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The fabrication of filter-less fluorescence detection sensor array using CMOS image sensor technique

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Abstract

A novel sensor array, which is filter-less fluorescence detection sensor, was successfully fabricated using CMOS 5 μm silicon integrated circuit technology. Previously filter-less fluorescence detection sensors were proposed and fabricated, and they were able to sense fluorescence intensity. CMOS image sensor technique was applied for the filter-less fluorescence detection sensor, and it was able to operate a charge accumulation mode. Consequently, it was confirmed that general CMOS image sensor technique can be applied to the novel filter-less fluorescence detection sensor.

Keywords: Fluorescence; Filter-less; CMOS image sensor

1. Introduction

Conventionally, fluorescent labels and an expensive fluorescent scanner are used for DNA analysis [1]. The fluorescent scanner requires a special light source with a band pass filter. It is, in consequence, relatively bulky. On the other hand, the biochemistry field has need of a straightforward space-saving fluorescence detection system.

To realize these requests, integration of the conventional system is required. A microchip possesses the following merits. Firstly, it is possible to miniaturize. Then, it is easy to incorporate micro total analysis system (μ-TAS). Furthermore, if fluorescent information may be obtained, without using a fluorescent scanner and optical microscope, fluorescence analysis would be easier than in a conventional system.

New methods of spectroscopy without special light filter have been proposed and demonstrated by our latest work [2]. It was confirmed that the proposed sensor has separately detected fluorescence light intensity and excitation light intensity.

It is expected to fabricate fluoresce sensor array, because the DNA analysis is carried out by array construction. However, it was difficult to fabricate sensor arrays using the previous sensor structure, because it utilized current as an output signal. With array construction, current signal becomes small and detection of fluorescence becomes difficult. In order to solve this problem, converting current signal into large voltage signal is necessary.

For the first time, in this paper, we report a novel filter-less fluorescence detection sensor applied as the CMOS image sensor technique (e.g. charge accumulation technique) and its output is a voltage. The technique is easy to use in array construction. The charge accumulation technique is widely used in the CMOS-based image sensors [3].

2. Principle

A new method is presented for on-chip spectroscopy, functioning without the need for a special light filter. When a semiconductor is illuminated, photons are absorbed and electron–hole pairs are generated. The excess carrier generation rate, $g(x)$, at the absorption depth, x, will be given by [4]:

$$g(x) = \frac{\phi S \lambda}{hc}[\alpha \cdot \exp(-\alpha x)] \quad (1)$$

where ϕ is the radiation intensity, λ the wavelength, α the absorption coefficient, S the area of the sensor, q the elementary charge, c the speed of light in vacuum and h is the Planck's constant.

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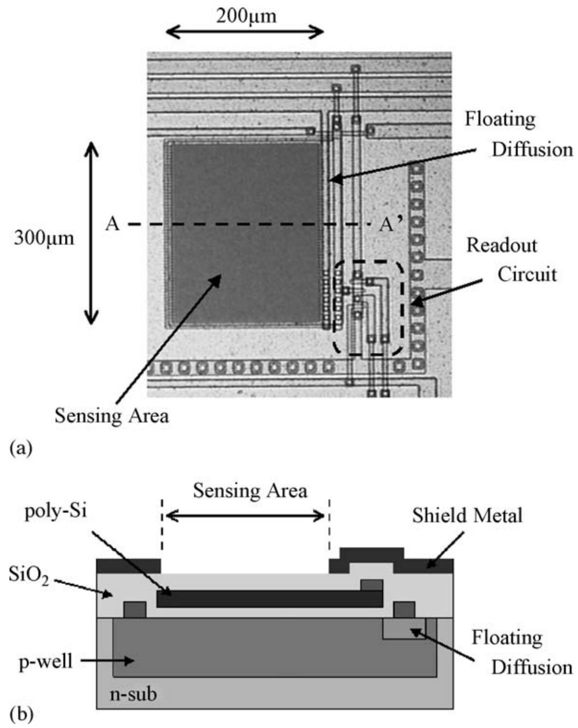

Fig. 1. (a) Photograph of 1-pixel and (b) cross-sectional view of A-A′.

Excess carriers are collected from $x=0$ (surface) to w, and contribute to a current given by:

$$I = -q\int_0^w g(x)\,\mathrm{d}x = -\frac{\phi q S \lambda}{hc}(1-\mathrm{e}^{-\alpha w}) \quad (2)$$

When two different light wavelengths are incident simultaneously, the currents generated to the absorption depths w_1 and w_2 are expressed in Eqs. (3) and (4).

$$I_1 = \frac{\phi_1 q S \lambda_1}{hc}(1-\mathrm{e}^{-\alpha_1 w_1}) + \frac{\phi_2 q S \lambda_2}{hc}(1-\mathrm{e}^{-\alpha_2 w_1}) \quad (3)$$

$$I_2 = \frac{\phi_1 q S \lambda_1}{hc}(1-\mathrm{e}^{-\alpha_1 w_2}) + \frac{\phi_2 q S \lambda_2}{hc}(1-\mathrm{e}^{-\alpha_2 w_2}) \quad (4)$$

where ϕ_1 and ϕ_2 are the intensities of wavelengths λ_1 and λ_2, with absorption coefficients of α_1 and α_2, respectively. Both illumination intensities (ϕ_1 and ϕ_2) can be found by solving these simultaneous equations.

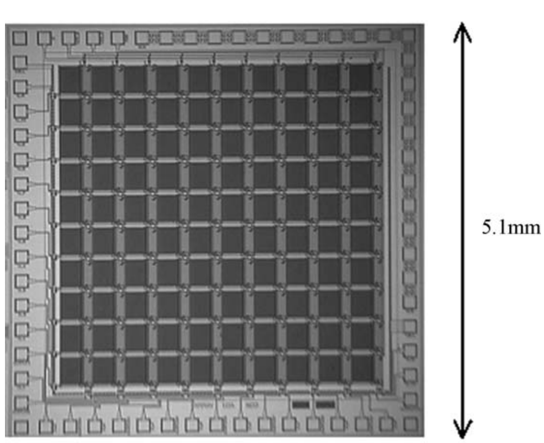

Fig. 2. Photograph of sensor array (10 × 10).

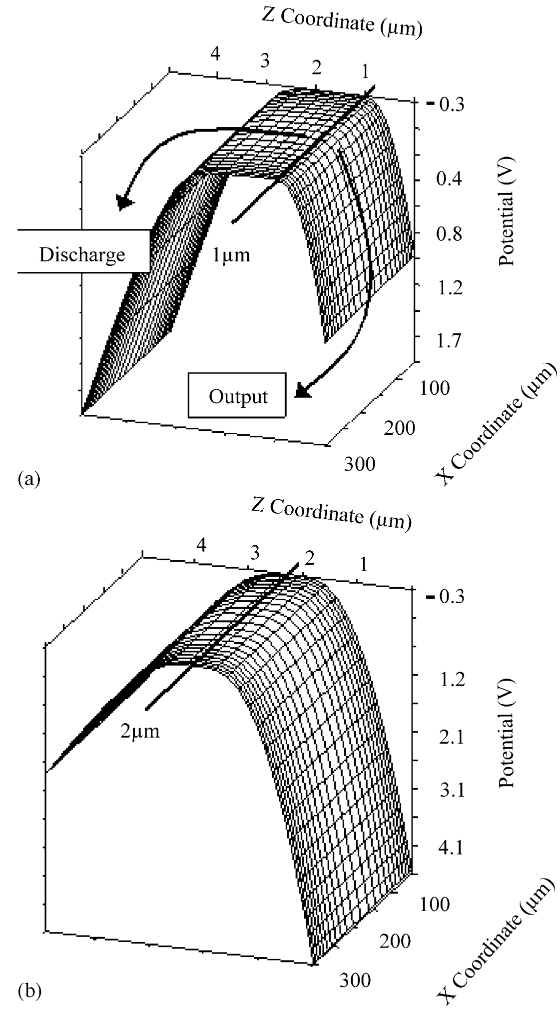

Fig. 3. An electric potential profile of filter-less fluorescent detection senor at gate voltage: (a) 1 V and (b) 5 V.

The sensor has detected about 1/300 of the ratio excitation intensity and fluorescence intensity using above principle. However, fluorescence detection becomes difficult when fluorescence intensity is weak. The current in the array structure will be about nanoampere or less.

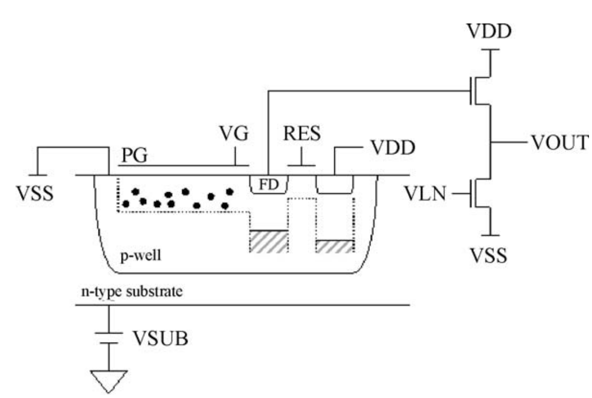

Fig. 4. Schematic of active pixel sensor unit cell and readout circuit.