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A Comparative Study on Detailed Structure of QDLEDs

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Abstract—*As the world is moving towards contraction of devices using nanomaterial can help in enhancing the characteristics of the device. Materials in nanoscale region especially Quantum dots whose size is in between 2-10 nm in diameter, shows extraordinary tunability which enables them to be used in wide range of applications in science and technology. Quantum dots possess electronics and optical properties between bulk material and smaller molecules/atoms proving it proficient for various applications like in photovoltaic devices, optical amplifier, optical computing, bio-sensing, biomedical etc. For this particular paper we focused on quantum dots used in Light Emitting Diode (LED) application as they are about to replace the market of LEDs as Quantum Dots Light Emitting Diode (QDLEDs or sometimes referred as QLEDs) are extremely energy efficient, durable, having longer life and can produce light of any desired colour. Due to the introduction of mass production of QDLEDs the cost has reduced and is expected to go down a bit more making it cost effective too. Therefore in this paper a comparative study on the basis of efficiencies of different types of QDLEDs that are Inorganic LEDs, Organic LEDs and Hybrid LEDs, is presented. Also their comprehensive structures are discussed in brief.*

1. INTRODUCTION

Miniaturization is the need of hour. The CMOS technology is thus rapidly growing towards large scale integration on a single chip leading to smaller size consuming smaller area, lower power consumption, faster speed etc. But reducing the size also leads to various challenges especially short channel effects. Thus the world is moving towards nanotechnology where the dimensions are in nanometers. Various application of using nanomaterials in electronic devices is photovoltaic devices which includes solar cell, LED, LASER, photo detectors etc. [1, 2] Also nanoparticles can be used in sensing application. In this paper we have reviewed how quantum dots facilitate the efficiency of a LED which has now replaced the world of lighting from tungsten and incandescent lamp by using the same energy but producing light for longer duration. So the light bulb of the future may just be a small piece of semiconductor. Instead of heating tungsten to at least 1,700^{o}C or exciting fluorescent gases, LEDs can produce the same lumens with much less electricity. LEDs are mercury free, and have the advantages of being environmental friendly, energy efficient, long lifetimes, durable and minimum heat loss. New LED lights can produce equivalent light of 100W incandescent while consuming only 13W of power. Due to its high power to light conversion efficiency which is approximately 50% greater than simple tungsten lamp, it can last up to as 50,000 hrs gradually dimming over time, compared to a typical 100W incandescent which can stand only 800 hrs. [4, 5]

A Light emitting diode (LED) is basically a p-n junction diode. When carriers are injected across a forward-biased junction, it emits incoherent light. This emission can be tuned in whole of the infrared spectrum by diffusing QDs (nanoparticles which can emit different colors by simply changing the size of the particle) in between the p-n junction.Such LEDs are then called Quantum Dots Light Emitting Diode (QD-LED or just QLED). To increase the efficiency and stability of QLEDs one can use the core-shell structure of quantum dots.

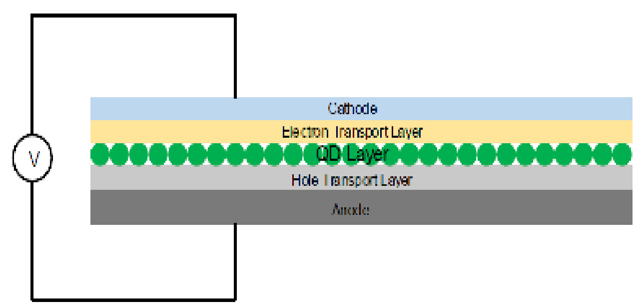

Fig. 1: Basic structure of QDLED

A typical QLED consists of three layers: emissive layer (multilayer or monolayer of quantum dots) sandwiched in between electron transport layer (ETL) and hole transport layer (HTL). ETL expedite the transport electrons from cathode to the emissive layer and block holes. Similarly HTL is responsible for the transportation of holes from anode to emissive layer blocking the electrons. On applying the electric field, the electrons and holes are attracted towards the quantum dot layer where they are captured by quantum dots and recombination of electron and hole takes place which results in releasing a photon. The basic requirement for achieving QLEDs with very high efficiencies is to have those quantum dots that have a high quantum yield for electroluminescence and a device structure that is optimized for efficient charge injection [36].

The charge transport layer chosen in QDLEDs, they can be categorized as organic QDLEDs in which the transport layer is of organic materials and are called organic light emitting diode (OLED), inorganic QDLEDs which constitutes of inorganic layer in LEDs and hybrid QDLEDs which utilizes the advantage of both organic and inorganic materials and both types are fused together to get hybrid LED (HyLEDs). While Inorganic LEDs and Organic LEDs each have their own unique advantages, Inorganic LEDs are especially appealing for their narrow bandwidth and simple color tunability, since changing the size of a quantum dot changes its emission wavelength. Inorganic LEDs may also have longer lifetimes than OLEDs. Also QLED based on colloidal quantum dot emitteroffer several advantages over other large-area LEDtechnologies, including size-controllable emission, wavelengthtunability and a narrow emission. Therefore such devices would be able to take full advantageto provide tunable, simple and coherent light sources.

2. ORGANIC LIGHT EMITTING DIODES (OLED)

Owing to various benefits (excellent performance, chemical versatility, mechanical flexibility, easy fabrication) of Organic light emitting diodes (OLEDs), they have now known as the next generation lighting and displays which makes them an absolute modern light source. [12, 16, 13, 18] An OLED is a solid-state semiconductor device (100 -500 nm) thick consisting of two layers namely, conducting layer and an emissive layer, both squeezed between two electrodes and deposited on a substrate. The conducting layer is built up of organic plastic molecules that conduct "holes" from the anode. The emissive layer is again a film consisting of organic compound that carry electrons from thecathode and emits light in return to an electric current. Due to this relocation of electrons induced by conduction starts in the organic layer and this conduction can be changed from that of an insulator to a conductor. The interface between the two layers of the OLED grants a potent site for the recombination of the injected electron-hole pair resulting in electroluminescence.Therefore, OLEDs are double charge injection devices which require the concurrent supply of both holes and electrons to the electroluminescent material. There are two main types of OLED devices, one are those which are made with small organic molecules and the others those are made with organicpolymers.[14,15]

A comparative table of few OLEDs made on the basis of various layers used and their External Quantum Efficiency (EQE) and luminance is presented in table I.

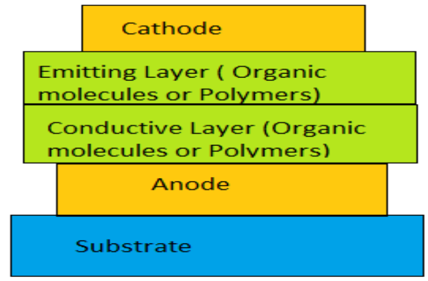

Fig. 2: Basic structure of OLED

3. INORGANIC LIGHT EMITTING DIODE

Although OLEDs have proven its efficiency but still it requires environment packaging resulting in increase of the final cost of the device. Therefore replacing organic layers byinorganic layers is quite beneficial as they are more stable than the organic dyes.

Table I: Comparative table of OLEDs

S. No	HTL/HIL	QD	ETL/HBL	EQE (%)	Luminance (cd/m2)	Ref.
1.	TPD	CdSe@ZnS	Alq3	0.52	190	10
2.	TPBi	ZnCdS@ZnS (red)	SpiroTPD	1	7	11
		(Orange)		2.7	13	
		(Green)		2.6	28	
		(Cyan)		0.2	3	
		(Blue)		0.4	15	
3	TPD/ PEDOT: PSS	CdSe@ZnS (red)	Alq3/TAZ	1	100	12
		ZnSe@CdSe@ZnS(green)		0.5	100	
4	Sp-TPD/PEDOT:PSS	ZnCdSe with oleic acid as capping ligand	TPBi	0.7	-	13
5	CBP	CdZnSe@CdZnS	Alq3/TAZ	0.5	-	14
6	TPD/PEDOT:PSS	CdSe@ZnS (red)	Alq3/TAZ	1.6	-	15
		ZnSe@CdSe overcoat-ed with ZnS (green)		0.65	-	
		ZnCdS (blue)		0.35	-	
		(white)		0.36	13.5	
7	PPV	CdSe multilayer	-	0.001-0.01	100	16
8	PVK	CdSenanocrystals	t-Bu-PBD	0.0005	-	17
9	Poly-TPD/PEDOT:PSS	CdSe@ CdS@ZnS (red)	Alq3	>2	9064	18

And also will enable air stable devices that do not require packaging consequently decreasing the cost of layers is advantageous as they are robust and are also anticipated to empower higher operating current.[26,24].

The structure of ILED is similar to that of OLED where the emissive layer is sandwiched between the HTL and ETL. Here ETL is n-type inorganic layer that inflate the inoculation of electrons into the emissive layer which can be a monolayer or multilayer of QD. The major need in these LEDs is to have a transparent anode. Also environment factor like temperature also modifies the properties of the emissive layer therefore it is very important to maintain the processing temperature which is usually 100-150^{o}C. Also, in ILEDs the operation of transfer of charge carrier is based only on direct charge injection which demands band alignment and therefore is one of the main reasons of low efficiency of ILEDs. Thus to increase the efficiency of these LEDs considerable approaches are explored. One is to validate foster energy transferexcitation of colloidal QD and another is to look up for new techniques for QD excitation. [20, 22, 23, 25]

A comparative table of few ILEDs made on the basis of various layers used and their External Quantum Efficiency (EQE) and luminance is presented in table II.

Table II: Comparitive study of ILEDs

S. No	HTL	QD	ETL	EQE	Luminance (cd/m2)	Ref.
1	NiO	ZnCdSe	ZnO:SnO2	0.09	1500	19
2	NiO/Wo3	ZnCdS@CdSe@ZnS@ZnCdSe	SnO2/ZTO/ZnO/ZnS	0.2	-	20
3	p-GaN	CdSe@ZnS	n-GaN	0.001-0.01	-	21
4	ZTO	CdSe@ZnS	ZTO/ZnS	0.15	1040	22
5	ITO	CdTe + LDH	-	0.031	232.7	23
6	NiO	CdSe@ZnS	ZnO	-	249	24

4. HYBRIDLIGHT EMITTING DIODES (HYLEDS)

The major obstacle of OLED to enter the market of lightening technology is because of its intrinsic low environmental stability which indeed forces the devices to be confine so as to boost their lifetime and this factor causes the increase in the final cost of the device fabricated. Thus to prevail these problems a different approach is used which includes metal oxides layer as an efficient electron injection contacts in inverted OLEDs. HyLEDs are nothing else but simply inverted OLEDs that engage air-stable metal oxides as the charge injection contacts. Therefore they are a potentialcompetitor to standard OLEDs, due to their undeniable advantage of intrinsic air stable electrodes and solution processability, which could indeed result in large area, low-cost light emitting devices.

For anode, a high work function and air stable metal is used. In order to have a simplified device the metal oxide is used as electron injection layer which indeed make the fabrication of

OLED having very simple or no encapsulation at all. This layer is deposited between metal and organic semiconductor and it should have very low CB so as to facilitate hole injection. These oxides can be SnO_2, ZnO and TiO2 etc. Now taking the cathode side into consideration, insulating metal oxide layer has been inserted (which could be Al_2O_3, MgO or

SiO_2) in between organic semiconductor and aluminium electrode which increases the efficiency of the device. The need of these metal oxides layers is due to their chemical stability, variety and specific physical properties which includes high charge mobility, transparency, low toxicity and also they are inexpensive.

A comparative table of few HyLEDs made on the basis of various layers used and their EQE, luminance and turn on voltage is presented in table III.

5. CHALLENGES AND CONCLUSION

There are a few challenges that QDLEDs are facing that are hindering it from coming into the market. These problems include Photoluminescence (PL) quenching, [25,26] auger recombination,[6] QLED outcoupling,[27] QD charging[35]. These issues degrade the efficiency of the device and work is being done to reduce these effects so as to increase the performance of QDLEDs.[38,39] Various schemes are proposed already for the same. A unipolar architecture was proposed by a team of MIT so as to eliminate the need of band alignment and packaging. [22] Here instead of p-i-n structure they used n-i-n structure and it showed 0.15% external quantum efficiency. Similarly homojunctions can be used for the same purpose. The most commonly used material for homojunction is ZnO where ZnO is N-type material and it is doped to get P-type layer.

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