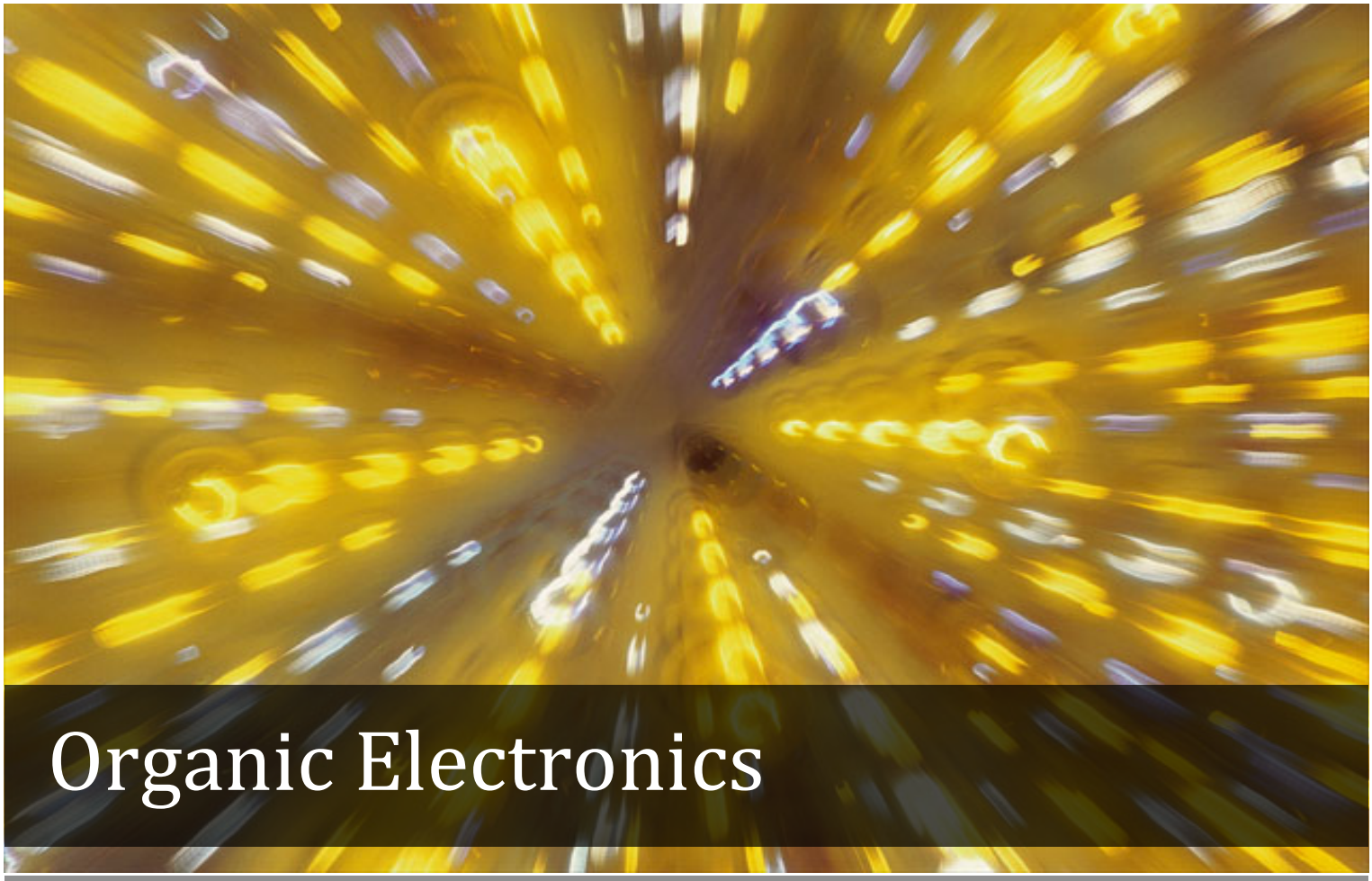

Organic Electronics

Wes Petree, Chris Woolly, Jesse Teahon, David Reavis

Organic Electronics have been studied for nearly 60 years. Within the last decade, much advancement has been made and organic electronics are becoming very popular in many modern devices.

11/30/20011

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OFETs

Organic Field-Effect Transistors

Jesse Teahon

11/30/2011

OFETs show promise as a substitute for modern devices. This section discusses the history, theoretical background, device fabrication, and future applications of OFETs.

Introduction

Organic field-effect transistors (OFETs) based on solution-processible polymeric as well as small molecular semiconductors have obtained impressive improvements in their performance during recent years. These devices have been developed to realize low-cost, large-area electronic products. OFETs have been fabricated with various device geometries. The most commonly used device geometry is bottom gate with top contact partly because of borrowing the concept of thin-film silicon transistor (TFT) using thermally grown Si/SiO_2 oxide as gate dielectric. Due to advantage of being commercially available high quality Si/SiO_2 substrate, it has dominated the whole community. Recently it has been shown that organic dielectrics are also promising for high performance OFETs. Organic dielectrics can be solution-processed, provide smooth films on transparent glass and plastic substrates, are suitable for opto-electronics like photo-responsive OFETs due to their high optical transparency, can be thermally stable up to 200 ℃ with a relatively small thermal expansion coefficient, and can possess a rather high dielectric constant up to 18 [1].

The immediate opportunity is also the use of the organic dielectric for the top-gate structured OFET as it does not destroy the underlying organic semiconductors. Top-gate bottom contact structure devices allow patterning the bottom source-drain electrodes on top of any flexible or rigid substrate first before building the rest of the device. Top gate top contact structure devices allow growing organic semiconductor films on top of any flexible or rigid substrate [1].

History

The field-effect transistor (FET) was first envisioned by J.E. Lilienfeld in 1930. Lilienfeld obtained a patent for the idea which hindered any progress in the area of FETs leading to the emergence of the bipolar junction transistor developed by Bell Labs. With the severe limitations of BJTs, FET development was necessary for further applications towards electronic devices. With the expiration of the patent, development of FETs and the companies who employed them quickly superseded the BJT generation.

The first Organic FET (OFET) was developed by a team led by Koezuka in 1987. The team utilized polythiophene as the active semiconducting material. The device was normally off type and the source-drain current was largely increased by a factor of $10^2 – 10^3$ by applying a gate voltage. The device was very stable and worked well in air following heat treatment [2].

OFETs have obtained impressive improvements in performance. In May 2007, Sony unveiled the first full-color organic LED display based on OFETs. Using OFETs, Sony was able to create a flexible plastic substrate on which the OFETs were developed.

Theoretical Background

A typical OFET is composed of a gate electrode, dielectric layer, organic semiconductor layer, and source-drain (S-D) electrodes. The dielectric layers are either inorganic dielectric materials or insulating organic polymers. The organic semiconductor is the core element of an OFET. It determines the charge carrier transport as well as the charge carrier injection. Inorganic semiconductors are classified into p-type or n-type materials, depending on the nature of the controlled dopant. Different from inorganic materials, organic semiconductor materials can be classified as p-type or n-type according to which type of charge carrier is more efficiently transported through the material. In fact, all organic semiconductors allow hole and electron transport; however, the carrier transport mobility is difficult to measure accurately. The organic semiconductor category is thus determined by the operation model of corresponding devices. For OFETs, both the carrier transport and the carrier injection influence the device operation model. In other words, aside from the properties of the organic materials, both the work function of S-D electrodes and the dielectric properties of the insulating layer could influence the device operation model. As a result, it is not appropriate to define p- or n-type semiconductors, but rather p- or n-channel transistors [3].

To demonstrate the operating principle of the OFETs, a simplified energy level diagram for the Fermi level of source-drain metal electrode and HOMO-LUMO levels of a semiconductor are shown in the following figures. If there is no gate voltage applied, the organic semiconductor which is intrinsically undoped will not show any charge carriers. Direct injection from the source/drain electrodes is the only way to create flowing current in the organic semiconductor. Such currents will be relatively small due to high resistance of the organic semiconductors and large distance between the source and drain electrodes [1].

When a negative gate voltage is applied, positive charges are induced at the organic semiconductors adjacent to the gate dielectric (p-type conducting channel is formed). If the Fermi level of source/drain metal is close to the HOMO level of the organic semiconductor, then positive charges can be extracted by the electrodes by applying a voltage, V_{DS} between drain and source. Such organic semiconductors with ability to conduct only positive charge carriers is said to be a *p*-type semiconductors [1].

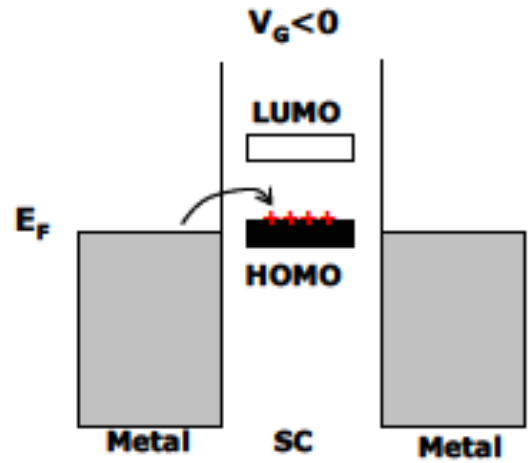

Figure 1: $V_G < 0$

When a positive voltage is applied to the gate, negative charges are induced at the semiconductor adjacent to the dielectric interface (n-type conducting channel is formed). If the Fermi level of source/drain metal is far away from the LUMO level, so that electron injection/extraction is very unlikely then low I_{DS} is expected due to high contact barriers. If the Fermi level of source/drain metal is close to the LUMO level of the organic semiconductor, then negative charges can be injected and extracted by the electrodes by applying a voltage, V_{DS} between drain and source. Such organic semiconductors with al carriers is said to be a *n*-type semiconductors. In recent times, significant improvements in charge carrier mobilities of organic semiconductor materials in OFETs have been made. Current benchmark for high mobility materials among various organic semiconductors are pentacene and fullerenes (for both $\mu \sim 6$ cm^2/V-s) for p-type and n-type, respectively [1].

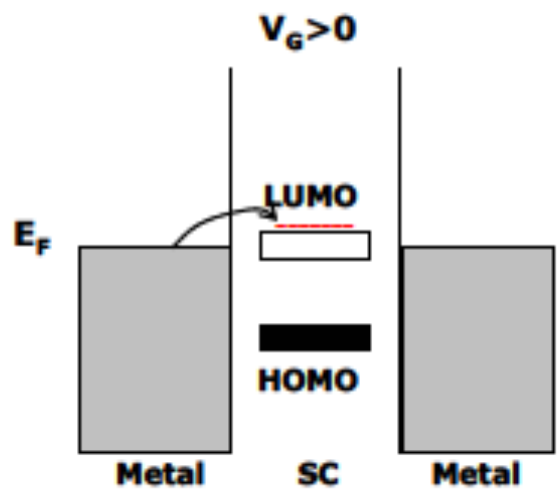

Figure 2: $V_G > 0$

Device Fabrication

According to different preparation sequences of the S-D electrodes and organic semiconductor layer, OFETs are fabricated in either the top or bottom S-D contact geometry shown in Figure 3 [1][3]. In the top contact configuration, figure 3 (a) and (d) on the following figure, the organic layer is located on a dielectric surface, and the S-D electrodes are deposited onto the top of the organic layer through a shadow mask. For devices

with top contact geometry, excellent electrode/organic layer contact and high device performance can be obtained. In bottom contact devices, the S-D electrodes are sandwiched between the gate dielectric layer and the organic semiconductor layer. Bottom contact S-D electrodes, Figure 3 (c) and (d) on the following figure, can be prepared on the dielectric layer using photolithographic techniques. Compared with top contact geometry, the bottom contact configuration is a more feasible geometry for many practical applications. Unfortunately, bottom contact devices usually suffer from lower device performance due to the poor contact. For the above-mentioned two configurations, both the dielectric layer and the gate electrode are fabricated before the organic layer deposition. These configurations correspond to the bottom-gate geometry. The bottom-gate geometry is the most used device structure. On the other hand, OFETs can also be constructed in the top gate configuration, where the gate electrode is the last device element deposited. With this geometry, the organic active layer can be well-encapsulated by the following deposition of the dielectric layer and gate electrode. For single-crystal FETs, the top-gate geometry ensures good dielectric/single-crystal contact [3].

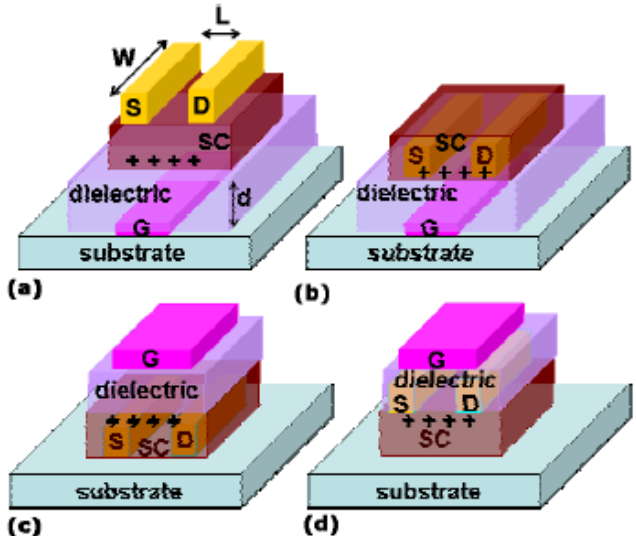

Figure 3: Contact and Gate Structures

Vacuum evaporation is an effective way to fabricate thin films of the small organic molecules. Organic semiconductor films are deposited by sublimation in a chamber under high vacuum. To achieve a highly ordered film, the deposition conditions have to be strictly controlled. Substrate temperature and evaporation rate are the most important factors influencing the film conditions. Larger grains can usually be obtained by increasing the substrate temperature. An ordered film with fewer boundaries in the active channel could improve the device performance [3] See Figure 4..

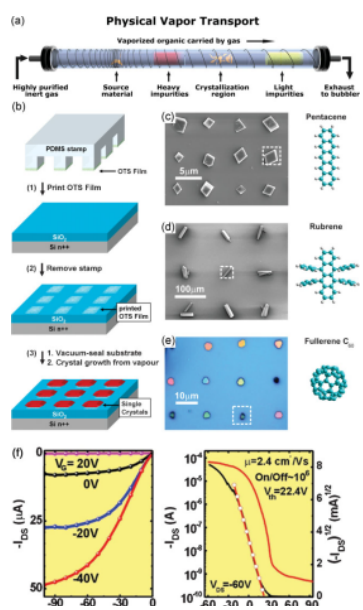

Figure 4: Physical Vapor Transport

Fabrication of the organic active layer using solution methods has attracted wide interest due to potential applications for ultralow cost organic devices. Spin-coating, drop-casting, and printing techniques are the most frequently used solution approaches. As far as organic semiconductors are concerned, both the thin film of polymer and small molecules can be fabricated using solution methods. Polymers are the most widely studied solution processing materials. To achieve efficient charge transport, polymers composed of microcrystallines are preferable [3].

In the electrode peeling transfer, source, drain, and gate electrodes, finely formed with a metal on a rigid temporary substrate, where micropatterning techniques such as photolithography and lift-off are applicable, are transferred onto a wide variety of flexible substrates without deletion. Figure 5 shows a schematic diagram of the fabrication process. In the present study, gold source–drain electrodes were deposited on a solid glass substrate through a shadow mask. SAM is formed on the electrodes by immersion of the substrate in a thiol solution and careful rinse. PCPX layer is formed by CVD. The gate electrode is formed by a spattering. A flexible adhesive substrate is attached on the top and peeled off. Pentacene is deposited on the surface, exposing the source-drain electrodes as an organic semiconductor [4].

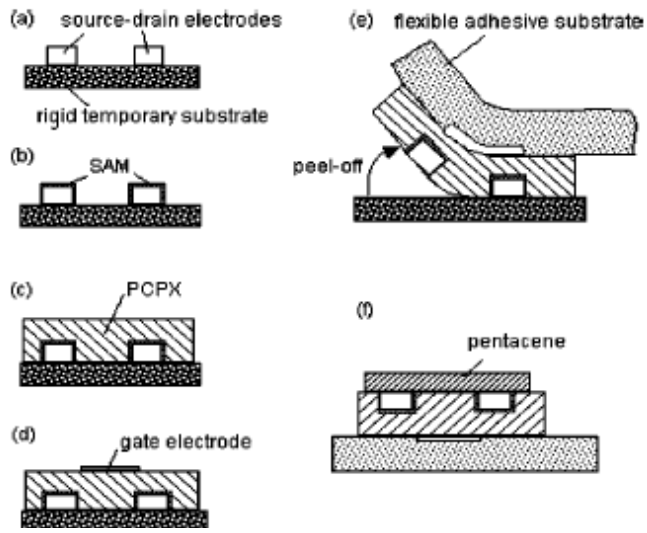

Figure 5: Electrode Peeling Transfer

Future Applications

A NOMFET, or nanoparticle-organic memory FET, is an organic memristive (memory resistive) transistor used to emulate biological neural synapses such as in human brains. They can be more capable of replicating the dynamic behaviors of biological spiking synapse than the CMOS transistor circuits used today. Using the CMOS transistors to generate the neurons, NOMFETs are a preferred method for replicating the synapse because "a great number of (CMOS) transistors are required to emulate the dynamic behaviors of biological synapses" [5].

The FET has a highly p+ doped Si Gate insulated with a thermally grown SiO2. The Source and Drains are Au, and the channel is a mixture of Au nanoparticles (NPs) with a p-type organic semiconductor, pentacene. See Figure 6.

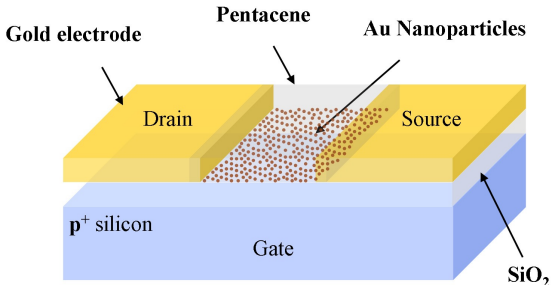

Figure 6: NOMFET Structure

A negative voltage applied to the Gate triggers the conduction between the Drain and Source. The negative voltage also gives the Au NPs a positive charge which induces repulsion between the holes trapped inside the Au NPs and those in the pentacene channel. This interaction causes a charge retention time in the NPs of up to a couple thousand seconds [1]. The current flows from the source to the drain, giving I_{DS} a negative value. When a voltage pulse of varying frequency, V_{AP}, is applied to both the Gate and Drain, the transistor begins to exhibit its biological synapse spiking characteristics. Figure 7 displays the NOMFET electrical configuration along with the circuit equivalent, showing the memristive properties of the pentacene channel [5].

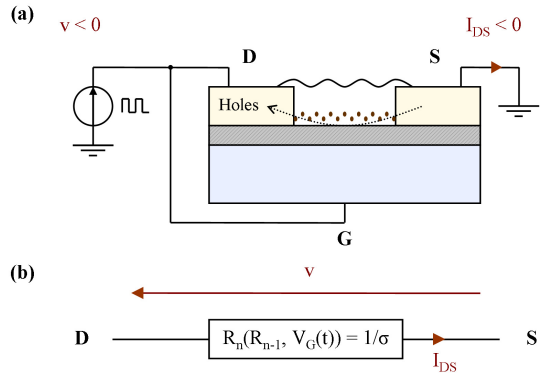

Figure 7: NOMFET Electrical Configuration

Conclusion

Organic dielectrics can be solution-processed, provide smooth films on transparent glass and plastic substrates, are suitable for opto-electronics like photo-responsive OFETs due to their high optical transparency, can be thermally stable up to 200 ℃ with a relatively small thermal expansion coefficient, and can possess a rather high dielectric constant up to 18. Over the past few years, OFETs have demonstrated tremendous progress towards viable applications. Mobilities of OFETs are comparable to amorphous silicon FETs, though progress still needs to be made in order to replace FETs in other applications such as high mobility electron transistors (HEMTs) and other high speed applications. In the advancement of OFETs, progress in mobility, stability, and costs are left to be desired. Until then, OFETs are only applicable to lower mobility devices.

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OTFTs

Organic Thin-Film Transistors

Chris Woolly

11/30/2011

In this section, we will be discussing the technology involved in developing and the modern-day application of OTFTs in everyday electronics.

Introduction

There are three types of semiconductors: inorganic, organic small molecules, and conjugated polymers. Below, in Table 1, we can see a comparison of the between organic and inorganic semiconductor materials.

Table 1: Inorganic semiconductors vs. organic semiconductors [1]

	Inorganic Semiconductors	**Organic Semiconductors**
Bonding	Ionic, Covalent, and Metallic (2-4 eV)	Van der Waals (<0.01 eV)
Charge Carriers	Electrons, Holes, and Ions	Polaron and Exciton Diffusion
Mobility	100-10000 $cm^2/(Vs)$	10^{-6}-1 $cm^2/(Vs)$

There are two kinds of bonding in organic semiconductors: Intramolecular and Intermolecular. Intramolecular bonding involves both ionic and covalent bonds (C-C and C-H). The intermolecular bonding, however only involves Van der Waals type bonding, which has a very small binding energy (<0.01eV). This differs from the ionic, covalent, and metallic bonds that inorganic semiconducting materials possess, which are much stronger (2-4 eV).

Theoretical Background

Polarons and Excitons

Where inorganic materials rely on the flow of electrons, holes, and ions, organic materials utilize the diffusion, dissociation, and radiative recombination attributes of excitons, and the charge carrying/repulsing properties of polarons. A visual model of the excitons and polarons in polymer materials is depicted in Figure 1.

An exciton is a Coulomb-bound electron-hole pair with an electrically neutral charge. In organic semiconductors, excitons have been attributed to binding energies ranging from 50meV to almost 1 eV. However, the more typical range is from 300meV to about 400meV [2]. Excitons have a limited lifetime, usually in the nanoseconds range. After the lifetime ends, the excitons radiatively recombine, causing photoluminescence.

A polaron is a charge carrier that distorts its surroundings due to the organic materials having a non-rigid lattice. If it is carrying an electron, it pulls the positively charged ions and repels the negatively charged ions, and vice versa for when it is carrying a hole. Polarons have a mass just above that of an electron. Their larger size combined with the low Van der Waals binding energy, causes polarons to have a very low mobility. "The fact that there are no free charge carriers in conjugated polymers, but negative and positive polarons with much lower mobilities instead, seriously reduces the mobility in organic devices, which is usually four to six orders of magnitudes below that of inorganic semiconductors." [2]

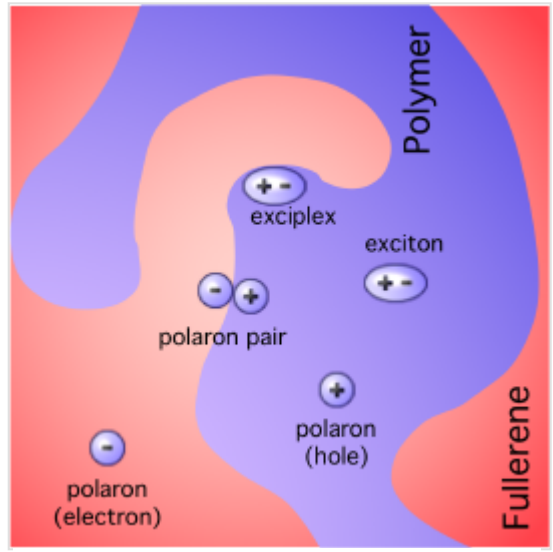

Figure 1: Polarons and excitons represented in a polymer material [3]

Materials

There are two overarching types of organic semiconducting materials, small molecules and polymers.

Small Molecules:

- Pentacene
  - FET channel material
- Anthracene
  - FET channel material
- Tetracene
  - FET channel material
- Rubrene
  - OLED Fluorescent dye
  - FET channel material
- Perylene
  - OLED Fluorescent dye
- Quinacridone
  - OLED Fluorescent dye
- Alq_3
  - OLED Emissive material
- Triphenylamine
  - OLED hole transport layers

Polymers:

- PPV
  - OLED Emissive material
  - FET channel material
- Polyfluorene
  - OLED Emissive material
  - FET channel material
- Others will be discussed in the rest of this section

Organic vs. Inorganic

Advantages of Organic:

- Lightweight
- Flexible
- Biodegradable
- Low cost
    - No vacuum processing
    - No lithography
    - Cheap substrate
- New applications

Disadvantages:

- Poor conductors of electricity
- Smaller bandwidths/lower mobility
- Shorter lifetimes
- Heavily dependent on stable environment

Organic Thin Film Transistors

Pentacene

Pentacene is the most commonly used polymer for the channel region in OTFTs. It is normally a p-type material, but when it is doped with rubidium, it serves as an n-type material. Where most organic transistors have conductivities between 10^{-9} – 10^{-14} S/cm at room temperature, pentacene can achieve conductivity of 150 S/cm when heavily doped with iodine and 2.8 S/cm for the rubidium doped n-type material [8].

Organic Dielectrics

Advantages of organic dielectrics

- Capable of being solution-processed
- Form smooth films on plastic or glass substrates
- Can be used in photo-responsive OFETs because of their high optical transparency
- Thermally stable up to 200ºC with a relatively small thermal expansion coefficient
- Some have dielectric constants close to 18 [6]

When using polymer gate dielectrics in organic thin-film transistors, the carrier mobility is increased three-fold from those that use inorganic dielectric OTFTs [5].

Some typical polymer dielectrics include polyimide; benzocyclobutene (BCB); epoxy; PVP; PS;PMMA; PVA;PVC; PVDF; PαMS; CYEPL; and a combination of BCB, PI, and DNA which is used in BIOFETs. Figure 1 shows the chemical makeup of some of these polymers. BCB is often used due to its broad donor-like states as compared to using thermal oxide and PECVD silicon nitride [4].

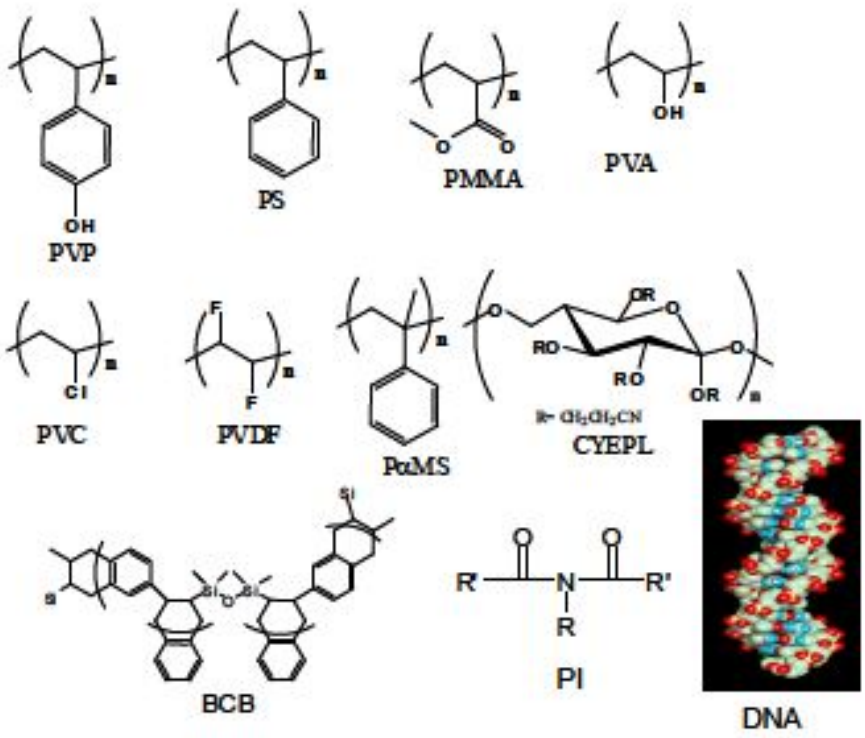

Figure 2: Chemical structures for dielectric polymers

Film Fabrication

For films greater than 1μm, some fabrication processes include solvent casting, thermal spraying, spin coating, SAM technique, floating technique, and Langmuir-Blodgett film [7].

Solvent casting is the simplest technique. It is when a polymer is dissolved in an organic solvent. Salts are added, and the mixture is shaped into a desirable geometry. The solvent evaporates, and the remaining polymers along with the salts are placed in a bath, dissolving the salts. Finally, you are left with a porous polymer structure.

Thermal spraying is used for thickness greater than 20μm. The polymer powder is injected into a heat source and sprayed onto a preheated substrate.

In spin coating as shown is Figure 2, involves laying a polymer solution on top of the substrate. The substrate is then spun at a high velocity to spread the coating across the substrate using centrifugal force. This allows for a great amount of thickness control. While it is spinning, evaporation occurs, and this evaporation rate has a direct relation to the spin speed.

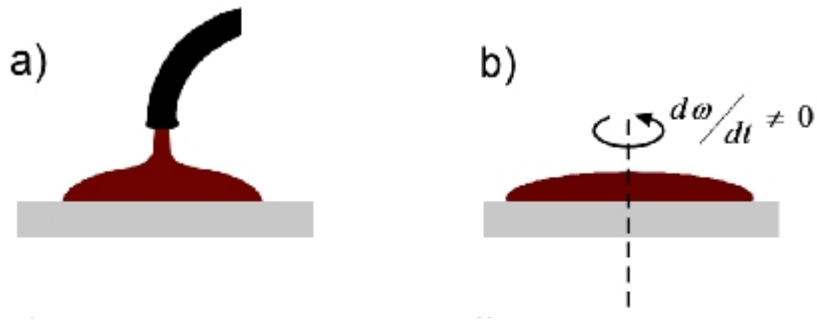

Figure 2: Spin coating a) Dispensation b) Acceleration

Surface absorption of monolayers (SAM) technique allows the development of monolayers by a spontaneous chemical synthesis at the interface as the system approaches equilibrium.

The Langmuir-Blodgett films are polymers deposited onto solid surfaces. The substrate is immersed into the polymer liquid material.

Some techniques used for thin film deposition include evaporation, sputtering, pulsed laser deposition (PLD), and plasma polymerization.

Applications

OTFTs are gaining use in different displays such as e-paper, LCDs, and OLED active matrices (AMOLEDs).

AMOLEDs (Figure 3) involve forming OTFTs into an array to switch on and off the current provided to each individual pixel. Two OTFTs are used at each pixel: one to switch on and off the storage capacitor charge and one to provide the voltage which, in turn, provides the necessary current to drive the pixel.

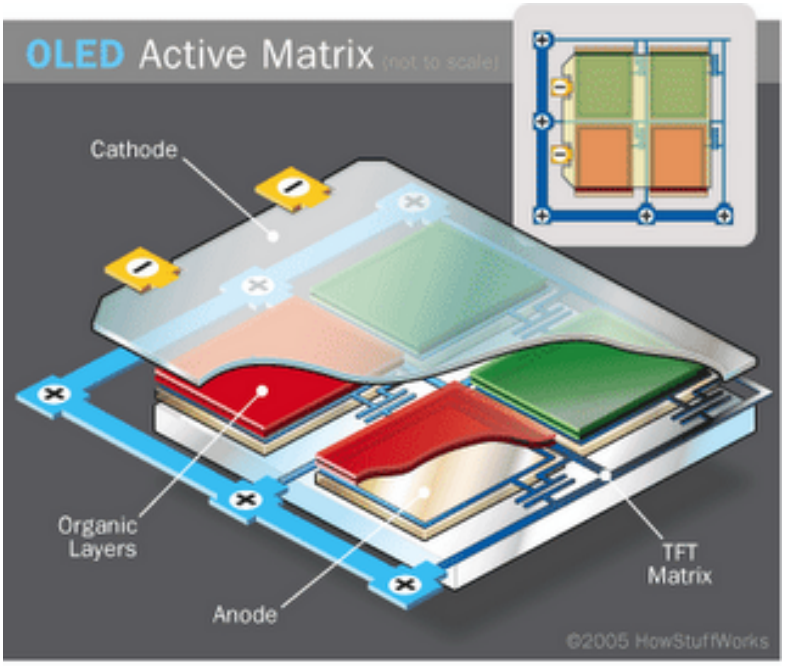

Figure 3: Active Matrix OLED display using TFTs

OTFTs are also being used in the organic RFID tag industry. RFID systems are used to identify and track objects using radio frequency magnetic waves. Organic materials used for RFID systems operate at low to medium frequency ranges. Therefore, they are capable of handling the Memory and Control Logic components, but not the RF Interference components.

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OLEDs

Organic Light Emitting Diodes

Wes Petree

11/30/2011

OLEDs have been developed over the last few decades and are becoming a popular choice for displays. A brief list of the history, theoretical background, fabrication processes, and types have been included.

Introduction

Organic Light Emitting Diodes, or OLEDs, are diodes that are made out of organic semiconductors instead of classical semiconductors such as Silicon and Gallium Arsenide. Conductive organic materials have increased greatly in their production and efficiency and are becoming more readily available.

OLED devices are becoming more and more popular. TVs and cell phone screens have begun using OLEDs as they have become cheaper to manufacture and more efficient. Many of the benefits of such devices include the ability to be flexible, transparent, and more energy efficient.

Organic technologies have been studied for nearly sixty years and advancements are made regularly with ongoing research. As with all technologies, as time goes on and advances are made, the efficiency and cost will only improve.

HISTORY

A. Bernanose and made the first observations of electroluminescence in organic materials in the 1950s. He was able to use large AC electric fields in air to materials such as acridine orange, either deposited on or dissolved in cellulose or cellophane thin films. The proposed mechanism was either direct excitation of the dye molecules or excitation of electrons. [1]

In 1960, Martin Pope and his group made the seminal discovery of ohmic, dark injecting electrode contacts to organic crystals, and described the necessary energetic requirements (work functions) for hole and electron injecting electrode contacts. Dark injecting hole and electron injecting electrode contacts are the basis of all current OLED devices, molecular and polymeric, as will be pointed out in the description of the requirements for the construction of successful OLEDs. [2]

In 1963, Martin Pope and his group made the first observation of direct current (DC) electroluminescence, under vacuum, on a pure, single crystal of anthracene, and also on anthracene crystal doped with tetracene. The injecting electrode was a small area silver electrode, at 400 V DC, and the proposed mechanism was field accelerated electron excitation of molecular fluorescence. [2]

In 1965, Martin Pope and his group refined their experiment and showed that in the absence of an external electric field, the electroluminescence in anthracene single crystal was caused by the recombination of a thermalized electron and hole. This paper proved conclusively that the conducting level of anthracene is higher in energy than the exciton energy level. [2]

Also in 1965, W. Helfrich and W. G. Schneider of the National Research Council in Canada produced double injection recombination electroluminescence for the first time in an anthracene single crystal using hole and electron injecting electrodes, the forerunner of modern double injection devices. In the same year, Dow Chemical researchers patented a method of preparing electroluminescent cells using high voltage (500–1500 V) AC-driven (100–3000 Hz) electrically-insulated one millimetre thin layers of a melted phosphor consisting of ground anthracene powder, tetracene, and graphite powder.Their proposed mechanism involved electronic excitation at the contacts between the graphite particles and the anthracene molecules. [1]

More conductive organic materials became available later in the forms of polyacetylene, polypyrrole, and polyaniline “Blacks”. Iodine-doped oxidized polypyrrole were also used, and later, oxidized and iodine-doped polyacetylene were experimented with. [3]

It was then discovered that some kinds of plastics could be altered into conductive materials, thus revolutionizing the approach to digital technology by offering a cheaper, more flexible, and smart alternative to expensive ceramic semiconductors.
It was not until Eastman Kodak scientists were experimenting with solar cells and noticed a blue glow that the patent was granted for OLED technology. [3]
Dr. Ching W Tang and Steven Van Slyke invented the first diode device at Eastman Kodak in the 1980s. This diode, giving rise to the term “OLED” used a novel two-layer structure with separate hole transporting and electron transporting layers such that recombination and light emission occurred in the middle of the organic layer. This resulted in a reduction in operating voltage and improvements in efficiency, and started the current era of OLED research and device production. [2]

Later, this concept was adapted for use with polymers culminated in the Burroughes et al. 1990 paper in the journal Nature reporting a very-high-efficiency green-light-emitting polymer. [2]

The diode they invented improved efficiency and lessened the amount of voltage needed for operation. However, the Kodak technology involved small molecule technology, which necessitates an expensive production process. A hybrid light-emitting layer was later invented that consists of non-conductive polymers doped with light-emitting conductive polymers and has both mechanical and production advantages. [3]

THEORETICAL BACKGROUND

OLEDs are comprised of organic conducting polymers that range in conduction from insulator to conductor and are therefore considered organic semiconductors. [1] Because the materials that are used are polymers and small molecules and not crystalline, they do not have a band gap as classical semiconductors have. However they do have what is known as the HOMO (Highest Occupied Molecular Orbital) and LUMO (Lowest Unoccupied Molecular Orbital) that are analogous to the valance band and conduction band respectively. [4]

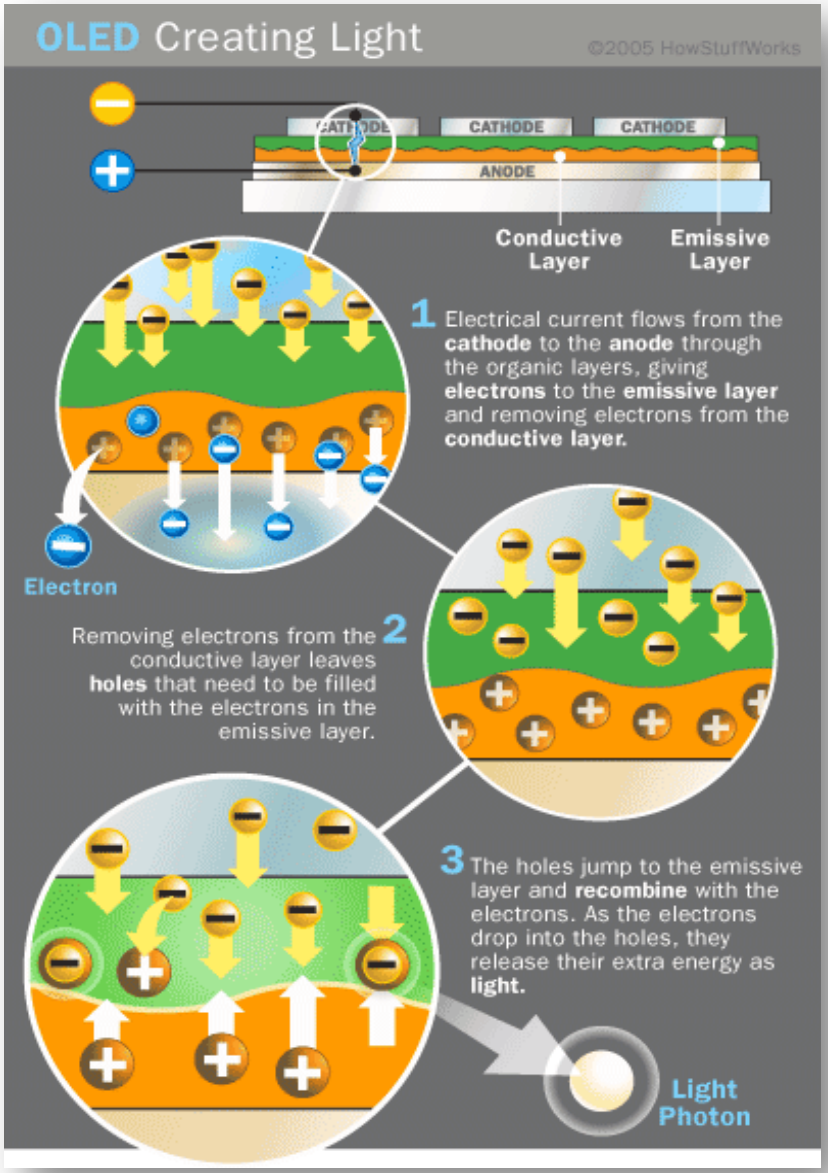

Figure 1: OLED Creating Light [5]

Similar to LEDs, the wavelength of the light that is emitted by the OLED depends on the energy difference between the HOMO and LUMO energy levels. However, dyes can be added to the organic material to change the color of light as well. [1] The basic layout of the OLED is 5 layers of materials. Two organic materials sandwiched between two contacts. These four layers sit on the substrate. The 2 organic layers are known as the conducting layer and

the emission layer. The conducting layer is an organic polymer that transports holes from the anode. The emission layer is an organic layer that transports electrons from the cathode. The emission layer is also the layer that recombination occurs due to faster hole mobility and slower electron mobility. [5] The anode is typically made from Indium Tin Oxide because it is transparent to visible light and has a high work function, which promotes injections of holes into the HOMO level of the organic material. [1] The cathode is typically made from Barium and Calcium because they have a low work function and promote injection of electrons into the LUMO level of the organic material. [1]

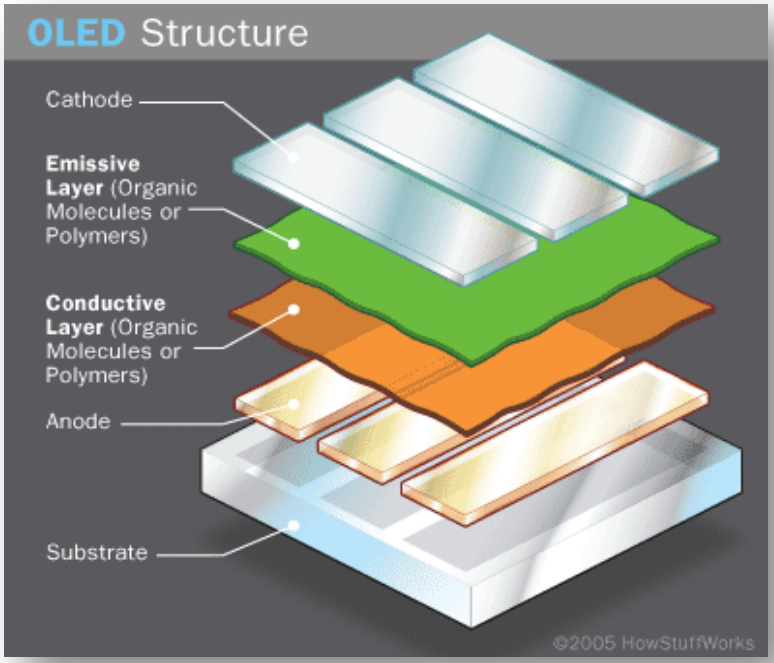

Figure 2: OLED Structure [5]

FABRICATION PROCESSES

There are three basic processes used to make organic semiconductors – Vacuum Deposition or Vacuum Thermal Evaporation (VTE), Organic Vapor Phase Deposition, and Spin Coating or Inkjet Printing. [5]

Vacuum Deposition

The first widely used process was the thermal evaporation in a vacuum. [1] This process was very costly but enables the formation of well-controlled, homogenous films, and the construction of very complex multi-layer structures. [1]

Organic Vapor Phase Deposition

Organic vapor phase deposition, also known as organic vapor jet printing (OVJP), makes use of a low-pressure, hot-walled reactor chamber, where a carrier gas transports evaporated organic molecules onto cooled substrates. There they condense into thin films. Using a carrier gas increases the efficiency and reduces the cost of making OLEDs. [1][5]

Inkjet Printing

Inkjet printing is widely becoming the industry favorite for creating large screens such as those for TVs. The organic materials are sprayed onto substrates in the same manner as inkjet printers print ink on paper. [5] This is basically the same technology as spin coating, however done in a linear fashion instead of radially while spinning. [1]

TYPES OF OLEDS

There are many different types of OLEDs. Some of the types include:

- SM-OLED
- PLOLED
- PMOLED
- AMOLED
- Top-emitting OLED
- Transparent OLED
- Flexible OLED
- Stacked OLED
- White OLED

SM-OLED

Small Molecule OLEDs, or SM-OLEDs, are traditionally what OLED usually refer to. Dr. Tang at Eastman Kodak first developed efficient OLEDs using small molecules. [1]

Molecules commonly used in OLEDs include organometallic chelates (for example Alq3, used in the organic light-emitting device reported by Tang et al.), fluorescent and phosphorescent dyes and conjugated dendrimers. A number of materials are used for their charge transport properties, for example triphenylamine and derivatives are commonly used as materials for hole transport layers. Fluorescent dyes can be chosen to obtain light emission at different wavelengths, and compounds such as perylene, rubrene and quinacridone derivatives are often used. Alq3 has been used as a green emitter, electron transport material and as a host for yellow and red emitting dyes. [1]

The process used for the fabrication of these devices is usually thermal evaporation in a vacuum. This makes the production process more expensive and of limited use for large-area devices than other processing techniques. However, contrary to polymer-based devices, the vacuum deposition process enables the formation of well-controlled, homogeneous films, and the construction of very complex multi-layer structures. This high flexibility in layer design, enabling distinct charge transport and charge blocking layers to be formed, is the main reason for the high efficiencies of the small molecule OLEDs. [1]

PLOLED

PLOLEDs, or Polymer OLEDs and also LEP (Light Emitting Polymer), involve an electroluminescent conductive polymer that emits light when connected to an external

voltage. They are used as a thin film for full-spectrum color displays. Polymer OLEDs are quite efficient and require a relatively small amount of power for the amount of light produced. [1]

Vacuum deposition is not a suitable method for forming thin films of polymers. However, polymers can be processed in solution, and spin coating is a common method of depositing thin polymer films. This method is more suited to forming large-area films than thermal evaporation. No vacuum is required, and the emissive materials can also be applied on the substrate by a technique derived from commercial inkjet printing. However, as the application of subsequent layers tends to dissolve those already present, formation of multilayer structures is difficult with these methods. The metal cathode may still need to be deposited by thermal evaporation in vacuum. [1]

PMOLED

Passive Matrix OLEDs, or PMOLEDs, are a type of OLED used primarily in displays. PMOLEDs have strips of cathode, organic layers and strips of anode. The anode strips are arranged perpendicular to the cathode strips. The intersections of the cathode and anode make up the pixels where light is emitted. External circuitry applies current to selected strips of anode and cathode, determining which pixels get turned on and which pixels remain off. Again, the brightness of each pixel is proportional to the amount of applied current. [5]

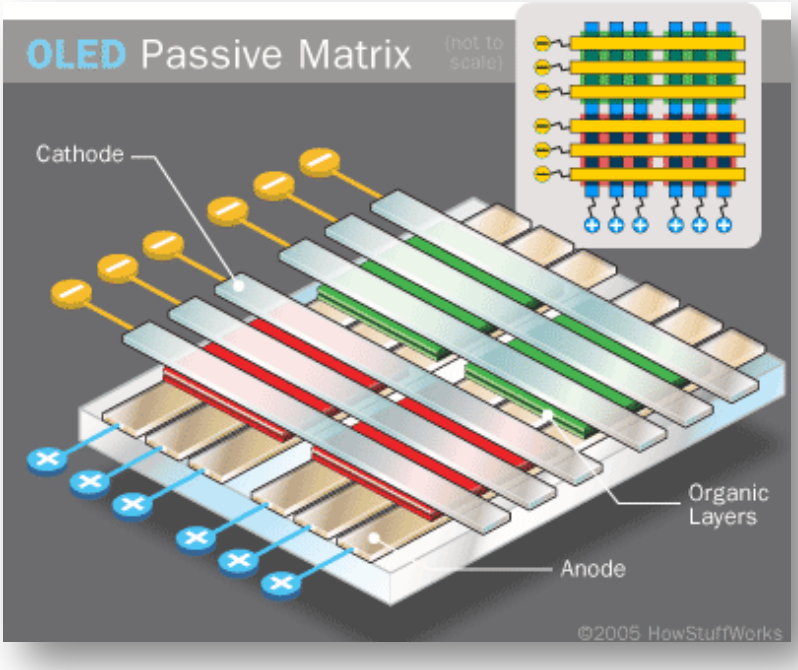

Figure 3: PMOLED Structure [5]

PMOLEDs are easy to make, but they consume more power than other types of OLED, mainly due to the power needed for the external circuitry. PMOLEDs are most efficient for text and icons and are best suited for small screens (2- to 3-inch diagonal) such as those you find in cell phones, PDAs and MP3 players. Even with the external circuitry, passive-matrix OLEDs consume less battery power than the LCDs that currently power these devices. [5]

AMOLED

Active Matrix OLEDs, or AMOLEDs, are also used in displays. AMOLEDs have full layers of cathode, organic molecules and anode, but the anode layer overlays a thin film transistor (TFT) array that forms a matrix. The TFT array itself is the circuitry that determines which pixels get turned on to form an image.

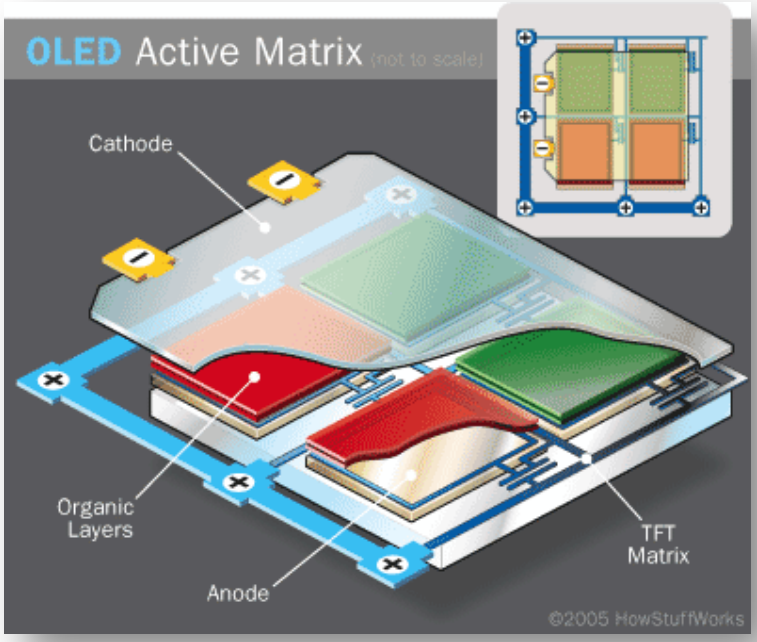

Figure 4: AMOLED Structure [5]

AMOLEDs consume less power than PMOLEDs because the TFT array requires less power than external circuitry, so they are efficient for large displays. AMOLEDs also have faster refresh rates suitable for video. The best uses for AMOLEDs are computer monitors, large-screen TVs and electronic signs or billboards.

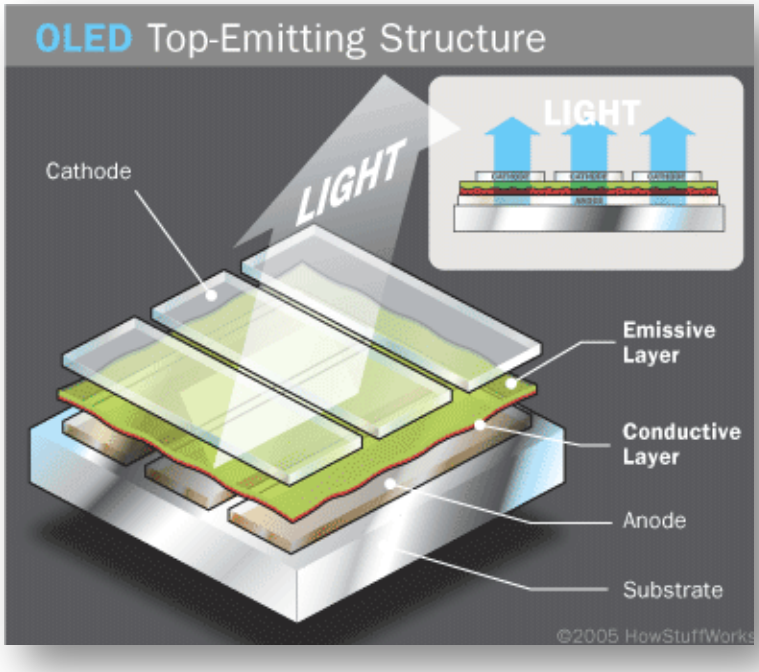

Figure 5: Top Emitting OLED Structure [5]

Top-Emitting OLED

Top-Emitting OLEDs use transparent cathode with a substrate that is either opaque or reflective. They are best suited to active matrix design for displays. One possible future application is for displays on smart cards. [5]

Transparent OLED

Transparent OLEDs are similar to Top-Emitting OLEDs, but have a transparent substrate as well. In fact, all components (cathode, anode, and substrate) of the OLEDs are transparent and are up to 85% as transparent as the substrate when the device is powered off. When a transparent OLED display is turned on, it allows light to pass in both directions. A transparent OLED display can be either active- or passive-matrix. This technology can be used for heads-up displays.

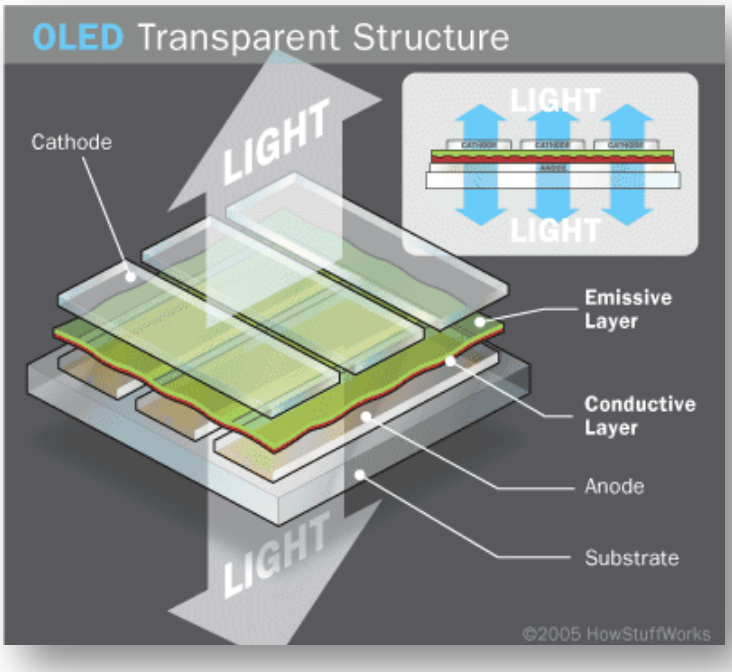

Figure 6: Transparent OLED Structure [5]

FLEXIBLE OLED

Perhaps the most interesting of all the OLEDs are of the folding variety. They are able to be folded and bent into any shape and will most likely revolutionize the cell phone industry, as the leading cause for cell phone repair or replacement is due to a cracked or broken screen. Foldable OLEDs have substrates made of very flexible metallic foils or plastics. Foldable OLEDs are very lightweight and durable. Potentially, foldable OLED displays can be attached to fabrics to create "smart" clothing, such as outdoor survival clothing with an integrated computer chip, cell phone, GPS receiver and OLED display sewn into it. [5]

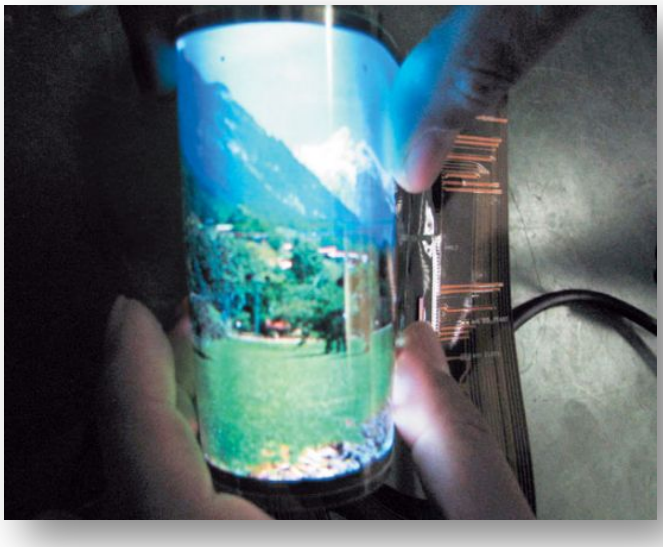

Figure 7: Samsung Flexible AMOLED Screen [6]

Figure 8: Samsung flexible AMOLED 4.5 inch 800 x 480 display only 2 mm thick (a) at CES 2011 and (b) at FDP-International 2010

Stacked OLED

Stacked OLEDs are used for displays where the sub-pixels (Red Green and Blue) are arranged vertically – one on top of the next – instead of horizontally – side by sided. This allows the light of each sub-pixel to shine all the way through the OLED and allows close packing of the LEDs – each OLED would be roughly the same size as the typical sub-pixel. With this type of configuration, the current resolution of displays can theoretically be tripled. [1]

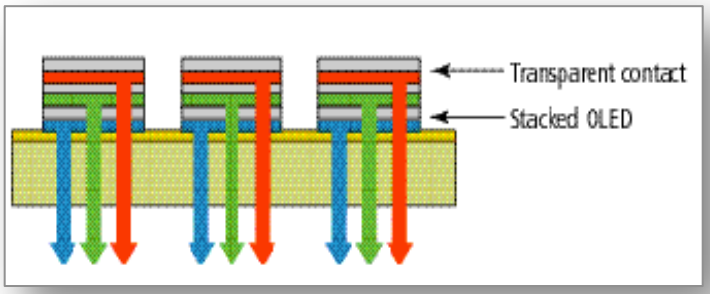

Figure 10: Stacked OLED Structure [8]

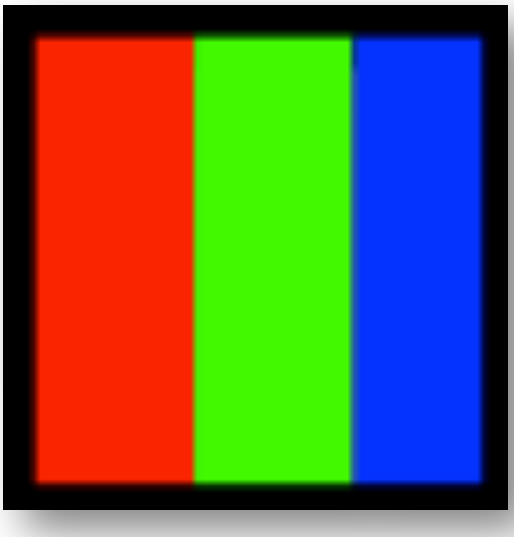

Figure 9: Current standard LED Structure with sub-pixels arranged side by side [9]

White OLED

White OLEDs emit white light that is brighter, more uniform and more energy efficient than that emitted by fluorescent lights. White OLEDs also have the true-color qualities of incandescent lighting. Because OLEDs can be made in large sheets, they can replace fluorescent lights that are currently used in homes and buildings. Their use could potentially reduce energy costs for lighting. [5]

ADVANTAGES AND DISADVANTAGES

Advantages

The LCD is currently the display of choice in small devices and is also popular in large-screen TVs. Regular LEDs often form the digits on digital clocks and other electronic devices. OLEDs offer many advantages over both LCDs and LEDs:

- The plastic, organic layers of an OLED are thinner, lighter and more flexible than the crystalline layers in an LED or LCD. [5]
- Because the light-emitting layers of an OLED are lighter, the substrate of an OLED can be flexible instead of rigid. OLED substrates can be plastic rather than the glass used for LEDs and LCDs. [5]
- OLEDs are brighter than LEDs. Because the organic layers of an OLED are much thinner than the corresponding inorganic crystal layers of an LED, the conductive and emissive layers of an OLED can be multi-layered. Also, LEDs and LCDs require glass for support, and glass absorbs some light. OLEDs do not require glass. [5]
- OLEDs do not require backlighting like LCDs (see How LCDs Work). LCDs work by selectively blocking areas of the backlight to make the images that you see, while OLEDs generate light themselves. Because OLEDs do not require backlighting, they consume much less power than LCDs (most of the LCD power goes to the backlighting). This is especially important for battery-operated devices such as cell phones. [5]
- OLEDs are easier to produce and can be made to larger sizes. Because OLEDs are essentially plastics, they can be made into large, thin sheets. It is much more difficult to grow and lay down so many liquid crystals. [5]
- OLEDs have large fields of view, about 170 degrees. Because LCDs work by blocking light, they have an inherent viewing obstacle from certain angles. OLEDs produce their own light, so they have a much wider viewing range. [5]

Disadvantages

OLED seems to be the perfect technology for all types of displays, but it also has some problems:

- Lifetime - While red and green OLED films have longer lifetimes (46,000 to 230,000 hours), blue organics currently have much shorter lifetimes (up to around 14,000 hours) [5]
- Manufacturing - Manufacturing processes are expensive right now. [5]
- Water - Water can easily damage OLEDs. [5]

CONCLUSION

With so many companies researching the technology, it is clear that this is the direction the industry wants to go. With advantages of lower energy consumption and flexible displays along with transparent screens, it's no wonder why the industry wants to market such a technology.

Despite the advantages, there are still some disadvantages – primarily the cost. However, with the industry leaning so strongly on developing this technology, the cost will surely decline in the future. Incredible advancements have been made just within the last decade and one could almost be assured that these advancements will continue – perhaps exponentially.

OLEDs are rapidly becoming the device of choice for the fabrication of displays. They hold many advantages over traditional LED displays, but they still have some disadvantages. However, with all technology, OLEDs will improves with time and fabrication costs will continue to decline as advancements are made.

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OPVCs

Organic Photovoltaic Cells

David Reavis

11/30/2011

OPVCs currently are not as efficient as traditional photovoltaic cells. However, improvements have been made and the future looks promising. Included are some background and types of POVCs.

Organic Photovoltaic Cells

Organic photovoltaic cells (OPVC's) are photovoltaic cells in which organic materials are used for charge transport and light absorption. OPVC's take advantage of the molecular properties of organic conductive polymers.These properties can be manipulated through molecular engineering in order to change the properties of the material, such as the bandgap. OPVCs enjoy advantages over their inorganic counterparts such as having a high optical absorption coefficient and low cost of manufacture. Disadvantages include low efficiency, stability, and strength.

Background:

OPVC's are a new type of photovoltaic cell based on conjugated polymers and molecules from organic materials. These conjugated materials consist of alternating single and double pi bonds. These materials enjoy the advantage of it being relatively simple to alter properties such as the bandgap, and the ease of processing that comes with plastics. These traits, along with being environmentally friendly, flexible, and inexpensive have created considerable recent attention for OPVC's.

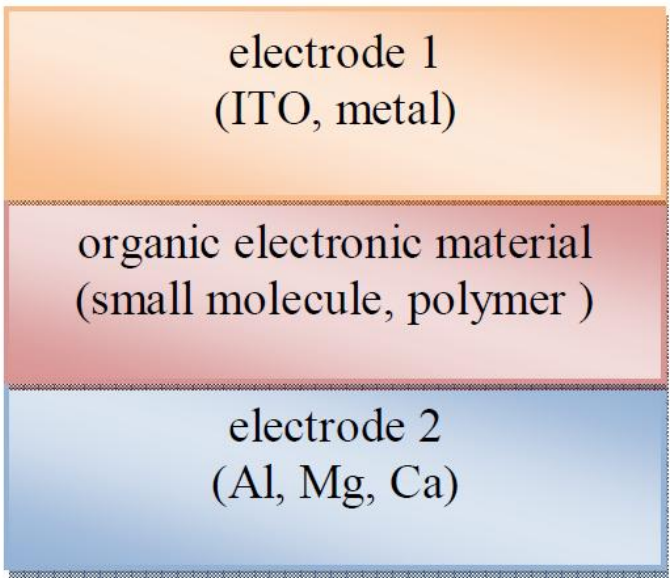
Types of OPVC's

There are various types of OPVC's, with each having their own advantages and disadvantages.

Single Layer:

The first generation of OPVC's was based on single layers of organic material sandwiched in between metal electrodes with different work functions. Common examples of these metals include Indium Tin oxide (high work function) and Al, Mg, or Ca (low work

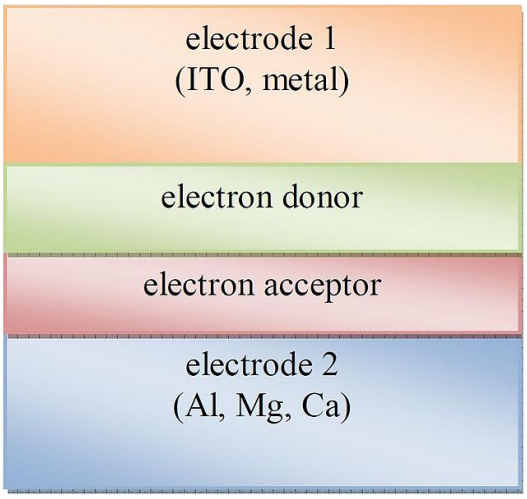
function). When light is absorbed by the organic layer exciton pairs are formed, with electrons excited to the lowest unoccupied molecular orbital (LUMO), and holes to the highest unoccupied molecular orbital (HOMO). The different work functions of the metal electrodes creates a potential difference which seperates the exciton pairs, pulling the electroncs to the positively charged electrode, and holes to the negative. Disadvantages include very low power quantum efficiency (<1%) and power conversion efficiency (<.1%) due to the weak electrical fields inability to breakup the generated excitons



Single Layer 1

Bilayer:

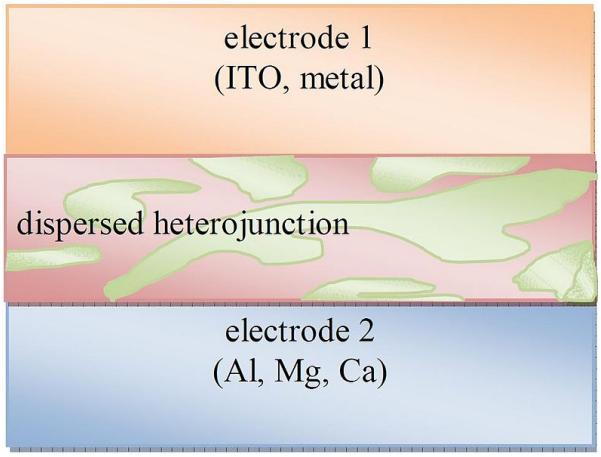
The next advancement in OPVC's was the bilayer heterojunction concept in which two layers of organic material were sandwiched between the electrodes. These two layers have specific electron and hole transportation properties. These properties allow for a greater potential difference which is better able to break up the exciton pairs than in the single layer variety. This structure can also be called planar donar-acceptor heterojunctions because the layer with the higher electron affinity acts as the acceptor, while the other layer is the donor. Disadvantages include a polymer thickness (>100nm) that inhibits excitons from reaching the heterojunction interface.



Bilayer 1

Bulk Heterojunction:

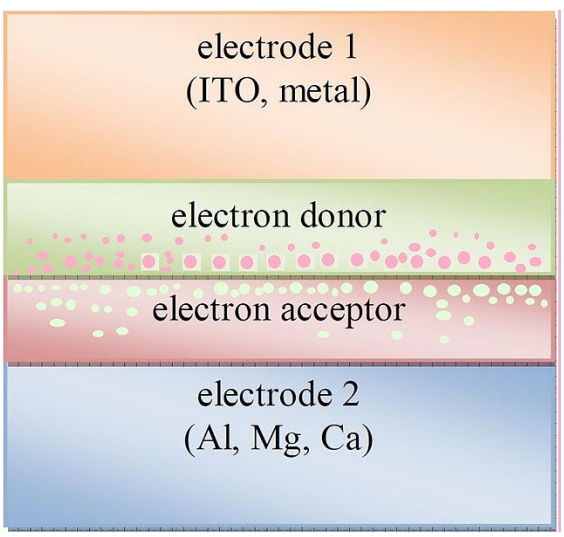
The bulk heterojunction concept involves blending two polymers having donor and acceptor properties while in solution. Upon solidification the material has a blend of both materials. In order to effectively absord light the semiconductor film thickness should be at least 100nm, while the diffusion length of the exciton is about 10nm. Blending of the materials is used to overcome this problem. If the length scale of the blend is made to be similar to the exciton diffusion length, the exciton pairs can reach the interface between the materials where they can break up more efficiently. The difficulty in creating such a material is that generally organic materials are not able to be properly mixed to form a solution. This can be overcome by creating the material while it is in out of equilibrium conditions, or by evaporating or spin coating the material.



Bulk heterojunction 1

Graded heterojunction:

Graded heterojunction OPVC's are similar to bulk heterojunction, except the blending is more gradual. This takes advantage of the short electron travel distance in the bulk material and the larger potential differences in the bilayer materials. Graded heterojunction materials enjoy a greater power conversion efficiency than their counterparts, in the range of 2.5%.



Graded heterojunction 1

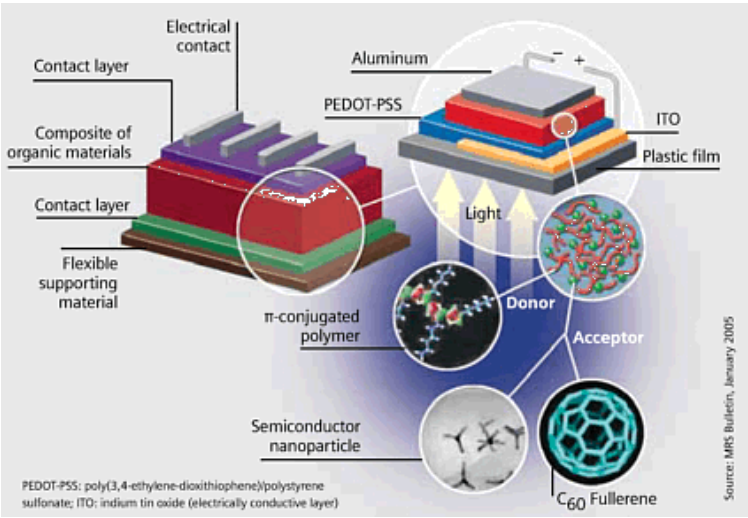
Hydrid OPVC:

Hybrid OPVC's take advantage of the benefits of both organic and inorganic semiconductors. They consist of an organic layer mixed with a traditional high electron transport material to form the photoactive layer. The three main structure types for the interface in hybrid OPVC's are mesoporous films, order lamellar films, and films of ordered nanostructures. In mesoporous films a porous inorganic material is saturated with an organic surfactant allowing the organic material to absorb light and then transfer the electrons to the inorganic semiconductor for transport. Order lamellar films use alternating layers of organic and inorganic material. Their structure and periodicity can be controlled while in solution, but their efficiency is not yet high enough to be viable. Films of ordered nanostructures consist of ordered structures of inorganic compounds surrounding electron donating organics. They have a high defect tolerance and seem quite promising due to rapid increases in efficiency.

Types of hybrid OPVC's

Polymer nanoparticle composite

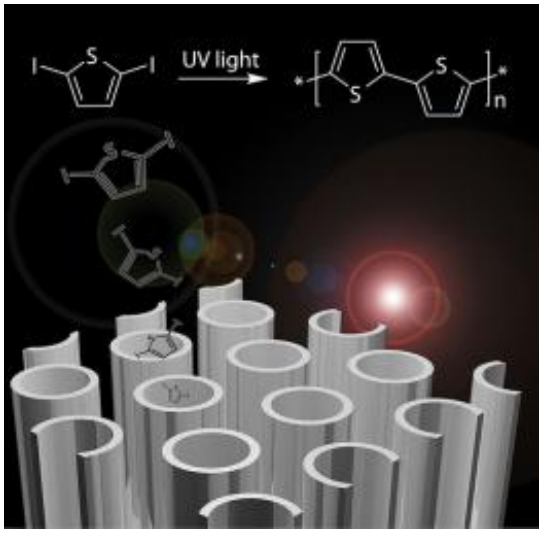
In polymer nanoparticle composite hybrid OPVC's nanoparticles whose size range from 1nm to 100nm are used to fine tune the electronic properties of the material such as band gap. The large surface to volume ratio allowed by the use of nanoparticles allows for a large area for charge transfer. Fabrication methods include mixing while in solution, spin coating, and solvent evaporation. Increases in efficiency and stability are needed before they will be commercially viable.



Polymer nanoparticle composite 1

Carbon nanotubes

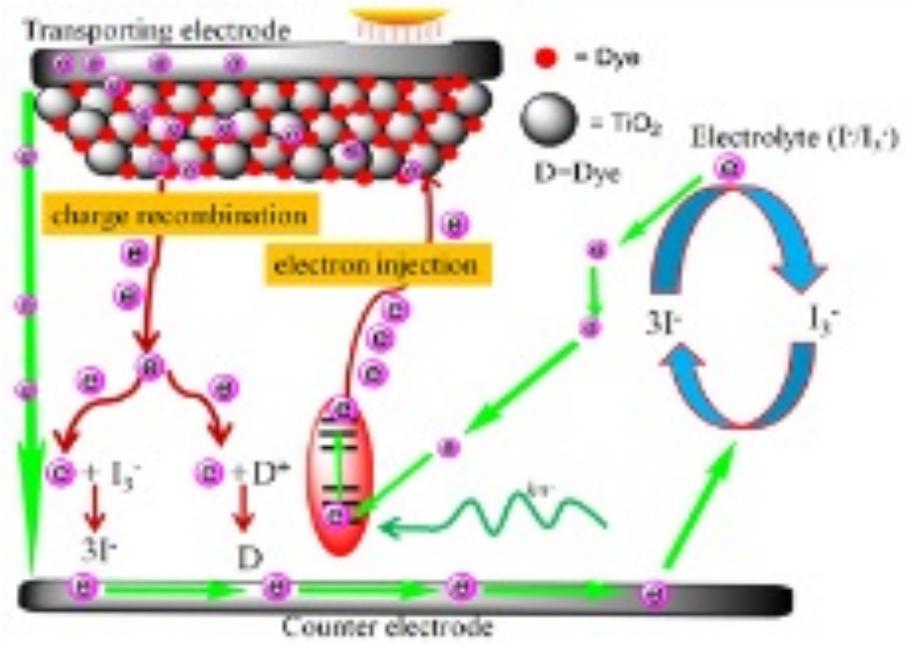
Carbon nanotubes have a high electron conductivity, high thermal conductivity, robustness, and flexibility by nature, which is beneficial for use in semiconductor materials. Problems that arise with the use of carbon nanotubes include difficulty in doping and degradation in an oxygen rich environment. To overcome oxygen degradation a passivation layer can be added, but this reduces the optical transparency and adversely affects efficiency.



Carbon nanotubes 1

Dye-Sensitized

Dye sensitized OPVC's are similar to their nonorganic variety in consisting of a photo-synthesized anode, an electrolyte, and a photo-electrochemical system. They include organic alone with inorganic materials such as TiO2 which are absorbed in a dye and then enclosed in an electrolyte. Dye sensitized OPVC's enjoy high efficiencies compared to the other kinds of OPVC's, but have the disadvantage of a short diffusion length which shortens carrier lifetime.



Dye sensitized 1

Conclusion

Organic photovoltaic cells are rapidly advancing and enjoy several benefits over their inorganic counterparts. These advantages include low material and substrate costs along with low fabrication equipment cost. Due to these cost advantages they do not have to achieve nearly as high of a solar efficiency as inorganic cells do to be just as economically efficient. The fabrication processes involved in making OPVC's require low energy and temperatures, and are efficient in material use. They are light weight and flexible by nature, which will allow numerous future commercial products to take advantage of them. Disadvantages of OPVC's include a high susceptibility to oxidation, moisture, and heat. It will take time to overcome the technological hurdles associated with properly packaging them so they will not fail when exposed to outdoor weather. They also are less efficient in charge transport and have a low power conversion efficiency. As research progresses these drawbacks will be overcome and OPVC's will be seen everywhere.

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