Degradation of OLED devices: study methods and solutions

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Abstract

The fast technological evolution of our world requests the necessity to make this development sustainable. In order to achieve this goal more relevance has been given to the energy consumption and environmental impact of the modern society consumerism.
These considerations point out the need to increase the effort in research of unconventional materials, new concept and system architecture for devices that could help to overcome these challenges.
Nanotechnologies offer the best chance for this innovation and particularly organic electronics has been encouraged thanks to new attractive properties and promising applications.
Organic materials could be processed in thin film accommodating the issue of preservation of manufacturing energy usage despite from bulky and costly processes of inorganic industries. Fabrication techniques, including spin or spray coating, ink-jet or roll-to-roll printing, can be applied at low-temperature and over large area substrates. This is promising to maximize production throughput and to reduce costs. Also many other advances have been reached in the electronic applications of organic materials such as the spread of light-weight, transparent, flexible and disposable devices. Particularly, in recent years, OLEDs (Organic Light Emitting Diode) have been successful commercialized both for display applications and light source. OLED-based displays are nowadays commercialized both for high performances cell displays and TVs, becoming the major competitors of other well established technologies, like LCD or LED.
In imaging application, very often Active Matrix approach is used to supply the display. In recent years the use of another Organic Electronics device, Organic TFT (OTFT), has been exploited as Active Matrix driver with encouraging results.
In the last years also OLED-based light source have been introduced on the market. OLED panel technology allows overcoming some of the more critical issues of the preceding technologies such as very low energy conversion, as for incandescence source light, lack of good colors and the use toxic elements as for fluorescent tube and costly manufacturing processes and point light source as for the more recent LED technology.
Despite all these amazing results, important drawbacks still remain in the field of organic electronic devices. Low charge carrier mobilities or still expensive manufacturing cost, but the more critical is extreme sensitivity to ambient conditions, temperature, light, and particularly oxygen and moisture, which could degrade their optical and electrical characteristics.
This work of thesis sets in this scenario and the aim of this research is the study of degradation phenomena through methodology that leads to the identification of the different mechanisms of degradation involved, responsible of device short life time.
The present work has been developed focusing the attention on the various degradation mechanisms in OLED and the possibility to use their nature to develop innovative analysis methods. For this purpose has been exploited both extrinsic and intrinsic degradation. Critical issues in this field are

the complexity of the involved phenomena and the relatively recent interest of the scientific community in the intrinsic degradation topic.
In the organization of the thesis work, after a brief presentation of the main features of organic electronics, an overview of the basic principles of permeation and typical encapsulation solutions are presented. In particular, specific attention has been paid on barrier requirements and solutions presented to protect the devices. These solutions, besides being the way to control extrinsic degradation, are also used to isolate other degradation components becoming a tool for studying the intrinsic degradation in organic devices. It has been also pointed out the importance to evaluate the barrier characteristic in terms of WVTR and here has been presented some solution to evaluate ultra-high barrier permeation. The study has been then centered on the design and development of a Calcium corrosion test for the evaluation of ultra-high barrier. It has been investigated all the aspect of layout and setup to achieve a higher sensitivity level. This measurement method has been employed for the design and optimization of both a glass to glass and Thin Film Encapsulation barrier permeation system. In the first case (glass to glass) the developed encapsulated system has been used in an effective way to estimate lifetime of a simple OLED structure and validate the system performances.
Afterwards, the investigations have been focused on intrinsic degradation process. For this purpose the glass to glass encapsulation system has been also used to neglect external agents within the development of an innovative method based on accelerated environmental aging conditions for the study of intrinsic degradation phenomena components. Thus an innovative methodology to study this issue has been proposed and tested on a case study.
In order to reach this goal resulted very important to separate extrinsic degradation component from the intrinsic one so in this thesis we worked on the following topics reaching very satisfying results:

- reliable evaluation of permeation barriers using the electrical calcium corrosion test
- glass to glass and thin film encapsulation permeation barrier system
- devices (OLED) lifetime under accelerated aging conditions
- intrinsic degradation study: methodology and application

Regarding the first topic a measurement system based on Calcium corrosion test has been first studied, designed and developed taking into account every detail leading to a result alteration. Then first a glass to glass and later a thin film encapsulation system has been designed and developed in the same way. The Calcium corrosion test measurement system was then used to measure the barrier performances of the developed encapsulation systems revealing values of WVTR in line with literature results obtained through the selected techniques. Particularly had been detected a WVTR value of 4 10^{-6} g m^{-2} day^{-1} and approximately 10^{-2} g m^{-2} day^{-1} respectively for glass to glass and Thin Film Encapsulation system.

Regarding OLED lifetime, using simple devices, experiments were conducted for one OLED-structure processed on glass. The structure used an ITO bottom contact as well as an aluminum top contact. The realized devices after 3000 hours have lost only a 20% in luminance from the initial value validating the performances of the developed encapsulation solution for devices realized on glass substrate in the same time of observation.

This result if from one side is very encouraging for lifetime issue on the other side is the key element that allows neglecting external effect during further degradation study. The results achieved on these topics results precious to focus on the last aspect faced during this work. In fact using our encapsulation system and applying different experimental techniques, typically not employed, has been possible to put in light single intrinsic degradation mechanism involved. Particularly has been decided to focus on possible phenomena that can occur during OFF-time periods (without electrically stressing the samples). Experiments have been conducted at different storage conditions on two types of blue OLEDs representing the worst stability case. This study revealed , in condition that allow to neglect other degradation source, that physical aging occurs for both types of devices, leading to irreversible time-dependent luminance loss. The proposed method in this case study (accelerated environmental aging conditions) coupled with other more common used analysis conditions allows to study the degradation topic in a more complete way.