An organic light-emitting diode (OLED), also light emitting polymer (LEP) and organic electro-luminescence (OEL), is any light-emitting diode (LED) whose emissive electroluminescent layer is composed of a film of organic compounds. The layer usually contains a polymer substance that allows suitable organic compounds to be deposited. They are deposited in rows and columns onto a flat carrier by a simple "printing" process. The resulting matrix of pixels can emit light of different colors.

Such systems can be used in television screens, computer displays, portable system screens such as PDAs, advertising, information and indication. OLEDs can also be used in light sources for general space illumination, and large-area light-emitting elements. OLEDs typically emit less light per area than inorganic solid-state based LEDs which are usually designed for use as point-light sources.

A significant benefit of OLED displays over traditional liquid crystal displays (LCDs) is that OLEDs do not require a backlight to function. Thus they draw far less power and, when. Because there is no need for a backlight, an OLED display can be much thinner than an LCD panel. OLED-based display devices also can be more effectively manufactured than LCDs and plasma displays.

ACKNOWLEDGEMENT

LIST OF FIGURES

1. INTRODUCTION

1.1. Overview

Imagine having a high-definition TV that is 80 inches wide and less than a quarter-inch thick, consumes less power than most TVs on the market today and can be rolled up when you're not using it. What if you could have a "heads up" display in your car? How about a display monitor built into your clothing? These devices may be possible in the near future with the help of a technology called organic light-emitting diodes (OLEDs). OLED is a flat display technology, made by placing a series of organic thin films between two conductors. When electrical current is applied, a bright light is emitted.

Organic light emitting diodes have been receiving a lot of attention over the world as a new type of display technology. OLEDs have many advantages over conventional display technologies. First, the fabrication process is easy, and devices are thinner and lighter than those fabricated by cathode ray tube (CRT) display technology. Second, there are also some advantages over liquid crystal (LCD) displays: OLEDS can be viewed from different angles and don't need a backlight. Finally, the drive voltage and power consumption are low. The first commercial OLED display was introduced by Pioneer Electronics as the front panel of a car stereo in 1997.

To enhance the colour or brightness, manufacturers can add complex chains of molecules (polymers) to the carbon-based layers. Unlike LCDs, which require backlighting, OLED displays are "emissive" devices, meaning they emit light rather than modulate transmitted or reflected light. Thin organic layers serve these displays as a source of light, which offers significant advantages in relation to conventional technologies. The prerequisites for a breakthrough of this technology in the market, which is estimated in 2010 to be worth over USD 2 billion, are the optimization of certain critical performance data such as lifetime and efficiency. This requires innovations in materials meaning that chemistry will decide about the future and the success of the OLED technology.

Video wallpaper - just a millimeter thick - could transform your living room wall into a flat screen and electronic film as thin as a sheet of paper could serve as your screen for the internet, the news, images or games. In future, all of this will be possible thanks to organic light-emitting diodes, so-called OLEDs. In this report you will learn more about this revolution in lighting technology.

2. OLED TECHNOLOGY

Many electronic appliances are at the threshold of a revolution that began with the discovery of polymeric conductors in the 1970s. Polymeric materials, which have historically been classified exclusively as electrical insulators, are now finding varied applications as both conductors and semiconductors. Expensive ceramic semiconductors that are brittle and difficult to pattern have historically been the driving force of the digital age for the last fifty years. But now combinations of properties exist today in polymers that are making many previously impossible appliances a reality.

Within a very short time organic conductors have been developed with the conductivity of metals such as copper, while organic electronics has evolved photoelectric cells, diodes, light emitting diodes, lasers and transistors. The result is that a class of plastic materials referred to as conjugated polymers are fast displacing traditional materials such as natural polymers (e.g. wood), metals, ceramics and glass in many applications owing to the combination of their physical/mechanical properties (light weight combined with physical strength) and ease of processability (the ability to mould the shape of plastic materials or extrude into sheet and rod through a die).

What this means is that OLEDs can be deployed in a wide range of electronic devices and can be used extensively throughout any given device. Active components of displays can be polymers, substrates can be polymers, logical electronics can be polymers, and so on. In the years ahead OLEDs will see applications in personal computers, cell phones, televisions, general wide area lighting, signs, billboards, communications and any of a number of information appliances.

2.1. Structure

The basic OLED cell structure consists of a stack of thin organic layers sandwiched between a transparent anode and a metallic cathode. The organic layers comprise a hole-injection layer, a hole-transport layer, an emissive layer and an electron-transport layer. When an appropriate voltage (typically a few volts) is applied to the cell, the injected positive and negative charges recombine in the emissive layer to produce light (electroluminescence). The structure of the organic layers and the choice of anode and cathode are designed to maximize the recombination process in the emissive layer, thus maximizing the light output from the OLED device. Both the electroluminescent efficiency and control of colour output can be significantly enhanced by "doping" the emissive layer with a small amount of highly fluorescent molecules.

2.1.1. OLED Components

Like an LED, an OLED is a solid-state semiconductor device that is 100 to 500 nanometers thick or about 200 times smaller than a human hair. OLEDs can have either two layers or three layers of organic material; in the latter design, the third layer helps transport electrons from the cathode to the emissive layer. In this article, we'll be focusing on the two-layer design.

An OLED consists of the following parts:

- **Substrate** (clear plastic, glass, foil) - The substrate supports the OLED.
- **Anode** (transparent) - The anode removes electrons (adds electron "holes") when a current flows through the device.
- **Organic layers** - These layers are made of organic molecules or polymers.
  - **Conducting layer** - This layer is made of organic plastic molecules that transport "holes" from the anode. One conducting polymer used in OLEDs is polyaniline.
  - **Emissive layer** - This layer is made of organic plastic molecules (different ones from the conducting layer) that transport electrons from the cathode; this is where light is made. One polymer used in the emissive layer is polyfluorene.
- **Cathode** (may or may not be transparent depending on the type of OLED) - The cathode injects electrons when a current flows through the device.

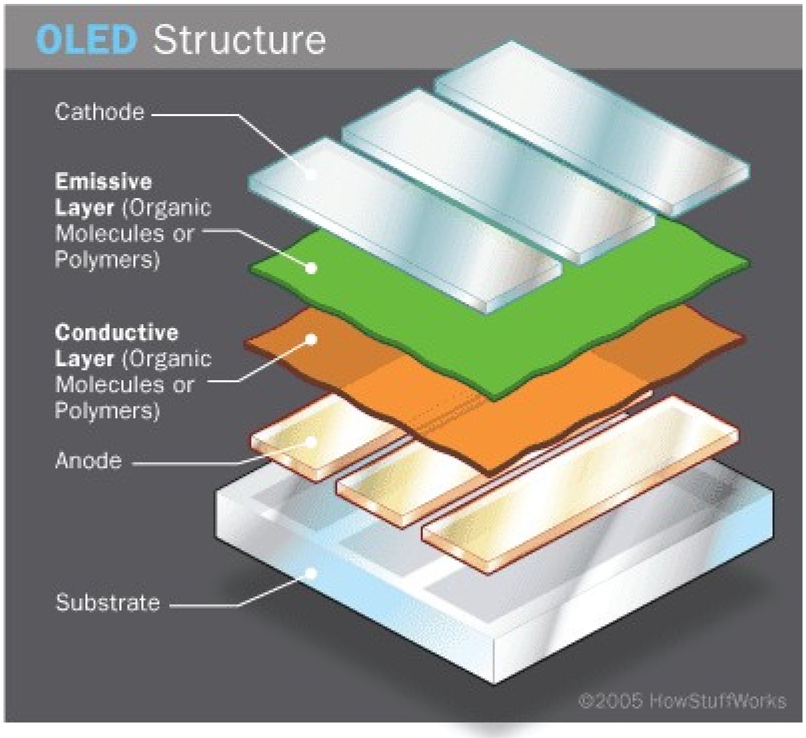


Figure 1 - OLED Structure

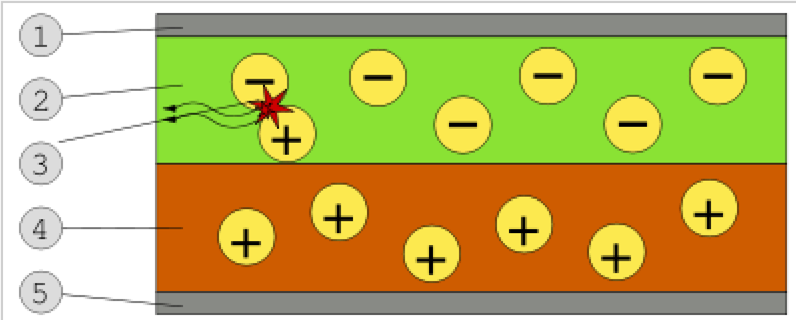
2.2. Working Principle

A typical OLED is composed of an emissive layer, a conductive layer, a substrate, and anode and cathode terminals. The layers are made of special organic molecules that conduct electricity. Their levels of conductivity range from those of insulators to those of conductors, and so they are called organic semiconductors.

The first, most basic OLEDs consisted of a single organic layer, for example the first light-emitting polymer device synthesized by *Burroughs et al* involved a single layer of poly(p-phenylene vinylene). Multilayer OLEDs can have more than two layers to improve device efficiency. As well as conductive properties, layers may be chosen to aid charge injection at electrodes by providing a more gradual electronic profile, or block a charge from reaching the opposite electrode and being wasted.

A voltage is applied across the OLED such that the anode is positive with respect to the cathode. This causes a current of electrons to flow through the device from cathode to anode.

Thus, the cathode gives electrons to the emissive layer, and the anode withdraws electrons from the conductive layer; in other words, the anode gives electron holes to the conductive layer.



Schematic of a 2-layer OLED: 1. Cathode (−), 2. Emissive Layer, 3. Emission of radiation, 4. Conductive Layer, 5. Anode (+)

Figure 2 - OLED Working

Soon, the emissive layer becomes negatively charged, while the conductive layer becomes rich in positively charged holes. Electrostatic forces bring the electrons and the holes towards each other and they recombine. This happens closer to the emissive layer, because in organic semiconductors holes are more mobile than electrons (unlike in inorganic semiconductors). The recombination causes a drop in the energy levels of electrons, accompanied by an emission of radiation whose frequency is in the visible region. That is why this layer is called emissive.

The device does not work when the anode is put at a negative potential with respect to the cathode. In this condition, holes move to the anode and electrons to the cathode, so they are moving away from each other and do not recombine.

Indium tin oxide is commonly used as the anode material. It is transparent to visible light and has a high work function which promotes injection of holes into the polymer layer. Metals such as aluminium and calcium are often used for the cathode as they have low work functions which promote injection of electrons into the polymer layer.

Just like passive-matrix LCD versus active-matrix LCD, OLEDs can be categorized into passive-matrix and active-matrix displays. Active-matrix OLEDs (AMOLED) require a thin film transistor backplane to switch the individual pixel on or off, and can make higher resolution and larger size displays possible.

2.3. Material Technologies

The development of new materials, particularly for achieving emission in the blue region of the spectrum, for organic light-emitting devices is the focus of intense investigation throughout the world. Scientists have developed a new class of materials that demonstrate exceptional promise for use as electron transport materials within an OLED device. The successful development of practical blue OLED devices would significantly impact advancement of OLED technology in both display devices and energy-efficient solid-state lighting.

These materials address the critical issue of achieving high quantum efficiency (photons generated per electron injected into an OLED device) at low voltages. Devices built at PNNL using the new materials have produced external quantum efficiencies at a brightness of 800 cd/m2 as high as 11% at only 6.3 V without using conductivity doping. One class of new OLED materials developed at PNNL are based on organic phosphine oxide compounds while another is based on organic phosphine sulfides.

2.3.1. Small molecules

OLED technology was first developed at Eastman Kodak Company by Dr. Ching W. Tang using small molecules. The production of small-molecule displays often involves vacuum deposition, which makes the production process more expensive than other processing techniques (see below). Since this is typically carried out on glass substrates, these displays are also not flexible, though this limitation is not inherent to small-molecule organic materials. The term OLED traditionally refers to this type of device, though some are using the term SM-OLED.

Molecules commonly used in OLEDs include organo-metallic chelates (for example Alq3, used in the first organic light-emitting device) and conjugated dendrimers.

Recently a hybrid light-emitting layer has been developed that uses nonconductive polymers doped with light-emitting, conductive molecules. The polymer is used for its production and mechanical advantages without worrying about optical properties. The small molecules then emit the light and have the same longevity that they have in the SM-OLEDs.

2.3.2. Polymer Light-Emitting Diodes

Polymer light-emitting diodes (PLED), also light-emitting polymers (LEP), involve an electroluminescent conductive polymer that emits light when connected to an external voltage source. They are used as a thin film for full-spectrum color displays and require a relatively small amount of power for the light produced. No vacuum is required, and the emissive materials can be applied on the substrate by a technique derived from commercial inkjet printing. The substrate used can be flexible, such as PET. Thus flexible PLED displays, also called Flexible OLED (FOLED), may be produced inexpensively.

Typical polymers used in PLED displays include derivatives of poly(p-phenylene vinylene) and polyfluorene. Substitution of side chains onto the polymer backbone may determine the color of emitted light or the stability and solubility of the polymer for performance and ease of processing.

2.4. Types

OLED design can be mainly classified into two; Passive matrix(PMOLED) and Active matrix(AMOLED).

2.4.1. PMOLED

PMOLED means Passive Matrix Organic light emitting diode. Like the first LCDs to be commercialized, the first OLEDs to reach the marketplace in the late 1990s used a passive-matrix drive configuration. Passive-matrix OLEDs are particularly well suited for small-area display applications, such as cell phones and automotive audio applications. Universal Display Corporation's PHOLED materials and technology are currently incorporated in a commercial passive-matrix OLED display product that is manufactured and sold by Pioneer Tohoku Corporation for use in a cell phone product (shown above) and under evaluation for a number of other products. Universal Display Corporation has designed and fabricated several passive-matrix OLED prototypes to demonstrate the performance of its PHOLED technology and materials. The prototype shown here is a 128 x 64 pixel display built on a glass substrate using our green and red PHOLED materials system.

OLED displays are activated through a current driving method that relies on either a passive-matrix (PM) or an active-matrix (AM) scheme. In a PMOLED display, a matrix of electrically-conducting rows and columns forms a two-dimensional array of picture elements called pixels. Sandwiched between the orthogonal column and row lines, thin films of organic material are activated to emit light by applying electrical signals to designated row and column lines. The more current that is applied, the brighter the pixel becomes. For a full image, each row of the display must be charged for 1/N of the frame time needed to scan the entire display, where N is the number of rows in the display. For example, to achieve a 100-row display image with brightness of 100 nits, the pixels must be driven to the equivalent of an instantaneous brightness of 10,000 nits for 1/100 of the entire frame time.

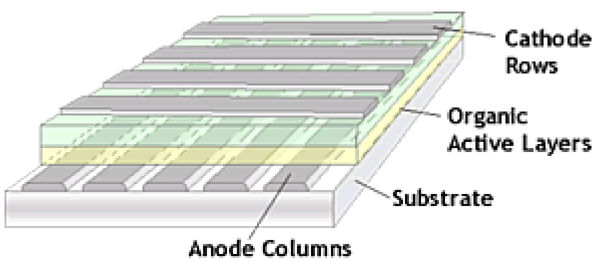


Figure 3 - PMOLED

While PMOLEDs are fairly simple structures to design and fabricate, they demand relatively expensive, current-sourced drive electronics to operate effectively. In addition, their power consumption is significantly higher than that required by a continuous charge mode in an active-matrix OLED. When PMOLEDs are pulsed with very high drive currents over a short duty cycle, they do not typically operate at their intrinsic peak efficiency. These inefficiencies come from the characteristics of the diode itself, as well as power losses in the row lines. Power analyses have shown that PMOLED displays are most practical in sizes smaller than 2” to 3” in diagonal, or having less than approximately 100 row lines. PMOLEDs make great sense for many such display applications, including cell phones, MP3 players and portable games.

2.4.2. AMOLED

Active-matrix OLED displays provide the same beautiful video-rate performance as their passive-matrix OLED counterparts, but they consume significantly less power. This advantage makes active-matrix OLEDs especially well suited for portable electronics where battery power consumption is critical and for displays that are larger than 2” to 3” in diagonal, as shown in this ultra-thin Sony prototype above.

An active-matrix OLED (AMOLED) display consists of OLED pixels that have been deposited or integrated onto a thin film transistor (TFT) array to form a matrix of pixels that illuminate light upon electrical activation. In contrast to a PMOLED display, where electricity is distributed row by row, the active-matrix TFT backplane acts as an array of switches that control the amount of current flowing through each OLED pixel. The TFT array continuously controls the current that flows to the pixels, signaling to each pixel how brightly to shine. Typically, this continuous current flow is controlled by at least two TFTs at each pixel, one to start and stop the charging of a storage capacitor and the second to provide a voltage source at the level needed to create a constant current to the pixel. As a result, the AMOLED operates at all times (i.e., for the entire frame scan), avoiding the need for the very high currents required for passive matrix operation.

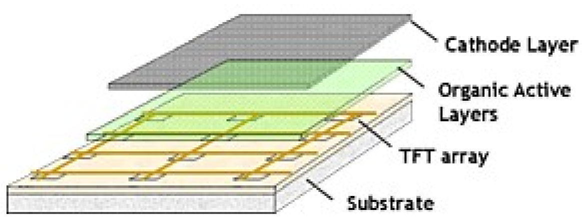


Figure 4 - AMOLED

Two primary TFT backplane technologies, poly-Silicon (poly-Si) and amorphous-Silicon (a-Si) are used today in AMOLEDs. Next-generation technologies such as organic TFTs (O-TFTs) are also under development. While still in the research phase, O-TFTs are beginning to show promise for use with OLEDs. For more information on our activities in O-TFT development, please link to Novel Organic Electronics.

- **Poly-Silicon TFT Backplane Technology**

Poly-Silicon backplane technology is a technology-of-choice for OLEDs today because it provides excellent mobilities that meet OLED current drive requirements. Poly-Si technology also allows for the integration of the drive circuitry directly onto the substrate. There are several key challenges, however, to address: reducing threshold voltage non-uniformities of poly-Si, installing additional manufacturing capacity, and demonstrating commercially-viable manufacturing yields. With these issues resolved, poly-Si AMOLEDs should offer excellent performance as some early-stage prototypes and products suggest.

- **Amorphous-Silicon Backplane Technology**

Amorphous-Silicon backplane technology, until recently, had been dismissed as an acceptable backplane technology for OLEDs because the mobility of a-Si were considered too low to meet OLED current drive requirements. In large part due to the development of Universal Display Corporation’s high-efficiency PHOLED technology, a-Si is now considered to be a viable backplane technology for OLEDs. PHOLEDs’ lower current density requirement, on the order of a few micro-amps (mA) per pixel, makes this possible. In 2003, Universal Display Corporation and AU Optronics Corporation demonstrated the first full-color display combining AU Optronics Corporation's a-Si backplane with Universal Display Corporation's PHOLED materials and technology. The incorporation of red PHOLED pixels alone (with green and blue fluorescent OLED pixels) reduced the power consumption by 42% compared with an otherwise equivalent all-fluorescent device.

While the long-term stability of a-Si TFTs needs further enhancement for use with OLEDs, a-Si technology offers several potential advantages over poly-Si technology. Existing a-Si capacity is significantly larger because the a-Si process is more mature and less costly. A-Si also currently supports larger substrate sizes (approaching 2 meters x 2 meters) compared with poly-Si capacity that today supports less than 1 meter x 1 meter substrates. Given these factors, a-Si backplanes may lead to less expensive AMOLED displays, particularly for larger size applications. A-Si also requires lower processing temperatures than poly-Si. This may help pave the way for building AMOLEDs on polymer-based flexible substrates earlier than is expected with poly-Si technology.

Apart from these there are other types on OLEDs distinguished by their physical properties. We shall see some of them now.

2.4.3. PHOLED

PHOLED Phosphorescent OLED technology and materials make it possible for OLEDs to attain up to four times greater efficiency than previously thought possible. Universal Display Corporation pioneered this technology with our partners at Princeton University and the University of Southern California, using the principle of electrophosphorescence to convert up to 100% of the electrical energy in an OLED into light. This compares favorably both to traditional fluorescent OLED technology, where approximately 25% of the electrical energy is converted into light, and to backlit liquid crystal displays (LCDs) where as much as 90% of the light from the backlight is reduced by the color filter array and other display components.

A significant advance for the OLED industry, Universal Display Corporation's proprietary PHOLED technology and materials offer excellent performance with:

- Record-breaking power efficiencies that translate into up to four times lower power consumption with less heat generation, scalability to larger sizes based on reduced power losses and enhanced light output, and potential compatibility with amorphous-Silicon (a-Si), as well as poly-Silicon (poly-Si) TFT backplane technologies for active-matrix displays
- Vibrant, bright colors for monochrome and full-color applications
- Long operating lifetimes with spectral stability over time

Using our PHOLED technology a 2.2” full-color, active-matrix PHOLED operating at a brightness of 200 candelas per square meter (cd/m 2) consumes only 125 milliWatts (mW) under video-mode conditions (with illumination of 30% of the pixels). This compares favorably with 180 mW for an equivalent backlit LCD and 240 mW for a fluorescent OLED, under similar conditions. These performance features make PHOLEDs well suited for passive-matrix and active-matrix displays, as well as lighting and other opto-electronic applications.

PHOLED technology and materials are also well suited for use in a variety of manufacturing processes. Today, PHOLED materials are commonly used in vacuum thermal evaporation (VTE) systems today, and are also compatible with OVPD™ organic vapor phase deposition systems. PHOLED materials may also be compatible with laser induced thermal imaging (LITI) and other novel deposition/patterning techniques, now under development.

In addition, solution-processible PHOLED materials are under development for use with ink-jet printing equipment. Innovation has led us to develop a suite of PHOLED materials with excellent spectral, efficiency and lifetime performance characteristics. We continue to develop additional materials and device architectures with enhanced performance, such as expanded colors, higher efficiencies and longer lifetimes to improve OLED product performance and to lead to future generations of OLED products, including OLED TVs, desktop monitors, white light sources and much more.

2.4.4. TOLED

TOLED transparent and top-emitting OLED technology uses a proprietary transparent contact structure to create displays that can be transparent, that is, top- and bottom-emitting or, selectively, top-emitting only. TOLEDs can significantly enhance display performance and open up many new product applications.

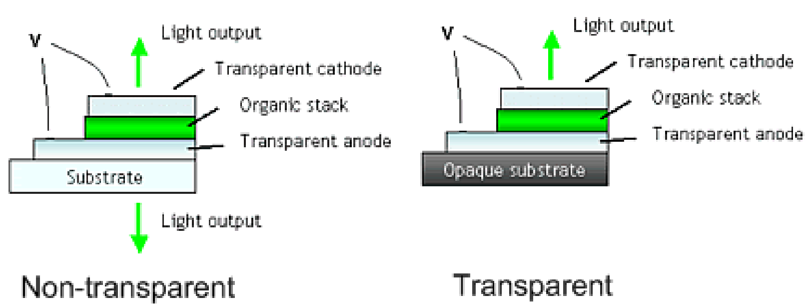


Figure 5 - TOLED Comparison

By comparison to conventional OLEDs, TOLEDs use a transparent compound cathode (top electrode) that allows light to emit from both surfaces (transparent on left) or selectively from the top surface by using an opaque substrate or film (top-emitting on right).

- **Transparency**: TOLEDs can be 70% to 85% transparent when switched off, nearly as clear as the glass or plastic substrate on which they are built. To better picture this, please refer to the video (to the right) where a simple transparent OLED pixel is shown turning on and off. This feature paves the way for TOLEDs to be built into vision-area applications, such as architectural windows for home entertainment and teleconferencing purposes, and automotive windshields for navigation and warning systems. TOLEDs may also enable the development of novel helmet-mounted or "heads-up" systems for virtual reality, industrial and medical applications.
- **Top emission**: Using the same transparent structure, TOLED technology can also be used for top-emitting structures for active-matrix displays and with opaque substrates. Especially desirable for high-resolution, active-matrix OLED applications, a top-emitting structure can improve the effective active area and the power consumption of the display by directing the emitted light away from the thin film transistor (TFT) backplane rather than through it (see schematic below). Top-emitting OLEDs can also be built on opaque surfaces such as metallic foil and silicon wafers. To illustrate this point, the video (to the right) shows an icon-format TOLED demonstrator that Universal Display Corporation built on metallic foil with Palo Alto Research Center (PARC), a subsidiary of Xerox Corporation, and Vitex Systems, Inc. Potential TOLED applications include smart cards or displays on furniture, automotive parts and other opaque surfaces, to suggest a few.

2.4.5. FOLED

FOLED flexible OLEDs are organic light emitting devices that are built on flexible substrates such as plastic or metallic foil. FOLED displays can offer significant performance advantages over LCD displays that are typically built on rigid glass substrates and contain a bulky backlight.

FOLEDs Offer Revolutionary Features for Displays

- **Ultra-lightweight, thin form**: FOLEDs are thinner and lighter weight than other displays. This means that cell phones, portable computers, wall-mounted televisions and other products that use them can also be lighter and smaller.

- **Durability**: FOLEDs can also be more durable - less breakable and more impact resistant - than other displays. With glass breakage a major cause of display-containing product returns, this is a highly desirable commercial alternative.

- **Flexibility**: FOLEDs may be manufactured on a variety of substrates. FOLEDs built on optically-clear plastic films and thin, bendable metallic foils are currently under development at Universal Display Corporation. Such displays may be made to bend, flex and conform to many surfaces. For example, FOLEDs may someday be found affixed to curved helmet face shields, shirtsleeve cuffs and automotive instrument panels. The potential flexibility of FOLEDs may also enable the realization of Universal Display Corporation's proprietary Universal Communication Device. In the meantime, earlier-generation FOLEDs may provide limited conformability for applications that include a cell phone that conforms to the shape of your hand or a portable DVD player that has a curved surface to enhance the audience's viewing experience.

- **Cost-effective processing**: FOLED technology opens up prospects for high-throughput, roll-to-roll processing (R2R) of OLEDs in the future, providing the basis for their truly low-cost mass production.

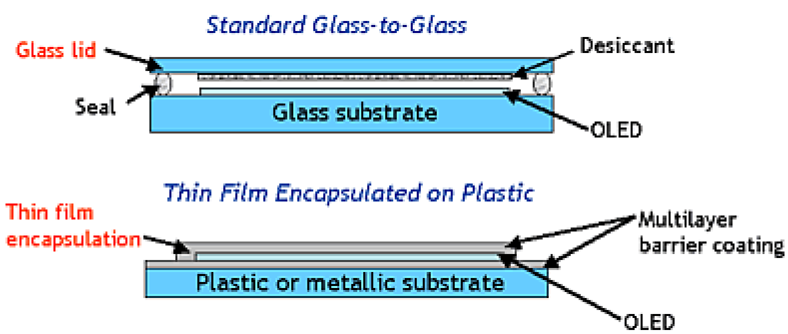


Figure 6 - FOLED Comparison

Key challenges for FOLEDs relate to flexible substrates, flexible packaging and encapsulation. The Company's program is focused on developing the requisite technologies to realize the Universal Communication Device and products like it. The U.S. Department of Defense is partially supporting our efforts with the objective of providing soldiers with lighter, thinner, flexible displays in the future.

Flexible Substrates

Today, the primary substrate candidates are thin plastics, such as PET and PEN polyester films. While these materials offer many attractive features, they also currently impose limitations with respect to thermal processing and barrier performance. Companies are developing coatings for these substrates as well as new plastic substrates to compensate for these constraints. Universal Display Corporation is actively working with a number of these companies.

The novel use of metallic foil substrates for FOLEDs is a complementary approach to the glass and plastic displays that Universal Display Corporation has made possible through its proprietary FOLED and TOLED® top-emitting technologies. Flexible metallic substrates provide excellent barrier properties, thermal and dimensional stability over a broad temperature range, and cost-effectiveness. They also offer potential near-term integration with backplane technology for active-matrix FOLED displays.

FOLED Packaging and Encapsulation

To protect an OLED from the degrading effects of water and oxygen, the conventional solution for glass-based OLEDs has been to seal the OLED with a glass lid (or metal can) using an ultraviolet-cured epoxy resin (see schematic below). A 'getter' material is often incorporated within the package to eliminate residual water and oxygen or any that may find ingress through the seal. FOLED packaging, however, is much more challenging. The standard sandwich construction that works well for glass-based displays is insufficient or problematic for FOLED displays where the ability to conform or flex the display is key. Universal Display Corporation is working to further the development of a variety of approaches that may provide the necessary protective properties.

2.4.6. White OLEDs

Since Edison's development of the incandescent bulb, the efficiency of the incandescent bulb has not increased much beyond 15 Lumens/Watt (lm/W). More efficient fluorescent tubes today offer efficiencies in the range of 50 lm/W, but possess a significantly less attractive color quality than incandescent bulbs. Imagine a highly-efficient, bright, uniform white light source that is built to be ultra-thin, lightweight, conformable and inexpensive.

Solid-state white lighting using PHOLED, TOLED and FOLED technologies represents a true breakthrough for next-generation lighting. Among the exciting advances in white OLED lighting technology are the following:

- PHOLED technology and materials present the potential to combine the power efficiencies of fluorescent tubes with the pleasing color quality associated with incandescent bulbs in a thoroughly new flat form factor. In collaboration with Toyota Industries Corporation, at the 2004 Society for Information Display Symposium and Exhibition, we reported record-breaking white PHOLED performance exceeding 18 lm/W at an operating voltage of < 6.5 V, brightness of 1000 cd/m2 and CIE color coordinates of (0.38, 0.38).
- Universal Display Corporation is developing a variety of white light emitting device architectures that offer a range of spectral coverage, color temperature and efficiency profiles. Certain device designs also offer the ability to tune dynamically the white spectral characteristics of the device. This means that a room occupant could change the room lighting from a cool to a warm white as desired.
- The development of FOLED technology has generated tremendous excitement for the possibility of thin, flexible OLED lighting panels. Imagine installing OLED lights, as though they were wallpaper, where and when you want them.
- The integration of TOLED technology with these lighting approaches offers the opportunity to create "smart windows" that provide multiple functionality – sunshine during the day and lighting at night.

White PHOLED Lighting Initiative

While OLED technology developments have spawned record-breaking peak power efficiencies and excellent white color quality, much work remains to meet the requirements of the general lighting industry. To this end, the U.S. Department of Energy (DOE) has established a Solid State Lighting (SSL) initiative to accelerate the development of OLED and inorganic light emitting diode (LED) technologies for general lighting. LEDs can make very effective "point source" lights and OLEDs may be excellent "diffuse" large-area light emitters. Universal

Display Corporation has earned a number of DOE research contracts to support various aspects of its technology development in this area.

The potential for OLED lighting is tremendous if key performance targets are met through these programs. OLEDs may support better architectural designs and new products that improve lighting quality and the power consumption profile of end users. OLED lights may be integrated into furniture, worn in clothing, and employed in ways yet to be envisioned. OLED technology may also find earlier opportunities in less demanding lighting applications such as specialty colored lighting needs; low- to medium-brightness backlights for portable electronics and automotive instrument panels; interior and point-of-purchase signage; headwear and footwear lighting; and a variety of novelty/toy, decorative, safety and holiday lighting.

2.5. Construction

The biggest part of manufacturing OLEDs is applying the organic layers to the substrate. This can be done in three ways: Vacuum deposition or vacuum thermal evaporation (VTE) - In a vacuum chamber, the organic molecules are gently heated (evaporated) and allowed to condense as thin films onto cooled substrates. This process is expensive and inefficient.

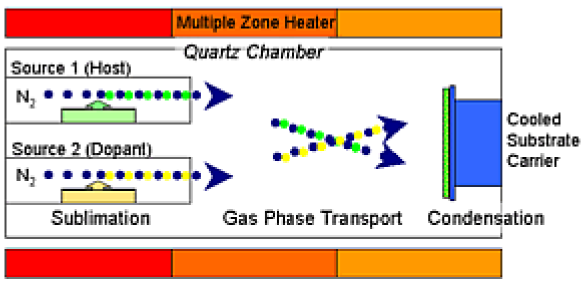
2.5.1. Organic vapor phase deposition (OVPD)

Vapor phase deposition is an OLED manufacturing technology with the potential to increase the performance and reduce the cost of OLED production. Several years ago, the research team at Princeton University, led by Dr. Stephen R. Forrest, demonstrated a novel process called OVPD™ organic vapor phase deposition. The OVPD process offers the possibility to deposit high-quality, organic films with better performance and cost characteristics than achieved using today’s conventional vacuum thermal evaporation (VTE) process.

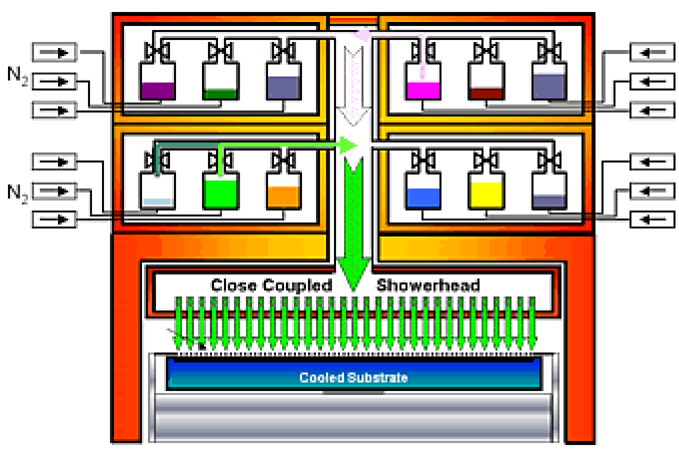
Aixtron AG, built and installed the first pre-production OVPD tool at Universal Display Corporation facilities in Ewing, New Jersey (see photos). *Aixtron AG* has also installed its first OVPD pre-production tool at the facilities of RiTdisplay Corporation in Taiwan.

OVPD Process Features

The OVPD process employs an inert carrier gas to precisely transfer films of organic material onto a cooled substrate in a hot-walled, low-pressure (typically 0.1 – 1 Torr) chamber. The organic materials are stored in external, separate, thermally-controlled cells. Once evaporated from these heated cells, the materials are entrained and transported by an inert carrier gas such as nitrogen, using gas flow rate, pressure and temperature as process control variables. The materials deposit down onto the cooled substrate from a manifold located only several centimeters above the substrate. For patterned displays, a shadow mask can be placed very close to the substrate. OVPD offers multiple advantages and end-user benefits.



Novel OVPD process employs a heated carrier gas to transport and deposit organic films onto a cooled substrate.



This production equipment design combines UDC's patented OVPD process with Aixtron's proprietary Close Coupled Showerhead (CCS) design. Courtesy of Aixtron AG.

Figure 7 - OVPD Process

- **Higher Deposition Rates.** Deposition rates with OVPD can be several times higher than the rate for conventional VTE processes because the OVPD deposition rate is primarily controlled by the flow of the carrier gas.

- **Higher Materials' Utilization.** Because the organic materials do not deposit on the heated surfaces of the chamber, materials' utilization is much better than with VTE where the materials deposit everywhere. This feature should translate into lower raw material cost, less downtime and higher production throughput.
- **Better Device Performance.** The OVPD process can provide better film thickness control and uniformity over larger areas than VTE. With three-variable process control, OVPD offers more precise deposition rates and doping control at very low levels. As a result, sharper or graded layer interfaces can be more easily achieved. In addition, multiple materials can be co-deposited in one chamber without the cross-contamination problems commonly experienced in VTE systems.
- **Shadow Mask Patterning.** OVPD offers better shadow mask-to-substrate distance control than is possible with VTE up-deposition. Because the mask is above, instead of below, the substrate, its thickness can be dictated by the desired pattern shape rather than the need for rigidity. Thus precise, reproducible pixel profiles can be obtained.
- **Larger Substrate Sizes.** Because the Aixtron AG-proprietary showerhead can be designed to maintain a constant source-to-substrate distance, OVPD may be more readily scaled to larger substrate sizes. This also may render OVPD more adaptable to in-line and roll-to-roll processing for flexible displays.

OVPD is an innovative technology for the thin film deposition of small molecular organic materials. It utilizes the advantages of gas phase deposition, where the materials are transported to the substrate by an inert carrier gas.

2.5.2. OLED Inkjet printing

With inkjet technology, OLEDs are sprayed onto substrates just like inks are sprayed onto paper during printing. Inkjet technology greatly reduces the cost of OLED manufacturing and allows OLEDs to be printed onto very large films for large displays like 80-inch TV screens or electronic billboards.

CDT is sole supplier of the Litrex range of Ink Jet Printers (70/120/142/M4 (Gen 4)). Cambridge Display Technology have also partnered industry leaders across the globe to offer a fully inclusive ink jet package. To support the Litrex printer range CDT can offer materials, print heads, know-how and skills development packages.

Recognizing the importance of developing this field of expertise and supporting its licensees and partners in scaling up for production, CDT has installed the largest ink jet printing facility of its type, and offers a total solution covering all aspects of making displays using ink jet printing.

The focus for the efforts is a solution which is:

Proven,

Fast,

gives reliable operation and high uptime,

produces high resolution PLED displays.

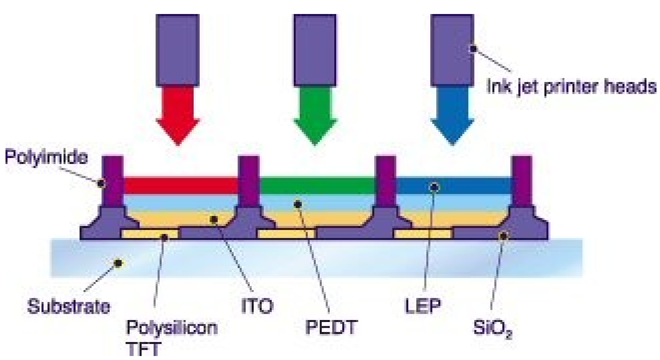


Figure 8 - OLED Inkjet Printing

In 2005 CDT announced another important step in the development of polymer light emitting diode (P-OLED) display technology with the production of a number of 14 inch full color displays using ink jet printing. The displays were produced at CDT's Technology Development Centre in the UK, and feature a resolution of 1280 x 768 pixels x RGB, equivalent to almost three million sub-pixels, or over 30 million ink jet drops.

The active matrix panels use an amorphous silicon backplane, and were made using a multi-nozzle approach - up to 128 nozzles - with no interlacing, and are believed to be the first of their kind ever produced.

The development strengthens CDT's view that multi-nozzle ink jet printing is the best approach to achieving scaleability and a low TAC time in the manufacture of high quality P-OLED displays.

Earlier this year, CDT demonstrated several 5.5 inch displays, and the latest 14 inch displays are part of a continuing program to develop both the underlying P-OLED technology and the means of manufacture. The WXGA+ panels were produced using printers from the Litrex Corporation, a company in which CDT currently has a 50% holding.

Also in the year 2005 Toppan Printing Co., Ltd. has developed the world´s first full color organic light emitting diode (OLED) display using a printing method for the patterning of RGB light emitting polymer layers. A 5-inch QVGA (320x240 pixels) passive display prototype has been successfully produced using this method.

2.6. Products

OLED technology is already used in some devices. On this page we will name some products that are powered by OLED displays. Most of them are cellular phones or portable music players, but also other products use this new technology.

- **Cellular/mobile phones**

There are many mobile phones that use OLED displays. Samsung has several models like the SGH-E700, E715 or E730. All these models use an external OLED screen with different resolutions (64 x 96, 96 x 96 pixels) and different color depths (either 256 colours or 65k colours). The Samsung SGH-X120 uses a main OLED screen with 128 x 128 pixels.

The S88 phone from BenQ-Siemens uses a two inch active-matrix OLED display with about 262k colors and 176 x 220 pixels. LG Electronic offers several mobile phones with an OLED technology. LG LP4100 has an external display powered with the new technology. LG's model VX8300 has an organic light-emitting diode display with 262,000 colors and a resolution of 176 x 220 pixels.

Other mobile phone manufacturers like Motorola, Nokia, Panasonic or SonyEricsson are also using organic light emitting diodes for their external displays.

- **MP3 players**

MobiBLU ships an mp3 player that features an OLED display, the DAH-1500i model. The popular Creative Zen Micro has also an organic LED display with 262k colors. The Sony NW-A3000 and NW-A1000 both have an OLED display. The Zen Sleek music player from Creative has a new 1.7 inch organic LED display. The Gigabeat audio player from Toshiba features also an OLED screen.

- **Digital cameras**

The Kodak EasyShare LS633 is the world's first digital camera with an organic LED display. The Sanyo Xacti HD1 is a high definition camera that features an OLED display. Other digital cameras with an OLED screen are from Hasselblad (H2D-39 and 503CWD for example).

- **OLED keyboard**

A Russian company has showed a prototype of an OLED keyboard. The keys are displayed with OLED technology. Thus the whole keyboard is highly configurable. The position, appearance and function of the keys are switchable. In addition, the keyboard looks awesome because of its LEDs.

The keys can display icons as well as regular symbols. Its possible to associate keys with mathematical functions, HTML codes or other special characters. It is also possible to configure a gaming keyboard layout for first-person shooters, strategy games or other purposes. There are preconfigured layouts for Quake, Photoshop and other mainstream games and applications.

- **Windows that light-up at dark**

It is true, this could be possible with OLED. This is because organic light emitting diodes can be transparent. A window could act as a normal window at day, but at night it can be used as a light resource. This vision can replace the boring old bulb in the middle of every room. It is getting even better: nearly every surface can become a lighting source. It does not matter if its curved or flat - OLED sheets are flexible and ultra-flat.

OLEDs can mimic a natural feeling of light in the dark. If turned off, they are transparent - an ideal precondition for windows. It is also imaginable that tables, cupboards or other furniture are used as a light source.

The problem is (as in general for OLED) the fast burnout of the blue component. Blue is one of the major colors needed to make white light. Physicist are working to resolve this problem.

- **OLED television**

OLED TVs can not be bought yet, but OLED has high potential to make it in common tv screens in the future. Why? The answer is simple: Organic LED are ultra-flat, very bright and consume less power. OLEDs can even become cheaper to produce than traditional LCDs. Right now, the opposite is the case, but its theoretical possible. At CES 2007 Sony, Samsung, LG and other companies showed some prototypes of OLED TVs. First production is expected in 2008 or 2009. A Sony spokesman said that OLEDs are the key technology in the future for every flat-panel TV over 40 inch.

- **Others**

Other devices or products that use organic light-emitted diode technolgy include car navigation systems like Becker Traffic Pro, bluetooth headsets or car audio systems.

2.6.1 Sample Product

Just to show what this technology has brought to the market we shall see an example of a device featuring the technology.

Sony XEL-1 OLED TV

Sony's OLED (Organic Light Emitting Diode) TV, the XEL-1, is truly the next big thing in television technology.

The XEL-1 is an 11 inch display that is only 3mm thin. The measurements of the XEL-1 are 287×253×140mm.
Sony has put the ultra-thin display on a pedestal with a flexible arm. At 11 inch the Sony XEL-1 is a nice stylish desk accessory.

The latest which weighs two kilograms and is about 3mm thin, features a resolution of 940×540 and contrast ratio of 1,000,000:1, stated Sony. It boasts a 3 millimeter thin panel and offers unparalleled picture quality with amazing contrast, outstanding brightness, exceptional color reproduction, and a rapid response time. It delivers astounding performance in all the key picture quality categories. OLED technology can completely turn off pixels when reproducing black, resulting in more outstanding dark scene detail and a contrast ratio of 1,000,000:1. OLED also creates unmatched color expression and detail and enables rapid response times for smooth and natural reproduction of fast moving images like those found in sports and action movies. The XEL-1 features the latest connectivity options including two HDMI™ inputs, a digital tuner, and a Memory Stick® media slot for viewing high-resolution photos.

- **Blazing Fast Response Time**

When turned "on," individual organic elements are stimulated directly by electric current, and therefore response time is incredibly fast.

- **Exceptional Color Reproduction**

Sony's unique "Super Top Emission" technology, which combined with a special mircro-cavity and color filters, enhances color purity, achieves extraordinary high color contrast. In fact, 105% of the NTSC color space can be achieved!

- **Energy Efficiency**

OLED technology delivers a more efficient means of utilizing light, which is generated by the organic material itself instead of an always on backlight; also, when elements are in their "off" state, they consume no power whatsoever.

The first Sony OLED TV has a resolution of 960x ×540px, but takes input resolution up to 1080p. The Sony XEL-1 has an integrated digital TV tuner for Japan. Other features of the Sony OLED TV include USB, LAN interface, 1x HDMI port, headphone plug and S-Force sound. Sony started shipping the XEL-1 OLED TV on December 1st for $1,740. This is a very high price for an 11 inch TV, but it is the first OLED TV to buy. Early adoption always had its price. The new OLED TV will last 30,000 hours, about 10 years for someone using the TV eight hours a day. An equivalent Sony LCD TV lasts twice that long, Sony said.

Figure 9 - Sony XEL-1 OLED TV

2.7. Advantages and Drawbacks

There are advantages as well as drawbacks of OLED displays and technology. First we will discuss the advantages and later on the possible drawbacks.

2.6.1 Advantages

- LCD technology engages a backlight, whereas OLED has no backlighting function. Hence an LCD is not possible to display true black, OLED has a so called off element which produces no light and consumes no power. In general, organic LED technology consumes less power. This is especially useful for devices that are supplied by battery power. As there is no backlighting they can have a thinner form and a more light weighted character.
- The manufacturing process of OLEDs is different to those of LCD technology. OLEDs can be printed onto almost any substrate with inkjet printer technology. That is why new applications like displays embedded in clothes or roll-up displays are possible.
- Because of the different manufacturing process it is possible to produce OLED displays at a lower cost in comparison to liquid crystal displays (LCDs) or plasma displays.
- OLED technology allows an increased brightness and a higher contrast. A wide range of pixel sizes as well as a wide viewing angle are one of the benefits. The viewing angle can be up to 160 degrees. The response time for full motion-video is faster and greyscale is more excellent. Other benefits are low power consumption and low operating voltages between 2 and 10 volts usually. Displays powered by OLED are allowing a broader operating temperature range than traditional displays.
- LCD technology is wasting power because the liquid crystal acts as a polarizer which filters out half of the light emitted by the backlight. As mentioned above, OLED hat no backlighting and therefore not this drawback. But there are some other drawbacks we will discuss right now.

2.6.2. Drawbacks

- The major drawback is the limited lifetime of organic materials. This problem still needs to be solved to push OLED technology to be more successful in the future. Blue OLEDs have only a lifetime of around 5,000 hours, when used in flat panel displays, which is much lower than the typical lifetimes of LCDs or plasma displays. But there are various experimentations to increase the lifetime, some are reporting that they already reached a lifetime up to 10,000 hours and above.

- Organic materials can easily be damaged by water intrusion into the displays. Therefore an improved sealing process is necessary for OLED displays.
- The development of the technology is restrained by patents held by Kodak and other companies. For commercial development of OLED technology it is often necessary to acquire a license.

3. CONCLUSION

OLED is emerging as the new technology for thin panel displays. It can be used for mp3 players, cell phones, digital cameras or hand-held gaming devices. The field of applications for OLED displays has a wide scale.

According to a report of Maxim Group revenues will rise from 600 million dollars in 2005 to more than five billion dollars by 2009. Other reports have shown that the total number of sold OLED units grew up to over fifty percent in the past year. It is expected that this number will rise up to 80 or 90 percent in the following year.

One of the future visions is to roll out OLEDs or to stick them up like post-it notes. Another vision is the transparent windows which would function like a regular window by day. At night it could be switched on and become a light source. This could be possible because OLED allows transparent displays and light sources.

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