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General mechanisms of organic electronics

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Chapter 1

Introduction

This document will discuss the mechanisms in a general way.
Fundamentals of organic electronics, component manufacturing methods.
Based on this technology and its practical uses, from the
OLED, useful for various display devices such as TV screens, radios, players
digital, to solar cells, obviously including even transistors.

Recently, some organic electronic components have attracted a lot of attention.
They are proposed as a true alternative to
conventional silicon-based (and therefore inorganic) electronic components. In fact, they do not
require high-temperature passages or expensive equipment.
CO2 deposition is necessary to manufacture organic components; on the other hand, low cost,
brightness, lightness and flexibility are some of the advantages.
of the advantages of these devices, which lead us to believe that they will have
Its use is widespread in electronics, from "smart cards" for information
personal or building entry cards, even cards for
inventory control, but also as an alternative to current transistors
or light-emitting devices.

During the studies of these materials, composed mainly of carbon, nitrogen,
oxygen and hydrogen, it was observed that, depending on the bonds
intermolecular particles are capable of behaving both as semiconductors and
of the insulators; the discovery that further relaunched the studies occurred when
It was observed that some even possessed photoconductive properties: this
The result initially raised hopes that, using these substances, it would be possible
create equipment for solar cells or superconductors with very low
Prices. However, the first major problems arose: one of them, above all, concerns the instability of the
compounds, since many organic materials degrade upon exposure to air, water, or light. Furthermore,
there are limitations both on how to use organic structures as actual components,
and on
the different steps and processes that can be used to

Handling and manipulating them (such as connecting metallic contacts to organic materials).
Since electrons are primarily located in covalent bonds, their mobility in
organic materials is much lower than in semiconductors: this
implies that their applications will have to be in the low-frequency range;
furthermore, since organic structures are not necessarily regular lattices, there is
a limited number of positions where impurities can be added to increase their
mobility (doping).
Finally, due to the instability of the compounds, only some of the materials and impurities
tolerate the doping process.

1.1 Types of materials

In general terms, we can say that crystalline solid materials, based on their behavior in
response to an electric current, can be divided into three
categories:

- drivers
- insulators
- semiconductors

The difference can be intuitively explained by the different energy band structures with which
they are represented.

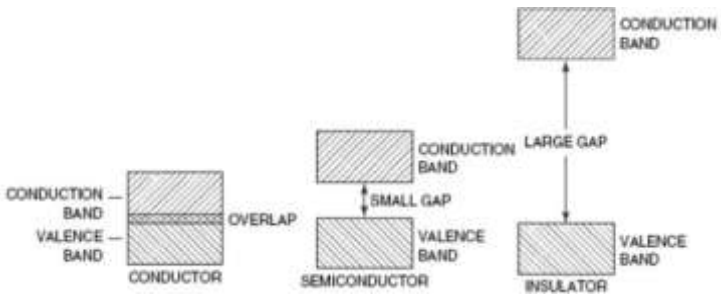


Figure 1.1: Conduction and valence bands in semiconducting conductors and insulators

In conductors, the upper band is partially filled, which allows for and explains their high
electrical conductivity. In insulators, however, the valence band is
completely filled, while the conduction band is partially filled.
It turns out to be completely empty. Furthermore, the separation between the two
bands, called the energy gap, turns out to be very high (many eV), hence its name: it is precisely
this high energy between the two bands that
prevents conduction in these materials. In semiconductors, although

The conduction band is usually empty, and the energy gap between the two bands is
relatively low (around 1 eV), allowing for an easy transition of electrons from the band
from valence to conduction, even in the presence of thermal or optical stimuli. Furthermore, its
Electrical properties can be easily modified through the doping process, which consists
in inserting atoms with a different valency into the semiconductor structure. If the atom
The inserted atom has one or more electrons than the atom it has replaced; it acts as a donor of
electrons, and the semiconductor in question is called an n-type semiconductor. Typically,
The electrons in these atoms are more easily excited to the conduction band, which increases the overall conductivity of the medium. Similarly, if the inserted atom has fewer electrons than the semiconductor, it becomes an acceptor, and we call it a type II semiconductor.
p.

PN Union

PN junctions are formed by bringing a p-type semiconductor and an n-type semiconductor into contact.
They are divided into two types:

- homogeneous articulation
- heterogeneous union

The difference lies in the fact that the first consists of the union of two materials with the same energy gap (that is, it is obtained from the same material), while the second occurs when there are different materials in contact, and with different energy "jumps".

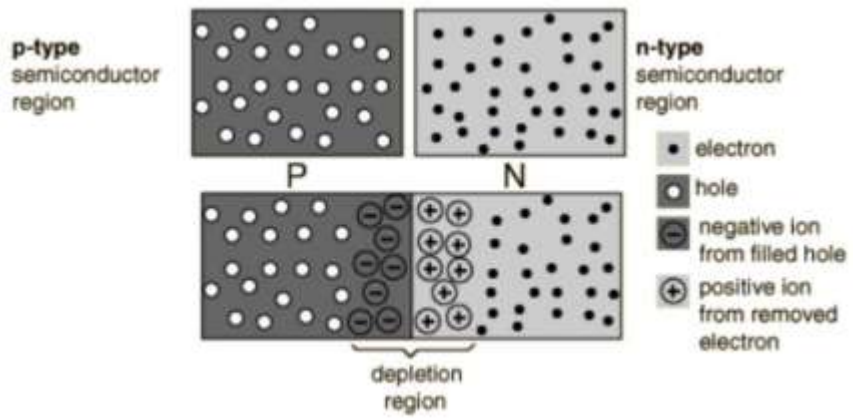


Figure 1.2: Simplified representation of a pn junction

At the interface between the two semiconductor dopings, a kind of reciprocal diffusion occurs: holes from the p region pass into the n region, leaving a charged space in their place.
negative; similarly, the electrons from the n region move to the p region, thus leaving a
positive charge in region n. This creates a space subjected to an electric field which, once
Once equilibrium is reached, it prevents the diffusion of electrons and holes. This region of space where
The region where diffusion has occurred is called the depletion region, since the charge carriers
that should be present are not. Figure 1.2 graphically represents what is
He just described it.

1.2 Organic materials: polymers and small molecules-

cabbage

Some of the problems with organic materials mentioned above were overcome in the 1980s, when Ching Tang and Stephen Van Slyke succeeded in joining numerous
small molecules in a long, stable tangle: these long molecules, or monomers, were
stable enough to act as a PN junction diode. Similarly,
Richard Friend developed a similar structure using polymer chains, or long chains
of organic monomers. They claimed it was possible to create resistant sheets that could withstand the torsion and bending.

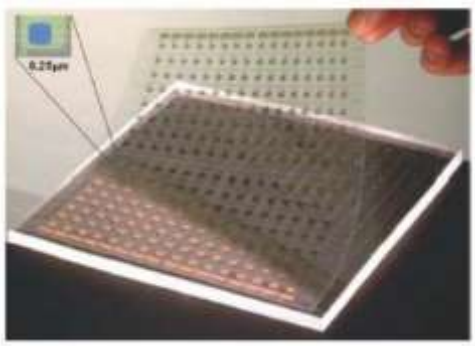


Figure 1.3: An example of a flexible organic sheet

As just introduced, organic devices can be classified into two categories: those derived from small molecules or those based on polymers.
These latter ones can be processed with specific deposition techniques, developed
It has been thoroughly tested for traditional polymers; however, its performance is several orders of magnitude lower than that of small molecules. Promising results have been obtained.

celebrated by devices formed from small molecules, although they require a high degree of internal order: the reason for the importance of internal order will be discussed later in the article.

Small molecules

Generally, the basic molecule in the development of this technology is pentacene, which has achieved, with some of its derivatives, a mobility on the order of a few cm² V. If ÿ1 we consider a diode s^{-1}.

Organic, this is obtained according to the generic theory of inorganic PN diodes. For devices These small diodes have an electron-rich layer, the p-layer, which is evaporated onto a contact substrate (indium tin oxide, ITO). Subsequently, organic molecules are also evaporated into the n-layer (evaporation is one of the methods that can be used to apply organic materials to metals).

In these steps, the temperature must be able to vaporize the organic compound without damage or degrade it. Furthermore, since reagents sometimes combine with substances Organic, the only method to create an image, a pattern, of a device consists of using low-resolution masks. To improve device performance, studies have been conducted and Various techniques are still being studied: one consists of

For example, by heating the substrate and proceeding with the deposition very slowly. In all the In these cases, the objective of these techniques is to improve the arrangement of molecules after deposition.

Polymers

The construction of long polymer chains is relatively simple: given that the Polymers are more stable and possess multiple binding sites than compounds obtained from small organic molecules. They can be converted into their precursor, applied to the substrate (or electron-rich layer), and then subjected to a treatment (usually simple heating) to recover their initial organic state. In this way, greater control over the

application of the precursor, both for its greater stability and its solubility, which allows its application to the substrate in solution. However, the metallic contacts must evaporate in the device and, as will be explained later, the bonding of metals to organic materials is a complex process.

Chapter 2

OLED Organic Light Emitting diode

As mentioned earlier, significant discoveries were made around the 1980s and 1990s, both related to the formation of molecules with PN-like behavior and to polymers (long chains of monomers), which tended to be flexible and more resistant to environmental conditions, although they could also degrade rapidly when exposed to oxygen or water. Materials capable of emitting light, conducting current, and exhibiting typical semiconductor behavior were studied. The ability to transport charges (electrons and holes), for example, is due to the overlap of orbitals (generally p-type) of neighboring molecules: this characteristic is, in fact, responsible for the conductive properties of the resulting organic compounds. The relative position of individual materials modifies this overlap, which proves to be a starting point for developing and increasing a material's mobility.

2.1 Structure and operating principle

Both polymeric and molecular OLEDs are based on a similar operating principle to silicon diodes: these molecules accept oppositely charged particles, electrons and holes, from the anode and cathode contacts respectively, which, through an external voltage generator, move towards the recombination region, where they form a neutral bond state, also called an exciton.

More precisely, if we consider a simple pn junction without an electric field Externally, the two n-doped and p-doped regions are separated by the depletion region. However, if a suitable electric field is applied—that is, if the junction is polarized—the depletion region contracts and charge carriers shift from one side to the other.

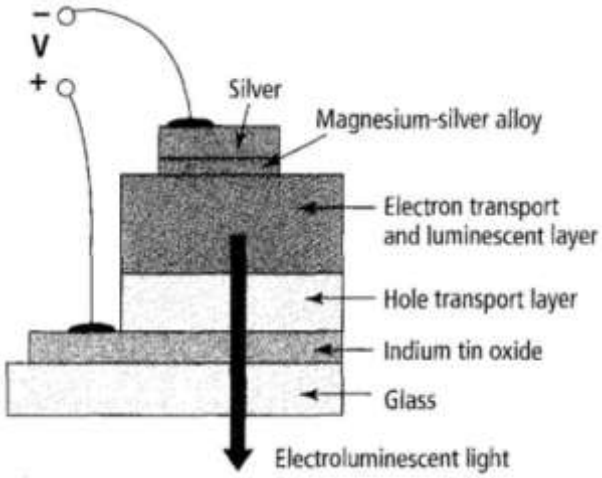


Figure 2.1: Generic structure of an OLED

allowing their recombination and the subsequent formation of excitons and emission of photons (as will be briefly described).

In our case, however, since we are not considering crystalline solids but rather molecules and simple atoms, we are not talking about valence and conduction bands, but rather about HOMO (the highest occupied molecular orbital) and LUMO (the lowest unoccupied molecular orbital). Furthermore, charge transport in organic materials also differs from the inorganic model.

But the general and simplified treatment we will give will not suffer from this discrepancy.

There are generally two types of excitons that can be formed by recombination of charge carriers, called singlets and triplets (on average they form in a 1:3 ratio). As explained by the principles of quantum mechanics, a few nanoseconds after the formation of singlets, their de-excitation occurs, involving the emission of photons, called luminescence. The triplets formed, on the other hand, have a lifetime on the order of a few milliseconds, even a few seconds, but their de-excitation produces heating rather than bright emission. However, if an atom of a heavy metal, such as iridium or platinum, is placed in any organic molecule, the patterns of singlets and triplets mix, forming light emissions with durations on the order of

100ns 100µs: This type of emission is called phosphorescence.

Going into detail, electrons are injected from the cathode, typically calcium or Magnesium (the latter chosen for stability reasons) is used as the anode; however, a thin, transparent ITO (indium tin oxide) film is used for injection into the holes. The recombination efficiency,

which, as already mentioned, leads to the creation of a singlet, is mainly influenced by the superposition of electron and hole densities, which originate between the charge injection and the emission layer.

Even with a simple single-layer device, the electro-

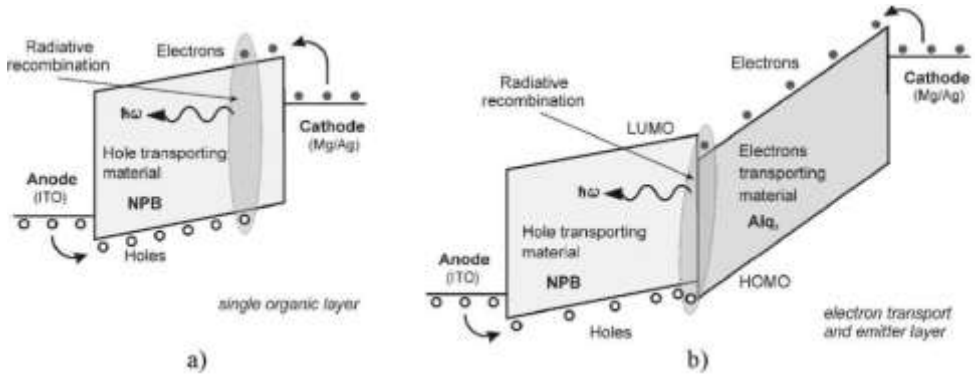


Figure 2.2: Power diagram for OLED with: (a) a single layer; (b) two layers

luminescence, however its performance is poor, since the electrons and holes reach opposite contacts and, therefore, the excitons are dampened at the electrodes.

Two-layer or "unique heterostructure" devices introduce a separate hole transport layer. Holes are injected into both the combined emitter and the electron transport layer; in this way, they recombine with electrons near the interface, increasing the amount of emitted radiation.

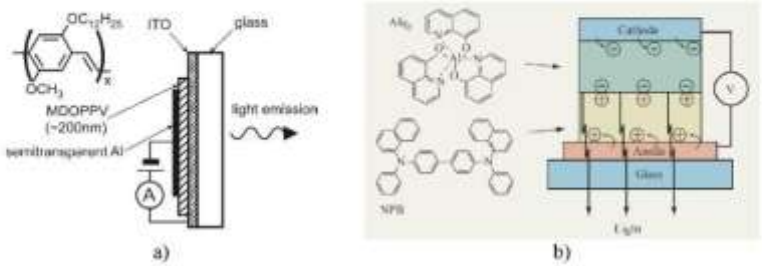


Figure 2.3: OLED schemes: (a) single layer; (b) single heterostructure

This same mechanism helps us understand how the good results that can be obtained with this technology are not solely due to the individual materials used, but underlines how necessary it is to have a deep understanding of both optical and electronic behavior.

of these materials, in order to design a structure that maximizes its performance.

The light emission of a device varies depending on several factors,
Among those we mention are the most important:

- the number of electrons (and holes) injected into the electrodes: an increase in these this results in a greater emitted light power;
- External quantum efficiency: defined as the ratio between the emitted photons and the injected electrons (or holes).

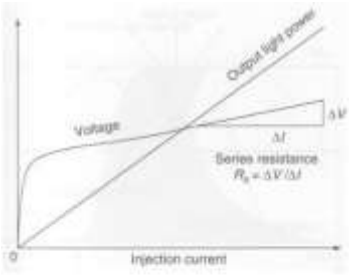


Figure 2.4: Characteristic VI

As we can see, as the current in the device increases, so does the value.
the resistive effect of the diode, which causes the loss of some of the available power due to dissipative effects, usually in the form of heat.

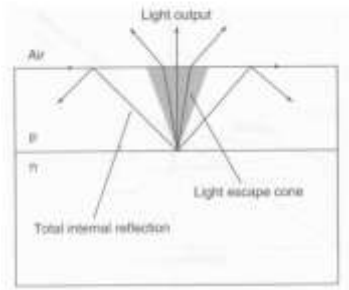


Figure 2.5: Reflection of the generated light

To better explain the processes involved in light emission, external efficiency is
It can be divided into two components: internal and optical efficiency.
Internal efficiency represents the ratio between the photons generated within the LED and the electrons injected. Since a charge carrier can recombine through radiative or non-radiative processes, internal efficiency is primarily limited by non-radiative recombination (the formation of triplets, which do not emit useful light radiation).

Optical efficiency represents the fraction of photons that actually leave the LED.
This parameter is limited primarily by the internal reflection of the material: as can be observed
In Figure 2.5, only the rays that strike the interface between the semiconductor and the air, and that are normal to it, can continue their path.

2.2 Applications: Color screen

One of the main reasons why OLEDs have attracted so much interest is their potential use in color screens, which could eventually replace the current passive matrix LCDs.

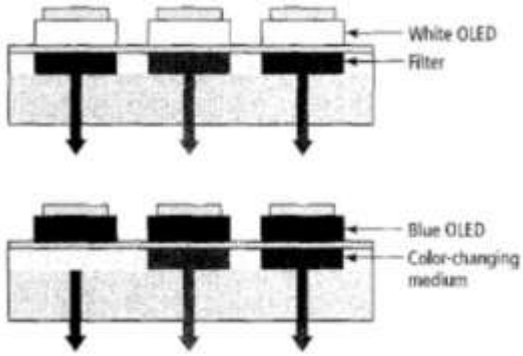


Figure 2.6: Schemes for generating three primary colors

To generate a colored image, it is necessary to obtain three elements very close together.
Yes, each one capable of emitting light of a primary color (red, green, and blue). Among the methods proposed to obtain this result, two stand out: the first consists of using a white light source and directing the light through three filters of different colors (using materials capable of modifying the wavelength and, therefore, the color of the radiation that falls on them); this
The method requires photolithography combined with the deposition of metallic contacts using low-level, high-precision masks, which increases costs unsustainably.

Another method involves distributing several color filters in a region very close to the source. and direct the light through them. This method sacrifices radiation efficiency, since the filters They absorb most of the radiation that falls on them, but it involves simpler processes. and economical. It has recently been discovered that, by using a single source of blue light or In ultraviolet light, this loss is minimized. The filters used are called CCM (change media). (of color), since they are compounds capable of absorbing in a...

It efficiently captures blue light and then re-emits the acquired energy in the form of green or red light, depending on the type of material used.

Organic thin films enable entirely new display architectures, which, among other things, can lead to the creation of low-cost, high-resolution, full-color displays. An example of this has been demonstrated at Princeton University in New Jersey, where bidirectional (upward and downward) transparent OLEDs (TOLEDs) have been shown to play an important role in high-resolution displays. In addition to being transparent light sources, they can be used in a stacked structure: the ITO layer of one TOLED can serve as a gap injection electrode for a second TOLED built on top of the first (Fig. 2.7).

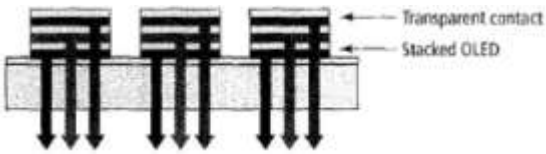


Figure 2.7: Simplified diagram of a TOLED

Each individual device in the stack can be processed and controlled specifically. to emit a specific color with a specific intensity, which will propagate to the adjacent transparent organic layer, the transparent contact, and the" glass substrate. In this way, the entire pixel area under the vertical stack can emit any combination of the three primary colors.

Recently, an OLED with this type of structure has been built (fig. 2.8), called SOLED (Stacked OLED): Since each element of the stack is independent, this structure allows control of brightness, color, and grayscale for each pixel of the screen.

Although complex designs are needed to obtain the appropriate layers for this function, this structure is more compact than the three-element arrangement currently used in cathode ray tube displays and LCD screens, and therefore allows for higher resolution image display.

One problem encountered in the "stack" structure we just described is the The formation of unwanted optical cavities between the different layers, where resonance phenomena occur that alter the emission spectra of the OLEDs. While these effects are usually avoided through meticulous controls of the thickness and composition of the different layers, some researchers have suggested that a multicolor display may be made up of engineered OLEDs.

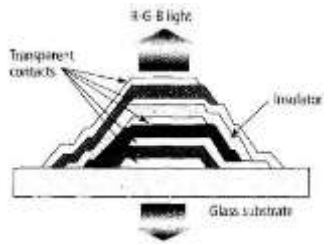


Figure 2.8: Diagram of the SOLED built at Princeton University: it consists of an evolution of the single TOLED

Positively with cavities (formed by insulating layers) used instead of simple colored filters.

These characteristics allow for the construction and implementation of new visualization architectures, which offer advantages such as low cost, very high resolution, and moderate energy consumption. To achieve good results, various difficulties have been encountered, leading current technologies to generate the necessary schemes (patterns).

through printing processes called "inkjet printing", characterized by their low cost, the reduction in the number of processes and the control that can be had over the result, instead of the evaporation processes, which were the first to be used to obtain the small structures on the substrates.

So far we have considered devices based on small molecule technology; if polymers are used, additional problems arise: the chemical properties of the solutions and solvents employed in the various printing processes of these materials, which will be discussed shortly, must be known and kept under strict control. In fact, in polymer solution deposition processes, the solvent used for one solution can often dissolve the other, thus altering the patterns and the device's performance.

Even with this technology, the methods for obtaining a color screen remain
The aforementioned properties, with some variations due to the characteristics of the solutions (for example, diffusion problems in areas adjacent to the theoretical ones), have been considered more suitable for use as backlighting for LCD screens or, more generally, for monochrome displays with high uniformity.

The development of reliable organic devices remains an open challenge. Driving
Charging these materials, which behave practically as insulators, requires very intense electric fields (15 MV/cm), so only OLEDs with a minimum thickness allow their use with relatively low operating voltages. However, this

slight...

A minimal charge, along with a reactive electrode, necessary to ensure efficient charge injection into the organic film, can contribute to the rapid degradation of the component and its characteristics. The problem is exacerbated when the device is directly exposed to the atmosphere, where, for example, oxygen contaminates and reacts with the surface layers: in fact, just a few hours of air exposure are enough for significant device degradation. However, a simple solution consists of

Encapsulating the device in an inert atmosphere allows for a significant improvement in its performance. useful life, exceeding 20,000 hours of operation.

Research on OLED has already produced some satisfactory results (which are (These will be analyzed in the final chapter of this thesis). Furthermore, numerous theoretically economical methods have been developed for their production, both on rigid surfaces and flexible materials. Their improvement, development, and dissemination in the near future could represent significant advances. significant in both performance and cost, placing them at the same level as screens current ones (LCD, plasma, etc.).

2.3 Production methods

As mentioned earlier, two main OLED production technologies have been developed in the last decade: the first, based on conjugated polymers, and the second, films composed of small organic molecules. Since these new technologies are still in their early stages, it will be necessary to improve production techniques and, in particular, the equipment used.

Molecular OLEDs are produced using vapor deposition techniques, often with low-level masks, since the materials used are too delicate for photolithography. On the other hand, PLEDs (i.e., polymer OLEDs) are produced using mechanisms that affect their solutions, such as rotational techniques (monochrome) or printing techniques (color).

Molecular devices

In these devices, small molecules of organic substances are deposited onto a thin film, with dimensions between 5 and 100 nm, through thermal sublimation processes of high vacuum. This technique heats the selected powdered molecules in an environment of vacuum, up to a controlled temperature: it must be high enough to evaporate them, but not too high to avoid their decomposition (between 250 and 400 degrees). The molecules The evaporated particles are collected on a cold substrate, thus forming a film whose thickness can be controlled.

with great precision, so much so that almost a single layer of molecules can be obtained.

Molecular OLEDs are formed on a glass or plastic substrate to form multilayer structures approximately 100 nm thick. The substrate is coated first. with a transparent electrode, such as ITO (indium tin oxide) or polyaniline: this will be the anode of the device. Next, a thin void carrier layer (HTL) is placed, generally composed of diamines (organic compounds containing nitrogen). About A layer of light-emitting organic material is deposited on the surface of the HTL, with a thickness Similar to the previous one, which is also used as an electron transport layer (ETL). Finally, the device is completed with the deposition of a cathode, usually of a metal. with low extraction labor, where "extraction labor" is defined as the amount minimum energy that allows an electron to leave the surface of the metal (low extraction work is necessary to have low resistance to electron injection from the anode to the ETL); this layer is usually composed of calcium or a magnesium and silver alloy.

The color of the emission obtained varies according to the chemical composition of the different layers: the Green light can be obtained by doping the electron-conducting organic matrix (called Alq) with a small amount of fluorescent dye or iridium phosphate. The pigment perylene, when doped into a well-defined electron matrix (known as CBP), allows blue emission. Finally, Alq or CBP can be doped with lanthanide complexes or porphyrin pigments.
(molecules formed by carbon, nitrogen and hydrogen), light emissions are obtained efficient.

red.

Researchers in this field have encountered numerous difficulties in construction of thin components to ensure operation with voltages between 5 V and 10 V. OLEDs are vulnerable to short circuits caused by defects in the thin film or by the

Surface contamination of the substrate with dust particles or impurities is a concern. Furthermore, these materials tend to be mechanically brittle and are easily affected by the chemicals used in photolithographic processes. For this reason, in addition to traditional low-resolution methods such as shadow masks, expensive dry processing techniques are often employed for the deposition of metallic compounds for contacts. Nanolithography techniques are expected to be developed in the coming years.
improve the techniques already used in the industry, such as injection molding or printing inkjet.

Polymeric devices

The most efficient polymer-based components exploit a two-layer structure similar to that of molecular devices, or use a single

A mixture of electron-hole carrier materials. Unlike vacuum-grown molecular OLEDs, the polymers or their precursors are typically distributed in liquid form on ITO-coated substrates. Subsequently, once the film is reduced (in particular,
its thickness), for example, by centrifugation methods, solidifies by simple heating. While the application of the organic layer is carried out by potentially economical chemical processes, the low-consumption cathode still needs to be applied by deposits
into the void.

Polymeric OLED structures can be simpler than molecular ones.
We just saw. The first polymer layer, in contact with the ITO, can only serve
to inject and transport holes, or it can be built to inject and transport electrons and
holes, and also to obtain light emission. In addition, polymeric OLEDs usually operate at a lower operating voltage than molecular ones: in fact, thanks to their higher conductivity, operating voltages range between 2 V and 5 V.

The controls of film composition and required thickness uniformity, both
For both single-layer and bi-layer OLEDs, vapor deposition methods are very simple.
but they are problematic with rotational techniques. Since polymers are obtained at
Starting from solutions, great care must be taken with multilayered structures so that, by
For example, the solvent used in the second layer does not dissolve the first. Therefore, the
Chemical compatibility between successive polymer layers fundamentally limits the complexity of the structures obtainable with these methods.

As with molecular components, modifying the chemistry of polymers produces
OLEDs emit different types of light. Typically, adding electron-donating groups to the polymer chain shifts the emission towards the orange end of the spectrum; conversely, adding electron-accepting groups shifts it towards the blue end.
emitted radiation.
In any case, even the simplest chemical substitution can lead to unpredictable changes in efficiency and reliability.

2.4 Results and performance

As shown in Figure 2.9, in recent years there has been a huge increase in the performance improvement of OLEDs, both polymeric and molecular, even compared to typical silicon LEDs.

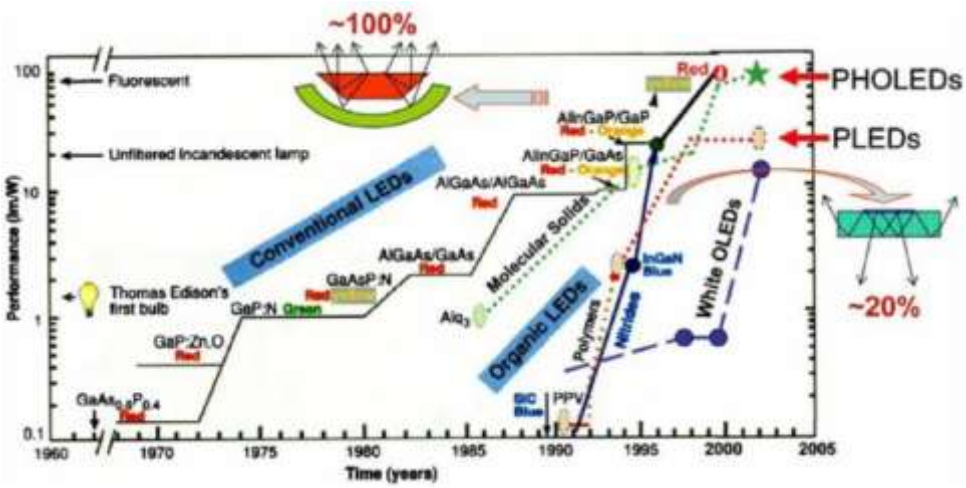


Figure 2.9: Evolution of LED and OLED performance

The improvements obtained in increasing the efficiency of light emission of the OLEDs have indeed opened up the possibility of their use in many battery-powered applications, such as cell phones, Game Boys, and other small digital devices, as valid substitutes.
Current LCD screens, such as those in monitors, offer lower resolutions and are still required to use backlighting, which is expensive in terms of energy consumption and would be useless for the
OLED screen.

Typically, the efficiency of an OLED, using a single fluorescent material, is on the order of 1%; using certain acceptor materials in which the radioactive host (fluorescent or phosphorescent) is low doped concentration in a thin molecular conductive film, the efficiency can be substantially increased to 20% or more for phosphorescence or about 5% for fluorescence.

One difficulty initially encountered with OLEDs was the high voltage required to ensure device operation: the voltages involved were on the order of hundreds of volts, definitely too high for large-scale applications. Through numerous technological innovations, which have led to an overall improvement in the production methods of these devices, it has been possible to achieve

devices with much thinner films than the previous ones, capable of operating at voltages of around 10 V, certainly less problematic than the previous ones.

Furthermore, significant progress has been made in increasing the lifespan and stability of these instruments. While initially the maximum

Performance declined after 1,000 hours of operation; current performance
The devices guarantee more than 10,000 hours of operation at high brightness. This limit is
This is due to the compounds that emit blue
light: The best performance of blue OLEDs, derived from phosphorus, is in the order of 15,000-20,000 hours of operation, after which instability problems may appear.
The degradation is too intense. Conversely, there are numerous stable compounds that emit in the red and green range.
They provide lifespans on the order of 106 hours. Researchers in the field are still working to fully understand the reasons for these differences in behavior, and above all to find a solution that can be used in the mass production and (hopefully) low-cost manufacture of OLED devices.

A few years ago, the efficiency of the best OLEDs surpassed that of lamps.
incandescent: polymer devices reached 20 lm/W.
(with yellow or green emissions), phosphorescent molecular OLEDs have reached peaks of 70 lm/W, with the PHOLED being green (phosphorescent
OLED), while typical incandescent lamps have a lower brightness of 20 lm/W.
Therefore, it is reasonable to think that much higher values will soon be available.
High (like the 80lm/W of fluorescent room lamps) will be
It was probably achieved using phosphorescent molecular OLEDs.

Chapter 3

OTFT Organic Thin Film Transistor

3.1 Introduction

Another device that has attracted a lot of attention recently is the organic thin-film transistor (OTFT). In fact, they are indispensable for most switching systems, such as displays or, in general, communication equipment. While TFT semiconductors based on silicon or germanium crystals have existed for many years and are widespread, they are quite expensive and require complex manufacturing processes.
manufacturing.

In fact, researchers expect that organic TFTs can replace semiconductors, at least in some low-frequency applications, and consequently, reduce its cost.

3.2 Structure and operating principle

In general, an organic TFT operates with a channel that carries majority charges between two destinations. The configuration of an OTFT, as shown in Fig. 3.1, can be top-contact, where the drain and source contacts are evaporated onto the organic semiconductor layer, or bottom-contact, where the organic semiconductor layer is deposited onto prefabricated source and drain electrodes. Although the image resembles the structure of its semiconductor counterpart, in this case, the gate and dielectric do not produce a "investment layer" to facilitate cargo transport.

In fact, we are talking about MISFET (Metal-Insulating Field-Effect Transistor-Semiconductor) precisely to emphasize that, in the case of organic materials, the separation layer between the gate and the semiconductor is a true insulator. Normally (for example, using a semiconductor of the type

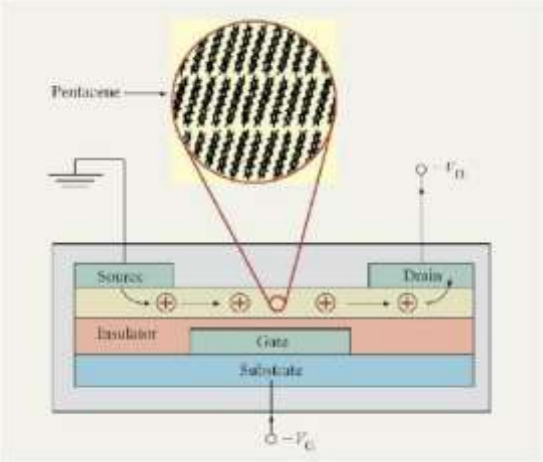


Figure 3.1: A typical organic TFT

p) Organic FETs operate in accumulation mode, and the current between the source and drain is controlled by applying a negative voltage to the gate. In this way, charges are generated at the interface between the insulator and the semiconductor, resulting in a
increased FET conductivity.
Conversely, if a positive voltage is applied, the same region is depleted of charges until a population inversion is achieved, causing the component to turn off.

We can recognize two types of materials among those used in
OTFT, with different properties and characteristics:

- sorted organic materials
- disordered organic materials

In ordered organic materials, numerous regular positions are available to accept or donate charge, as in conventional semiconductors; in contrast, in disordered organic materials, only a few positions can accept or donate charge, and it is precisely this limitation that restricts electron mobility and, consequently, current flow. Despite this mobility issue, disordered organic materials are more easily produced using printing or evaporation techniques.

This is one of the obstacles that researchers face in producing organic TFTs at low cost and with acceptable performance.

Another concern for designers and researchers of these devices is the on/off ratio (i.e., the ratio of current flowing when the device is active to leakage current when it is off): as long as the ratio is high, the low mobility can be compensated for by adding more transistors. This ratio

It is obtained by reducing the currents.

Due to leakage between the active materials and the surrounding dielectrics. During the investigation, it was observed that
They made several attempts to determine the type of structure that would be used to obtain the best
results, for example, by varying the order of the materials in the device, until results are obtained
satisfactory. Finally, the search for materials that are truly suitable for the necessary processes.
This was also an important step: in fact, they had to possess certain mechanical and chemical properties,
to be stable and withstand the stresses inherent in the processes.

3.3 Semiconductors, dielectrics and organic electrodes

Nicholas

As mentioned, in an organic thin-film transistor (OTFT), the gate controls the flow
of current between the drain and source electrodes. Normally, a higher voltage (modulus) is applied
The gate generates a greater current flow. The semiconductor material for a transistor of
Fast switching requires high charge carrier mobility and a high on-to-off current ratio (to control a single
pixel in liquid crystal displays, these are required).

mobilities greater than 0.1 cm² V). Therefore, as can be seen in Fig. 3.1, to construct a
OTFT requires conductive materials (for the electrodes), semiconductors (for the active channel), and insulators.
ÿ1 s
and an on/off ratio of approximately 106).

(for the gate dielectric).

Organic Semiconductors

As seen previously, there are two types of organic semiconductors, depending on the type of carriers
majority charge carriers: p-type (holes) and n-type (electrons). To facilitate charge transport, the layer
Organic semiconductors are usually composed of oligomers or ÿ-conjugated polymers, in which
Most of the ÿÿ bonds must be in the direction of current flow. This requires that the
semiconductor molecules adopt the same orientation both through deposition techniques in
vapor phase as well as solution phase. It is also important that the thin film has a structure
compact, dense and well connected. "

The morphology of the semiconductor is closely related to its chemical nature and
Physics of the dielectric surface: by tracing a pattern on the surface of the dielectric itself, it is possible
to obtain an organic semiconductor design only in the desired locations. This technique is used,
For example, to reduce crosstalk between multiple devices. Therefore, with proper control
From the dielectric surface, it is possible to obtain matrix structures in the organic semiconductor on
a larger area, necessary, for example, to increase the performance of transistors.

There have also been great advances in the development and research of materials: initially only a small group of polymers and oligomers provided mobilities between 0.01 and 0.1 cm2 V but in recent years a wide range of molecules and polymers with mobilities of a few cm2 V and on/off ratios greater than 105 have been developed.
-1 ÿ1 s -1 ÿ1 s ,

The CMOS structure is preferable in the fabrication of organic materials devices, as it allows To limit consumption with relatively simple electrical designs. To obtain these structures, it is necessary to They need n-channel and p-channel materials, which should guarantee similar performance and mobility. For p-type compounds, the most common materials are pentacene derivatives (CH3), while For n-type compounds, the basic compounds are fullerene (CO), naphthalene (CH), and perylene (CH). Recently, it has been reported that some semiconductors possess a bipolar behavior, which would further simplify the production of the devices (in fact, they do not require two separate modeling phases, one for the channel and one for the p channel).

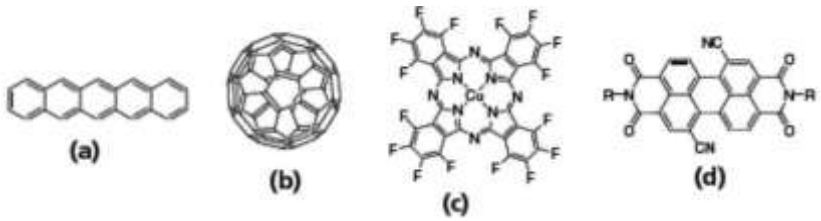


Figure 3.2: (a) pentacene; (b) fullerene; (c) naphthalene derivative; (d) perylene derivative

Dielectrics

The dielectric layer of an organic transistor must be as thin as possible, without holes or malformations, and ideally with a high dielectric constant at low operating voltages. To achieve this, numerous organic, inorganic, and organic-hybrid materials have been studied. inorganic.

Woven network polymers are generally the thinnest ultrafine dielectric materials resistant and durable. The addition of inorganic nanoparticles with a high dielectric constant to the polymer matrix of the material also significantly increases the resulting dielectric constant of the thin film.

Furthermore, a SAM (self-assembled monolayer) with a dense and highly ordered structure allows for an even thinner and higher-quality dielectric: it consists of a Surface treatment of the dielectric layer is an important method for improving transistor performance. Most of the loads introduced into the...

The semiconducting layer is limited to the first 5 nm of the semiconducting film itself, adjacent to the interface with the dielectric. Therefore, the physicochemical characteristics of the dielectric surface have a significant effect on charge transport. For example, if we consider a SiOÿ dielectric, the SiOH group on its surface tends to accept electrons.
(and therefore to subtract them from the adjacent n-channel). However, if the SiO surface is treated With a specific organic material, a significant reduction of electrons can be obtained extracted, thus improving the mobility of the n-channel semiconductor.

These treatments of the dielectric therefore also modify the characteristics of the adjacent semiconductors: for example, pentacene (the aforementioned organic semiconductor) is one of the compounds with the highest mobility values measured so far: this value, however, depends strongly on the type of SAM applied to the surface of the dielectric, precisely because it interacts with the morphological structure of the first layers of the pentacene.

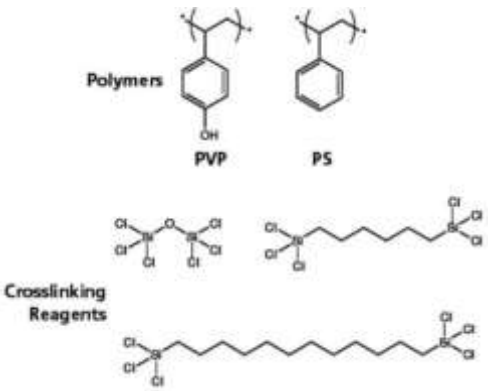


Figure 3.3: Polymer dielectrics and braided network

Electrodes

For an organic transistor to function correctly, charge injection from the electrodes It must be efficient. This requires that the electrode's extraction work be matched to the level of energy of the organic semiconductor, so the energy barrier for charge injection be low. Typically, electrodes such as gold, palladium, or indium tin oxide are used for organic p-channel transistors.

Surface modifications to the electrode using a SAM can lead to improved charge injection into the semiconductor.
This is because, in this case as well, the morphology of the semiconductor varies.

depending on the different characteristics of the electrode surface.

Organic materials that can be treated in solution are the most sought after because its low production costs. Therefore, Some research groups have developed gold or silver nanoparticle inks that can be treated at less than 200ºC to make them compatible with low-cost plastic substrates.

Current candidates for future electrode development, based on efficiency and low cost, are conductive solutions based on polymers and carbon nanotubes. In any case, a better and deeper understanding of the structural properties of these materials is necessary to design and exploit the

maximizing the possibilities of these innovations, which are candidates to be, in In the not too distant future, it will be the basis for flexible, low-cost electronic devices.

3.4 Production methods and performance

Currently there are mainly two methods for producing organic TFTs: the first is The first is based on evaporation processes and consequently on the deposition of formed vapors, while the second exploits the application of solutions, similar to what happens with OLEDs.

Evaporation processes consist of heating a sample of organic matter and Let it cool on the surface of the substrate. This The process produces organic materials generally with an ordered structure; However, it is slow and requires high vacuum procedures (and therefore environments). controlled by a pumping system), which are usually expensive. Therefore, researchers have tried to advance towards techniques that use the solutions instead of evaporatives.

The solution techniques include numerous variations in how, for example, a solution can be applied using printing or rotary techniques. The latter uses a device capable of rotating at high speed to reduce the amount of active material present on the substrate to a certain thickness. The techniques of

The printing process uses masks or printheads to direct the active material and, therefore, Therefore, create the pattern on the substrate. Furthermore, the solution... may contain the active material, or a precursor thereof, which may "It's more manageable: often, if a precursor is used, later on A heating process is carried out to convert it into the actual active material. Generally, these procedures result in disordered organic materials; therefore On the other hand, heating and annealing increase the material's structure and mobility. Recently, dielectrics and drivers that can also be applied through... Organic solutions: this would allow the manufacture of circuits only

Through printing processes, which are much more economical than evaporation. Obviously, as with inorganic semiconductors, we aim to minimize the size of individual components to achieve higher density, lower power dissipation, even lower costs, and higher switching speeds. Analyzing the methods for obtaining a pattern of the active material on the substrate in more detail, we can identify three basic ones:

- Direct printing
- Optical lithography
- printing through masks

Direct printing uses electronically controlled devices, such as printheads Inkjet printing is used to distribute small droplets of solution onto a substrate. Because printing distributes all the optical material in a single step, production is high and the unit cost is low.

Optical lithography works with some organic materials, as well as with... Inorganic semiconductors. While this process allows for the highest resolutions, it is also the most expensive, as it requires complex optical systems and multiple reagents. Furthermore, since many organic materials react with light, only certain stable polymer chains are treated in this way. While this method can produce a specific pattern in organic materials, it can also be used to produce a wide variety of structures in other materials, such as silicon, which can be used to print organic patterns.

Finally, mask printing is the last method for obtaining patterns: They make openings in a screen, spray the active material through them and deposit it onto the substrate.

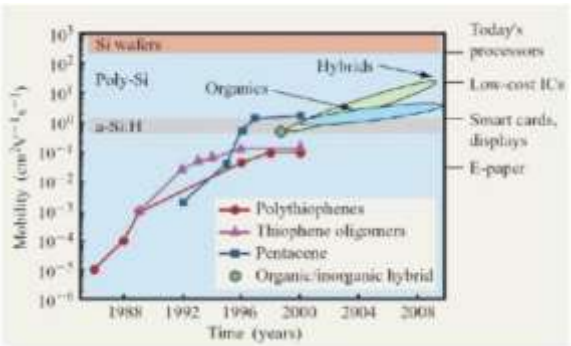


Figure 3.4: Performance of organic and hybrid semiconductors

Currently, simple organic materials with ordered structures have Higher-order mobilities between $^{-1}{}_{s}{}^{\ddot{y}1}$ Organic Semiconductors 0.1 and 1 cm2 V, such as some compounds in the acene series (polycyclic aromatic chemical compounds), including anthracene and pentacene, have at least room temperature, mobilities within this range and sometimes independent of temperature.

In Fig. 3.4 we can observe the mobilities of some representative classes of Organic materials. Pentacene films obtained by evaporation have achieved mobility on the order of that of amorphous silicon, used, for example, in the production of TFTs to guide liquid crystals in flat panel displays. Measurements on single crystals of pe-type pentacene and n-type perylene, which achieved the best results, led to mobilities of 2.7 and 5.5 cm^2 V, respectively, smaller than individual $^{-1}{}_{s}{}^{\ddot{y}1}$, a few more orders silicon crystals. A new class of materials, called organic-inorganic perovskites, have also achieved the mobilities of amorphous silicon. Although these materials could become useful for applications that do not require high switching frequencies, they do require high supply voltages.

In addition, a new category of devices, called OLETs, “organic light-emitting transistors”: They combine, in a single device, the switching functionality of a transistor with the ability to generate light emission. OLETs represent a new class of organic devices that could pave the way for “nanolight sources” and highly integrated organic circuits. Furthermore, this… The new structure could increase the lifespan and efficiency of organic photoemissive materials, properties related to different conduction configurations compared to standard OLED architectures and optimized charge carrier budgets.

Chapter 4

OSC Organic solar cells

4.1 Introduction

Solar cells, also known as photovoltaic cells, are devices that generate electricity by absorbing sunlight. They are the basic building blocks of photovoltaic modules, in which individual cells are arranged in an array to optimize the surface area of the array.
module.

The most common photovoltaic cells are made of crystalline material, usually Silicon, and, depending on the purity of the semiconductor, offers different efficiencies (efficiency is defined as the percentage of energy absorbed and transformed relative to the energy incident on the module's surface). In fact, values range from 56% obtained with amorphous silicon to approximately 1213% with polycrystalline silicon, even reaching peaks of 20% for monocrystalline silicon.

These yields vary depending on many factors, such as the light intensity at the that the cells are subjected to, the operating temperature of the materials, the efficiency of the materials used, the angle at which the rays reach the surface, and the lifespan of the cell, to name a few.

The fields of application for these devices are multiple: from small devices such as calculators, watches (made of amorphous silicon) where the photovoltaic module powers them autonomously, up to larger, more efficient and expensive devices, such as photovoltaic panels for homes and industries, where the modules instead work alongside the electrical grid in the supply of energy.

4.2 Structure and operating principle

Figure 4.1 illustrates the internal characteristics of a photovoltaic cell. As can be seen, The structure is similar to that of a simple PN joint, but it has important differences. Typically, a thin, highly doped n-type region is located above a thinner region. large p-type, weakly doped.

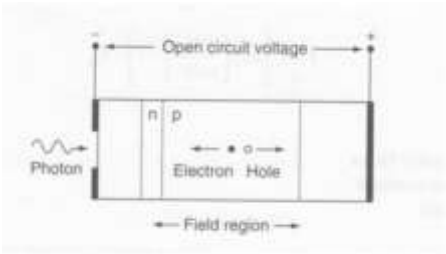


Figure 4.1: Structure of a solar cell

Doping. In the structure of a cell, an attempt is made to prevent the formation of intrinsic regions for keep the equivalent series resistance of the cell low.

Charge diffusion also creates a depletion zone in this case, where there is a electric field. The latter is responsible for the separation of the electron-hole pairs generated by the absorption of photons (from light radiation). Electrons move toward the n-doped side, holes in the opposite direction, as in a normal pn junction. However, by keeping the external terminals disconnected (at rest), the photogenerated charge carriers create a forward bias at the terminals themselves, called Voc (open circuit). Figure 4.2 shows the IV characteristic in a solar cell, where we can observe that Voc is related to a zero current leaving the cell. The total current within the diode is also zero in this case, since the photogenerated voltage Voc causes an internal current that is exactly equal and opposite to the photocurrent. Conversely, in the ideal resistance case

external zero, the current is Isc, that is, the short-circuit current.

When an external resistor Rex (a load) is connected to the solar cell, the voltage The photogenerated material imparts a current, the trend of which is shown in Figure 4.2. The value of this The current is obtained, as a first approximation, by the difference between the dark current and the photocurrent, but for a more detailed analysis it would be necessary to consider the internal resistances and the resulting voltage drops.

The IV power supplied to the load therefore depends on the type and the characteristics of this, and can be determined graphically from figure 4.2. The optimum operating point (i.e., the one that covers the largest area) is given by Pmax = Im Vm. If the IV curve were ideally a rectangle, the maximum power would be obtained with Pideal = Isc Voc; therefore, the factor of merit of current solar cells is defined as the ratio between Pideal and Pmax.

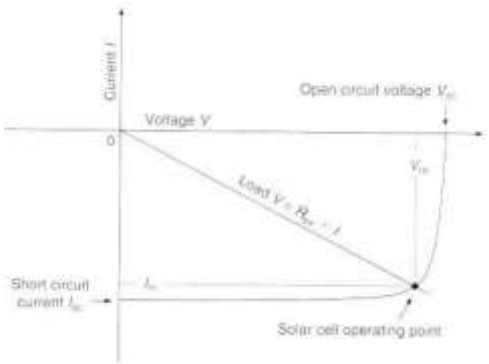


Figure 4.2: Characteristic VI of a solar cell

Differences with inorganic solar cells

When comparing organic solar cells with traditional inorganic cells, some important differences emerge:

As mentioned earlier, the mobility of cargo carriers in
The optical absorption coefficient of organic semiconductors is much lower than that of inorganic semiconductors. However, this disadvantage is partially offset by the high optical absorption coefficient (> 105 cmÿ1), which allows for very thin active layers (< 100 nm).

The gap between the highest occupied molecular orbital and the molecular orbital
The lowest unoccupied space (HOMOLUMO) of most organic semiconductors studied is on the order of 2 eV. These values limit the portion of incident solar radiation collected to approximately 30%. In any case, the synthesis of organic semiconductors with minimal gaps is at the forefront of ongoing research.

Optical absorption leads to the formation of tightly bound excitons instead of free carriers.
Furthermore, the diffusion wavelengths of these excitons are typically quite short, on the order of 10 nm. Until recently, this has been the main obstacle to the success and development of organic solar cells.

4.3 Performance and results

The operations that occur in an organic solar cell can be summarized in three fundamental steps:

• Optical absorption that generates bound excitons (ÿAbs)

- Dissociation of excitons into separate carriers (ÿDis)
- Collection of holes and electrons at the anode and cathode respectively. (ÿRac)

The overall efficiency of an organic solar cell can be calculated as the product of the probabilities of each fundamental step, i.e., ÿEf f " = ÿAbs ÿDis ÿRac

It is possible to obtain quite high absorption efficiencies using active layers of appropriate dimensions or by exploiting absorption techniques. “confinement” of light. Furthermore, since solar radiation (Fig. 4.3) has For a given emission spectrum, the choice of the active material for its absorption must be made with great care: in fact, the materials

They are generally used with a wide range of absorption frequencies, precisely to take full advantage of the sun's broad emission spectrum.

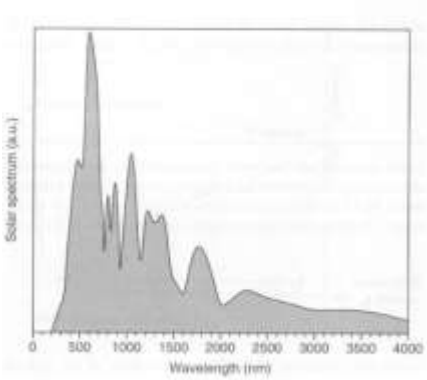


Figure 4.3: Emission spectrum of the sun

Furthermore, the accumulation coefficient of the different charges on the opposite electrodes It is usually high and in any case is linked to the electric field that is formed. In the cell. An important step is being able to obtain exciton dissociation coefficients high. Actually, the dissociation of excitons... This occurs under the influence of intense electric fields, or in particular, at the interface that is formed between the donor and acceptor semiconductors. In this In place, the difference between the ionization potential of the donors (IP: Ionization Potential) and the affinity of the electron acceptors (EA: Electron Affinity) It is sufficient to overcome the binding energy of the excitons.

The efficiency of exciton transport to the donor-receptor interface is the main problem to solve in order to obtain solar cells. Organic with acceptable conversion efficiencies. For this reason, components where the light-generating site is at a distance equal to the exciton diffusion length from the interface between the donor material and

Acceptor materials are preferred. Generally, there are two approaches to meeting this requirement:

- heterogeneous bonding between two layers (bilayer heterojection)
- bulk heterojection of the substrate

Bilayer heterojunction solar cells

This component consists of the superposition of two layers of organic material, a donor and an acceptor, in which the thickness of the same is kept strictly less than the diffusion length of the exciton.
This allows most of the photogenerated excitons to reach the interface between the donor and acceptor material, the place where they are dissociated into two opposite charge carriers.

Outside these layers are two electrodes, which are placed in carefully relate the donor and acceptor levels to improve the extraction efficiency of the respective carriers (more precisely, the highest orbital levels occupied by the donor are considered with the lowest free levels of the acceptor).

A modification of the two-layer heterostructure has already been studied and tested and it has yielded good results, increasing the cell's efficiency by 5%. This involves inserting a layer between the two distinct layers mentioned above.

Intermediate, formed by a mixture of acceptor and donor molecules. This structure It has been called a hybrid molecular heterojunction.

Planar mixed (or PMHJ, Planar Mixed Molecular Heterojunction), and the intermediate layer can be obtained by co-evaporation of the donor and acceptor materials.
As mentioned earlier, this novel structure has increased the efficiency of the solar cell, especially when using copper phthalocyanine as the donor material and C60 as the acceptor material.

Bulk heterojunction solar cells

This concept involves mixing organic semiconductor acceptors and donors in the same solution. Then, through rotational operations, thin films are formed from this solution which, once solidified, lead to the formation of a nanoscopic mixture of both materials. In this way, it is possible to obtain almost complete dissociation of the excitons. However, this method for forming the active layer has some disadvantages, such as reduced carrier mobility.

Therefore, research in this area focuses on improving the properties of the charge carriers of the mixtures by controlling and analyzing the morphology of the resulting film.

The performance efficiency (ÿEf f) of organic solar cells has experienced Significant growth has been observed in recent years: in less than a decade, it has risen from 2.5% to an impressive 56% thanks to technological innovations achieved by researchers in this field. Specifically, work has focused on materials research and their production techniques (for example, by paying closer attention to material morphology or using slower-speed processes) to improve absorption efficiency and, in particular, electron dissociation.

4.4 Dye-sensitized solar cells

Another application of organic materials in solar cells is in DSSCs (dye-sensitized solar cells). These cells use a dye extracted from plants to mimic the way plants and certain algae convert sunlight into energy. Although these solar cells are still in the research and development phase, they have already shown promise as cost-effective alternatives to silicon cells for harnessing sunlight, a renewable energy source.

These cells were invented in the early 1990s through a collaboration between M. Gratzel and B. O'Regan. The first cells only absorbed part of the spectrum (ultraviolet and deep blue), but with technological advances and discoveries, it became possible to broaden their response frequencies. The most efficient dyes were simply called "black dyes" because of their very dark color.

Although the performance of these solar cells is lower than that of silicon cells, their production is much cheaper. The efficiency of this technology is around 1012%, but given the rapid evolution of these cells, researchers are confident. In fact, a technique has recently been applied that has significantly increased the efficiency of these devices. It consists of building a large number of very small cells: to give an idea of the size of a cell, approximately 3,500 are needed to achieve a thickness equivalent to that of a human hair. Thanks to this method, it has been possible to absorb more incident rays, reducing the amount of reflected (and therefore lost) light.

Further improvements are expected in the future, and once they have reached the desired performance With silicon-based cells, large-scale production could begin, allowing this low-cost alternative to spread and develop further.

Chapter 5

Recent methods of Low-cost production

Following the discovery of the first organic transistors, the last decade has seen "
A major breakthrough in the field of organic electronics. In fact, it has been shown that a number
Significant studies of circuits with organic transistors obtain results comparable to those of
silicon-based. However, one of their advantages is their low theoretical production cost.

In general, there are two methods for reducing production costs in electronics. The first
It consists of increasing the component density in integrated circuits (efficiency of
packaging) and is expressed as the ratio between the number of devices on a board and the area of
The same. The second involves using cheaper tools and materials: this is the case.

From organic electronics. The most effective methods for obtaining a pattern (a drawing, a structure)
In a broad area, printing methods are used: these methods allow working with substrates
inexpensive materials, such as glass, plastic, and metal sheets," can be used. High resolution is also possible.
of printing, if necessary: in this case, we are talking about micro-contact printing (µCP).

In this section we will briefly describe the techniques that are being used or will be used.
It is used for the low-cost production of organic devices.

5.1 Inkjet printing

Inkjet printing technologies offer two main opportunities: reduction
of the production costs of organic devices and the possibility of new configurations of the
own devices.

There are two main methods for obtaining an inkjet print: the piezoelectric and the
acoustic. There is also a thermal printing method, but it is not used in the organic sector because
because heat degrades most of the materials used very easily.

These direct printing methods have been considered to reduce the number of processes in the production of a device and, therefore, the costly and time-consuming treatments used.

Piezoelectric method and acoustic method

In the piezoelectric process, a liquid organometallic substance is used which, after undergoing heat treatment, is transformed into, for example, solid copper. This technique allows the construction of three-dimensional micromechanical systems and electrical circuits from nanoparticles of metallic suspensions.

An inkjet printer creates a pattern on the desired material by ejecting tiny droplets of ink, one by one, from a nozzle. It can move two-dimensionally at approximately 1 mm from the substrate. Each droplet is deposited onto the substrate by a pressure pulse, typically generated by a deformable piezoelectric crystal inside a small chamber connected to the nozzle (a piezoelectric crystal expands or contracts when a potential difference is applied to two of its faces; conversely, if these two faces are connected by an external circuit, a current flows—the piezoelectric current). Using the piezoelectric method, for example, it is possible to deposit a pattern of a conductor (usually copper) at low temperatures onto a material.

a glass substrate.

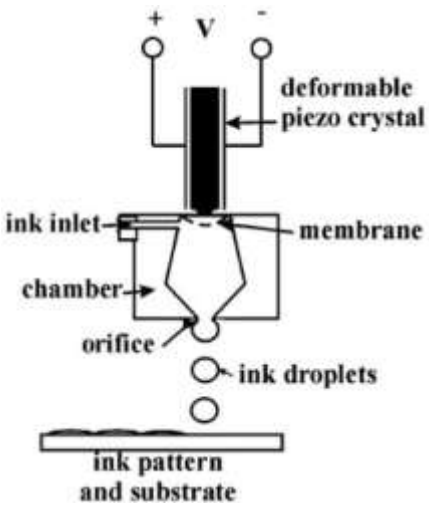


Figure 5.1: Diagram of the piezoelectric printing method

This printing method allows you to obtain the desired pattern on a polymer substrate quite easily, for example, by depositing the drain and source contacts to obtain a generic TFT.

Progress is being made with this technique: in fact, using an acoustic wave printer, it has also been possible to directly print the semiconductor layer. This technology uses a high-frequency transducer located behind an acoustic lens. The transducer emits an acoustic wave through the lens, which concentrates the energy, forming a pressure wave that overcomes the surface tension of the underlying liquid and allows a droplet to be expelled. The absence of a nozzle avoids clogging problems, a disadvantage of the previous system.

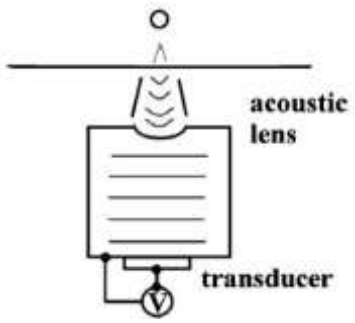


Figure 5.2: Diagram of the acoustic wave printing method

These printing techniques show great promise for large-scale electronics production due to their versatility: in fact, printing contacts, semiconductors, and dielectrics onto large substrates is relatively easy with these techniques. The only drawback is the low resolution achievable: patterns typically reach resolutions of around 50-100 µm, but, for example, the promising acoustic wave technique can achieve accuracies on the order of 510 µm, although this increases production costs.

5.2 µCP

The microcontact printing (µCP) process is based on the selective transfer of a chemical compound to the substrate via a flexible polymer mask, resulting in the formation of exposed and covered regions on the substrate itself. Once the chemical compound is applied to the predefined areas, the substrate is treated using various methods, typically producing a negative replica of the mask.

The effectiveness of this method depends primarily on the mask used: it can be produced in various ways depending on the type of material to be treated, and it can also be flexible or rigid.

There are primarily three methods for obtaining a pattern in these Flexible electronic components:

- µCP followed by an etching treatment
- µCP followed by selective electropolymerization
- µCP followed by plating (non-electrical)

Using the engraving method, the first results have been obtained in the Processing of organic components. The main steps for obtaining, for example, a TFT using this method involve depositing a metallic layer (for example, by evaporation) onto a substrate. A layer of material that must withstand etching is deposited using a microchip. The metallic regions not covered by this material are then removed, leaving only the desired contacts. This technique allows for high-resolution results, especially with metals such as gold, silver, or copper.

The “selective electropolymerization” technique is based on a similar principle to the one just described, but with one difference: in the previous case, the thin metallic film was deposited on the substrate and then removed locally; in this case, a compound is placed on the substrate to obtain a “negative” of the desired pattern; where this compound is not present, it is possible to deposit the metallic contacts (in the case of the TFT, the drain and the source).

Finally, the "non-electrical coating" technique consists of depositing a material, which can be hydrophobic or hydrophilic, on a substrate or a thin metallic film. Depending on the result, it is immersed in a solution (whose chemical parameters, such as pH or temperature, must be carefully controlled) and, depending on the nature of the solution, it is possible to deposit metals or even polymers in the desired areas.

Chapter 6

Commercial applications

The application areas for these organic devices are numerous: OLEDs and OTFTs, for example, can perform the same function as the LEDs and TFTs currently found in computer screens, televisions, e-readers, and mobile phones; OTFTs can be used in disposable circuits or, for example, in RFID (radio-frequency identification), valid replacements for current barcodes. This is possible because the results obtained with organic devices are comparable to those obtained with amorphous silicon, making all devices that use the latter potential candidates for being built with organic components. Furthermore, the application areas for these components have expanded due to the characteristics and properties offered by organic materials, both from the perspective of production processes (the possibility of printing circuits on flexible materials) and for economic reasons (the low production and material costs).

6.1 RFID and active sensors

The acronym RFID stands for "radio-frequency identification" and refers to a set of systems that enable the automatic recognition of objects. In fact, it can be considered a type of barcode capable of exchanging information wirelessly, but which can also be updated in various ways. While this technology is emerging, it is expected to become widespread due to its enormous potential and the broad range of fields in which it could be used.

Operating principle

The object is identified using an antenna capable of reading a digital chip (called a tag or transponder) attached to the object. This transponder can contain numerous

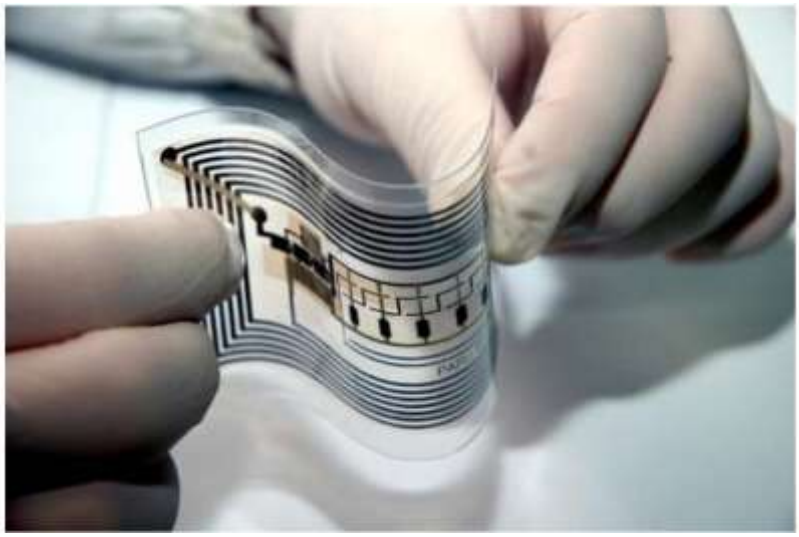


Figure 6.1: Example of flexible RFID

Information about the item, such as its identification code (thinking of a supermarket), the production
date, the manufacturer, or the expiry date, which may be static or change over time, if subject to certain conditions.

The label generally does not need electricity to function as
It generally works using the principles of magnetic induction: When subjected
to the magnetic field of the receiving antenna, it is able to accumulate energy
that allows it to transmit (over short distances) the stored information. Components that work in
this way are called passive tags. If greater
transmission power is required (for example, because the transmission distances are
greater), the tag can simply be battery-powered: this second

The component group is indicated by the name of the active tags.

Applications and future prospects

The applications of this new technology are numerous, and what is impressive is its rapid spread. In fact, currently...
It is used in the transport of goods, just like a simple RFID.
It is possible to check if a certain product is present in a warehouse and in what quantity:
greater dissemination of this information could lead to an increase in warehouse
efficiency, cost reduction, and overall benefits for the entire transport chain.

Even retailers could exploit the potential of these devices, which would allow them
would allow for greater control over the goods in

sales, but that in the not too distant future they may be able to recognize if a product is still in good condition or has degraded, thus avoiding unpleasant surprises for customers.

Furthermore, this technology could prove very practical in environments where
This is especially relevant in environments such as libraries, government agencies, the military, and hospitals that require quick access to documents, books, or texts. Wider adoption of RFID technology could ensure greater control, enhanced security, and, above all, significantly faster processing of both critical and everyday tasks.

Other applications of this recognition system are numerous, from its use in passports and personal identification cards, to the identification of animals, from electronic ticketing systems to the detection of environmental parameters of a greenhouse, a landfill, a museum or a chamber with controlled parameters.

Finally, we would like to remind you that the market for manufacturers of these devices could also greatly benefit from the spread of this technology, based on continuous research and development aimed at improving performance and reducing production costs (which are already lower than those of silicon-based RFID devices).

6.2 OLED screens on the market

Three years ago, Sony ushered in the era of OLED televisions and screens: in December 2007, the Japanese company launched an 11-inch screen that used this innovative technology.



Figure 6.2: EXL1: Sony 11-inch OLED monitor

It is only 3 mm thick, capable of meeting high-definition demands, and is also equipped with Ethernet and USB ports, making it versatile. The main features of this OLED screen are its high image resolution and extremely high contrast ratio (1

The 1 million to 1) has minimal thickness and moderate weight (a couple of kilograms). Furthermore, it offers a very wide viewing angle and lower image latency, preventing annoying lag. trail effects, often present in video playback.

Although Sony has been producing OLED screens in large quantities since 2004, applying The results on small screens suitable for mobile phones or MP3 players, this is the This is the first attempt to achieve a screen of this size. The product's launch price, which It cost around $2,500, and was paid for by the manufacturer, although at that time the cost of Production cost was around $5,000 per unit.

However, recently, two major display manufacturers have made decisions Contradictory: on the one hand, Sony decided to suspend production of the EXL1 and, therefore, suspend production of screens with this technology; on the other hand, LG invested in research and development to obtain a 15-inch screen that would initially be launched only on the market American. The main reason for this separation probably lies in the limited success of the EXL1, but it is justified by its unusual dimensions and, above all, its price, which was not within everyone's reach.

6.3 Electronic paper

The word EPaper evokes the purpose for which these objects were designed: to mimic the appearance of an ink print on a simple sheet of paper (which is precisely why we refer to it as electric ink, "eink"). Unlike an LCD screen, whose pixels are backlit, the operating principle of the EPaper is based on the reflection of light, just like a simple sheet of paper (as shown in Figure 6.3).

Operating principle

The main components of electronic ink are millions of tiny microcapsules, so large as the diameter of a hair. Inside these capsules are particles white particles with a positive charge and black particles with a negative charge: these hundreds of particles They are suspended in a transparent fluid. By applying a suitable electric field, it is possible orienting the particles, making only those of the desired color visible on the outer surface, such as is shown in Figure 6.4. Furthermore, by adjusting the applied field voltage, a a kind of ratio between the amount of white and black particles shown: we speak, Therefore, shades of gray instead of black and white images; current technologies They offer up to 16 shades of gray.



Figure 6.3: Partially illuminated electronic paper

Furthermore, another important feature of these objects is that they only require power when the current image is modified: this translates into a very long battery life, since consumption, especially when displaying text (for example, in a newspaper or a book), is very low.

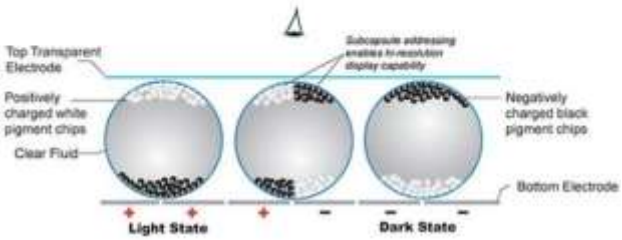


Figure 6.4: Cross section of the microcapsules that form the electronic ink.

The size of a microcapsule is on the order of hundreds of µm, which means there are approximately 100,000 of them in one square centimeter.
Each of these microcapsules contains hundreds of black and white particles and can be individually targeted: with this method, both simple letters of a text and high-resolution images can be easily obtained.

These screens are built by printing electronic ink onto a thin film of glass, plastic or even paper, behind which there is another layer of material, with the circuits necessary to control the screen itself.
The latest printing techniques for this ink have confirmed that it can be printed on almost any surface to produce a display.

There are numerous types of electronic paper on the market, of different sizes, weights and costs, but generally the properties common to most of them are:

They are lightweight, flexible, and comfortable to read.

Future developments

A recent advance in this technology has resulted in the appearance on the market of electronic papers capable of reproducing color images. The basic technology is as described above; the difference lies in the fact that within the microcapsules there are multi-colored particles sensitive to different polarization voltages, which allows for obtaining
a combination of these colors.

The aspects to improve in this new model are battery consumption, which is higher than
In the previous model, the limited number of colors (we're talking about the ability to display several thousand colors) was a drawback. However, considering that this is a relatively recent technology (just over ten years old), it's quite plausible that significant new developments will occur in the coming years, leading to cost reductions and, consequently, wider market penetration for these products.

Chapter 7

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