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Research Article

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Optical Design of a PMMA Sensor Film for Organic Light Emitting Diode

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Abstract

The organic light emitting diode (OLED) is an optoelectronic system that operates on the principle of electroluminescence, i.e., the recombination of electrons and holes in the organic/active layer. It serves as the primary source of light for the sensing film that is used to sense the sample (bioreceptor) target analyte. The PMMA (Polymethyl methacrylate) sensor film is used to detect analytes (blood and glucose) with a 540 nm working range. The OLED is simulated to overcome glass/substrate losses resulting from total internal reflection and also to achieve maximum the OLED device's outcoupling efficiency by putting into practice a few of the most useful layers, such as injection layers, blocking layers, and so on, in a systematic way because the sensitivity of the sensing film is dependent on the amount of light emitted from OLED. To reduce substrate losses and improve the effectiveness of light extraction, a layer of magnesium fluoride (MgF_2) nanospheres was placed on the substrate.

Keywords

Finite difference time domain, Organic light emitting diode, Light extraction, Sensor

Introduction

A sequence of organic thin-film structures are sandwiched between two conductors in an OLED, a flat light-emitting device. Organic layers include the injecting layer, the transmitted hole layer, the emissive/organic layer, and the blocking layer. It operates by the electroluminescence theory that is that electrons from cathode and anode merge into organic layers when sufficient voltage is applied through cathode and anode and generate light. Organic materials had their electroluminescence in the early 1950s for the first time. OLED works without a backlight because it emits visible light. Two forms of LED's are inorganic LED and organic LED. OLED can produce different colors of light by putting red, blue and green OLED materials in sub pixel location. Thus, it produces RGB light respectively [1].

A diagram of Jablonski is a diagram that shows the electronic conditions and transitions between the molecules [2]. The states are organized by energy vertically and grouped by spin multiplicity horizontally. Electrons are excited as the system absorbs energy and are elevated into ahigher energetic state. Some of the electrons are in the so-called HOMO before excitation, in the ground state (Highest Occupied Molecular Orbital). They are in the LUMO after they enter an aroused state (Lowest Unoccupied Molecular Orbital). Photons, particles produced by electromagnetic radiation or light, must have certain energy content to activate electrons. The photon energy can be determined through equation 1, where h is the Planck constant and v is the light frequency.

$$E_{photon} = hv \quad (1)$$

The Spontaneous emissions of electromagnetic radiation are fluorescent and phosphorescent, respectively. The difference is that fluorescence stops immediately after excitative radiation is off, while after glow with fractional durations of a second up to hours can occur during phosphorescence.

The biosensor is an analytical system that transforms biological signals into electrical signals. Information concerning physiological changes or processes can be registered, detected, and transmitted. It specifies the particular substance's presence and concentration in any solution. Two components are used in the biosensor: biological and physical components. The biological component contains enzymes, cells, etc. The physical component contains a transducer, amplifier, etc. The biological component recognizes and interacts with an analyte and produces a physical change that can be detected by the transducer. There are different kinds of biosensors. They are electrochemical biosensors, immunosensor, magnetic biosensors, thermometric biosensors, acoustic biosensors, optical biosensors, etc. We are using an optical biosensor in our project. This biosensor measures the interaction of an optical field with a biorecognition sensing element. It measures the change of light [3-5].

The healthcare industry is linked to some of the most innovative applications of thin film sensor technology. Many types of substrates, including ceramic materials and high-grade specialty steels, may be deposited on, and fused to thin films. According to research, these sensors have a faster and more precise reaction time, and their smaller size allows for more precise installation and less external circuitry. According to study studies, thin film sensors have demonstrated the required repeatability, durability, and accuracy. Thin-film sensor manufacturing techniques have advanced to the point that they can now be produced quickly, cheaply, and to highly accurate specifications. The thin film method of manufacturing has several advantages [6-8].

The optical properties of a material are the measure of interaction with light. The appearance of material depends on its optical properties. The optical properties include refraction and material's refractive index (RI), polarization, reflection, absorption, photoluminescence, transmittance, diffraction, dispersion, scattering, color, photosensitivity, and so on. For selecting the sensing film required for our project, we mainly focus on optical characteristics like RI, reflection, absorption, and transmittance [9, 10].

In OLED there still exist some losses. To overcome this, there is a lot of scope for research i.e., by incorporating various nanophotonic structures [11-13]. OLED is widely used in displays, however OLED in a biosensing application is still under research. This gap we are trying to fill by developing an idea to design a simple OLED for sensing.

Experimentation

Modelling of OLED using nanostructures

In order to model OLED for sensing application, we have implemented the following sensing film and analytes as shown in figure 1.

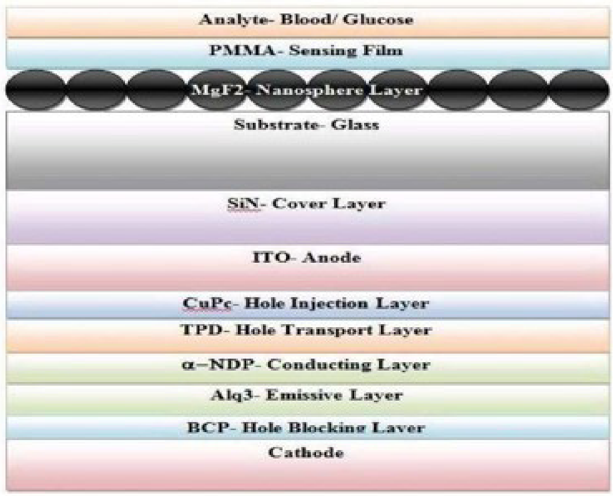

Figure 1: OLED structure for sensing application.

Sensing film: PMMA

Because of its long-term stability, low cost, low optical loss in the visible spectrum, great scratch hardness, and low glass temperature, PMMA is one of the most researched polymers. PMMA film has a RI of 1.4887. The interaction between the analytes and PMMA film is anticipated to have no effect on the film's RI [14].

Analytes: blood (RI - 1.3875) and glucose (RI - 1.33469)

In figure 1, the proposed OLED structure i.e., it is implemented on one side of a glass substrate, while the sensing component is implemented on the other side of the substrate on a nanosphere layer. The light from the OLED interacts with the sensor surface on which the analyte is deposited, after passing through the glass substrate and nanosphere layer. The light's characteristics, particularly its intensity, are modulated by its interaction with the analyte molecules. As a result, the light intensity recorded can be linked to the dosage of analyte on the sensor surface [15, 16].

Modeling and analysis of the OLED sensor

We can use two sorts of methods to analyze the results for the suggested design: numerical method (Finite - difference time domain approach) and analytic method (mode expansion method) [17, 18]. The FDTD (Finite Difference Time Domain) technique can be used as a powerful analytical tool because it can be used to any kind of complicated structure. This is FDTD's advantage over other analytical techniques. Much more powerful outcomes are obtained when the FDTD and mode expansion approaches are combined. The result is that the effect of using the FDTD nanospheres and analyze the results on light out-coupling from the OLED device. The modelling structure is shown in figure 2.

Lumerical FDTD is a 3D Maxwell solver able to analyze ultraviolet, visible, and infrared radiation interactions with complicated structures using wavelength characteristics. It precisely simulates optical and photonic devices on the wavelength scale and also contributes to the design,

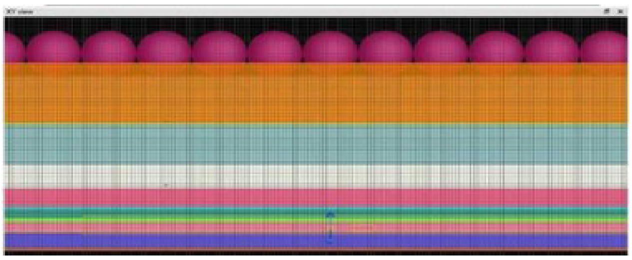

Figure 2: Modeling of OLED using FDTD.

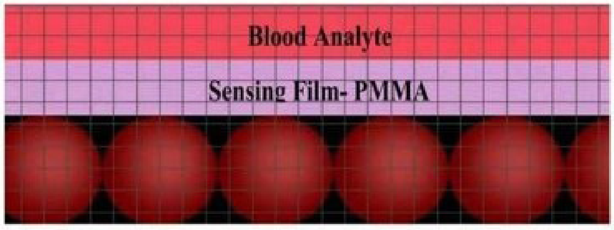

Figure 3: Modeling of blood analyte immobilized onto sensing film.

analysis, and optimization in a 3D CAD environment. It's a sophisticated and detailed material modeling that matches the data automatically. The research capabilities are extensive and advanced both in time and frequency areas [19].

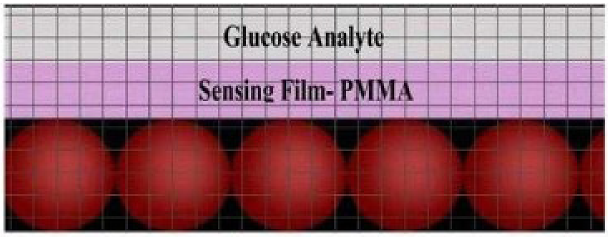

Figure 4: Modeling of glucose analyte immobilized onto sensing film.

Results and Discussion

Material database of OLED sensor structure

Further, the PMMA sensing film is placed over nanosphere that can sense at an operating wavelength of 540 nm (Table 1). All the optical properties of PMMA are taken into account while selecting the sensing film. It is used as sensing film due to its advantages like transparency, lightweight and stability. This sensing film makes sure that whether OLED is working as sensor or not. The sensing filmis able to absorb and transmit our operating wavelength range. And this sensing film should be capable of sensing various kinds of analyte. The modelling is done using FDTD method as shown in figure 3 and figure 4. Figure 3 and figure 4 say that OLED with sensing film behaves as a sensor [20-23].

Figure 5 and figure 6 show the viewing angles for the proposed OLED design with sensing film on glass substrate. The viewing angles of both are plotted. The contour plot of the viewing angle of OLED with glucose as analyte shows more out coupling efficiency compared to viewing angle ofOLED with blood as analyte. From figure 5 and figure 6, we can also conclude that there is a sensitivity that exists when we place analytes over the OLED.

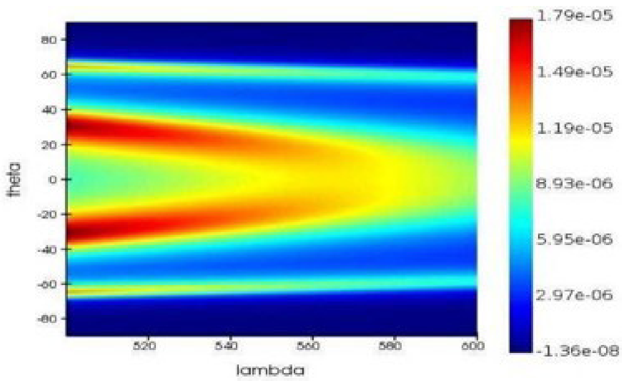

Figure 5: Viewing angle of OLED with analyte - blood.

From figure 7, the far field electric intensity of conventional OLED without analyte, OLED with blood as analyte and OLED with glucose as analyte is plotted. We found that OLED is operating as a sensor, as evidenced by the variation in the intensities with reference to various analytes. Hence, this is referred to as a dipole power transmission-based sensor.

Table 1: Materials and properties.

Layers in an OLED	Materials	Thickness layer (nm)	RI
Cathode material	Aluminum	120 nm	-
Hole-blocking lay	Bathocuproine	10 nm	1.686
Organic/Active layers	Tris(8-hydroxyquinoline) aluminum(III)	60 nm	01.68
	a-NDP	30 nm	-
Hole-transport lay	Diphenyl benzidine	50 nm	01.67
Hole-injection lay	Copper-phthalocyanine	25 nm	0.47
Anode layer	Indium-tin oxide	120 nm	01.8
Cover-layer	Silicon nitride	160 nm	01.9
Substrate	Glass	587.5 nm	1.5
Nanosphere	MgF_2	100 nm	1.36
Sensing film	PMMA	50 nm	1.48
Analytes	Blood	50 nm	1.38
	Glucose	50 nm	1.33

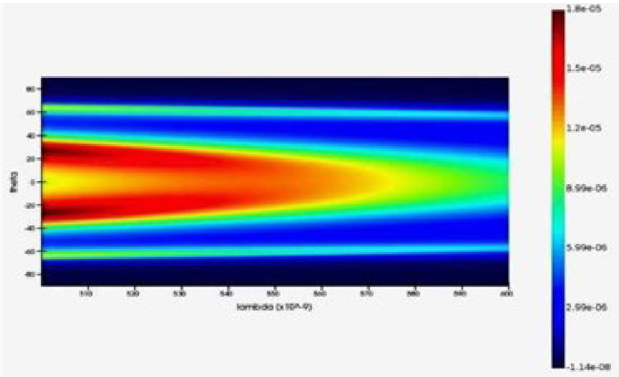

Figure 6: Viewing angle of OLED with analyte - glucose.

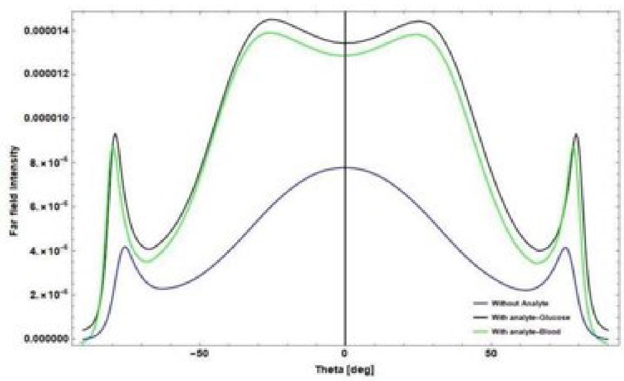

Figure 7: Far field intensity plot without and with analyte (Blood and glucose).

As a next step, we have placed an analyte to check whether the sensing film senses various kinds of analyte. The analytes used for our implementation are blood and glucose. The proposed design not only senses these two analytes but also is capable of sensing other analytes, can be taken as future work by the interested researchers.

Conclusion

Presenting an enhanced OLED light extraction model with the sensor achieving maximum light, since the sensitivity of the sensing film is dependent on the quantityof light out-coupled from the device. The light extraction effectiveness of the OLED device has been increased using a variety of effective layers, as well as the dielectric nanosphere layer of MgF_2 material, where the sphere's diameter and spacing are changed and have retrieved maximum light extraction for 100 nm diameter and zero spacing. The calculations and analysis were performed using FDTD simulation. Blood and glucose were the analytes utilized in our research study. The suggested device is not just responsible for sensing these two analytes, but also additional analytes. The proposed OLED operates as a transmission-based sensor. The OLEDs and sensing element are fabricated on substrates, resulting in a simple and portable device with the opportunities to grow in the medical sector for sensing applications due to its robustness, flexibility, cost-effectiveness, and performance. There is still scope for improving the design by adding photodetector to detect the electrical properties to analyze the sensed parameters of the analytes.

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Conflict of Interest

None.

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