

Some 84,000 Osram light emitting diodes have given a new look to the glass facade of Aquarius Hall at the Park Hotel Weggis, near Lake Lucerne. LEDs are also finding a wide range of applications as indicator lamps and in backlighting (bottom right).



It's gloomy and cool in the unlit room. Dr. Norbert Stath throws a switch and suddenly everything appears to be bathed in the light of glittering stars. Hundreds of tiny dots of light illuminate arrangements of plastic roses. A lighting console plays a combination of colors and sounds, and a slot machine blinks on, inviting us to try our luck. Of course, more serious applications are also being demonstrated in the showroom of Osram Opto Semiconductors in Regensburg, Germany — like a traffic light or an emergency exit sign. Stath, who's in charge of innovation management, points out several unique automobile taillights. Phaeton, Maybach and

A Bright Future

Light-emitting diodes are outstanding performers. They have a long lifespan, use little energy and produce lots of light. In a few years, they might even compete with the incandescent bulb.

other illustrious brands are mentioned. All of these exhibits have one thing in common: They're illuminated by light-emitting diodes, or LEDs. We're all quite familiar with these tiny light sources that tell us which washing machine program has been selected or

whether the airbag in our car is operational, and provide safety illumination on bicycles even when the bike isn't moving. But in the future these tiny starlets will also be used more and more in applications served by incandescent or fluorescent bulbs today: as

headlights in cars, as flash units in cell phone cameras (see article, p. 5), or even to illuminate rooms.

Market researchers predict double-digit growth rates for optical semiconductors. Osram president Dr. Wolf-Dieter Bopst projects a world market of about seven billion euros by 2007. This excellent outlook was one reason why Osram opened the world's most advanced optical chip factory near Regensburg in April 2003. The plant will enable Osram to double its capacity for opto-chips by 2005.

But before LEDs can achieve the status of a universally used light source, scientists still have some work to do. While the life span of red LEDs can be as long as 100,000 hours (compared with 1,000 hours for an incandescent bulb), their brightness is still insufficient for many applications. In particular, the highly popular white LEDs — which incorporate additional fluorescent materials to create yellow wavelengths besides blue to produce white light — generate much less brightness than conventional light sources.

LEDs for the Olympics. LEDs already leave other technologies in the dust when it comes to advertising billboards and sports stadiums. Their power consumption is moderate, so they produce little heat. Moreover, individual

Compared to the **efficiency of LEDs**, **incandescent lamps are simply heating elements that also emit a little light.**

LEDs for individual image pixels can be controlled independently of one another. As a result, the image screen can be bent in any direction, or even reach around a corner. The organizers of the 2008 Olympics in Beijing are planning to set up LED image screens hundreds of square meters in size on the outer walls of the stadiums, on which the action will be displayed. Among the three basic colors of red, green and blue, it's the green LEDs that remain a source of concern due to their low efficiency.

Product development engineers are pursuing several strategies to increase the light output of LEDs.

⑥ **Chip materials:** Optimized manufacturing processes will allow improved control of material properties and minimize material defects. Here, an important factor is development of precision methods of doping the semiconductors with foreign atoms. When an electron and a hole recombine in an atom, light is emitted. But if the doping is imperfect, many electrons can't contribute to

the generation of light, because they are captured by the "wrong" atoms. The quantum efficiency — the yield during the conversion of electrons into photons — presently ranges from 15 to 30 percent depending on the wavelength, and scientists are striving to increase that to somewhere near 50 percent. A higher quantum efficiency would also reduce heat losses. Heat could cause problems in dense arrays of LEDs — for instance in auto taillights. An accumulation of heat also lowers semiconductor efficiency, thus giving rise to a vicious circle.

⑥ **Chip design:** To the naked eye, small LEDs look like tiny cubes a few tenths of a millimeter in size. But under the microscope they reveal themselves to be much more intricate structures. Scientists are working with new shapes — some of them bizarre like an inverted pyramid — to increase light output. That's because only a small portion of the light photons find their way out of the chip, since the semiconductor material has a high refractive index, sometimes above 3.0, which results in a higher proportion of total reflection at the boundary layers (see illustration, p. 41). Light that would otherwise strike the surface at a shallow angle is reflected back into the interior, where it's absorbed — much like light from a diver's lamp that's directed at a small angle against the water's surface.

Two years ago Osram achieved a breakthrough that helped alleviate this problem. Normally the light-emitting semiconductor layers are grown on a layer of gallium arsenide, silicon carbide or sapphire, which then serves as a substrate for the completed LED. The Osram researchers, however, removed the light-absorbing substrate and deposited a metallic coating that serves both as a mirror and as a bonding material for a foreign substrate. "This thin-film technology has suddenly enabled us to double the light yield," says Stath.



⑥ Housing design: Other light losses occur at the boundary with the plastic sealing material. This material has a refractive index of 1.5 — only about half that of the semiconductor. But the refractive indices should be as identical as possible to minimize total reflection. Even a small increase in the refractive index of the sealing material would greatly improve the proportion of emerging light.

High Potential. If all goes well, it should be possible in ten years to produce white LEDs that yield 100 lumens per watt (lm/W). Today's best LEDs manage 25 to 30 lm/W, and Osram's new Golden Dragon LEDs deliver 40 with a lifespan of 50,000 hours. According to Stath, models with a yield of 50 lm/W will enter the market in 2005. By comparison, a 12 lm/W incandescent bulb with an efficiency of only five percent is merely a heating element that also emits a little light. Theoretically, the maximum yield in LEDs is as high as 200 lm/W. "The practical limit is probably somewhat lower," says Stath.

Power laser diodes are an especially hot development. What distinguishes these diodes is an optical resonator that greatly amplifies the intensity of the light. Osram already has laboratory models for infrared light

— tiny rods measuring 1x10 millimeters — that can produce an optical output of 80 watts in continuous operation with an efficiency of 50 percent and must therefore be water-cooled. Continental Temic has used such pulse lasers in developing an automatic distance control system for automobiles that's less costly than radar-based versions. "You can also employ infrared lasers to illuminate the roadway and use a night-vision system to turn night into day," says Stath.

But Osram researchers won't settle for infrared light. They intend to use the extremely high light yield of power lasers for visible wavelengths, especially for blue and green light. In pursuit of this goal, they're experimenting with optical crystals that produce 0.5 watts of visible light from every three watts of infrared light. This approach has already been successful in the lab, Stath notes, and work is progressing on miniaturization.

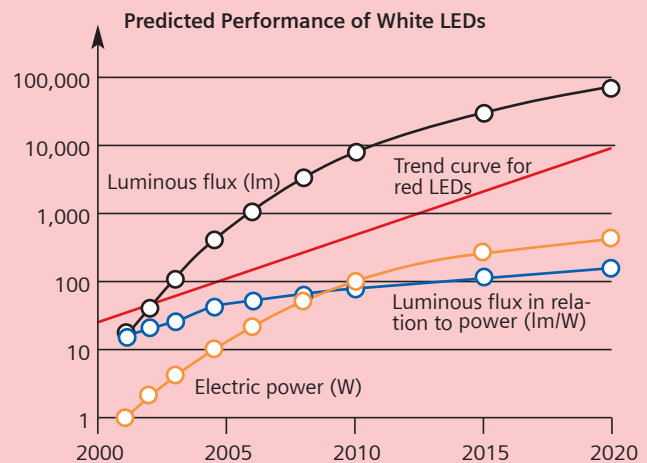
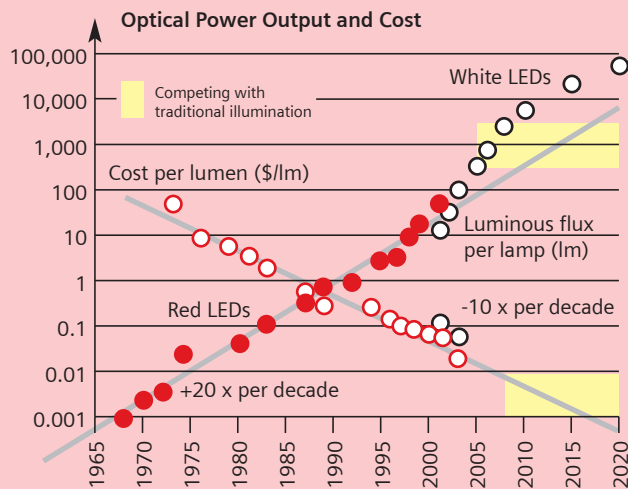
If successful, these lasers could find widespread application in projection technology. This might, for instance, turn laser TV — once so highly touted, only to be pronounced dead — into a hot item after all. Small semiconductor lasers would take the place of large, costly solid-state lasers, paving the way for large-screen projection television.

Moore's Law II? Roland Haitz, former head of research at Agilent, has noted the applicability of Moore's law to microchips. He calculates that the light yield of red LEDs has grown 20-fold every ten years since the late 1960s. At the same time, says Haitz, the price per lumen drops to one-tenth every decade.

The trend is similar for white LEDs (see illustration below). Haitz predicts that by 2015 white LEDs will be available at price and power levels that make them attractive as general light sources. Considering its much longer life and lower power consumption, the "LED bulb" should be affordable by the end of the decade. A 75-watt incandescent bulb produces about 900 lumens. In white LEDs this output will be reached around 2006 — but at a power consumption of only 25 watts. By 2020, lamps with arrays of LEDs will be producing up to 100,000 lumens — enough, according to Haitz, to "attack" applications such as lighting up sports stadiums.

But everything is taking too long for Haitz, who is challenging the governments of the industrial nations to invest more money in LED development. His rationale: In the U.S. alone, replacing all conventional light sources with LEDs would eliminate the need

TREND PROJECTIONS FOR RED AND WHITE LIGHT-EMITTING DIODES

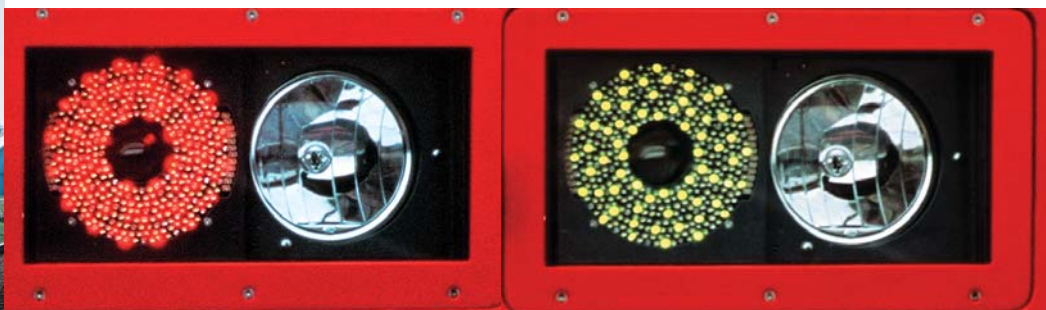


Light-emitting diodes aren't limited to special applications. Both in terms of light output and of costs, light-emitting diodes are making great strides as they approach the regions (marked yellow) in which LED-equipped lamps can compete with conventional light sources (a lumen is the measure of the radiated power emitted in all directions by a light source evaluated at spectral eye sensitivity).

Source for both graphic illustrations: Presentation by Roland Haitz before the German Physical Society, March 2003.



Siemens has developed a special headlight for the new BR 189 Europa Locomotive. The headlight consists of over 400 LEDs that can produce a wide variety of patterns.



to build 40 large power plants. "I'm convinced that LEDs will revolutionize lighting technology and become the dominant light source," he asserts.

LEDs for Dinner. Many industries are only now discovering the potential uses and benefits of light-emitting diodes. Furniture designers and architects are already using LEDs for accent lighting, marker beacons and special lighting effects. For example, the Park Hotel in Weggis, Switzerland, uses 84,000 red, green and blue LEDs — and changing light patterns — to create different moods in the dining room.

New design choices along with durability also appeal to automakers. Siemens VDO alone installs 700 million LEDs annually to illuminate car dashboards. Some 320 LEDs glow in every Audi A8. The trend, however, is away from fully saturated colors like Volkswagen-blue or BMW-orange, and toward mixed colors — or even white, as in the latest Mercedes E-Class, says Dr. Heinrich Noll, Department Manager Optics/Light Technology at Siemens VDO. Ophthalmologists believe that light with a broader spectrum of wavelengths, such as white, creates less eye fatigue.

The next trend might be the introduction of LEDs in black-panel displays. Already popular in Japan, these displays are characterized by instruments that are illuminated by particularly bright LEDs.

Especially bright light emitting diodes are also used in new automotive head-up displays. For instance, in the new 5-Series BMWs information is reflected from the windshield. Siemens VDO has even introduced cockpits in which the driver can choose a favorite color. "When the fuel level gets low, the gas gauge could change color from green to red," says Noll.

LED Headlights. The greatest challenge facing automotive lighting engineers involves headlighting. "We're convinced that the futuristic LED headlight will hit the road before the end of the decade," predicts Osram CEO Wolf-Dieter Bopst. That would please not only automotive designers, but also lighting engineers, who could develop headlighting that would illuminate the roadway much more precisely and even change beam direction in curves. Where cost isn't the key factor, where LEDs are already used in headlighting, as in the Siemens 189-model-series Europa Locomotive.

Since the locomotive is designed for use in 14 European countries, it must be able to adapt to meet different regulations in individual countries. Depending on the country and the activity (forward, reverse, switchyard operation, etc.) the triple headlighting must oper-

ate and flash with various patterns and colors. "Each of our headlighting contains 248 white, 66 green and 102 red LEDs — all of them very bright," says Christian Thoma, project manager at Siemens Transportation Systems.

Although all LED technical hurdles appear surmountable, it will be quite a while before conventional lamps disappear from the market. "LEDs will have to work their way up the ladder," says Norbert Stath. Wherever the advantages of LEDs make a difference — small size, color, lamp life — they will catch on. But it will be a long time before the LED replaces the incandescent lamp, 15 billion of which are sold every year. Of course, the incandescent lamp hasn't totally replaced its predecessor yet either. In Germany alone, 114,000 tons of candles are still sold every year.

■ Bernd Müller

HOW LIGHT ESCAPES FROM A LIGHT-EMITTING DIODE

In conventional LEDs only a few photons succeed in escaping from the surface. Many are reflected or absorbed within the substrate. But there's a way out: A reflecting metallic film beneath the active layer doubles the light yield to 50 lm/W (right).

