

# Research on Different Physical Property Characterization Approaches for OLED Materials

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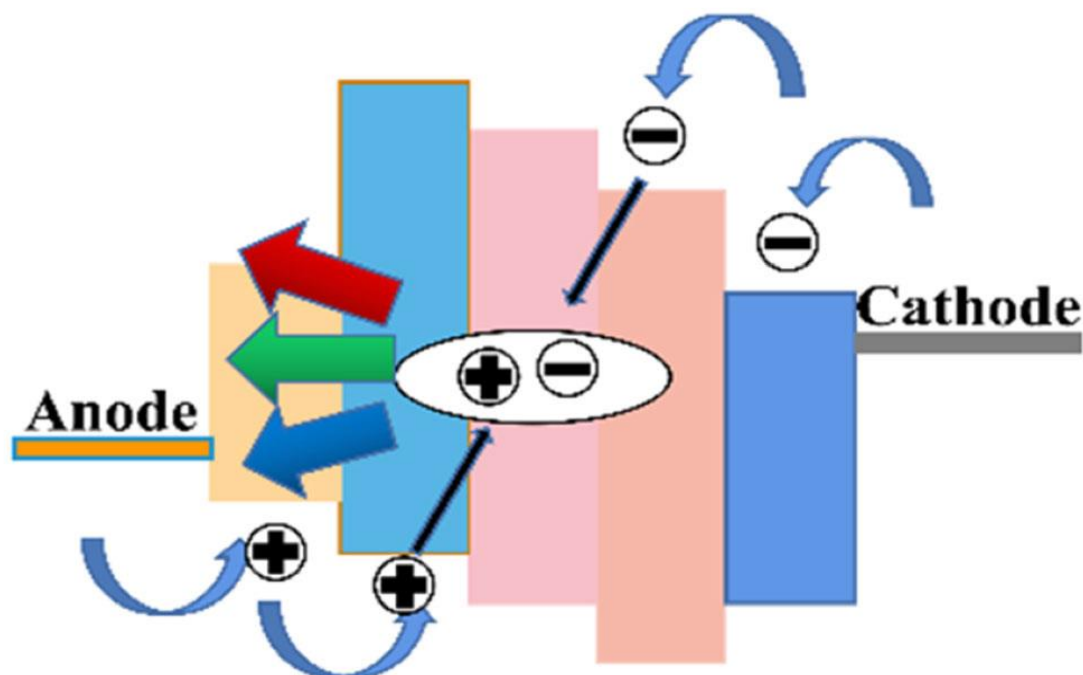
**Abstract.** Organic light-emitting diode, which is also commonly known as OLED, is one of the advanced materials for the development of the modern display technology. In the past decade, it has been well developed and successfully applied in display, lighting, screen devices and other fields. Before formally releasing them in the market, OLED materials need to be comprehensive tests on their performance to determine all parameters, of which their physical properties are of great importance to be included. In this paper, to systematically investigate on physical properties of OLED material, different approaches have been studied, including electroluminescence spectroscopy (ELS), photoluminescence spectroscopy (PL), time-correlated single-photon counting (TCSPC), and other approaches. At same time, this study also provides detailed information of each method of these characterizations for OLED materials. Through these analyses, the optical as well as electrical properties of these materials are well-studied. Overall, this research aims to gain a deeper understanding of OLED materials, which not only contributes to its future development, but also paves an avenue for the new generation of materials with advanced functions.

**Keywords:** Organic light-emitting diode; optical property; electrical property; characterization approaches

## 1. Introduction

In the 20<sup>th</sup> century, display technology as a human-machine interconnection and information display window has been widely used in military, civilian, and other fields [1]. In the 1980s, liquid crystal display (LCD) began to be widely used in information digitization and has achieved impressive results [2]. However, LCD has an obvious disadvantage, which is that it is not self-luminous, but only relying on backlighting or ambient light to display images. Moreover, LCD shows slow response time (milliseconds) due to a small viewing angle and cannot be used at low temperatures and other shortcomings [3]. Therefore, people were trying to find a new type of light-emitting materials which could replace liquid crystals, which has led to the birth of organic light-emitting diode (as known as OLED) [4]. Compared with LCD, OLED has characteristics of thin and light structure, low power consumption, high resolution and self-luminous, and successfully could be used to replace LCD in many electrical appliances in recent years [5, 6].

OLED is an organic semiconductor light-emitting diode whose emitting layer is composed of organic compounds. [7, 8, 9] The basic principle of OLED is organic electroluminescence. Firstly, applying an external voltage can let the electrons fill holes in the corresponding organic compound, in which way to release energy. Secondly, molecules of emitting materials absorb this energy, and then the ground state could be excited to the excited state. Finally, during the reverse process in which the molecule returns to the ground state, the radiation transfer induces the occurrence of luminescence [8, 10]. The principal schematic diagram is shown in Fig. 1 [8].



**Fig 1.** OLED light-emitting process [8].

Due to this special self-luminous nature of OLED, it has numerous applications in the marketplace. Each OLED material needs to do comprehensive tests to guarantee the quality before formally being released into the market, of which the physical properties is one of important aspects. For example, the material zinc (II) 8-hydroxyquinoline ( $Znq_2$ ) was studied by Nagpure's group. They analyzed the surface morphology of the material for flatness by different microscopy approaches. Finally, it was concluded that the better the flatness of the material, the better the performance of the material [6]. The thickness of the luminescent layer of OLED was investigated by Fadavieslam. He recorded the light absorption of indium tin oxide (ITO), which is assisted by the characterization of a double-beam spectrophotometer, which shows the wavelength of 285 – 800 nm. Ultimately, this experiment concluded that the increase of wavelength results in greater transmittance value of ITO [11].

In this paper, three parts will be presented. The second part will present several common approaches for characterizing the physical properties of OLED materials. The last part will summarize the whole paper.

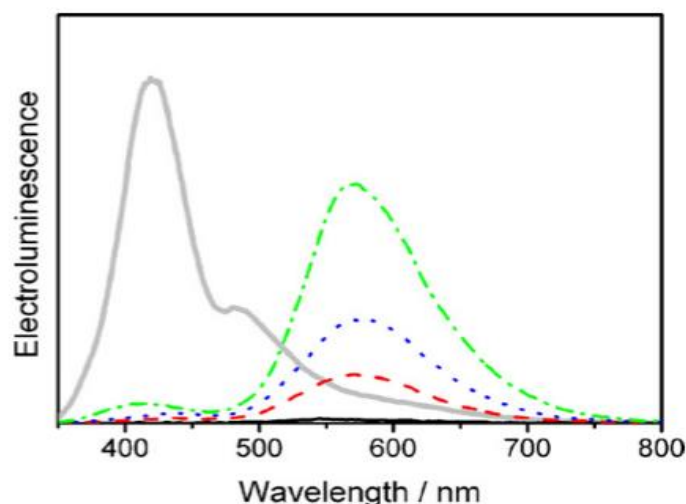
## 2. Characterization on physical properties of OLED materials

### 2.1. Optical property

#### 2.1.1. Electroluminescence spectroscopy

Electroluminescence is a process in which direct electrical energy is converted into light energy. This kind of luminescence does not have the phenomenon of first converting electrical energy into heat energy, which leads to an increase in the temperature of the object and luminescence. Therefore, this kind of light is called cold light.

According to the above principle, the electroluminescence spectrum can be obtained by conducting electroluminescence spectroscopy (ELS) characterization on OLED materials. The peaks shown on the spectrum indicate that the material has the maximum emission near a certain wavelength. Murakami Iha's group performed ELS on the inclusion of different ratios of *fac*-[ClRe(CO)<sub>3</sub>(bpy)], (where bpy refers to 2,2'-bipyridine) into poly(N-vinyl carbazole) (PVK), and the spectra obtained are shown in Fig. 2. The results show that with the increasing addition of Re (I) complex, the luminescence is turned from blue to red. Besides, the higher proportion of Re (I) complex results in the stronger intensity [12].



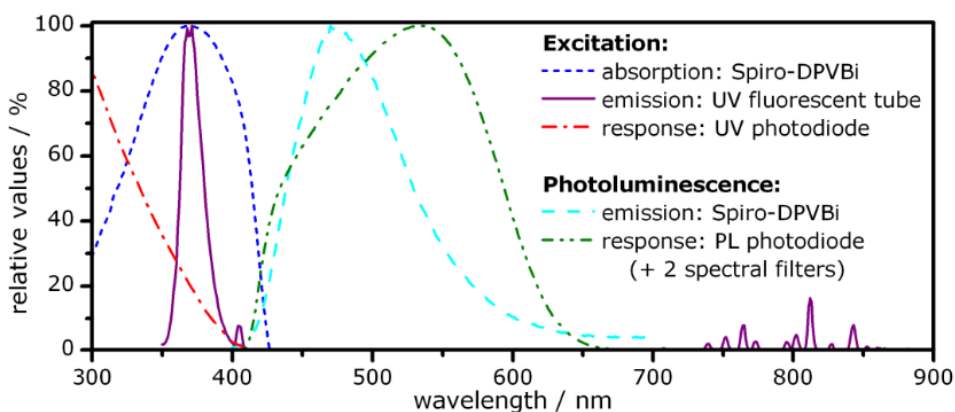
**Fig 2.** Electroluminescence spectra of 0% (grey line), 3.1% (black line), 5.3% (red line), 11% (blue line) and 25% (green line) the ratio of *fac*-[CIRe(CO)<sub>3</sub>(bpy)] and PVK in this material [12].

### 2.1.2. Photoluminescence spectroscopy

Photoluminescence (PL) is a phenomenon in which an external light source is in need to assist an object to induce the occurrence of optical property, thereby gaining energy that produces excitation leading to luminescence.

The PL characterization is a non-destructive test approach to characterize the luminescent properties of semiconductor materials quickly and easily when the excitation light energy is not very large [13]. It has many applications – 1. Component determination; 2. Identification of impurities; 3. Impurity concentration determination.

The photoluminescence spectra of spiro-9, 9'-bifluorene (Spiro-DPVBi) and PL photodiode was measured by Karl Leo's group. The spectra are shown in Fig. 3 [14]. As can be seen from this figure, the Spiro-DPVBi reaches its luminescence maximum at about 460 nm out, while the PL photodiode is at 550 nm.



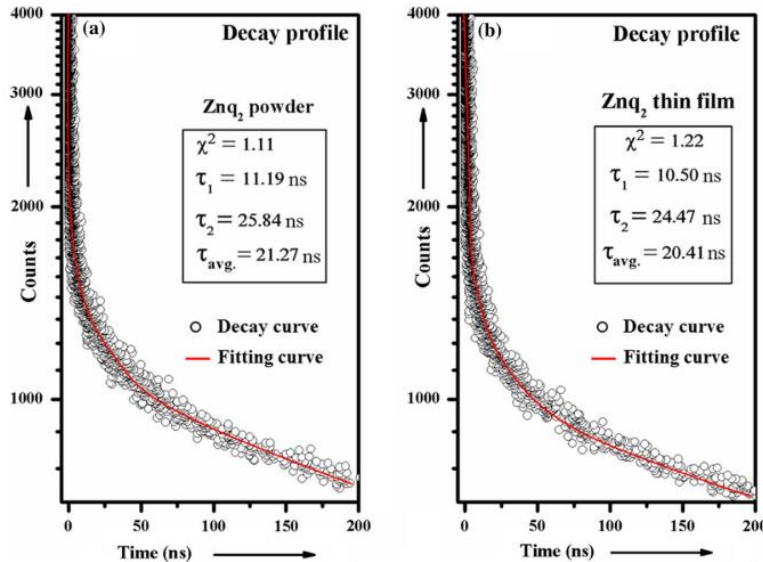
**Fig 3.** Photoluminescence spectra of Spiro-DPVBi and PL photodiode [14].

### 2.1.3. Time-correlated single-photon counting

The relaxation of molecules from excited to low-energy states can be characterized by the time-correlated single-photon counting (TCSPC). Macroscopically, this method is mainly study the decay of luminescence for OLED materials. In principle, the excited state of the sample and its energy releasing to another photon will have time difference, and TCSPC can be used to detect this process. Specifically, the experiments can be repeated several times to give the decay data.

Nagpure's group has done a study of zinc(II) 8-hydroxyquinoline (Znq<sub>2</sub>) together with the corresponding thin film material concerning their optical properties, in which TCSPC was employed for the lifetime decay characterization [6]. The life decay curves of the obtained Znq<sub>2</sub> powder and

Znq<sub>2</sub>: poly (methyl methacrylate) (PMMA) film are shown in Fig. 4. To better fit the data, the authors performed a biexponential fit to the Znq<sub>2</sub> powder and its Znq<sub>2</sub>: PMMA film. Ultimately, the fitted curves lead to the conclusion that the luminescence lifetime of PMMA films is superior to that of the powder.

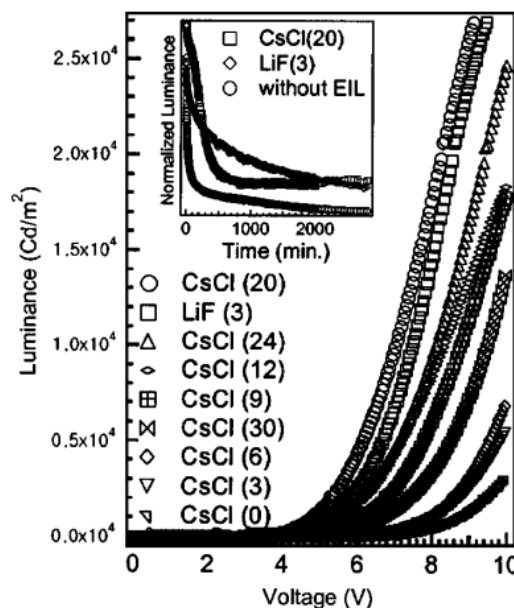


**Fig 4.** The lifetime decay data plots of (a) Znq<sub>2</sub> powder and (b) the thin film material of Znq<sub>2</sub> : PMMA [6].

**2.1.4. Luminance-voltage characteristics**

The luminance-voltage relationship curve reflects the optical properties of OLED devices. It is similar to the current-voltage relationship curve of LED devices. Specifically, the current density increases slowly when the driving voltage is low, and a slow increase can be found in the brightness. In contrast, both current voltage and brightness will have a rapid increase trend at higher driving voltage.

Jeong’s group investigated the enhancement of electron-transporting layer (EIL) brightness by the thickness of the CsCl layer, and Fig. 5 reveals results from this study [15]. As the results shown from this figure, the brightness enhancement of EIL is the largest when the CsCl layer reaches 20 Å.



**Fig 5.** Luminance -voltage plots of different EIL thickness in the Alq<sub>3</sub>-based device [15].

## 2.2. Optical property

### 2.2.1. Current density-voltage characteristics

The current density-voltage characteristic is the main parameter that characterizes the electrical performance of OLED. In OLED devices, the plot of current density with voltage reflects the electrical properties of the device, which is similar to the current density-voltage relationship of LEDs with a rectification effect. In specific, at low voltage, the increase of voltage leads to the slow grow in the current density. When the voltage exceeds the critical value, a rapid sharp will occur to the current density curve.

In the research, Fadavieslam measured the current density-voltage curve of the material by applying an external voltage to both sides of the OLED and then instrumenting it. The resulting curve is shown in Fig. 6 [13]. From the figure, it can be observed that, generally, with the decrease of the thickness of the light-emitting layer (EML), the on-state voltage will be correspondingly reduced.

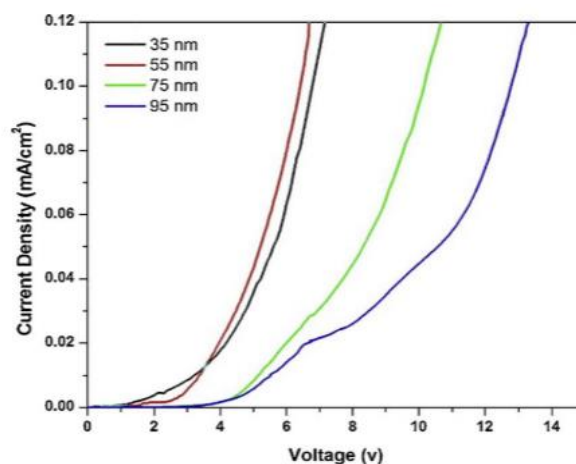


Fig 6. The plot of current density versus voltage of OLED with different thickness [11].

### 2.2.2. Resistance-voltage characteristics

The electrical performance of OLED will also be influenced by the resistance-voltage characteristic. The main reason why the resistance of OLED varies with voltage is that at low voltages, the depletion layer is unable for allowing carries to pass through, which will end up with the higher resistance for the device. Then, the resistance of the device is reduced by increasing the voltage so that the carriers can overcome the barriers and it is easier for the carriers to pass through.

Fadavieslam also performed resistance-voltage tests on OLED of different thicknesses, as shown in Fig. 7 [11]. The results show that as the voltage resistance increases, the performance of OLED was decreased. Besides, the resistance of the device decreases with the thickness of the EML.

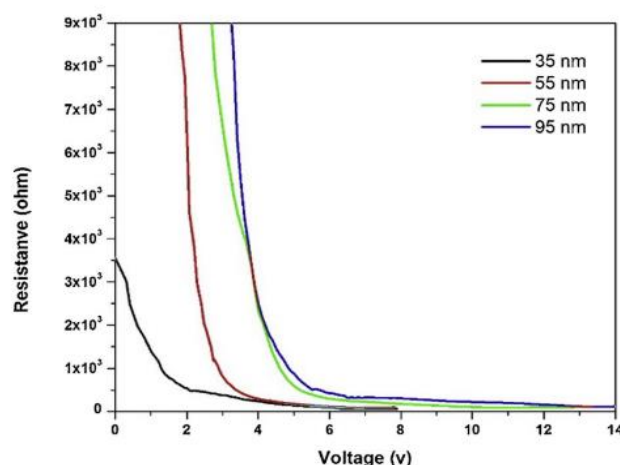


Fig 7. The plot of resistance and voltage OLED with different thickness [11].

### 3. Summary

In summary, there are various approaches to analyze the optical as well as electrical performance of OLED samples. In terms of optical properties, the maximum luminescence of a material at a certain wavelength can be measured by electroluminescence spectroscopy, which gives the detailed emission information of the material. Besides, photoluminescence spectroscopy can be used to measure the luminescence properties of a material as well as surface defects. The luminescence lifetime of a material can be measured by TCSPC. All these optical properties are crucial in ensuring applications are viable and practical. For electrical properties, the current density-voltage curve and resistance-voltage density curve of OLED materials can be conducted by instruments, which are key parameters for determining the electrical performance of OLED materials. With the development of the characterization means, the performance of OLED materials can be more comprehensively understood and developed, which can fully take advantage of OLED in advanced materials and everyday life.

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