Semiconductor Optoelectronics, *Vol. 42 No. 1 (2023), 981-985*
https://bdtgd.cn/

Semiconductor Optoelectronics
ISSN: 1001-5868

APPLICATIONS OF OPTOELECTRONIC SENSORS IN BIOMEDICAL ENGINEERING

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ABSTRACT

In this paper application of some optoelectronic sensors for invasive and non-invasive human health test is presented. Optoelectronic technology plays an important role in medical diagnosis. The main attention is paid on their basic operation principle and medical usefulness. The paper presents also own research related to developing of tools for human breath analysis. Breath sample unit and three gaseous biomarkers analyser employing laser absorption spectroscopy designed for clinical diagnostics were described. The analyser is equipped with sensors for CO, CH_4 and NO detection. The sensors operate using multi-pass spectroscopy with wavelength modulation method (MUPASS-WMS) and cavity enhanced spectroscopy (CEAS). Optoelectronic sensors (OS) are applied in many life and scientific activities, e. g.: environmental monitoring, industry, chemical analysis, biology, and medicine.

INTRODUCTION

Current medical applications of OS include pulse oximetry, heart rate monitoring, measuring the amount of oxygen in the blood, blood glucose monitoring, urine analysis, dental colour matching, and exhaled biomarkers monitoring. These sensors must meet strict requirements, they should be safe, biocompatible, reliable, stable, suitable for sterilization, immune for biologic rejection and miniaturized. Maintaining of these devices should be as simple as possible. Idea of the OS operation bases on analyses of light-matter interactions. Main processes which occur in the matter illuminated by radiation at a given wavelength λ_1.
The nature of the interaction depends on specific features of the matter. The result of the interaction can be used as matter signature (marker). For example, scattered light is used for liquid investigation (blood flow monitoring or glucose detection). Substances characterization (identification) by analysis of their specific absorption spectrum is of high significance for medical measurements. OS based on absorption usually quantify the change in intensity and spectrum of light that is transmitted through the sample. Reflectance sensors are also designed for such specific analysis but for the substances of low transparency. When excited molecule of the sample returns to the ground singlet state S_0, it can emit photons at longer wavelength range than the absorbed one. The absorbed radiation can also cause *fluorescence* at wavelength different than λ_1. Due to internal conversion the molecule can also return to the S_0 state via triplet state T_1 in case of *phosphorescence* phenomenon. This effect lasts longer than fluorescence, and produces lower energy radiation (longer wavelength). For both cases, the emission intensity is proportional to concentration of excited molecules.

Parameters measured commonly in medical diagnosis can be divided into physical and chemical ones. Since stimuli are not electrical, there is several energy conversion steps in the medical sensor before it produces an electrical signal, that is measured and interpreted as representing the parameter of interest. In case of the OS, photon flux is always detected by a photo detector providing a conversion into the electric signal. For example, a periodic stress acting on a fiber-optic pressure sensor, first results in strain in the fiber, which causes a change of its refractive index and change of optical transmission, which finally results in modulation of the photon flux registered by a photodiode. In fiber-optic OS, the light may be directly modulated either by the parameter being investigated and acting on the fiber or by special reagent connected to the fiber. The optical properties of the reagent vary with the change in the stimulation agent of measured medium. Such a probe is often called an optrode. Fluorescence, absorption, Raman scattering, evanescent-wave and plasmon resonance are the main physical phenomena of its operation. The simplest fiber OSs classification is based on the subdivision in *intrinsic* and *extrinsic sensors*.

In intrinsic sensors, the fiber plays a role of a light guider and transducer. In this case, the investigated substance modifies refraction index (n) or losses coefficient (δ) of the fiber. Then the radiation transmitted in the fiber will vary depending on the substance quantity [4].
Extrinsic sensors use the optical fiber to guide the light from the source to sensing area (outside the fiber) where a light modulation takes place. The modulation can concern various light parameters such as intensity, wavelength, polarization angle, phase, or time delay [1]. Next, modulated light is collected and transmitted through the fiber to photodetector. The investigated substance produces direct modulation of the light or acts on a transducer, which finally cause the change in light parameters.
Light intensity monitoring is the simplest solution for most of OS. However, its measurement is sensible to changes in light source parameters, fiber couplings, fiber attenuation, signal noises, etc. These factors reduce accuracy of the measurement. Therefore, such interferometric configuration as Sagnac, Michelson, Mach-Zehnder and Fabry-Perot are used for error minimizing [5].The medical test can be carried out on a living organism (in vivo) or outside the body (in vitro). Furthermore, taking into account the sample testing procedure, the medical sensors can be divided into [6]:

1. non-invasive sensors, in which the probe remains outside of human body or on the skin surface (contacting),
2. minimally invasive (indwelling),
3. invasive sensors, in which the probe must enter the human body through the nostrils, throat, butthole, ears, or implantable.

In the next sections we shall briefly discuss the principles and ideas of invasive and non-invasive optoelectronic sensors used in medicine. The first group included: endoscopic imaging, bile sensor, pH meter, oxygen and carbon dioxide sensors, cardiac and pressure sensors. Following examples are shown as non-invasive devices: pulse oximeter, blood flow-meter, glucose meter, sensor of prostate cancer, optical coherence tomography and human breath analysers. We will also take a brief look at the results of our research related to development ultrasensitive gas sensors, which can be applied in human breath analysing and clinical screening.

SECTION SNIPPETS

Endoscopic imaging

Development of flexible fibers has facilitated manufacturing of many modern medical devices, e.g.: *endoscopic imaging systems* [7]. Such instruments comprise a light source, optical fiber, CCD unit, image processing unit, and instrument channel. The endoscope fiber transmits light from a source into the body, illuminating the cavity where the endoscope has been inserted. Light reflected off the body part travels back to CCD unit, and electrical.

Pulse oximetry

Pulse oximetry is a non-invasive medical sensing method to measure human pulse rate and arterial blood oxygenation. Typical pulse oximeter is composed of two light-sources with different peak emission wavelengths and a single photodiode. A pulse oximeter sensor based on organic materials, which are compatible with flexible substrates. The sensor is composed of flexible organic polymer photodiode (OPD) and two organic light-emitting diodes (OLEDs): green

Human breath analyzers – based on own works

Metabolic processes occurring within the human body create a wide variety of volatile organic compounds (VOCs) in the exhaled air. About 3000 various compounds were already detected. Nitrogen, carbon dioxide, oxygen, water, argon and other products of metabolic processes within the body are the main components of the exhaled air. VOCs are related to a person's diet, stress level and immune status. Compounds like acetone, ethane, pentane and isoprene are known in the medical practice.

DESCRIPTION

People's needs for vision are no longer constrained by the original foundation due to recent historical developments. The application of organic optoelectronic materials and devices around the world has received significant attention from organic electroluminescence. According to recent findings from relevant scientific research, organic photovoltaic cells can be used as a clean and renewable energy source to significantly reduce the current energy needs of society, organic light-emitting diodes can be used in flat-panel displays and solid-state lighting, and organic storage, sensors, and other similar technologies hold great promise for future use. It is clear that the main focus of upcoming new energy research will be the study of organic optoelectronic materials and the technologies they enable. Historically, covalent modification of the molecular structure has been used as a regulation technique to update conventional organic optoelectronic materials. Recent years have seen the development of novel, efficient ways to control the characteristics of excited states through physical stimulation (such as mechanical force, temperature, electric field, and magnetic field). An organic complex of the mononuclear metals platinum and iridium as well as an organic optoelectronic device with host and guest doping. It is based on the popular smart image sensor that is now in use.

The simulation results indicated that Polyvinyl Carbazole (PVK) had been extensively used as a blue luminescent material and whole transport layer in electroluminescent device research employing PVK without energy transfer. White light cannot be produced by simple platinum and iridium metal complexes. The photovoltaic performance of OPV devices is improved by choosing the proper solvent to manage the bulk hetero junction. Phase separation involves solvents significantly. Optimizing the D-A interface results in efficient charge isolation, effectively separating excitons at the D-A interface and developing continuous electron and hole transport channels, and effective charge transport between electrodes plays a positive role in organic solar cells, which consist of an electron donor (D) and an acceptor (A). The application prospects for organic optoelectronic materials are quite promising under the current economic and social growth that is occurring at a rapid rate. Because light-emitting diodes can effectively convert electrical energy into light energy, which has a wide range of uses in contemporary society, including lighting, flat-panel displays, and medical devices, there are currently effective solutions to the problems of luminous brightness, efficiency, and lifespan. First, white light with high efficiency can be used in the lighting industry. Different types of lighting and lanterns create fresh visual effects. In addition to being utilised for stage lighting, colourful lights can also be used to create expansive full-color, high-definition flat-panel displays. Organic optoelectronic devices differ from organic optoelectronic materials in that they are less expensive, lighter, and easier to design, and need less material synthesis. They may also be converted into large-area displays, flexible displays, and displays that are foldable and flexible. The screen can draw more attention from all directions due to its easy setup method, etc. Optoelectronic devices have evolved in recent years with a variety of uses. Electronic devices that can retrieve photos and smart cards, as well as memory cards and sensors with great applications, are advantageous to modern living. When it comes to organic optoelectronic devices, the interface significantly affects the device's performance and lifespan. The photoelectric conversion feature of photoelectric devices is used by image sensors. It does this by converting the light picture on the light sensitive surface into an electrical signal that is proportionate to the light image. Digital cameras and other imaging devices frequently use image sensors. Light-emitting diodes are a common light-emitting technology in the field of electronic display, which can significantly improve the efficacy of the response and offer a broader viewing angle.

For the purpose of fluorescence visualisation of lysosomes, a newly unsymmetrical meso-CF3-BODIPY fluorescent dye was presented. It emits at $\lambda em \approx 640$-650 nm with good quantum yields (0.7-0.9). According to its concentration in the culture media, this BODIPY 1 can accumulate in cell lysosomes, with the pace of its absorption by the cell, intracellular transport, and rate of saturation of the cell with the substance all varying. A high BODIPY concentration's stressful effects on cells may be responsible for the reported absorption limit of the chemical by cells at a concentration of BODIPY 1 in the culture medium.
After analysing the data, it was determined that 5 μM was the most practical concentration of the substance under test for fluorescent staining of lysosomes because it resulted in intense fluorescent staining that gradually increased throughout the day and had no toxic effects on cells, unlike when BODIPY 1 was used at high concentrations. Accordingly, it can be inferred that the synthesised BODIPY is simple to use, stable in the form of an aqueous solution, doesn't need particular storage conditions, and is appropriate for staining intracellular structures.

CONCLUSION

Selected optoelectronic sensors for medical applications were presented. These devices can operate in invasive or non-invasive modes. The first group of the sensors includes: endoscopic imaging, bile sensor, pH meter, oxygen and carbon dioxide sensors, cardiac and pressure sensors. However, the most needed are the noncontact sensors that are able to perform the detection or the measurement procedures without physical contact with human body or the specimens such as blood, urine or other bodily.

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