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(Research Article)

# Evaluating the capability of Ceylon $TiO_2$ synthesized by closed process in OLED performance enhancement

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## Abstract

$TiO_2$ has been recently used in organic light emitting devices (OLED) in different layers as embedded nano particles, nano composites. These nano materials are reported to be useful in enhancing OLED device performance such as charge injection. Usually, $TiO_2$ is industrially synthesized by either sulfate or chloride processes, which are known to be environmentally hazardous methods. Here we are comparing $TiO_2$ synthesized by a closed processes under low temperature against commercial $TiO_2$ to be used in OLED applications by preparing submerged $TiO_2$ nanoparticles in 2, Poly(9-vinylcarbazole (PVK) by spin coating and vacuum depositing organic semiconductor diodes and later trying to evaluate charge transport characteristics.

**Keywords:** Thin film; OLED; $TiO_2$; PVK

## 1. Introduction

The conventional LED and OLED follow the same mechanism of recombination of electrons and holes in emitting light. However, the charge transport and processes impacting on recombination rates are different. A typical OLED consists of multilayer architecture [1]. The different types of layers consist of cathode, anode, emissive layer, hole-injection layer, hole-transport layer, electron-injection layer, electron-transport layer and sometimes blocking layers also. Assisting transport or blocking is achieved by matching the HOMO and LUMO levels and creating large energy gaps respectively. There have been many attempts to succeed in aligning HOMO and LUMO levels [2,3]. Titanium dioxide, an inorganic insulator has been used in OLEDs to achieve different aspects such as to improve the photonic efficiency [4], used as thin buffer layer to enhance the efficiency of OLED [5], to achieve enhanced current-voltage characteristics and photoluminescence (PL) properties by embedding $TiO_2$ in both hole transport layer (HTL) and emitting layer (EL) [6]. In current study we evaluated, the performance of $TiO_2$ used in an organic light emitting diodes by comparing with commercially available $TiO_2$. The Ceylon -$TiO_2$ was synthesized, following the closed process involving a rotatory autoclaving followed by refluxing and stationary solvothermal treatment of ilmenite, below 170 celsius instead of conventional open processes, which have drawbacks like cost and environmental impacts reported by Rajakaruna *et al.* [7].

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**Table 1** Three device configurations were fabricated. Device 3 act as a reference device.

| Configuration | Device Name |
|---|---|
| ITO/PEDOT:PSS/PVK + com $TiO_2$/Al | Device 1 |
| ITO/PEDOT:PSS/PVK + Ceylon $TiO_2$/Al | Device 2 |
| ITO/PEDOT:PSS/PVK/Al | Device 3 |

## 2. Methodology

We developed three devices without a proper emissive layer with the idea of clarifying the charge injection nature with following configurations. The ITO substrates were cleaned using deionized water, acetone, 2-propanol and then cleaned with UV – ozone exposure in which is a common procedure for cleaning.

In all devices, poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) thickness was maintained to 50 nm by controlling the rpm of spin coating at 600/2600 and 2000 rpm [8]. 2, Poly(9-vinylcarbazole) (PVK) and PVK + dispersed titanium dioxide ($TiO_2$) layers were controlled around 100 nm by spin coating and vacuum deposited aluminium at 100 nm. $TiO_2$ particles were submerged in PVK solutions using chloroform as the solvent, with subsequent 8-hour ultrasound sonication to achieve homogeneity. PVK+$TiO_2$ layer thickness was verified by using profilometry.

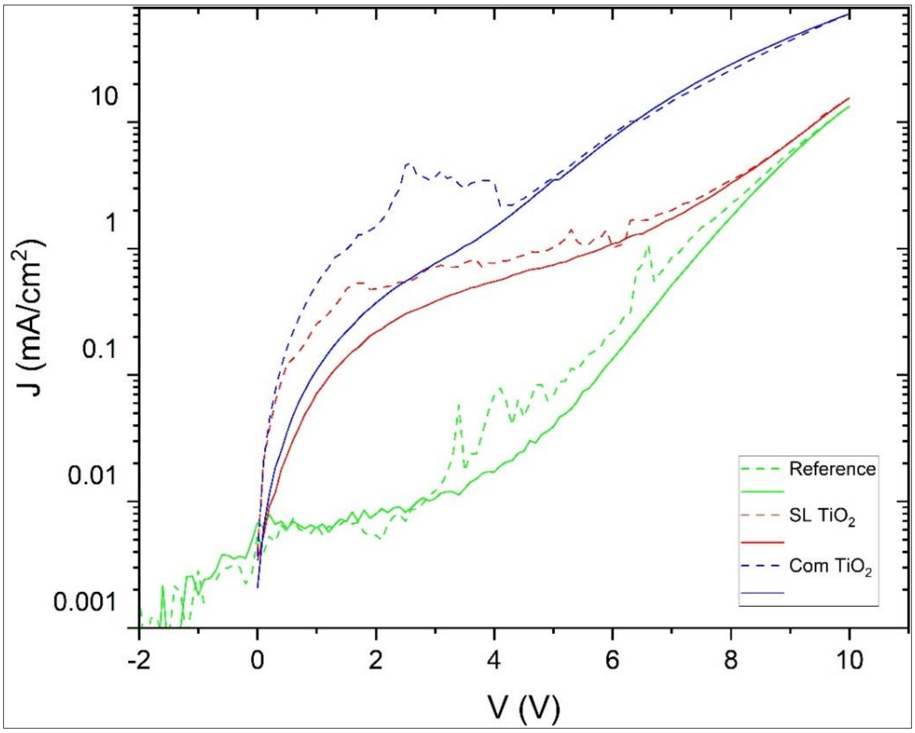

**Figure 1** Current Density - Voltage Curves of three devices. Green colour lines representing the reference device and red colour is the Ceylon $TiO_2$ version and blue lines representing the commercial $TiO_2$ where, forward scan in dashed line and reverse scan in solid.

## 3. Results and Discussion

The J-V curves for three devices suggest a current density harvested from the Ceylon variant is par with the reference device, and the commercial one shows a much better J-V characteristics with high current density values and possibly lower operating voltages. This type of improved behaviour from commercial $TiO_2$ embedded devices has already been reported from PVK + nano composite $TiO_2$ embedded devices [4] and devices with different forms of $TiO_2$ incorporated in different layers [9,10]. However, once the scale is changed to logarithmic scale, we can clearly see the correspondence of two $TiO_2$ devices in the range between 0 – 4 V region.

$$m = \frac{\Delta \log J}{\Delta \log V} \qquad \text{(Eq 1)}$$

The scattered forward scan and a smooth reverse scan with hysteresis in J-V curves can be explained in terms of charge traps, and material nonuniformity in the PVK + $TiO_2$ or electrodes. Furthermore, from double log J-V curves, the slope (Eq 1) is calculated to be of showing ohmic character below 1 V for device 1 and 2 respectively where the reference device shows ohmic character until 4 V, quite similar to previously recorded values in ohmic region [11]. Hence we expected to observe space-charge-limited-current from these devices around 10 V, but was not observed. Though we were able to observe trap-filled-limited current with higher *m* values (Device 1 - 4.5, Device 2 - 5.6 and Device 3 - 8.9) can be used to predict the abundance of traps in the devices. Also one can proclaim that the addition of $TiO_2$ may have had an effect of these traps by improving trap-filled-limited current of $TiO_2$ devices. Then again, we measured the displacement current response (DCM - displacement current measurement) from all three devices. Usually in OLED devices DCM experiments will reveal the interface effects such as charge accumulation at interfaces [12]. But DCM for these devices revealed the non-existence of such interfacial effects from all devices.

## 4. Conclusion

Based on our observations, we can suggest that the Ceylon $TiO_2$ also can be used in OLED applications to get the same effects with device quality improvements. But it is important to acknowledge that the submerging nano particles may have influenced the homogeneous spread of thin films and repeatability of the devices. In conclusion we admit that Ceylon $TiO_2$ can be a candidate for OLED while further investigation on light emission and charge transport characteristics need to be systematically evaluated.

## Compliance with ethical standards

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### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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