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A novel fused sensor for photo- and ion-sensing

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Abstract

A novel sensor device, comprising of fused photo-sensors and ion-sensors, is proposed. We describe how a prototype device was successfully fabricated using a CMOS process. In the proposed device, a photo-sensor and an ion-sensor are fused in the same pixel, enabling the photo-signal and the ion concentration density to be detected simultaneously in the same sensing area. Therefore, the relationship between light distribution and ion distribution can be clarified by using this novel sensor array. The dependence of the photo-sensing region on the power of the input-light was measured. It was found that the output signal is proportional to the input-light power, and is not influenced by the pH value of the solution. The dependence of the output signal on the pH was also investigated, and it was found that it was not influenced by the light intensity.

Keywords: Ion-sensor; Photo sensor; Sensor fusion; ISFET; CCD

1. Introduction

The field of sensor fusion has been receiving much attention recently, because sensing capability has been shown to be improved by combining sensors. Two of the most useful tools that are available in chemical analysis are the detection of fluorescence from a chemical reaction (for example, DNA chips), and the measurement of changes in the concentration of ions (for example ISFETs). If sensors could be built that could simultaneously obtain information about fluorescence intensity and ion concentration in the same sensing area, then highly sensitive and multi-functional chemical sensors would have been realized. Moreover, it is easy to identify a suitable chemical reaction that could be used to fabricate a sensing array. The literature includes publications covering chemical imaging methodologies using a laser-scanning technique [1]. We have previously proposed chemical imaging sensors to measure pH values using a charge couple device (CCD) [2]. Moreover, the sensitivity to pH could be increased by the charge accumulation process inherent in the CCD technique [3]. In this paper, we propose a novel sensor structure in which we fused together a photo-sensor and an ion-sensor.

2. Device structure

2.1. Pixel structure

Fig. 1 shows a schematic diagram of the proposed fused sensors. Since the sensing regions of the photo-sensor and the ion-sensor are common (as shown in this figure) information regarding fluorescence and ion concentration can be obtained from the same region by using a chemical reaction. The sensing region of the proposed device consists of layers of Si_3N_4 and SiO_2 on a p-type Si substrate. The structure of the sensing region is almost the same as the gate electrode of an ISFET. Photo-signals are detected in the sensing region, and electrons generated in the depletion region below the sensor are integrated in the FD (photo) region. The principle of the sensor is based on photo-gate-type photo-detectors. The depth of the surface potential in the sensing region (corresponding to the ion concentration) is measured and converted to a charge using the CCD technique [3], and these signals are

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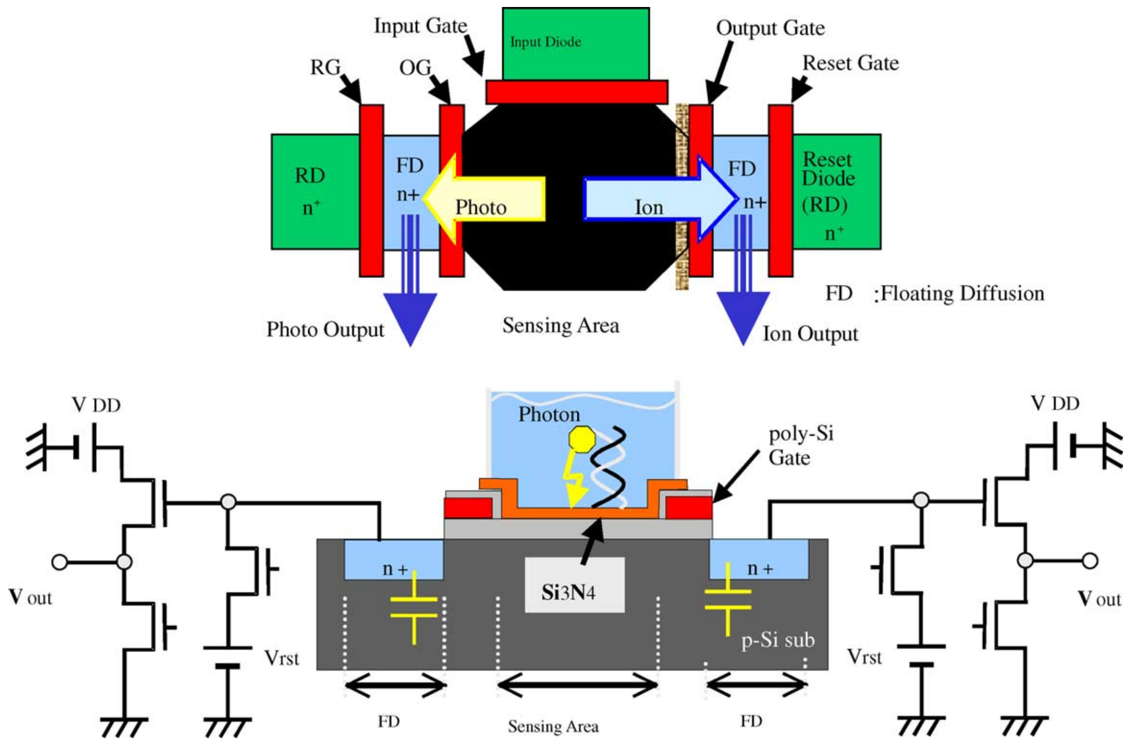

Fig. 1. The concept and a schematic diagram of the proposed fused sensors.

then transferred to the FD (ion) region. The potential of the FD region is changed by these signals, and can then be read by source–follower circuits. The principles used to convert the ion-signal to a specific charge and the basic operations involved are explained below. The photo-signal and the ion-signals are read out by the individual source followers.

2.2. Ion sensing

The ISFET is one of the most useful ion-sensors, but the output signals from the proposed ion-sensor are different from those produced by an ISFET. The output signal from the ISFET consists of a voltage shift between the gate and the source. However, the signal from this device is a charge whose density varies according to the depth of the potential well under the ion sensing region. A reference electrode is inserted into the electrolyte to keep the potential of the electrolyte constant. The reference electrode is biased at a voltage V_{RS} during the measurements.

The procedure that was used to measure the ion-signal is shown in Fig. 2. This figure shows a potential well diagram during the measurement of an ion-signal. For the duration of the ion measurement, the output gate for photo-sensing (OG2) is closed in advance. The Si_3N_4 film acts as a hydrogen-ion-sensitive membrane. A potential well is formed at the surface of the Si substrate under the sensing region. As the potential on the sensing region is varied, the potential on the Si_3N_4 film changes and the depth of the potential well in the p-type Si under the sensing region is varied. (When the pH value is being sensed, it is varied according to the Nernst equation, theoretically 59mV/pH at room temperature.) As the potential becomes higher, the depth of this potential well becomes deeper. Each sensing pixel has a sensing region, three diffusion regions (input diode, floating diffusions for photo-sensing and ion-sensing) and two gate electrodes (input gate and output gate). The clock cycle is initiated by resetting the floating diffusion region used for the ion sensing (FD1) (Fig. 2(a)). The potential of the input diode then decreases and electric charge flows into a potential well under the sensing region (Fig. 2(b)). The depth of the potential well is determined by the magnitude of the pH value. The potential of the input gate is fixed optionally, and determines the lowest sensing value. If this potential was higher than the potential under the sensing region, the charge could not be stored. The size of the charge packet is determined by the potential difference between the input gate and the sensing region and by the area of the sensing region. The input diode is initially reverse-biased with respect to the input gate potential. The input diode is next pulsed briefly from VD1 to VD2 and then reset to VD1 (Fig. 2(c)). The potential well beneath the sensing region floods with charge and any excess charge beyond the input gate potential overflows to the input diode region. A charge corresponding to the pH value in the sensing region remains in the charge packet. Finally, the output gate for the ion sensing (OG1) is turned on and the charge is transferred to the FD1 region (Fig. 2(d)), where after OG1 is turned off again. The charges are then read out using a conventional source follower circuit.