DOI 10.5162/12dss2015/P7.3

A readout platform for spectral sensors

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Abstract

We present a card-size, photocurrent-based readout platform for spectral sensors based on a wavelength sensitive photodiode. The resolving capacity for wavelength shift and ratiometric measurements is examined using different LEDs. With the introduced setup a wavelength shift resolution of 0.1 nm and a limit of detection of 0.001 for the ratiometric measurement was achieved. On the basis of the obtained results, we discuss several advantages and drawbacks of this interrogation approach for spectral sensors.

Key words: spectral sensors, wavelength sensitive photodiode, wavelength shift, ratiometric measurement

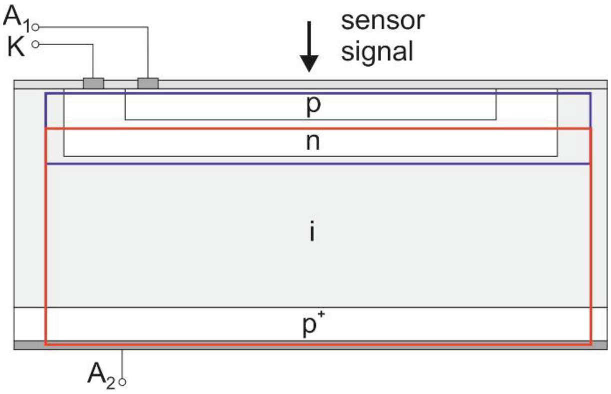
Introduction

Spectral sensors detect environmental parameters, e.g. temperature, humidity or gas content, on the basis of a specific change in their spectral properties. Wavelength shift or ratiometric change of two peak signals are the common working principles [1, 2]. They offer unique characteristics, like high sensitivity, electrical passivity and applicability under extreme conditions (temperature, humidity, electromagnetic fields, …). Their types are versatile and range from simple punctual sensors to multiplexed fiber inscribed versions and two-dimensional sensor materials. Although many of them are brought to application maturity, their commercial breakthrough is still outstanding. Often the reason for this is a missing cost-efficient readout system.

We present a wavelength sensitive photocurrent-based interrogation unit to utilize the dormant potential of spectral sensor technology for process monitoring, chemical analytic, biosensing and many others fields. The core element is a wavelength sensitive photodiode (WSPD), which enables to detect spectral changes. It combines the simplicity of an intensity measurement setup with the robustness of spectral readout. The article is structured as follows: We describe the working principle and the readout electronics of the WSPD. We then illuminate its capacity for wavelength shift and ratiometric measurements and highlight advantages and difficulties. Finally, we provide an outlook on suitable spectral sensors for our WSPD-interrogation unit.

Fundamentals

a)



b)

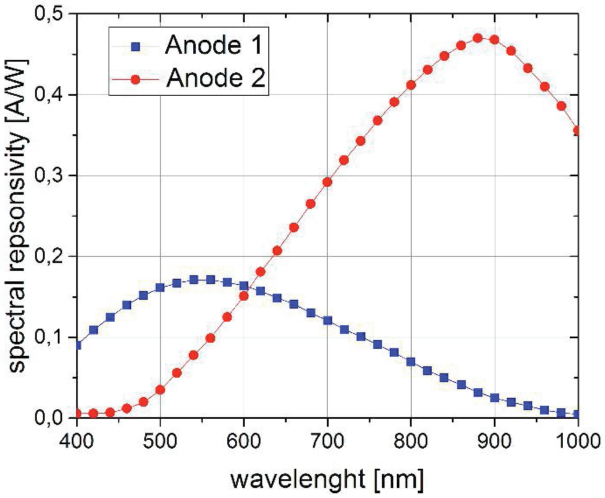


Fig. 1 (a) Photodidode structure of the WSPD (b) Spectral responsivity curves of the stacked photodiodes [3]

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The wavelength sensitive photodiode is composed of two vertically stacked silicon photodiodes with different spectral responsivity characteristics, see Fig.1. Through this structure, the central wavelength of monochromatic signals or the centroid of a polychromatic light distribution can be determined by the ratio of the two generated photocurrents I_1 and I_2. Thus, intensity fluctuations of the spectral sensor signal have no influence on the readout. This allows us to calculate the centroid wavelength λ_C as follows

$$\lambda_C = s(\lambda) \cdot \log \frac{I_1(\lambda, P) + I_{off1}}{I_2(\lambda, P) + I_{off2}} \qquad (1)$$

, where s describes a scale factor and P the incident optical power [4]. The currents I_{off1} and I_{off2} denote offset values, which consider that the temperature dependence of the dark current and the noise behavior for the stacked photodiodes are different. The noise effects of the amplifier electronics are also included.

Furthermore, a high adjustment tolerance for the setup is feasible as the operability of the WSPD is independent of the angle of incidence, polarization and the spatial intensity distribution of the sensor signal.

Readout electronics

For driving the WSPD as well as collecting and processing its sensing signals, a high-resolution, low noise readout electronics was realized. The electronic circuitry contains three functional units connected to a microcontroller: sensor and temperature signal acquisition, light source control and power supply. In Fig. 2 the circuit board is shown.

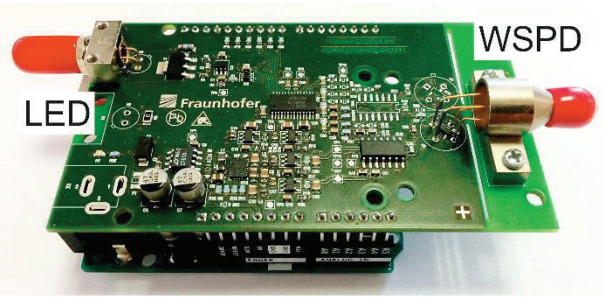

Fig. 2: WSPD interrogation electronics

As WSPD-device element we use the WS7.56-TO5i from First Sensor, which is mounted in an optical fiber plug connector. The generated photocurrents of the WSPD are amplified and processed according to formula 1 by a logarithmic amplifier (LOG 112, Texas Instruments). To reduce the noise level of the calculated voltage signal, low-pass filtering with a cutoff frequency of 100 Hz is applied. Moreover, a temperature sensor (LM45B, Texas Instruments) is placed near the WSPD for monitoring the environment. Both signals are sent to the microcontroller (Arduino Uno) via an analog/digital-converter (ADS1248, Texas Instruments) and are then displayed with a LabVIEW-program.

Results and Discussion

A setup consisting of different fiber coupled LEDs was used to evaluate the measurement performance of the WSPD interrogation electronics. The experiments were performed under laboratory conditions to guarantee a stable operating temperature for the WSPD. Firstly, we measured the centroid wavelength of the LEDs. The spectra from each LED were analyzed for reference using a grating spectrometer (iHR550, Horiba). The acquired data are depicted in Fig. 3.

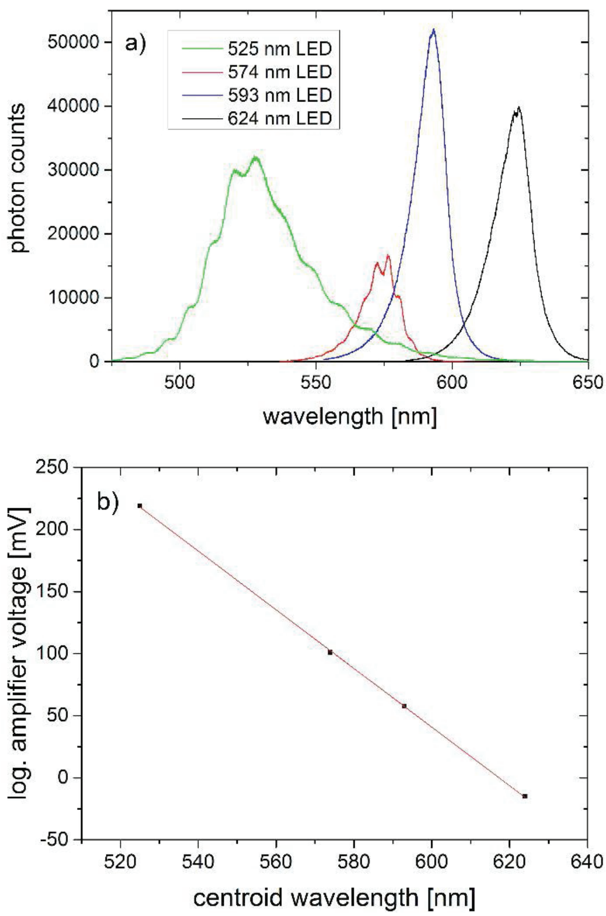

Fig. 3 (a) Spectra of different LEDs (b) Measured centroid wavelength of the LEDs.

In Fig. 3 b, we see a highly linear curve for the measured LED centroid wavelengths. These

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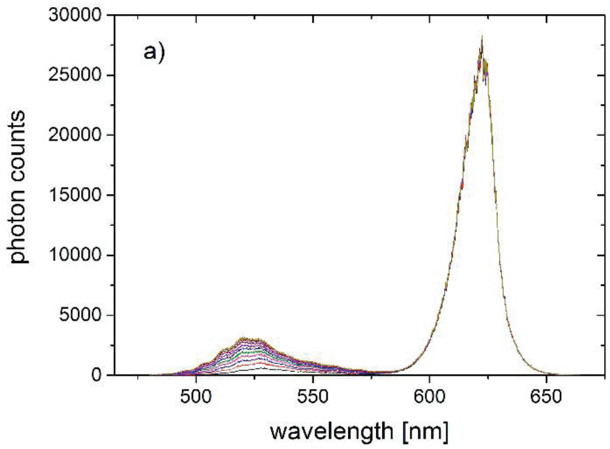
results are in agreement with the expectation according to the attained LED spectra (Fig. 3 a). It should be noted that we do not determine the central wavelength of the LEDs, but the centroid of the spectral distribution. A spectral resolution of approx. 0.1 nm can be obtained with our WSPD interrogation electronic.

In our second experiment, we used two LEDs simultaneously to carry out a ratiometric measurement. One LED served as baseline and the other one was varied in its optical power, see Fig. 4 a.



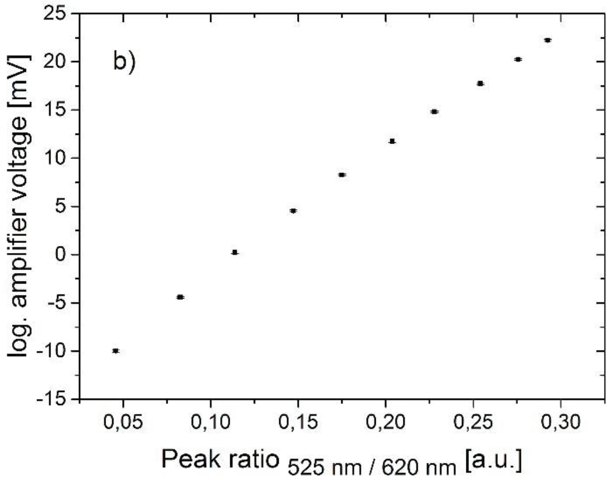


Fig. 4: (a) Ratiometric spectra consisting of a baseline at 624 nm and a varying peak intensity at 525 nm. (b) Calculated peak ratios.

The calculated peak ratios are displayed in Fig. 4 b. A slight nonlinearity can be seen. As mentioned previously, the centroid of the spectral distribution is determined. While the peak intensity of the 525 nm LED is increased, the peak shape is changing too, which results in a small nonlinear blueshift of the centroid. In our case a variation of the peak ratios of approx. 0.001 a.u. can be distinguished.

Conclusion and Outlook

The utilization of a wavelength sensitive photodiode for reading out spectral sensors is evaluated. A compact electronic platform is realized and its suitability for wavelength shift and ratiometric measurement is demonstrated. The system is working independently of intensity fluctuations and permits a simple setup geometry similar to common photodiodes. In order to reach an optimal performance, the knowledge about the shape and behavior of the spectral signal is necessary. This is due to the fact that the WSPD measures the centroid of the whole spectral distribution. Furthermore, the operating temperature of the WSPD has to be monitored or stabilized, because of the different noise properties of the stacked photodiodes.

Although, the WSPD approach has to overcome some challenges, such as temperature dependency, the important characteristics, like cost-efficiency, miniaturization, high-resolution, robustness and simple handling are fulfilled for a successful fusion with spectral sensors. In future works the unique solutions, only possible with WSPD, will be shown with a localized plasmonic sensor substrate and a photonic crystal structure.

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Acknowledgment

The authors thank First Sensor AG, Berlin for providing the responsivity data of the WS7.56. This work was funded by FhG Internal Programs (Grant No Attract 692271)