Brilliant Plastics

Organic light-emitting diodes (OLEDs) could revolutionize the market for displays. OLEDs are self-luminous, rich in contrast, extremely flat, and video-capable. Numerous manufacturers have now introduced their own brands for OLED products, including Osram Opto Semiconductors.

This is the future of displays,” says Dr. Bernhard Stapp as he places a miniature TV on the table of his office in Regensburg, Germany. The housing fits on the surface of a credit card. It is only a few centimeters high, and attached to it is a mount with a thin display that shows a film with impressions of Paris. “I don’t mean that future displays will be this small, but they will be this thin and this vivid,” says Stapp, head of Research and Development at Osram Opto Semiconductors, the opto-electronics unit of Osram, a Siemens company. As the film is playing, Stapp rotates the housing. Unlike liquid crystal displays (LCDs), which provide a good picture only when viewed from the front, the display seems razor-sharp and full of contrast from any angle. In addition, it...
A SPECTRUM OF COMPETING TECHNOLOGIES

OLEDs are divided in two worlds. Two types of organic chemicals emit light when a voltage is applied to them: long-chain polymers and small molecules. Furthermore, two underlying phenomena are involved: fluorescence and phosphorescence. And in the field of display technology, there are two contrasting architectures: active-matrix and passive-matrix. Osram Opto Semiconductors is currently producing only passive-matrix displays made of polymers. Here, the anode and cathode consist of narrow conductor paths that cross at 90 degrees and enclose the polymer layer (see graphic). The points at which these electrodes intersect form pixels. Light is radiated outward through a transparent electrode made of indium tin oxide. Passive-matrix displays are relatively easy to manufacture, but because of losses in their electrical conductors, they are limited in size to screen diagonals of about five centimeters. This limitation is absent in active-matrix displays, which are more complex. Here, each pixel is individually activated, which requires an integrated circuit at the display level. The ideal solution would be thin-film transistors made of polycrystalline silicon, but they are not yet widely available. If integrated circuits use competing amorphous silicon technology, however, power consumption is too high.

In a passive-matrix display the cathode and anode form a square grid. Pixels made of OLED material are excited by an electrical current, causing them to emit light.

Full-color displays are manufactured almost exclusively with OLEDs made of small molecules that offer the needed color spectrum. The molecules are applied in the form of a powder, often a material known as Alq3 (tris(8-hydroxy-quinoline)aluminum). For blue light, the “spiro compounds,” which consist of cross-linked biphenyls or oligophenyls, can be used. These OLEDs are created by vacuum-depositing the layers through a mask, but this technique could entail problems for mass production or for larger displays. However, polyphenylene vinylene (PPV) or polyethyleneoxythiophene (PEDT: PSS), which are used by Osram, can be applied to large surfaces using “spin coating” technology.

Currently, laboratories are finding that the most efficient approach is to use small molecules, which are sometimes capable of both opto-electric excitation states: fluorescence and phosphorescence. In the past, polymer OLEDs had used only what scientists call the “singlet state.” This state arises when the voltage pumps energy into the polymer’s electrons, which then release this energy as visible radiation when they return to the ground state — the phenomenon of fluorescence. At the same time, electrons are excited to the “triplet state,” which occurs three times as often but has less energy. When these electrons fall back to the ground state, they also give off radiation, but it is usually invisible; this is phosphorescence. Techniques like the use of certain doping agents can be used to activate the triplet state and incorporate it into the emission, which could increase the efficiency of polymer OLEDs by a factor of up to four.

shines without delay all by itself. LCD displays, on the other hand, must be illuminated from behind, which accounts for about 90 percent of their total energy consumption — more than half is absorbed by polarization filters alone. The new display is made of plastic, metal and glass; its luminescent layer has a thickness of less than half a thousandth of a millimeter. Such displays use OLEDs (organic light-emitting diodes), which are now hitting the market and are likely to compete with LCDs in a number of fields.

When researchers at Kodak created the first small-molecule OLED in the mid-’80s, a torrent of development ensued. Shortly thereafter, Cambridge Display Technology made OLEDs from polymers, or long-chain plastics. Today, researchers know of a large number of organic materials that emit light when a voltage is applied to them. The light might be yellow, green, red or blue — all are possible. But the road from successful laboratory tests to large-scale industrial production may be rocky. OLED diodes are extremely sensitive to moisture and oxygen and must therefore be encapsulated behind glass. Standards of cleanliness during manufacturing are as stringent as those in the semiconductor industry. And scientists are still attempting to identify the optimal materials. Not all colors are emitted with the same efficiency, which drives up power consumption, shortens life-span and thereby hinders widespread use of large, full-color displays for the time being.

Market Potential. Twenty years after their invention, OLEDs are now on the verge of a commercial breakthrough. According to a study conducted by the U.S. market research firm iSuppli, sales of OLED displays will increase in volume from $500 million in 2004 to almost $2.5 billion in 2009. At the SID trade show in Baltimore this year, the Asian company International Display Technology and its partner IBM introduced a prototype color display with a 50-centimeter diagonal. And Sony presented a display measuring 60 centimeters, but composed of four adjacent pieces. In 2003, DuPont, Philips, Kodak and Osram introduced their own brands for their
OLED products. Displays made by Pioneer for car stereos and cell phones have been on the market for some time already. Philips now has a shaver with an OLED display in its product line and Kodak has a digital camera. With its Pictiva brand, Osram OS is targeting the display market for flip phones, car stereos, household appliances — and all areas in which self-luminous and extremely flat displays are needed. “The range of uses is extraordinarily broad,” says Stapp. “There are applications that no one has even seriously considered yet, like displays that have to work at low temperatures, or divers’ watches. There could even be costume jewelry with OLED displays.”

15,000 Hours. Siemens’ Osram subsidiary has built a mass-production facility for small polymer OLED displays in Penang, Malaysia. “We can convert 30,000 square meters of glass into displays per year,” says Production Director David Lacey. The small, yellowish-green displays don’t seem all that impressive compared with the full-color models of the competition — but appearances can be deceptive. “We produce robust displays of consistently high quality; their service life is 15,000 hours,” says Lacey proudly. “You can’t even place an order yet for the large displays shown at the trade shows.” A chemist himself, Lacey knows what he is talking about. He has been working in the field for almost ten years. “It was fascinating to experience the developments in OLEDs from the very start, from the time when they stayed lighted only a few hours to the point where they were ready for the market,” he adds.

OLEDs consist of several thin layers, each of which has a unique structure. During production, a substrate glass that has already been coated with a transparent anode of indium tin oxide (ITO) is covered with a metallic structure that makes electrical contacts possible. The displays are then created by means of photolithography, initially appearing as patterns of tiny conductor paths on the glass surface. Then two layers of polymer are applied one after the other. A drop at a time, the synthetic material — which is either dispersed in water or dissolved in an organic solvent — falls onto the very rapidly rotating pane and spreads itself uniformly across the entire surface. After this “spin coating,” a laser removes the polymer from the spots that will serve as contacts and are necessary for sealing. The conductor paths for the cathode consist of a mixture of barium and aluminum; in a final step, the glass is encapsulated. An individual square pixel has a side length of about 0.3 millimeters. “We’ve automated the production process to a great extent,” says Lacey. “A lot of know-how went into our process, since there are a lot of factors that have a really critical impact on reproducibility and service life.”

Ink Jet OLEDs. “The next step is to produce full-color displays,” says Lacey. The first orange and green OLEDs are scheduled to go into production in Penang in early 2004. Meanwhile, Osram Opto’s research lab in San Jose, California, has already succeeded in manufacturing full-color, video-capable displays. There, scientists are using a process that is similar to the way an ink-jet printer operates. The pixel pattern is created by 128 nozzles that spray tiny amounts of polymer into recesses. In this process, the three primary colors of a pixel are applied one after the other in their own sections.

But the technology is not yet ready for large scale production. For instance, a technique is yet to be found to deposit the polymer with the uniform thickness required. Currently, globular drops tend to form. But the researchers are confident that they will be able to develop a reproducible technique over the next few years.

**OLEDs have a very complex structure.**

**Cleanliness standards for their production approach those for semiconductors.**
Filtered Colors. Dr. Wolfgang Rogler of Siemens Corporate Technology (CT) in Erlangen is also working on full-color displays. Together with Osram and materials manufacturer Covion, he is researching OLEDs that emit white light. The work is being conducted in the framework of a project sponsored by the German Federal Ministry of Research and Education.

The project’s partners intend to create colors with optical filters. The advantages of this approach are simpler design, since only one sort of OLED material is required, and filter technology that can be adopted from the world of liquid-crystal displays, in which colors are produced in a similar fashion. “One disadvantage, of course, is lower efficiency,” Rogler admits.

The problem is that every filter absorbs light, which ultimately means higher power consumption or a shorter service life. One solution could be polymers with a higher light yield, and Siemens CT is conducting research on those as well. As its long-term goal, the company is aiming for organic light-emitting diodes that have a luminosity akin to their inorganic cousins and which could even serve as light sources in the future. That would require raising the current efficiency rating of three to six lumens per watt to a competitive level.

“But right now we’re concentrating on extending service life,” says Joe Carr, head of the OLED unit of Osram Opto Semiconductors in San Jose, California. It might be possible to achieve this through improved encapsulation, in addition to optimized materials. Here too, the OLED researchers have a vision: flexible displays that could one day depict an electronic newspaper or, as curved screens, represent the automobile cockpit of tomorrow. Handcrafted demonstration models already exist, but they quickly become permeable and therefore work for only a few hours. Carr thinks it will be about ten years before a breakthrough is made in flexible encapsulations. Adds research director Stapp, “That’s still far away. But we know how to get there.”

Norbert Aschenbrenner

The flexible OLED display is a realistic vision. It is a long way off, but the way there is already known.

OLED applications will depend on improved reliability, and the technologies that will make higher information density and larger display sizes possible. For television, delicately structured active-matrix displays will be needed. OLEDs in smart cards will require development of new mass-production processes, and lighting applications will demand stability and long life.