



Ratiometric, filter-free optical sensor based on a complementary metal oxide semiconductor buried double junction photodiode



Ka Yi Yung^{a,1}, Zhiyong Zhan^{b,1}, Albert H. Titus^b, Gary A. Baker^c, Frank V. Bright^{a,*}

^a Department of Chemistry, University at Buffalo, The State University of New York, Buffalo, NY 14260, USA

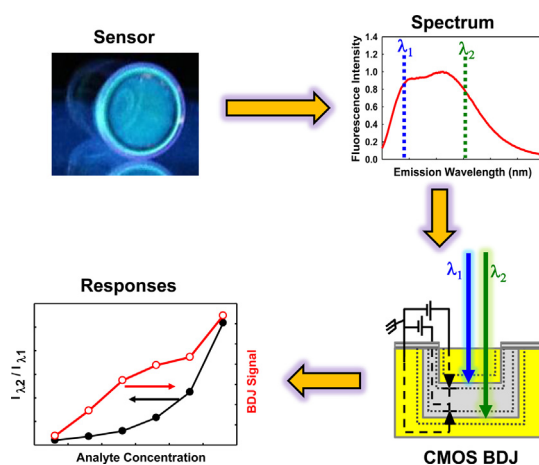
^b Department of Biomedical Engineering, University at Buffalo, The State University of New York, Buffalo, NY 14260, USA

^c Department of Chemistry, University of Missouri, Columbia, MO 65211-7600, USA

HIGHLIGHTS

- A detector for measuring signals at two wavelengths simultaneously.
- No optical filters, no moving parts.
- Functionally equivalent to a slew scanned spectrofluorimeter.
- Consumes orders of magnitude less power.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:

Received 3 February 2015

Received in revised form 21 April 2015

Accepted 11 May 2015

Available online 14 May 2015

Keywords:

Buried double junction
Complementary metal oxide semiconductor
Integrated circuit
Fluorescence
Ionic liquid
Sensing

ABSTRACT

We report a complementary metal oxide semiconductor integrated circuit (CMOS IC) with a buried double junction (BDJ) photodiode that (i) provides a real-time output signal that is related to the intensity ratio at two emission wavelengths and (ii) simultaneously eliminates the need for an optical filter to block Rayleigh scatter. We demonstrate the BDJ platform performance for gaseous NH_3 and aqueous pH detection. We also compare the BDJ performance to parallel results obtained by using a slew scanned fluorimeter (SSF). The BDJ results are functionally equivalent to the SSF results without the need for any wavelength filtering or monochromators and the BDJ platform is not prone to errors associated with source intensity fluctuations or sensor signal drift.

© 2015 Elsevier B.V. All rights reserved.

Abbreviation: BDJ, buried double junction; CMOS IC, complementary metal oxide semi-conductor integrated circuit; SSF, slew scan fluorimeter; $([\text{P}_{14,666}^+])$, trihexyl(tetradecyl)phosphonium cation; HPTS³⁻, 8-hydroxypyrene-1,3,6-trisulfonate; SNARF-1, seminaphthorhodamine-1 carboxylate.

* Corresponding author. Tel.: +1 716 6454180.

E-mail address: chefvb@buffalo.edu (F.V. Bright).

¹ Authors contributed equally to this work.

1. Introduction

Myriad detection strategies exist for chemical sensing [1,2]. Optical sensing is attractive because it can be minimally invasive and it allows stand-off detection [1,3–5]. However, optical sensing is not without its limitations. In most cases, one must operate

under conditions where the source, sensor, and/or detector do not exhibit appreciable drift/decomposition over time and the sensor per se must respond reversibly to the target analytes. In situations where there are system instabilities, one often resorts to kinetic or ratiometric methods [6–9]. Kinetic methods are often implemented within fluorescence-based schemes by using the sensing reporter excited-state fluorescence lifetime (τ) as the analyte-dependent information carrier [10–13]. Because τ often occurs on a time scale that is orders of magnitude shorter in comparison to system fluctuations and τ is generally intensity independent, this approach is an intrinsically less bias-prone detection modality. The down side of this approach is that the detection system is often substantially more complex and costly. Ratiometric methods are commonly exploited when the sensor reporter chemistry exhibits spectroscopically distinct absorbance and/or emission spectral bands that change in an analyte-dependent manner. One then need only measure the analyte-dependent absorbance and/or intensity ratio at two wavelengths to yield an analyte-dependent response. Thus, in ratiometric methods, one needs to discriminate the absorbance/intensity at two wavelengths. There are essentially three strategies for accomplishing this: (1) a spectrometer coupled to an array detector (CCD, photodiode array); (2) slew scanning to rapidly “jump” a monochromator between two wavelengths using a platform with a single photodetector (e.g., photomultiplier tube); or, (3) a system having two discrete detection channels for monitoring at two wavelengths. Each of these platforms can be costly, complicated, and/or consume substantial electrical power (e.g., CCDs, photomultiplier tubes). There are certainly advantages to platforms that have no moving parts (e.g., gratings) and that operate at low power.

In this paper, we report a complementary metal oxide semiconductor integrated circuit (CMOS IC) with a buried double junction (BDJ) [14–16] photodiode combined with on-board signal processing circuitry that provides a direct measurement of the intensity ratio at two emission wavelengths and eliminates the need for any moving parts, external circuitry, or optical filters. Although BDJ platforms have been used previously to realize color-

sensitive detection [14–16], this strategy has been used just one other time in chemical sensing to minimize Rayleigh scatter and perform detection at a single emission wavelength [17]. Here, we report a BDJ platform for real-time ratiometric intensity measurements at two emission wavelengths coupled with dual wavelength ratiometric chemical sensors for detecting gaseous NH_3 and determining aqueous solution pH. The NH_3 -responsive sensor is based on a recently developed photonic ionic liquid consisting of trihexyl(tetradecyl) phosphonium ($[\text{P}_{14,666}^+]$) cations paired with 8-hydroxypyrene-1,3,6-trisulfonate (HPTS^{3-} , pyranine) [18]. The $[\text{P}_{14,666}^+]_3[\text{HPTS}^{3-}]$ fluorescence emission spectrum exhibits two well-resolved bands that we previously used in a ratiometric mode for NH_3 , MeNH_2 , EtNH_2 , $n\text{-PrNH}_2$, Et_2NH , and Et_3N detection by using slew scan fluorescence (SSF) with a conventional monochromator as the wavelength selection device and photomultiplier tube as the detector. The aqueous pH sensor is based on seminaphthorhodamine-1 carboxylate (SNARF-1) sequestered within a sol-gel-derived xerogel film [19]. SNARF-1 exhibits a fluorescence emission spectrum with two pH-dependent fluorescence bands that have been exploited for ratiometric pH measurements in a variety of complex systems [20,21].

2. Materials and methods

2.1. Sensor fabrication and sample preparation

$[\text{P}_{14,666}^+]_3[\text{HPTS}^{3-}]$ was prepared as described elsewhere [18]. Thin films were formed by spin coating (500 RPM, 100 s) 250 μL of a 10 mM $[\text{P}_{14,666}^+]_3[\text{HPTS}^{3-}]$ solution (in EtOH) onto clean quartz microscope slides. SNARF-1 (Life Technologies) doped xerogels were prepared by using a protocol adapted from Dobmeier et al. [19]. Briefly, a tetramethoxysilane (TMOS, Sigma–Aldrich) sol was prepared by mixing 1000 μL of doubly-distilled deionized H_2O (dd H_2O), 500 μL of TMOS, and 10 μL of 0.04 M HCl (J.T. Baker) followed by 30 min sonication on ice. A SNARF-1-doped sol was prepared by mixing 75 μL of the aforementioned TMOS sol, 32 μL of 5 mM SNARF-1 dissolved in dd H_2O , and 300 μL of 0.01 M pH

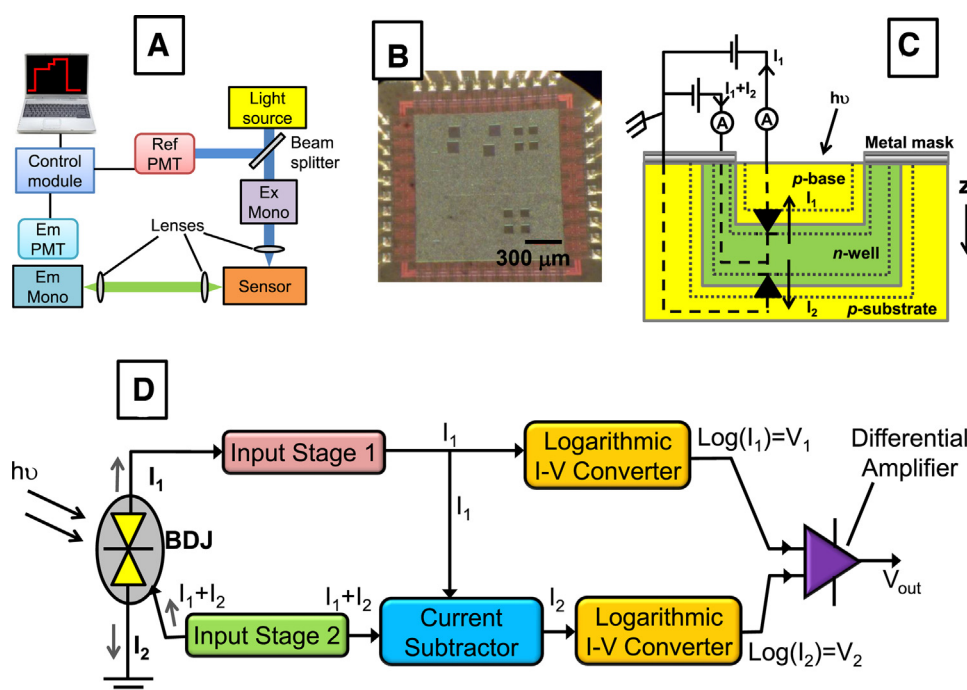


Fig. 1. Measurement systems used in this research. (Panel A) Slew scan spectrofluorimeter. (Panel B) BDJ detector chip. (Panel C) Cross sectional view through a BDJ detector chip structure. (Panel D) Basic BDJ detector chip signal processing topology.

Download English Version:

<https://daneshyari.com/en/article/1163234>

Download Persian Version:

<https://daneshyari.com/article/1163234>

[Daneshyari.com](https://daneshyari.com)