Improvement of dynamic range on filter-less fluorescence sensor with body biasing technique

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Abstract

We have previously proposed a filter-less fluorescence sensor, which uses light absorption coefficient depending on the wavelength in a silicon substrate and selectively readout different wavelengths. For improvement of dynamic range, we used a body biasing technique to optimize the potential distribution of sensing area for adequately acquisition a photocurrent. As a result, the dynamic range on filter-less fluorescence sensor was improved up to 58.06 dB at an 8 V substrate voltage.

1. Introduction

Fluorescence measurement is very important for biomedical field, and it is observed by fluorescence microscopy as a mainstream technology tool for its field researcher. However its bulky size is disadvantage for micro total analytical system and point of care testing. We have previously developed a filter-less fluorescence sensor which can detect different wavelength of an incident light simultaneously using an absorption depth of a silicon [1]. In this sensor, the ratio of excitation light intensity to the fluorescence intensity was achieved to be up to 400:1 [2]. However typical fluorescence intensity is very weak, and ratio of excitation light intensity to the fluorescence intensity is the range of 10^{-3}-10^{-6}. Therefore, it is necessary to enhance fluorescence detection property. In order to improve dynamic range, we used a body biasing technique to optimize the potential distribution of sensing area for adequately acquisition a photocurrent. This paper deals with the estimation of the potential distribution depending on the substrate bias and experimentally evaluation the wavelength selectivity.

2. Operational principle of filter-less fluorescence sensor

Fig.1 shows a simplified cross-sectional view and operational principle of filter-less fluorescence sensor. In order to detect the excitation light and fluorescence, we use light absorption coefficient depending on the wavelength in a silicon substrate. First, a positive bias is applied to n-type substrate and n$^+$ diffusion layer, and photo gate voltage of 0 V is applied (Fig.1 (a)). Second, a positive voltage V_{PG1} is set to photo gate. The excitation light and the fluorescence is illuminated in this condition, photo electrons are generated by the photoelectric effect, and we can obtain photo current I_1 by generated photo electrons (Fig.1 (b)). Third, different positive voltage V_{PG2} is applied to photo gate.

Then the similar measurement as (b) is done to obtain photo current I_2 (Fig.1 (c)). Finally, light intensity of each wavelength is calculated by following equations.

$$\begin{cases} I_{W1} = q \frac{\phi_{ex}S\lambda_{ex}}{hc}(1 - e^{\alpha_{ex}W_1}) + q \frac{\phi_{em}S\lambda_{em}}{hc}(1 - e^{\alpha_{em}W_1}) \\ I_{W2} = q \frac{\phi_{ex}S\lambda_{ex}}{hc}(1 - e^{\alpha_{ex}W_2}) + q \frac{\phi_{em}S\lambda_{em}}{hc}(1 - e^{\alpha_{em}W_2}) \end{cases} \quad (1)$$
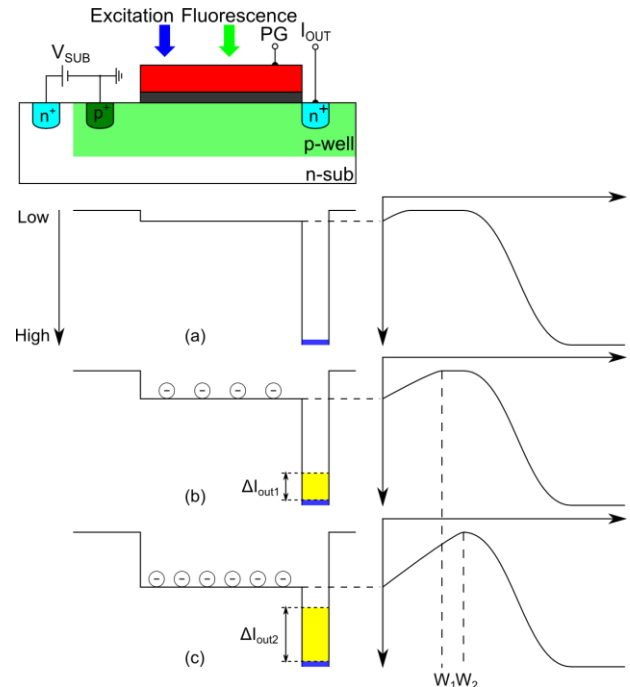

Fig.1 Simplified cross-sectional view and operational principle of filter-less fluorescence sensor.

3. Use a body biasing technique on filter-less fluorescence sensor

A degradation of the dynamic range on filter-less fluorescence sensor is caused by defective separation area in potential distribution, which is flat and broad potential peak. Inaccurate photocurrent is measured because photo electrons generated at a deeper area than potential peak are crossed over the potential peak by effect of thermal energy at room temperature. Fig.2 shows a conceptual diagram of the potential distribution at the sensing area in measurement. At the previous measurement condition, we found that the defective separation area was relatively large when the V_{PG1} was low, as shown in Fig.2 (a). In this study, we used a body biasing technique to reduce defective separation area. Sharp potential distribution is kept by applying

positive substrate bias voltage (Fig.2 (b)).

Fig.3 shows the relationship between substrate voltage and defective separation area. As a simulation result, it was confirmed that the defective separation area is reduced with the increase of substrate voltage, and defective separation area can be reduced to 0.5 μm or less when 8 V substrate voltage was applied.
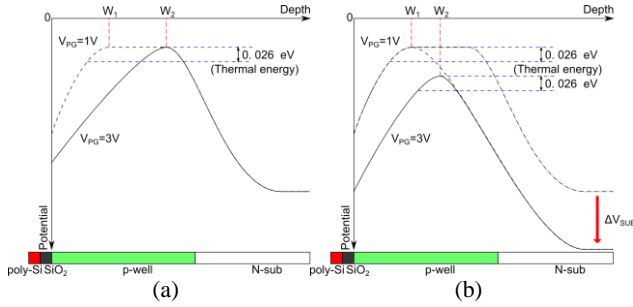

Fig.2 Conceptual scheme of the potential distribution in measurement, (a) previous measurement condition, (b) with variable substrate voltage.
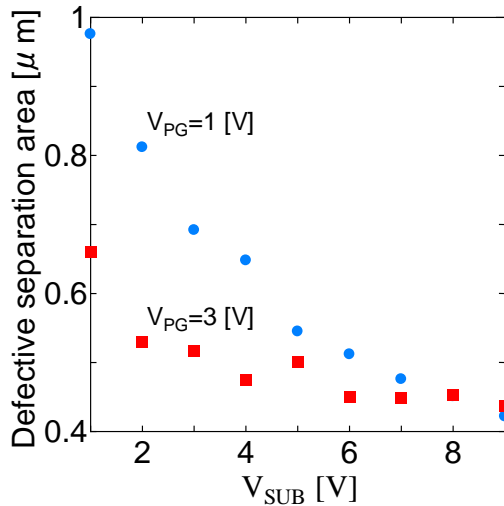

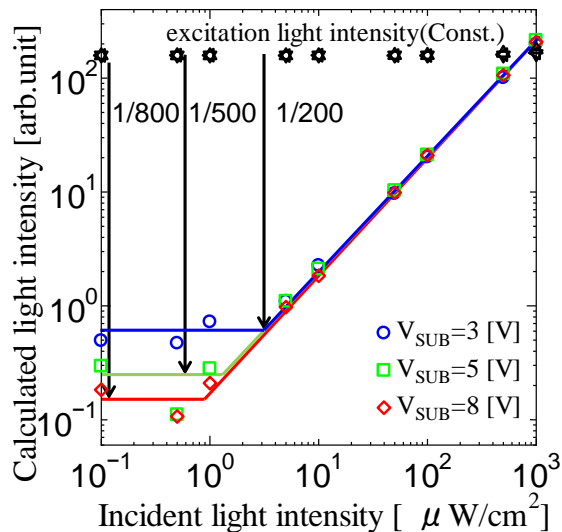Fig.3 Relationship between substrate voltage and defective separation area.

Fig.4 Measurement result of dynamic range of filter-less fluorescence sensor.

4. Experimental results

In order to verify the simulation result, we evaluated the dynamic range on filter-less fluorescence sensor. In our experiment, we used LED light sources as models of excitation light and fluorescence, and the sensor was illuminated with excitation light (wavelength: 468 nm, light intensity: 10^{-3} W/cm^2 const.) and fluorescence (wavelength: 525 nm, light intensity: $10^{-3} \sim 10^{-9}$ W/cm^2 variable). Photocurrent I_1 and I_2 were measured with the substrate voltage of 3 V, 5 V, and 8 V. Fig.4 shows measurement result of dynamic range calculated by above-mentioned method. With the 3 V substrate voltage, the readout photocurrent according to fluorescence was saturated under 1/200 of the excitation light intensity. On the other hand, we measured around 1/800 of the excitation light intensity by applying the 8 V substrate voltage. Therefore, the dynamic range was improved by optimizing the potential distribution by means of the body biasing technique.

4. Conclusions

For improvement of wavelength selectivity, we evaluated an effect of body biasing on a filter-less fluorescence sensor. The dynamic range on filter-less fluorescence sensor was improved up to 58.06 dB at an 8 V substrate voltage. The control of the potential distribution benefits to enhance the performance of the filter-less fluorescence sensor which is expected to use in biomedical field.

Acknowledgements

References

[1] Y. Maruyama, K. Sawada, H.Takao, M. Ishida, "A novel filterless fluorescence detection sensor for DNA analysis," IEEE Trans Electron Devices, 53(3), pp. 553-558, (2006)

[2] H. Ishii, Y. Maruyama, H. Takao, M. Ishida, K. Sawada, "Improvement in filter-less fluorescence sensor capability by optimization of potential distribution," The 4th Asia Pacific Conference on Transducers and Micro/Nano Technologies, (2008)

[3] H. Mutoh, "Simulation for 3-D Optical and Electrical Analysis of CCD," IEEE Transactions on Electron Device, vol.44 no. 10, pp. 1604-1610, (1997)

Appendix

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