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Abstract

All-Solid-State Optodes: Recent Developments and Applications †

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Abstract: The development of novel sensing materials and analytical systems remains challenging nowadays. Among various transduction principles employed in chemical sensors, the optical transduction is often preferred, due to the fast response time, simplicity of preparation, and easy signal acquisition of optodes. In this contribution, the main aspects of novel optical sensor development and their application in both single and array configurations for liquid sample analysis will be discussed. The applications of fluorimetric and colorimetric all-solid-state optical sensors and sensory arrays recently developed or under investigation for ecological monitoring, quality assessment, and medical and health care will be illustrated.

Keywords: optical chemical sensors; all-solid-state devices; ecological monitoring; water potability screening; heavy metal-pollutant assessment; medical and health care

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1. Introduction

Modern optical chemical sensors are characterized by their high sensitivity and low detection limits and have been developed for many analytes [1,2]. Moreover, the construction of the most modern optical sensors requires neither a wired connection with the detector, nor sophisticated or energy-consuming hardware, thus enabling wearable and wireless sensor development. The analytical signal of an optical sensor can be registered with consumer optoelectronic devices such as digital scanners, digital cameras (standalone or embedded in commonly used PCs), tablets and smartphones [3–6]. Even without any power supply in a so-called 'naked-eye' mode, i.e., when the sensor luminescence intensity changes upon interaction with the analyte, the analytical signal may be registered visually and may be especially useful in situations of rapid qualitative analysis and time-sensitive situations [7–9].

Optical chemical sensors, or optodes, transform changes of optical phenomena, as a result of the interaction between the analyte and the receptor and detect the intensity of photon radiation that arrives at a sensor [10]. The main three components of an optical sensor are the optically sensing element, the appropriate transducer, and the signal acquisition method, as seen in Figure 1.

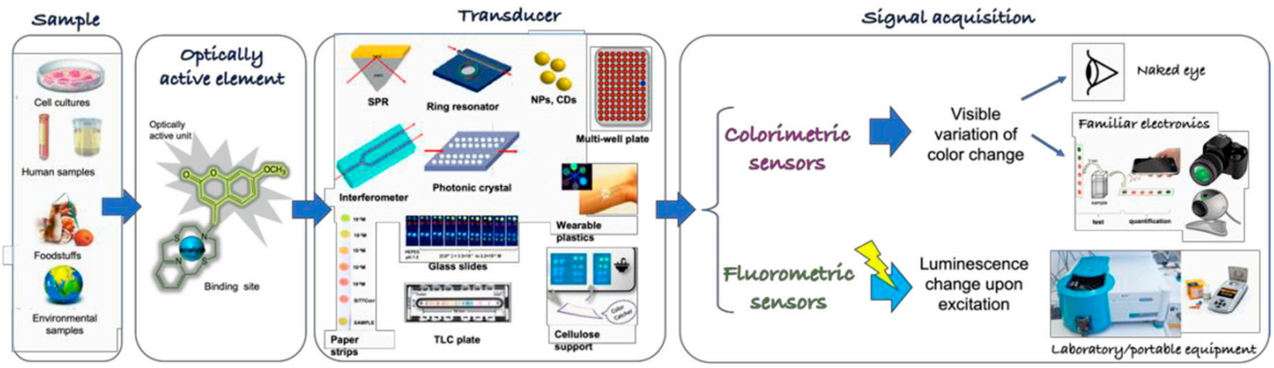

Figure 1. The schematics of optical sensor operating principles.

2. Discussion

The possibility of developing the new optical chemical sensors and improving their functionality and analytical properties to a very high degree depends on the availability of the appropriate optically active units as a main component of optode-sensing materials (often macromolecular compounds able to interact with analyte species through one or several selective or concurrent interaction mechanisms) and on the selection of the appropriate transducing/supporting material, especially for the construction of all-solid-state sensors. Nowadays, there is an unmet need to develop easy-to-handle and inexpensive optical sensors for fast and effective ecological monitoring, quality screening of foodstuff and potable water, heavy metal-pollutant assessment, and medical and health care tasks, among others. The present work will consider several important aspects of analytical systems based on chemical sensors with optical transduction, as previously developed in our research group, such as the choice and the composition of the sensing material, the selection of the solid substrate support, the overall design of the sensing device, the elaboration of the appropriate calibration procedure (including the necessity of incorporating internal standards), as well as the data evaluation methods. The suitability of qualifying paper, or cellulose-based, optodes as chemical sensors will be discussed. Finally, the practical applications of developing sensing devices for the assessment of several inorganic and organic pollutants for ecological monitoring purposes and health care applications will be illustrated.

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References

1. Lvova, L.; Di Natale, C.; Paolesse, R. Hybrid and optical multisensory systems for liquid analysis: Theoretical basis, trends and applications. In *Electronic Tongues Fundamentals and Recent Advances*; Shimizu, F.M., Braunger, M.L., Riul, A., Jr., Eds.; IOP Publishing Ltd.: Bristol, UK, 2021; pp. 9-1–9-51.
2. Caroleo, F.; Magna, G.; Naitana, M.L.; Di Zazzo, L.; Martini, R.; Pizzoli, F.; Muduganti, M.; Lvova, L.; Mandoj, F.; Nardis, S.; et al. Advances in optical sensors for persistent organic pollutant environmental monitoring. *Sensors* **2022**, *22*, 2649. [CrossRef] [PubMed]
3. Lvova, L.; Gonçalves, C.G.; Prodi, L.; Lombardo, M.; Zaccheroni, N.; Viaggiu, E.; Congestri, R.; Guzzella, L.; Pozzoni, F.; Di Natale, C.; et al. Non-enzymatic portable optical sensors for microcystin-LR. *Chem. Commun.* **2018**, *54*, 2747. [CrossRef] [PubMed]

4. Caroleo, F.; Diedenhofen, G.; Catini, A.; Di Natale, C.; Paolesse, R.; Lvova, L. Phosphorous(V) corrole fluorophores for nitrite assessment in environmental and biological samples. *Chemosensors* **2022**, *10*, 107. [CrossRef]
5. Lvova, L.; Caroleo, F.; Garau, A.; Lippolis, V.; Giorgi, L.; Fusi, V.; Zaccheroni, N.; Lombardo, M.; Prodi, L.; Di Natale, C.; et al. A fluorescent sensor array based on heteroatomic macrocyclic fluorophores for the detection of polluting species in natural water samples. *Front. Chem.* **2018**, *6*, 258. [CrossRef] [PubMed]
6. D'Andrea, A.; Pomarico, G.; Nardis, S.; Paolesse, R.; Di Natale, C.; Lvova, L. Chemical traffic light: A self-calibrating naked-eye sensor for fluoride. *JPP* **2019**, *23*, 117. [CrossRef]
7. Lvova, L.; Pomarico, G.; Mandoj, F.; Caroleo, F.; Di Natale, C.; Kadish, K.M.; Nardis, S. Smartphone coupled with a paper-based optode: Towards a selective cyanide detection. *JPP* **2019**, *24*, 964. [CrossRef]
8. Garau, A.; Lvova, L.; Macedi, E.; Ambrosi, G.; Aragoni, M.C.; Arca, M.; Caltagirone, C.; Coles, S.J.; Formica, M.; Fusi, V.; et al. N_2S_2 Pyridinophane-based fuorescent chemosensors for selective optical detection of Cd^{2+} in soils. *NJC* **2020**, *44*, 20834. [CrossRef]
9. Paderni, D.; Macedi, E.; Lvova, L.; Ambrosi, G.; Formica, M.; Giorgi, L.; Paolesse, R.; Fusi, V. Selective detection of Mg^{2+} for sensing applications in drinking water. *Chem. Eur. J.* **2022**, *28*, e202201062. [CrossRef] [PubMed]
10. Hulanichi, A.; Geab, S.; Ingman, F. Chemical sensors definitions and classifications. *Pure Appl. Chem.* **1991**, *63*, 1247. [CrossRef]