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Multilayer Approach in Light-Emitting Transistors

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1. Introduction

1.1 OLED Vs. OLET

Plastic electronics, i.e. electronics based on organic polymer and molecular semiconductors, is a key low-cost technology for new vast application areas. The scope of applications in plastic electronics is virtually endless. It ranges from opto-electronic devices and flexible organic light-emitting diodes (OLEDs) displays, to ultra-cheap, radio-frequency identification tags that can replace the now ubiquitous bar-codes, and to wearable computing and electronic bio-interfaces.

The first demonstration of the OLED dates back to the 1960s when electrically driven light emission from non-crystalline organic materials was first observed. After that, several studies were carried out by academic groups and companies (Kodak, Pioneer, Motorola, NEC, etc…) both for fundamental physics comprehension and application purposes. Nowadays electronic products containing displays are becoming more and more portable. Therefore, they need some peculiarities like lightweightness, flexibility, brightness, etc… These, with many others, are the strong points of the OLEDs. In fact they are thinner, lighter and more flexible with respect to their inorganic counterpart. Moreover, OLEDs can be as bright as LEDs and they consume much less power. Due to the organic processability, they are easier to produce and can be made on larger area. Finally OLEDs have large fields of view, about 170 degrees, a significantly advantage over, for example, liquid crystal displays. Of course, these devices present also some disadvantages: they have typically shorter lifetime (in particular lifetime of the blue emitter is critical, about 1.000 hours), they are not very stable and can easily be contaminated by water or oxygen.

In general, with respect to OLEDs, organic light-emitting transistors (OLETs) present some fascinating characteristics which overcome many physical and technical drawbacks in the realization of nano-scale integrated electroluminescent devices.

The main difference between the vertical (OLED) and planar (OLET) device geometry is a direct consequence of the different device structures. In OLED, charge transport occurs perpendicular to the organic layers (bulk charge transport) while in OLET the transport occurs horizontally (field-effect charge transport).

Under the typical biasing conditions, the electron and hole mobility can be about four orders of magnitude higher in OLETs than in OLEDs, thus affecting directly the material lifetime and exciton emission. In a typical OLED structure, the minority carriers travel only few tens

of nanometers to encounter the opposite sign carriers and to recombine radiatively. In OLETs, instead, both carriers must travel longer distances (typically tens of micrometers), which impose more requirements on the organic semiconductors charge transport properties.
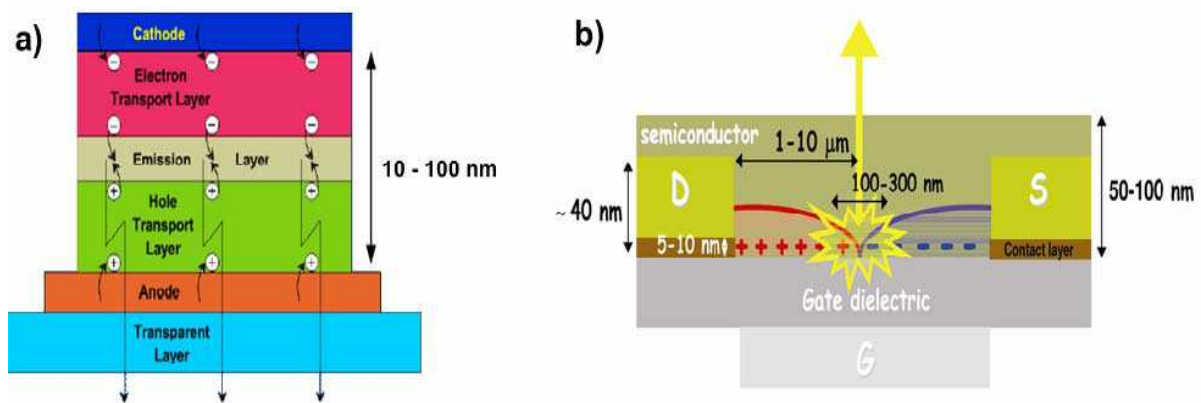

Fig. 1. Schemes of an OLED (a) and an OLET (b) showing for each the typical dimensions

A clear advantage of the OLETs is the virtually higher electroluminescence quantum efficiency inherent to the device structure. Indeed, in OLETs it is possible to drastically reduce the exciton quenching due to the interaction with charge carriers, with the externally applied electric field and with metal contacts.

For what concerns the exciton-charge interaction, even though the current density in an OLET is expected to be higher (1–10 A/cm^2, for a 1-nm-thick accumulation layer) compared to OLEDs (10^{-3}–10^{-2} A/cm^2), the spatial localization of exciton formation an OLET could favor an effective separation between the exciton population and the charge carriers thus avoiding any quenching for that kind of interaction. The presence of a third electrode helps to achieve a balanced charge carriers current, therefore further reducing exciton-charge quenching. In OLET, compared to OLED, all the operational requirements of the basic electronic and optoelectronic elements in active matrix displays, are satisfied in a single device structure. Indeed in conventional OLED electronics, such a high degree of integration cannot be achieved and, for each pixel, an electrical switch and a separate light source must be combined. Lastly, in OLETs is possible to control the position of the emission zone inside the channel length.

2. Approaches to OLETs

According to the previous section, it turns out how the OLET structure presents more intriguing potentiality compared to OLED. However, the actual degree of exploitation of this technology depends on the development of new organic materials combining multiple functionalities and high performances. Moreover, many structure-related issues are to be considered in order to get good electrical properties and intense light emission from the device.

Indeed, since FETs (and thus OLETs) are considered as truly interface devices, processes that take place in the device active region, like charge transport, energy/charge transfer, exciton formation, charge trapping, are strongly dependent on interface. In recent years it has been demonstrated that the chemical structure of the organic semiconductor is not the

only factor that determines whether an organic FET exhibits predominantly p-channel or n-channel behaviour. Processing and characterization conditions, device architecture, and choice of electrodes are important as well.

To get an insight into the main phenomena that happen at the interfaces, many aspects must be taken into account: the chemical and electronic interaction taking place at the different interfaces (dielectric/organic, organic/organic and organic/metal), the modulation of the molecular electronic structure in the active material due to the proximity with other functional layers (polarization, relaxation), the bonding and ordering of molecules at the interface (which strongly determine the growth morphology). For example, crucial processes of charge accumulation and transport in OLETs take place at the interface between the gate dielectric and the semiconductor. Thus, the properties of this interface and the dielectric have a huge influence on device opto-electronic performances.

Device parameters such as mobility, threshold voltage, sub-threshold swing, etc. depend not only on the nature of the semiconductor but also on the chemical structure and dielectric properties of the insulator. The requirements for gate dielectrics in OFETs are rigorous. They should show high dielectric breakdown strength, contain only minimal concentrations of impurities, that could act as traps, and must be easily processable and be environmentally stable.

From the point of view of light emission, the requirements depend on the approach used for fabricating the OLET, but regardless the implemented architecture, it is absolutely important the use of high emission efficiency organic materials. In the next sections we will discuss some issues related to the emission in different OLET approaches, each with its points of strength and weaknesses.

2.1 Unipolar OLETs

Historically the first demonstrated OLET was achieved in unipolar charge carriers transistors made by tetracene by Hepp et al. in 2003 (Hepp et al., 2003). The device was fabricated on Si/SiO$_2$ substrates in bottom-gate bottom-contact configuration, with gold electrodes. The material was chosen because of its good charge carrier transport and EL properties. The electrical characteristic of the OLET were typically of a unipolar p-type transistor and can be seen in Fig. 2, along with a picture of the illuminated channel (located near the drain contact). Despite the electrical unipolar behaviour, the observation of light emission from tetracene proved an undoubted presence of opposite charges recombining inside the material. Given the inhomogeneous illuminated channel area, Hepp et al. introduced then an empirical model in which they supposed different injection mechanisms at the source or drain electrodes as a consequence of the thin-film physical imperfections. In particular they assumed that, due to under-etching problems of the electrodes that act as a shadow mask, a thinner tetracene layer is formed at the organic/electrode interface resulting in a poor electrical contact.

During device operation, the channel is filled with holes. However due to imperfections of the electrode, holes cannot directly reach the drain through the channel, but they must travel a certain distance in the tetracene bulk film. On the other side, since the gate field is screened by holes at the dielectric/organic interface, there is a high electric field at the drain electrode. This strong field, magnified by the local spikes due to the imperfections on the contact, could be intense enough to allow injection of electrons into the organic (Murata et al., 2001). For more details, see fig. 3.
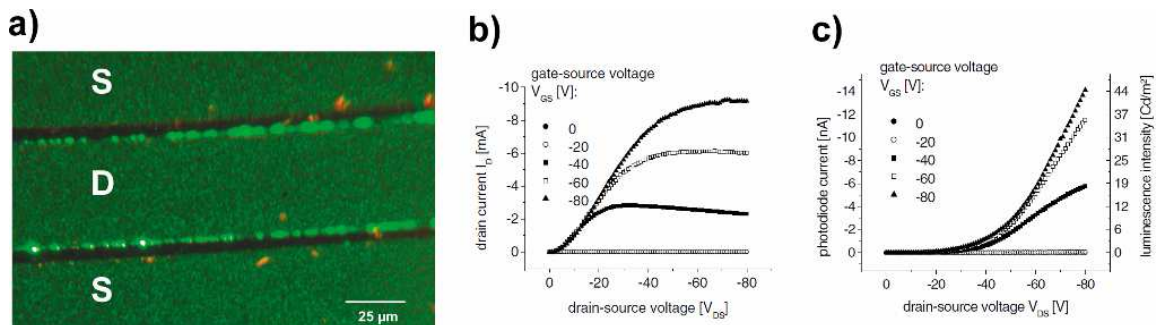
Fig. 2. Image of the illuminated channel with the typical green-light emission of tetracene (a), I-V characteristic (b) and electro-luminescence (c) measurement of the device, in the negative bias region
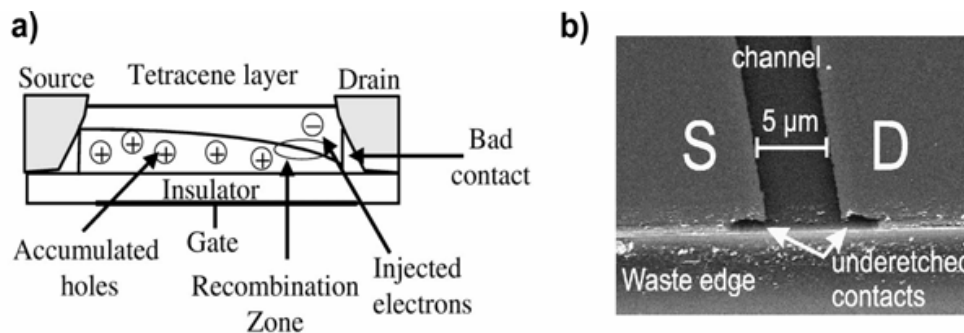

Fig. 3. Scheme of the device with the edge effect at the contacts proposed to demonstrate the electrons injection from the drain contact (a), example of a SEM image showing the underetching effect (b)

A successive study proposed a phenomenological model to explain the working mechanism of the OLET. The proposed model assumed that the voltage drop at drain electrode, caused by a contact barrier, induces a distortion of the Highest Occupied (HOMO) and Lowest Unoccupied (LUMO) Molecular Orbital levels of tetracene near the contact, thus determining the conditions for the tunnelling of electrons from the drain to the LUMO of the organic (Santato et al., 2004).

In the proposed model, the external quantum efficiency (EQE) is proportional to the tunneling probability and thus proportional to the drain-source voltage (V_{ds}), but it is independent from gate voltage (V_g). Indeed, increasing V_g leads to an overall increase of the electroluminescence (EL) but leaves unaffected the EQE.

Several other approaches have been performed on unipolar OLETs (Oyamada et al., 2005a). In particular, Oyamada et al. succeeded in demonstrating how the channel length could affect EQE of thiophene-derivative devices and they obtained, for a channel length of 0.8 μm, an EQE of 6.4×10^{-3}%. Although the noticeable EL improvement, it is worth of notice that in a configuration with a very small channel the contact resistance effects at the metal/organic interface are predominant with respect to the FET working mode. In the same year, Omayada et al. showed also a new single layer unipolar OLET with an EQE of almost 0.8%, made with a blend of 1wt%-rubrene doped tetraphenylpyrene (TPPy) (Omayada et al., 2005b).

Other studies have been done using spin-coated or drop-casted polymers like poly-phenylenevinylene, poly-fluorene or poly-arylenevinylene derivatives (Sakanoue et al.,

2004; Ahles et al., 2004; Swensen et al., 2005a) as active layer. These experiments, besides showing a possible extension of the concept of unipolar OLET, demonstrated the feasibility of wet-technique fabrication process that could open up many possibilities of large-area and low cost devices. Within the same studies, it was demonstrated also that the use of different metals for drain-source contacts could lead to a considerable increase of EL.

Generally speaking, despite the enhancement in EL in unipolar devices, the EQE achieved is still too low for any practical application. Indeed, some problems arisen from the type of architecture, limit drastically its potentiality. First of all the EL emission takes place in proximity to the metal electrode with a consequent quenching due to the interaction between exciton and metal surface plasmons. Moreover, the exciton formation and recombination occur in the same spatial region where charges flow, so leading to a significant exciton-charge quenching. In practice, unipolar OLETs suffer from the same negative effects of OLEDs.

2.2 Ambipolar OLETs

So far we showed a possible approach to fabricate OLETs, using a unipolar organic material (polymeric or small molecule) as the active single layer. In this case the emission is localized in a small region underneath the metal contacts.

Indeed, most of the scientifically and technologically remarkable properties that make light-emitting transistors desirable are, however, only present in ambipolar OLETs since they can provide an effective pn-junction within the device channel that allows exciton formation and radiative recombination.

The most simple structures are composed by a single organic material capable of transporting electrons as well as holes (single component approach) or by a combination of two unipolar transport materials (multi-component approach).

2.2.1 Ideal single layer ambipolar OLETs

In an ideal ambipolar transistor with just one polymeric or small-molecule semiconductor layer, the ambipolar regime is characterized by a hole and an electron accumulation layers, next to the respective electrode, that meet at some point within the transistor channel. There, oppositely charged carriers recombine. In electroluminescent materials, this leads to light generation within the channel. The length of each channel and thus position of the recombination zone depends on the applied gate and source-drain voltage and mobility ratio. The behaviour of an ambipolar field-effect transistor in the ambipolar regime can roughly be imagined as that of a saturated hole and electron channels in series within the field-effect transistors.
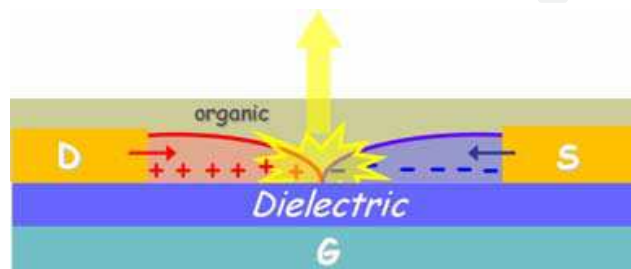

Fig. 4. Schematic of an ideal ambipolar OLET, when the two opposite charge carriers meet, there is exciton formation and consequently light emission

In general, ambipolarity in FETs is an attractive characteristic since it enables the fabrication of complementary logic circuits like CMOS transistors and permits a higher light emission efficiency due to the maximization of the exciton recombination through a better electron–hole charge balance. In addition, with an opportune tuning of the gate voltage, it is possible to move the emission through the channel length. On the other hand, one of the limiting negative aspect of this class of devices remain the poor mobility of charge carriers, usually of the order of 10^{-4} cm^2/Vs.

2.2.1.1 Ambipolar polymer OLET

The first research showing the feasibility of an ambipolar single layer OLET, was done by Swensen et al. (Swensen et al., 2005b). The material used was a poly-phenylenevinylene (PPV) derivative polymer, called SuperYellow (SY) and the device was done on a Si/SiO_2 substrate.

Previous studies on the same class of material/substrate FETs showed only p-type mobility. It was just after the discovery of the hydroxyl groups trapping effect for electrons and the consequent SiO_2 surface passivation process implementation (Chua et al., 2005), that it was possible the realization of electroluminescent ambipolar polymer transistors. In particular, the presence of a so called "two-color" geometry of the device was the key feature for enabling ambipolar transport from SY. In this reported geometry, they implemented the use of a low work-function metal (Ca) for the n-type injection electrode and a high work-function metal (Ag) for the p-type injection electrode. A spatially resolved recombination zone was then observed under ambipolar conditions controlled by the gate bias. The emission zone moved across the channel as the gate bias swept (see. Fig.5) and in case of balanced electron and hole currents the recombination was located at the channel centre.
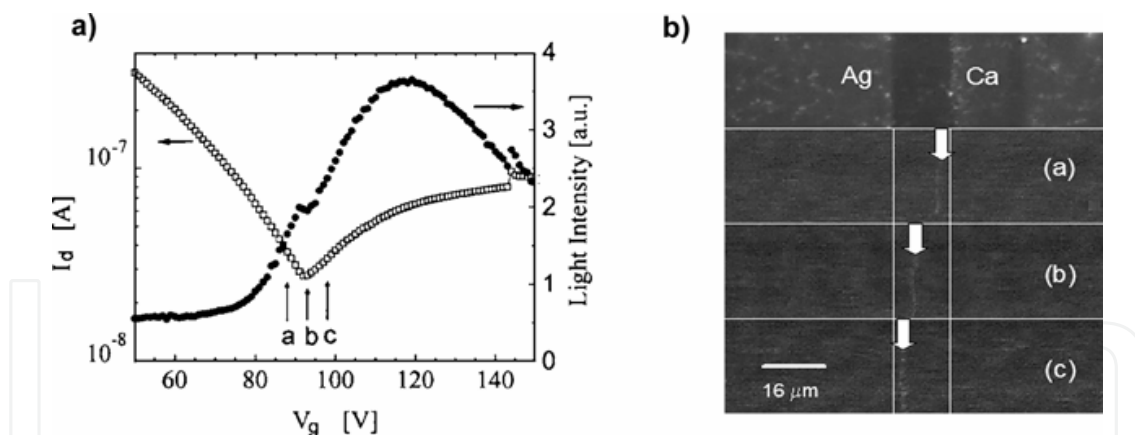

Fig. 5. Transfer characteristic of the SY OLET along with EL intensity (a), image of EL inside the channel at different spatial positions depending on gate bias (b)

Almost contemporary, another group achieved the same results using a spin-coated layer of a different conjugated polymer, poly(2-methoxy-5-(3,7-dimethyloctoxy)-p-phenylene-vinylene) (OC$_1$C$_{10}$-PPV)(Zaumseil et al., 2006). Also in this case, to obtain a good ambipolar behaviour, with balanced electron-hole charge densities, two different work function metals were used. For this material, the reported EQE was 0,35%, thus similar to the EQE of a bulk LED based on the same polymer.

Recently in 2008, again Zaumseil et al. fabricated ambipolar OLETs with poly(9,9-di-*n*-octylfluorene-*alt*-benzothiadiazole) (F8BT) and poly((9,9-dioctylfluorene)-2,7-diyl-*alt*-[4,7-

bis(3-hexylthien-5-yl)-2,1,3-benzothiadiazole]-2',2''-diyl) (F8TBT) (see Fig.6) (Zaumseil et al., 2008).
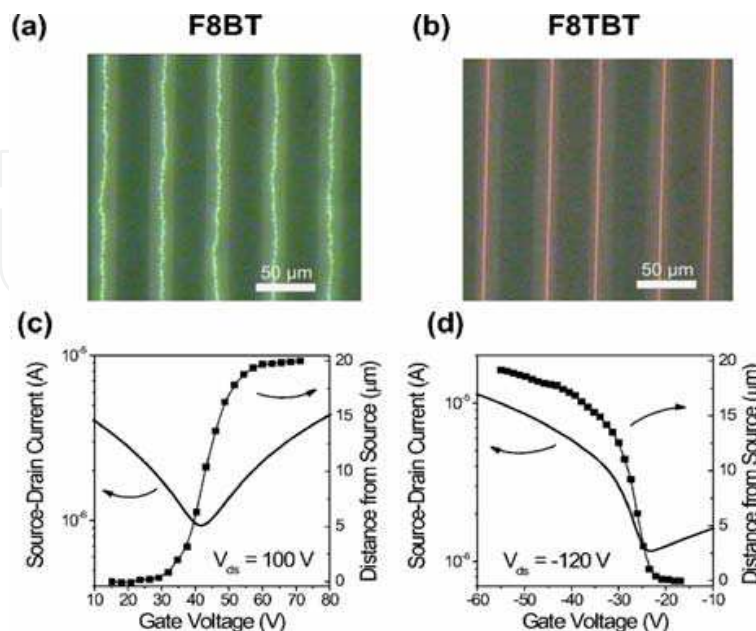

Fig. 6. Image of light emission from an interdigitated source-drain OLET made with F8BT (a) and F8TBT (b). Transfer curves and position of the light with respect to source contact for F8BT (c) and F8TBT (d)

In their study by using theoretical models they showed that the ambipolar regime can be thought of as a saturated electron channel and a saturated hole channel in series within the OLET channel. Within the model, EQE was expected to be constant, depending only on singlet-triplet ratio and not from, for example, voltage conditions. The increase of EQE with current density up to saturation, measured during the experiments, was considered as a consequence of trap-assisted non-radiative decay mechanisms at the semiconductor-dielectric interface. Furthermore, they demonstrated that, when complete recombination of all charges happened the maximum saturated EQE of F8BT, in top gate OLET configuration, is 0,8%. This conclusion signed a very important step in OLET fabrication showing clearly, for single layer devices, that an EQE of 0,8% is the highest limit.

2.2.1.2 Ambipolar small molecule OLET

Another approach in the realization of ambipolar single layer OLETs, using an intrinsic ambipolar light-emitting small molecule, was explored by Capelli et al., describing the realization of α,ω-dihexyl-carbonyl-quaterthiophene (DHCO4T) based device. The advantage in using a physical vapour deposited (PVD) small molecule instead of a polymer deposited by solution-processes is that, in the first case, the resulting film presents a more ordered and crystalline structure and thus, in principle, higher hole-electron mobilities due to larger charges delocalization.

Unfortunately electro-luminescence was present mainly in unipolar region (see Fig. 7). In order to have a better understanding of the phenomena, they tested the material in different conditions, changing dielectrics and metal contacts. Through this study, they showed the strong dependence of DHCO4T-based OLETs performances from the dielectric-organic interface. This aspect profoundly affects the electrical properties of both charge carriers in

terms of mobility and threshold voltage and thus electro-luminescence. They identified this main issue as the first cause of limited optoelectronic performances of their device (Capelli et al., 2008).
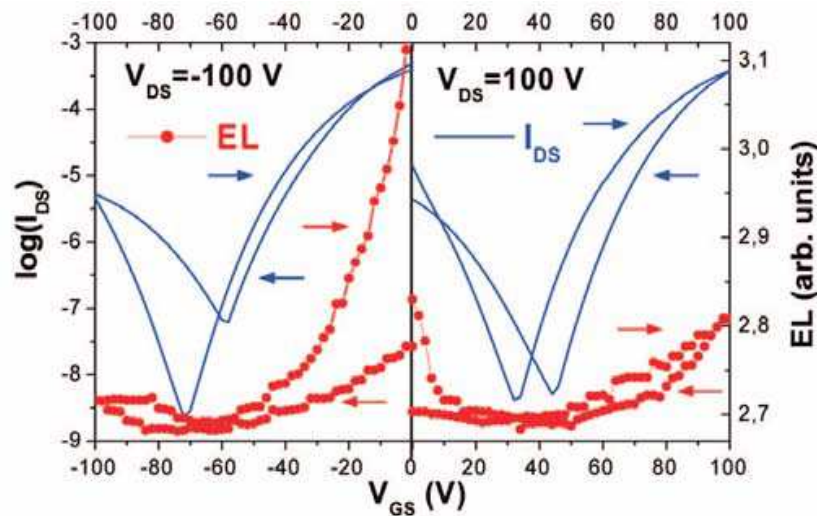

Fig. 7. Example of transfer characteristics of a DHCO4T OLET on SiO_2/poly-methyl-metacrylate (PMMA) substrate. The left plot is in p-type bias mode, while the right one is in n-type bias mode

2.2.2 Multi-layer ambipolar OLETs

In multi-component approach, OLETs can be obtained either by simultaneous co-evaporation of two unipolar materials realizing a bulk hetero-junction or by superposing two layers of unipolar materials in a bi-layer structure.

2.2.2.1 Bulk hetero-junction OLETs

In bulk organic hetero-junction approach, exciton formation and charge transport are competitive processes due to the dispersed interface between the p-type and n-type transport materials. Clearly, the wider the interface surface is, the higher the probability that electrons and holes recombine forming excitons. Nevertheless, connected percolative paths are needed for the charges to migrate by hopping so that interface can represent a physical obstacle for efficient charge transport. Furthermore, even if the interface morphology is precisely controlled during vacuum sublimation, well-balanced ambipolar behaviour has not yet been achieved.

The first documented fabrication of an ambipolar device belonged to this class of OLETs. In 2004, for the first time, Rost et al. proposed a new structure made by a co-evaporation with 1:1 ratio of *N,N'-ditridecylperylene-3,4,9,10-tetracarboxylic diimide* (P13) for n-type transport and α-quinquethiophene (T5) for p-type transport (see fig. 8) (Rost et al., 2004).These two materials are known for their good hole-transporting (T5, with mobility of 10^{-2} cm²/Vs) and electron-transporting (P13, with mobility of 10^{-1} cm²/Vs) properties. Of course, one of the most important prerequisite for having exciton formation and thus light formation, is the relative positions of the materials energy levels of highest occupied (HOMO) and lowest unoccupied molecular orbital (LUMO). Indeed, there must be the conditions to allow recombination in the material with the smaller energy gap.
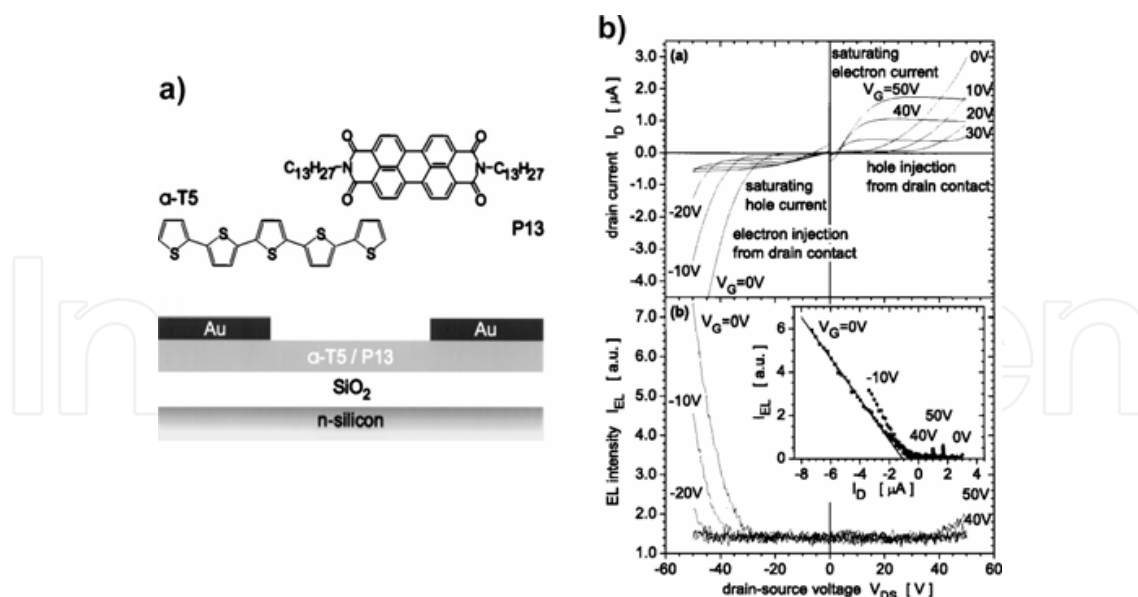
Fig. 8. Device and molecules chemical structures (a), I-V characteristic with EL emission at different gate biases

Through a fine control of the two materials co-evaporation, it is possible to obtain a good tuning of both charge carriers mobilities and quite good EL. However, in general, in this kind of device structure, the absolute mobility values are definitely lower, if compared to other fabrication strategies. In particular, Rost et al., after a deep investigation, found the best deposition parameter tuning in order to obtain very high mobility in both materials, though with low EL emission. Mobility values achieved were, respectively, 10^{-4} cm^2/Vs for hole transport and 10^{-3} cm^2/Vs for electron transport.

2.2.2.2 Bi-layer vertical hetero-junction OLETs

In this structure the organic layers are deposited in a vertical stack. Each layer is devoted to a single functionality and can be optimized by controlling the growth conditions of the different organic/organic, organic/metal and organic/dielectric interfaces. This approach, compared to others, presents the advantage of enhanced charge transport and mobility values. It is known that in OFETs the charge transport is confined to the first few layers next to the dielectric. Thus, electron and hole paths are confined at the interface between the first layer and the substrate and at the interface between the two organic films. If the two films are continuous, the charge transport should be uniform in both films over all the device channel area and therefore good transport properties are expected.

Dinelli et al. reported on a bi-layer of α,ω-dihexyl-quaterthiophene (DH4T) and P13 OLET that showed good ambipolar behaviour and light emission (Dinelli et al., 2006). They demonstrated, studying two different possible organic configurations (DH4T-P13 or P13-DH4T), that the device, in which DH4T was evaporated directly on the dielectric surface, had the best balanced mobility in ambipolar region (10^{-2} cm^2/Vs for both charge carriers). Through analysis of the interfaces in the two cases, they underlined the importance of having the best growth compatibility between the hole and electron transport materials in order to form continuous films and thus enhancing the optoelectronic performance. They observed also that EL occurs only when the device is biased with FET transport in the bottom layer and that the light emission originates, from P13, as expected from energetic considerations.

In the bi-layer approach, the spatial separation between charge carriers mainly prevents excitons formation inside the device channel, and so, EL is present only in unipolar bias region. This means that the pn-junction forms only underneath the electrodes as in the case of single layer unipolar OLETs. However, this structure has, up to date, the highest balanced ambipolar mobility ever obtained in OLETs.

Instead of implementing n-transport and p-transport materials in the bi-layer device realization, Heeger et al. utilized a structure comprising a hole transporting polymer, poly(2,5-bis(3-tetradecylthiophen-2-yl)thieno[3,2-b]thiophene) (PBTTT-C14) and a light emitting polymer, Super Yellow (SY), a polyphenylenevinylene derivative showing good output characteristics and brightness. Both materials were deposited by wet techniques (see. Fig.9) (Namdas et al., 2008).
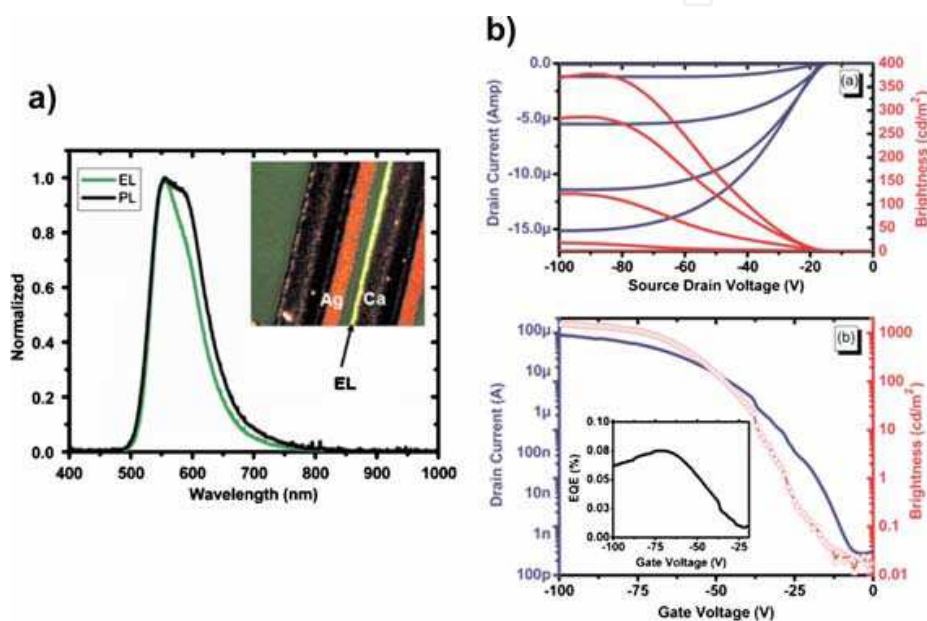

Fig. 9. Image of the EL emission spectrum of the device compared to PL emission of SY, along with a picture of the luminescent channel (a), I-V characteristic, transfer characteristic and EL curve of the bi-layer device(b)

It is well known that, in OLET devices, light emission is quite low due to the fact that the organic materials present either low carrier mobility with high photoluminescence (PL), i.e. amorphous materials or high mobility with weak PL, i.e. crystalline materials. In order to obtain good performances, materials should be capable of good ambipolar behaviour and have an high PL efficiency in thin film. In this case, although they did not achieve good ambipolar behaviour since electron transport was significantly lower than hole one, using two different metals as drain-source electrodes (Ag for hole injection and Ca for electron injection), they obtained a device showing intense EL, independent from the gate bias, with an efficiency of 0,35% and located under the electrode.

2.2.3 The tri-layer OLET approach

Lastly, a novel strategy in OLET realization, the tri-layer vertical hetero-junction, is presented. So far, we have seen OLETs based on unipolar single layer which reached high brightness but EQE as low as 0,2% due to exciton-charge and exciton-metal quenching effects. Then we reported on ambipolar single layer OLETs that enable, under proper bias

conditions, the spatial localization of the EL far from the electrodes, but since charge carrier and exciton coexists in the same region, large exciton-charge quenching happens. Finally we reported ambipolar bi-layer approaches for OLETs, but in each of the two cases proposed (superposition of either two unipolar semiconductors of different charge transport or a highly efficient luminescent layer over a unipolar conductive layer) the device architecture does not offer any control on the exciton quenching due to charge and metal electrodes interactions.

In this new tri-layer hetero-structure approach, proposed by Capelli et al. in 2010, it is reported an OLET enabling simultaneous control of the electrode induced photon losses, the exciton-metal and the exciton-charge interactions. In this condition they showed that devices could reach the considerable EQE value of 5%, out-performing the OLED state of the art based on the same emitting layer with an EQE of 2.2% (Capelli et al., 2010).

In the trilayer configuration the first organic thin-film in contact with the device dielectric layer is devoted to the unipolar field-effect transport. The second layer deposited onto is the recombination layer which presents high emission quantum efficiency and OLED-like vertical bulk mobility value. In the specific case a host-guest system with a dye doped matrix was used. The third layer is devoted to unipolar charge transport complementary to that of the first layer (see Fig. 10a).

The key idea of the vertical tri-layer heterojunction approach in realizing OLET is that each layer has to be optimized according to its specific function (charge transport, energy transfer, radiative exciton recombination). Clearly, matching the overall device characteristics with the functional properties of the single materials composing the active region of the OFET, is a great challenge that requires a deep investigation of the morphological, optical and electrical features of the system.

Fig. 10. Tri-layer device structure along with chemical structures of the organic materials used for the device fabrication (a), HOMO and LUMO energetic levels of the materials (b)

In this structure, the main aim is to enable charges to percolate into the middle emitting layer. In order to do so, first of all, material energetic levels must be considered. The LUMO level of the n-type transport layer should be equal or higher than the LUMO level of the guest matrix of the host-guest system consisting the middle layer, while the HOMO level of the p-type transport layer should be less or equal than the guest matrix HOMO level (see fig. 10b). In addition to these considerations, attention must be paid to the control over the interfaces morphologies, in order to allow the formation of a continuous stack.

Indeed, in this approach more than in others, functional interfaces play the predominant role in determining the performance of vertical tri-layer heterojunction. As in the case of the bilayer-based OLETs, it is clear that the interfaces between the dielectric and the bottom transport layer and between the recombination and the top transport layers are crucial for

guaranteeing good ambipolar field-effect electrical characteristics. Moreover interfaces between the bottom transport and the recombination layer and between the recombination and the top transport layer should provide the favourable conditions for the charge percolation to happen in the recombination layer and to form excitons.

Through the research, Capelli et al. found that the materials that best fitted these conditions were α,ω-dihexyl-quaterthiophene (DH4T) for p-type transport, α,ω-diperfluorohexyl-quaterthiophene (DFH4T) for n-type transport and tris-(8-hydroxyquinoline)aluminum (Alq3):DCM doped host-guest system.

For what concerns light emission, in ambipolar region EL is located inside the device channel far from electrodes, thus preventing photon losses due to exciton-metal quenching. Moreover, since the emission layer is separated from charge flows, the exciton-charge quenching is also prevented. The light generation process is based on the percolation of the opposite charges from the transport layers into the recombination layer. This percolation is made easier due to the transverse electric field generated by electrons and holes in the respective transport layers. In the tri-layer structure charges recombine in the middle layer because they cannot travel through several microns of opposite charge accumulation layer without recombining, similar to what happens in ambipolar single-layer OLETs in which charges recombine in the middle of the channel. Indeed, a self-regulated equilibrium exists between the amount of charges located in the transport layers and those entering the recombination one that prevent any possible exciton-charge interaction.
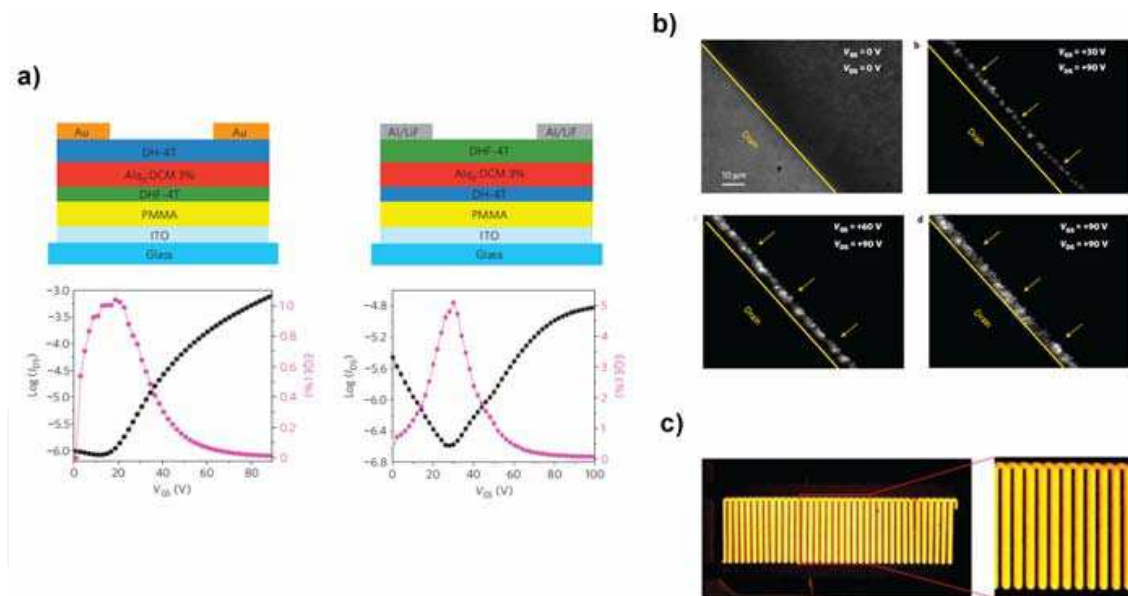

Fig. 11. Schemes of two tri-layer structure configurations and their EQE as a function of the applied voltage in a transfer characteristic (a), images of the EL channel moving toward the drain contact with increasing gate voltage (b), image of a tri-layer fabricated with an interdigitated structure (c)

This new OLET structure showed clearly the full potential of field-effect devices compared to OLED devices. The actual limits of this structure mainly depend on the materials performances. Future investigations on this structure will lead, surely, to the study of the implementation of a triplet emitter for the recombination layer, thus, potentially improving further the emission brightness.

An issue that actually must be addressed is the device operating voltage. Usually in OLED devices one of the most significant parameter is considered the power efficiency, that represents the power emitted at a certain voltage. Unfortunately in the tri-layer OLET device, the maximum light power emission is found at a gate voltage of 70 V. This issue could be overcome by developing an high capacitance gate insulator.

3. Future developments

After the demonstration of the first OLET in 2004 made by Rost et al., many great advancements have been achieved. These advancements opened up the possibility of many future developments of OLETs, tightly connected to their potential market application, especially for solid-state lighting.

Indeed, many interests are focused around OLETs, since their higher brightness and light emission efficiency with respect to OLEDs. The small spatial localization of the illuminated channel, prerogative of OLET devices (hardly achievable in OLEDs), could lead to the development of new high definition displays. The planar technology used for OLETs, will be surely exploited in future, to develop a new generation of devices, in which organic photonic field-effect transistors are used for both light generation and detection. One of the possible applications of this integration between light sensing and light generation effects in one device could be used for the fabrication of the so called "lab-on-a-chip", a miniaturized cheap and disposable device for bio-sensing that permits quantitative diagnostic tests, that up to date, are limited to laboratory or hospital facilities.

Moreover OLETs planar architecture is considered the ideal platform for the realization of resonant micro-cavity where the active region is separated by few microns from the injecting metal electrodes. This device configuration which prevents exciton quenching, will make OLETs suitable for the development of electrically-pumped organic lasers.

In addition to these promising technological scenarios of OLETs developments, the latest results, together with the continuous development of understanding of the chemical and physical properties of the device interfaces and the synthesis of new molecules by chemical tailoring, will surely open, new perspectives for the full exploitation of OLETs potentialities.

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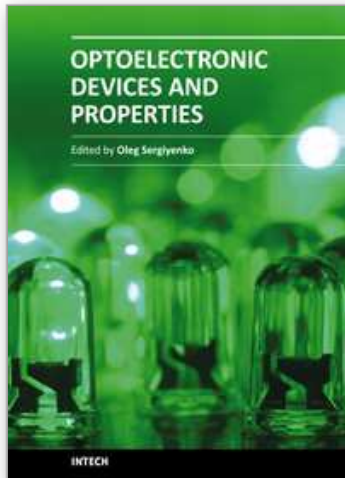
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Gianluca Generali, Stefano Toffanin and Raffaella Capelli (2011). Multilayer Approach in Light-Emitting Transistors, Optoelectronic Devices and Properties, Prof. Oleg Sergiyenko (Ed.), ISBN: 978-953-307-204-3, InTech, Available from: http://www.intechopen.com/books/optoelectronic-devices-and-properties/multilayer-approach-in-light-emitting-transistors

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