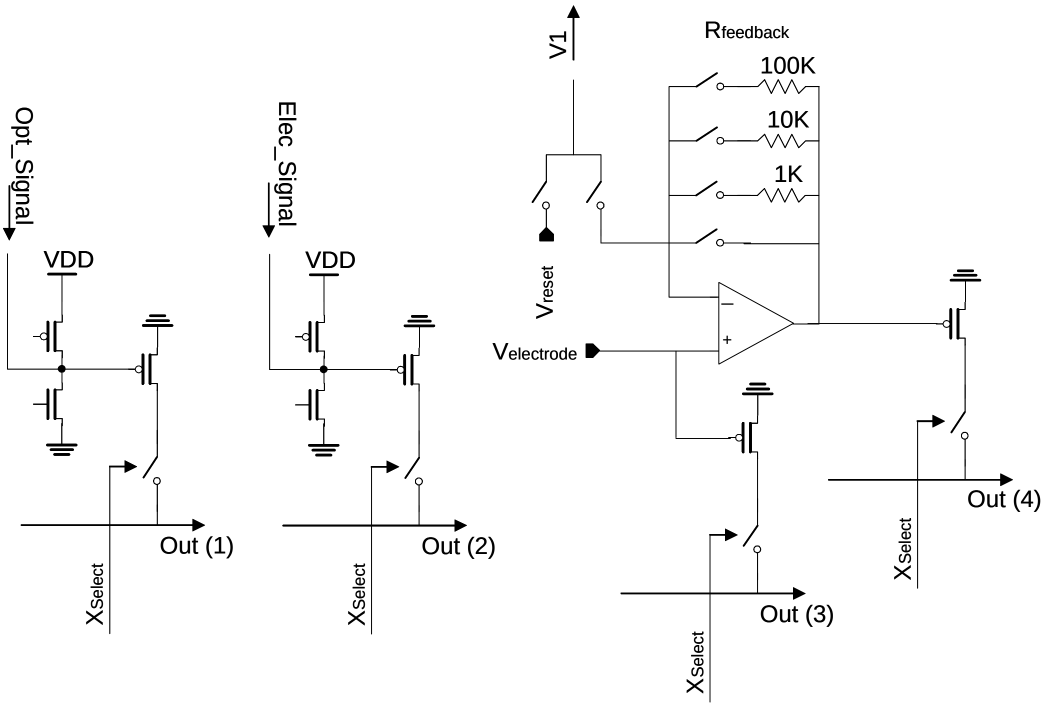

Fig. 2: Schematic of columnar circuitry of the optical / potential / voltammetric image sensor

for the amplifier, and (4) output of the amplifier. The 4-channel configuration enables to simultaneously operate the optical and electric imaging function. Furthermore, in voltammetric imaging operation, the potential of the electrode can be monitored via the output channel (3). The voltage difference between columnar circuit and sensing electrode due to the parasitic resistances in columnar **V1** line and transistors can be compensated owing to this feature.

3. Characteristics of the sensor circuitry

We have characterized the basic characteristics of the individual sensing functions of the sensor using TEG and image sensors with reduced functions that are compatible with the present design. Fig. 3 shows a sensing characteristic in capacitively-coupled potential sensing mode. We have succeeded to sense the on-chip potential in a voltage range wider than 5V. The potential sensing range wider than the operational voltage of the sensor (3.3V) is attributed to the measurement method. Fig. 4 shows the sensing characteristic of the amplifier unit for voltammetric sensing. It was confirmed that shows that the voltage-controlled current sensing circuitry implemented in the column can sense the current in a range wider than 100nA - 50μA (Fig. 3(b)). The imaging functions with the present sensor will be presented at the conference, too

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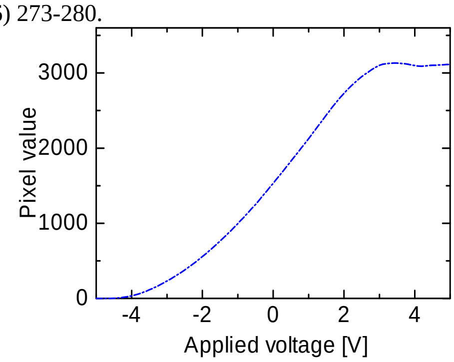

Fig. 3: Sensing characteristic of the electric sensing function in capacitive-coupled operation.

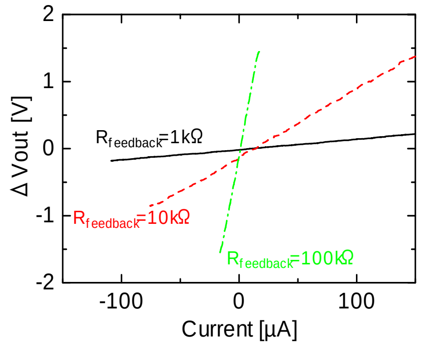

Fig. 4: Current sensing characteristic of the columnar amplifier unit for voltametric imaging.