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- Lighting and Phosphor Newsletter -

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R & D News

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1. BMW Laser Headlights Slice Through the Dark

Lasers are more efficient and offer a more natural white light

I am standing in a twilit underground lab looking at the most powerful car headlight in the world. Its source, a blue-laser diode, is 1000 times as bright as an LED but uses just two-thirds the energy.

I had to surrender my passport to see it, for I'm at BMW's highly secure, steel-and-glass research mecca, the FIZ (for Forschungs- und Innovationszentrum, or Research and Innovation Center), an immense complex in Munich replete with workshops, clay modelers' "caves," and a vast wind tunnel.

I'm basking in the glow of three of BMW's brightest lights: project founder Volker Levering, whose laser inspiration—a mental lightbulb, if you will—flashed on during a 2010 Christmas ski trip in the Alps; Stefan Weber, the current program leader; and Helmut Erdl, also among the technology's inventors.

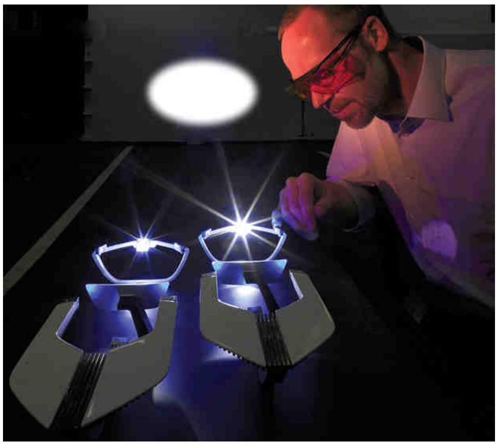
"A person may not be directly aware, but you can instantly feel the difference between good and bad light," says Weber, as he switches on a wall of fluorescent panels. I certainly feel the difference: The panels simulate a sunny day above ground, right up to the 6500-kelvin color temperature that photographers consider natural daylight.

These engineers want more than mere intensity: They want a focused, high-contrast white light that mimics that of the sun. BMW's system will deliver about 5500 to 6000 K—the highest color temperature that international regulations will allow. That level is much closer than today's headlights to the cool, blue end of the scale, which helps drivers pick out objects and eases eye fatigue.

Until the dawn of semiconductor lighting, the whitest brights any headlights could manage were high-intensity discharge (HID, also known as xenon) lamps, which BMW introduced on the 1991 7 Series coupe. HID light—still an optional upgrade on many 2014 cars—is between 2800 and 3500 lumens and above 4000 K, but it's weaker, yellower, and less energy efficient than either LED or laser light.

The incandescent bulb invented by Thomas Edison in 1879 has shown remarkable staying power, not least in automobiles. The first LED headlights shone from a car a mere six years ago, when Lexus introduced them on its LS 600h L sedan. Soon, the technological torch may pass to lasers. Laser light will debut in Europe in the 2014 BMW i8, a plug-in hybrid sports car that promises 2.45 liters per 100 kilometers (about 94 miles per gallon) and a 4.4-second surge from 0 to 100 kilometers per hour (or 0 to 60 miles per hour in 4.3 seconds).

The reign of the LED headlight may be ending even before it gets properly under way, says Shuji Nakamura. He should know: Nakamura invented both the blue laser and the blue LED, which made possible the whole world of powerful white solid-state lights. And his Silicon Valley start-up, Soraa, is developing laser systems to complement its LED lighting technologies.



"The laser, we believe, is the next generation of lighting, even for general applications" such as homes, businesses, and a variety of displays, Nakamura says.

BMW's engineers lead the way to the Nachtfahr, or night-driving simulator. A cutaway interior of a 5-Series sedan, with instrument panel, seats, and steering wheel, faces a darkened simulator screen.

On a nearby workbench rests the culmination of their 2.5-year project: a pair of laser light prototypes, looking like the lethal toys of a James Bond villain. Erdl demonstrates their power, dangling an incense stick into the barely visible beam. The stick immediately begins burning, filling the lab with a cathedral's scent.

But have no fear: The lasers will be safely contained, with no chance of bouncing their fierce rays off unfortunate retinas, even in the event of a collision. That's because the BMW lamps turn the intense blue beam into a tightly concentrated but nonlaser—and therefore eye-friendly—cone of white light.

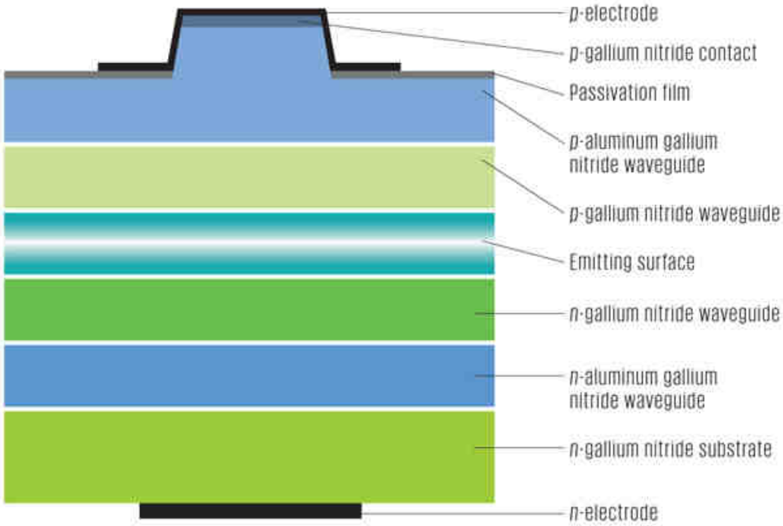
The production version will have up to four Class 4 blue-laser diodes. Collimating lenses will direct their beams onto a phosphorus plate that will convert the laser beams to white light, which will bounce off secondary optics and reflect onto the road. To show me how it works, here in the night simulator lab, Erdl dips a phosphorus wafer into a blue laser beam. The wafer blocks some laser photons and lets others stream through. Among the blocked photons, some stimulate—or "pump"—the phosphorus atoms to emit yellow light. The mix of blue light streaming through and yellow emitted from within produces brilliant white light. It's the basic technique used, at lower intensities, in most white-light-emitting LEDs.

Indeed, LEDs can approach that 6000-K, white-light nirvana. And for flooding an area with diffuse white light, LEDs are great, Nakamura says.

But he and other experts agree that lasers are much better and more efficient at precisely directing light onto a distant spot. That's exactly what's required in automotive lighting (and also in movie theater projectors, which will soon incorporate laser-based lighting systems).
"Wherever you want directional, flexible applications of light, the industry is moving like a freight train in the laser's direction," says Paul Rudy, general manager of the laser division of Soraa. "It's simply the best way to direct light through a complex optical system."

The reasons are clear. At just 10 square micrometers, the laser's active light-emitting area is 1/10 000th the size of a 1-square-millimeter LED. That makes it much easier for the laser to focus and project light exactly where it's needed. The tiny chip itself, with its vastly higher current density, makes it easy to produce dazzling light without multiple, relatively bulky LEDs. And the source is already tightly focused and concentrated, so the tiny movements of the chip can be translated into the large motions of the beam. With an LED, on the other hand, "the light tends to just fan out everywhere, and it's very hard to focus it optically," Rudy says.

"With a laser, you combine the high-brightness benefits of a lamp with the reliability, long life, and efficiency of an LED," he adds. That estimated life, by the way, is 30 000 hours. The lamps could easily outlive the automobile.



Gallium nitride lasers set up a resonant light wave not along their length, as do classic lasers, but crosswise, so that the light comes out from the edge. The compound semiconductor, perfected by Shuji Nakamura, has a large enough bandgap to produce the energetic waves in the blue spectrum.

Lasers also beat LEDs where it matters most: efficiency. It's true that LEDs are more efficient at turning electricity into light, though laser efficiency is rapidly catching up. But for overall system efficiency, it's no contest: LEDs are nowhere near as good at getting the light to where you want it to go. That intense laser, for example, can be beamed into a fiber-optic strand and lose only 10 to 20 percent of its initial energy, as opposed to what an LED could lose—up to 90 percent, experts say. A pair of the old halogen headlights drew about 120 watts from a car's battery; a couple of today's best LED headlights draw roughly 40 W. Laser light's usage is projected to drop below 30 W.

The rise of the technology can be traced back to Nakamura himself, whose first blue lasers hit the market in 2005. Low-power versions were driving Blu-ray players and PlayStations, with higher-power versions reserved for uses such as industrial welding. Engineers kept cranking up the power output in shorter-wavelength, indium gallium nitride chips, until 1-W blue lasers became available. It was a development ripe for new applications.

Digital display makers took a page from LED development, realizing they could also pump the stronger blue lasers into a phosphor to create brilliant light. The result was laser-based "lamp-free" displays, which are now being used in office, school, and home-theater projectors. Rudy calls semiconductor lighting a classic example of a maturing industry, with chip development on a steep upward curve and costs falling rapidly.

"The confluence of adjacent fields really brought laser to the forefront," he says. "And auto lighting is one awesome example of the application." Because BMW's blue-laser diodes measure just 10 micrometers, about one-tenth the length of rival LEDs, you can put them anywhere in an automobile and transmit their output light via fiber optics. That frees designers to create dramatically new headlight forms—or “eyes”—to heighten cars’ personalities and also to save space and redistribute weight.

The field is blowing open, Rudy and Nakamura say. Beyond cars, projectors, and displays, expect to see uses in cellphone “pico” projector displays and future head-mounted systems, such as those now used in Google Glass. Lasers may even end up lighting our homes, offices, stadiums—you name it.

For general lighting, what makes the lasers attractive is that they can be packed much more densely on a chip than LEDs can. Laser-based lights would not only be more energy efficient on a dollars-per-lumen basis but also more flexible, able to work as spotlights or floodlights at the flick of a switch. If costs continue to fall, Rudy says, laser lights could make the leap to general use in roughly 10 years.

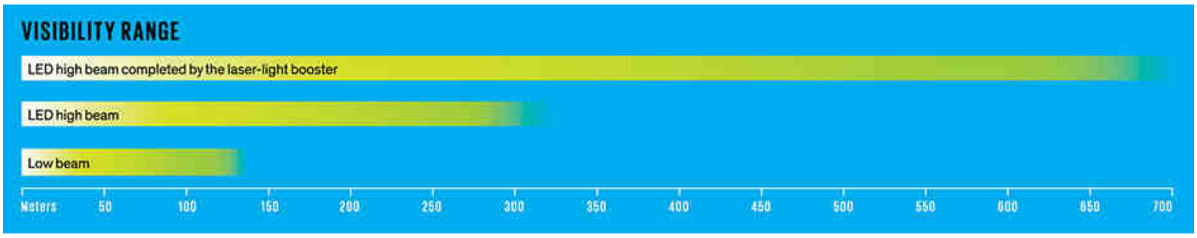
BMW intends to introduce the laser-based system on its 2014 i8 plug-in hybrid sports car. As with any plug-in vehicle, the i8 has a particular need to conserve battery electricity for propulsion, as well as for steering assist, entertainment, and heating and cooling. Finding small savings everywhere—even on the order of mere watts—translates directly into more miles of driving range.

Unlike slow-starting, single-brightness HIDs, the laser lights switch on in milliseconds and instantly go to 100 percent illumination. Easy to package in motorized modules, space-saving lasers “offer huge advantages for today’s projection systems,” Levering says.

Those innovations include BMW’s new Dynamic Light Spot, a pair of bumper-mounted spotlights that are separate from the headlights. The spotlights are linked to thermal-imaging cameras and a head-up driver display that brightly illuminates large animals and pedestrians far beyond headlight range. And BMW and other luxury brands are now introducing headlights that direct a “cone of darkness” toward oncoming cars, allowing drivers to keep bright beams on to maintain peak visibility [see sidebar, “Deer-Spotting Diodes”].

The cars of the future, BMW engineers envision, will automatically adapt to roadway environments by switching among hundreds of lighting programs, if not more. Laser light, Levering says, will dovetail nicely with those developments.

A few hurdles remain. In coming months, BMW’s team must still downsize the system and ensure durability outside the lab. As with LEDs, system cooling is a challenge. Directing airflow over the lamps is an obvious approach, supplemented by motorized fans or conductive materials. BMW is already trekking to Death Valley, Calif., and other locations to test performance in extremis.



Farsighted and efficient laser headlights are able to reach beyond the range of LEDs (and older technologies, such as incandescent bulbs) because they’re intrinsically bright and, more important, they can be directed to their targets with remarkable efficiency.

The preproduction i8 tucks four laser lights below its stretched hood, but the showroom version will use the laser system for the high beams only. The i8's low-beam LEDs will emit 50 candelas per square millimeter at their source, compared with 580 cd/mm2 for the laser high beams. That pushes visibility as far as regulations allow. The United States sets a lower limit on total overall light output than Europe does, but automakers generally design systems that can easily be tweaked to pass muster internationally.

As a further safety measure, the i8's high beams will operate only above roughly 40 km/h, to preclude the possibility of someone's staring into a static light. Photodiodes will monitor the high-power pumped lasers, switching them off if they fail during a collision or even just as the result of wear and tear. And the system automatically switches to low beams when oncoming cars are detected, as with current adaptive units.

My laser-guided tour of the FIZ complete, I head to BMW World, a dramatically billowing structure nestled among the BMW headquarters, one of its factories, and a tentlike swimming stadium built for the 1972 Olympics. There, throngs of car lovers ogle the i8 and its concept versions, snapping photos like mad, oohing and ahhing over all the carbon-fiber goodness.

It's all great stuff. But if and when you see your first BMW i8, do Herren Erdl, Levering, and Weber a favor: Spare a little love for those headlights.

This article originally appeared in print as "Whiter Brights With Lasers."

December 17, 2013

2. Intematix Announces Issuance of Red Nitride Phosphor Patents for LED Lighting

Intematix Corporation, a leading manufacturer of phosphor solutions for LED lighting, today announced that U.S. patent No. 8,597,545 was issued on December 3, 2013 by the United States Patent and Trademark Office. This patent covers novel formulations for red emitting, nitride based phosphors and include products in the company's XR phosphor product family. This award extends Intematix's innovation leadership in phosphors that improve the performance of LED lighting.

"This patent confirms XR red nitride phosphor as a proprietary Intematix innovation moving LED lighting to higher color quality and reliability," said Yi-Qun Li, Chief Technology Officer for Intematix. "We look forward to working with our customers on the next generation of LEDs with full spectrum performance and long lifetimes."

Red nitride phosphors play a central role in extending the color range of LED applications like general lighting and displays including TVs, monitors and tablets. Intematix red nitrides combined with GAL® green phosphors, arrangements covered by the company's previously issued patents, enable near-perfect color rendering up to 98 CRI. The XR red nitride also leads in color stability with less than perceptible 2SDCM measured color shift in accelerated aging testing. This performance results in lighting applications with long term color quality and consistency.

NOVEMBER 8, 2013

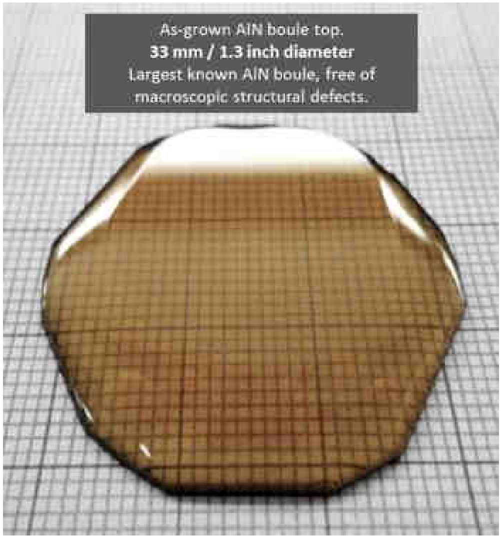
3. HexaTech Demonstrates Industry Leading AlN Crystal Growth Capability

Reports World's First 33 mm Low Defect Single Crystal Material

Aluminum nitride (AlN) material leader HexaTech, Inc., today presented a demonstration of what is believed to be the world's first 33 mm diameter, single crystal boule free of macroscopic structural defects. Due to its unique physical and electrical properties, AlN is viewed by many as the ultimate semiconductor platform for short wavelength, UV-C emitters and high power electronic devices.

HexaTech co-founder and Vice President of Crystal and Wafer Development, Dr. Raoul Schlesser, noted that "this result validates HexaTech's growth methodology and capability, and represents a significant stepping stone on our way to high-quality 2" diameter material and beyond."

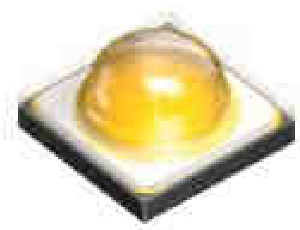
The company presented a slice from an as-grown boule, shown below in Figure 1, to evidence the structural quality achievable with HexaTech's proprietary growth technology.



"This crystal represents the tremendous progress seen during the last 12 months, where we've expanded our growth diameters from less than 20 mm, to over 30 mm, while maintaining every aspect of the crystal quality. Based on this success, we are even more confident in our strategy and ability to produce AlN boules of highest quality using a physical vapor transport (PVT) growth process". The PVT crystal growth technique has been key to the development of silicon carbide (SiC) crystals, where multiple groups have already demonstrated boule diameters up to 150 mm.

03.12.2013

4. Osram LED: Longer lifetime at high temperatures



Excessive heat generation is one of the main reasons why light-emitting diodes fail. With the Oslon Square, Osram Opto Semiconductors presents an LED that withstands high ambient temperatures particularly well. To ensure that the colors of several LEDs in a luminaire remain uniform even at higher temperatures, they are measured and binned at 85 degrees Celsius (°C), a temperature that comes very close to that encountered in lighting applications within buildings, in

everything from spotlights to retrofit light sources.
Osram has optimized the heat dissipation of the Oslon Square to allow an increase in the junction temperature. “With our new conversion technology, we can produce significantly thinner converter layers. The thinner layers better dissipate the heat, thus enabling the higher temperatures in the LED,” says Ivar Tangring, SSL Product Development at Osram Opto Semiconductors, explaining the advantages of the innovative technology. With that, the Oslon Square can reach a lifetime of considerably more than 50,000 hours even at high temperatures of up to 135° C in the LED.

Customers benefit from the properties of the new Oslon Square
Measuring and binning at operating temperatures of 85° C is of great significance to customers who further process the light-emitting diodes into luminaires. They receive precise information on parameters such as luminous flux or color stability, which they need to optimally define the properties of their products.
Furthermore, the improved temperature behavior leads to higher luminous efficacy in the application. “This luminous efficacy, meaning the ratio of luminous flux to applied electrical power, helps our customers to significantly optimize the price/performance ratio of their luminaire solutions,” Tangring emphasizes. Thanks to the higher permitted junction temperatures, fewer large heat sinks are required, and this simplifies the design of lamps and luminaires, because they can be smaller and therefore less costly.

Application in interior lighting
The Oslon Square is particularly suitable for the various applications in buildings. With a color temperature ranging between 2,400 and 5,000 Kelvin, it can generate either warm- or cold-white light. The color rendering index is over 80 and the luminous flux is an impressive 202 lumens (lm). Product variations with a different color temperature spectrum and higher color rendering indices are to follow.
At present, the new LED is undergoing extensive quality testing: The certification process under the LM-80 long lifetime standard is underway. The results of the 3,000 hour test are expected at the end of the year, those of the 6,000 hour test in spring 2014.

Technical data (GW CSSR M1.EC) – All data at a junction temperature of 85 °C:

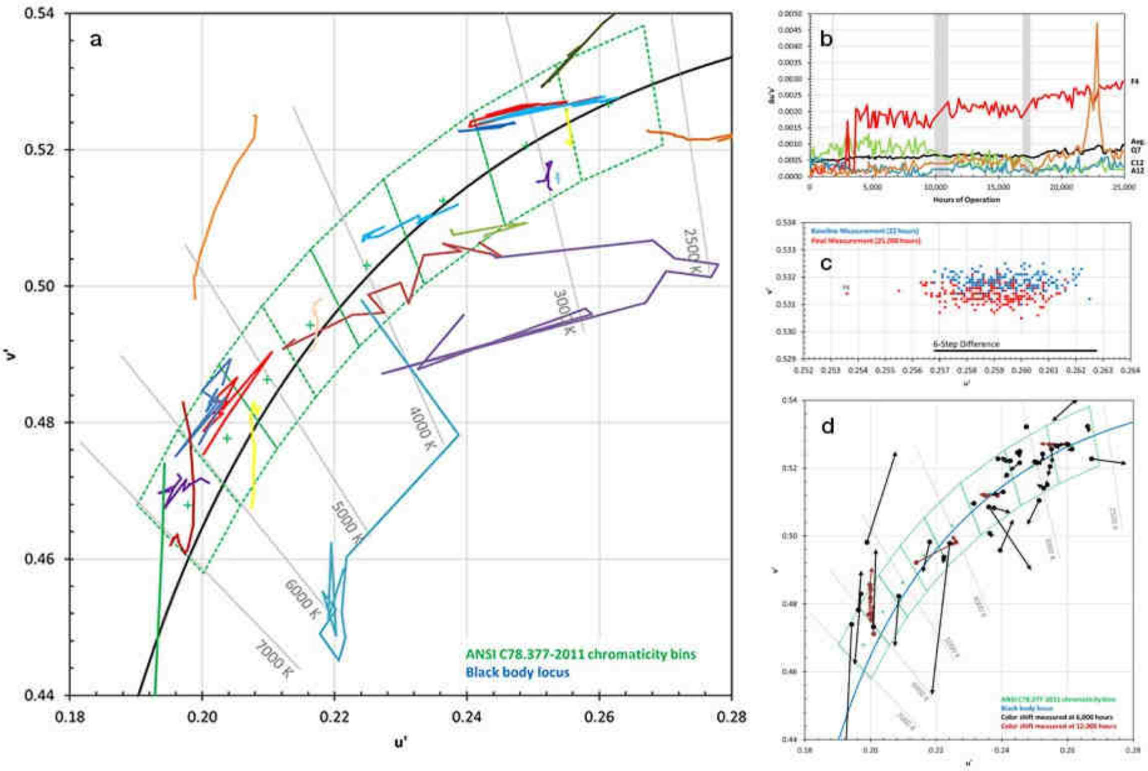
Housing dimensions	3 mm x 3 mm
Beam angle	120 °
Typical voltage (at 700 mA)	2.9 V – max. 3.2 V
Current	max. 1.8 A (previously 1.5 A)
Typical brightness (at 700 mA)	~ 202 lm (at 3,000 K)
Color rendering index (CRI)	min. 80
Thermal resistance R_{th}	3 K/W (previously 3.8 K/W)
Color temperature	2,400 – 5,000 K

Oct 28, 2013

5. DOE Publishes Report on Color Stability of LED Lighting Products

The U.S. Department of Energy (DOE) has published a new report, Color Maintenance of LEDs in Laboratory and Field Applications. Although concern for parametric failure of LED lighting products has largely been focused on lumen maintenance, color shift is a cause of early failure for some products, especially in applications where visual appearance is critical.

The report discusses field data from DOE's GATEWAY program showing that many LED lamps installed in museums have changed color beyond a reasonable tolerance well before their rated lifetimes were reached, and laboratory data from DOE's CALiPER program indicating that many early LED products shifted beyond acceptable tolerances in as short a span of time as a few thousand hours. But it also notes that testing of the L Prize®-winning lamp has shown that commercially available LED products can have exemplary color stability unmatched by traditional light sources.



Chromaticity over time for a subset of the lamps. When intermediate points are shown, the color shift appears unpredictable (a). Δu'v' for the best and worst performing lamps (b). Baseline and final (25,000-hour) chromaticity coordinates for each lamp sample (c). Initial and final chromaticity of lamps tested by CALiPER in 2008–2010 (d)

The report also discusses the metrics used for communicating color shift, and provides guidance for end users on how to monitor chromaticity and what to look for in manufacturer warranties. Also covered are the physical changes that have been shown to lead to color shift in some types of LED packages. As with lamps and luminaires, the data presented for LED packages shows that a wide variety of products are available. In order for specifiers and consumers to make educated choices, more detailed and standardized information is necessary.

For details, please download a PDF copy of the report.
For other Solid-State Lighting GATEWAY Demonstration Results please visit http://www1.eere.energy.gov/buildings/ssl/gatewaydemos_results.html or the DoE SSL website

December 5, 2013

6. Intematix Introduces ChromaLit Linear Remote Phosphor for LED Lighting

Intematix Corporation, a leading manufacturer of phosphor solutions for LED lighting, today announced the commercial availability of ChromaLit® Linear, a remote phosphor offering uniform luminance over any length, high flux density and a sleek, white off-state finish. This product received the Lux Award by Lux Magazine for Light Source Innovation of the Year and recognition by the Illuminating Engineering Society (IES) in its Progress Report featuring the most promising new lighting products.

Remote phosphor is a lighting system architecture where a separate phosphor component is powered by blue LEDs. LED lighting applications use this architecture and the increased light extraction it enables to reduce LED component count and costs. Lighting uniformity and consistency are also improved and supply chains are simplified.

Linear light sources are in widespread use for illuminating commercial and industrial applications worldwide. Office lighting and other commercial applications have been challenging for white LEDs previously because of the need to diffuse the point sources, reducing system efficacy. The ChromaLit Linear product delivers naturally uniform, high quality light with conversion efficacy of up to 215 lumens per radiant watt or up to 163 lumens per system watt when used with the most efficient blue LEDs available.

“ChromaLit Linear transforms industry thinking about LED linear lighting and remote phosphor,” said Julian Carey, Senior Director of Strategic Marketing at Intematix. “We can forget about low efficacy and pixelation because this product enables high light output, smooth uniformity, white off-state and new possibilities for applications from under-cabinet to troffers to high bay lighting.”

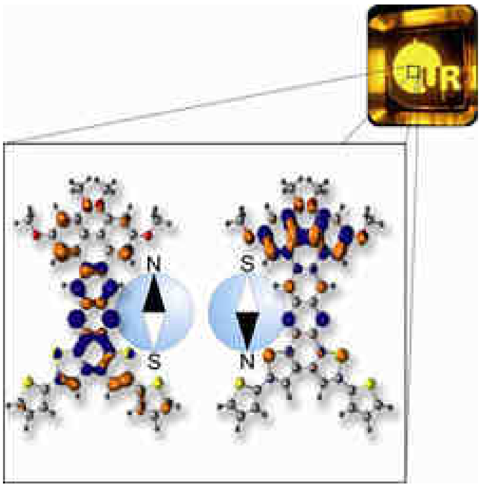
The ChromaLit Linear remote phosphor solution offers flexibility of length. Surface lumen density scales from 500 to 2500 lumens per linear foot and the system presents new design directions not possible with fluorescent and white LEDs. Intematix has also changed how designers think about remote phosphor because ChromaLit Linear has dramatically improved the off-state appearance and illumination quality. ChromaLit Linear offers 3 SDCM color consistency as standard and color temperature options from 3000K to 5000K and CRI of 80.

09.12.2013

7. Neuartige OLEDs für effizientere Emission

Ein neu entwickelter Typus organischer Leuchtdioden (OLEDs) eignet sich für besonders energiesparende und kostengünstige Bildschirme sowie für leuchtende Fliesen.

OLEDs ermöglichen brillante, kontrastreiche Displays für mobile Geräte, haben aber einen wesentlichen Nachteil: Sie können normalerweise nur ein Viertel der eingesetzten elektrischen Energie in Licht umwandeln. Der Wirkungsgrad ließ sich bisher nur durch Dotieren mit teuren Elementen wie Platin oder Iridium erhöhen. Erfolg mit einem anderen Ansatz, die Lichtausbeute auch ohne Edelmetalle zu erhöhen, hatten nun Forscher der Universitäten Bonn und Regensburg gemeinsam mit Kollegen von der University of Utah in Salt Lake City und vom Massachusetts Institute of Technology (MIT) in Boston, USA.



Das Funktionsprinzip organischer Leuchtdioden ist einfach: Ein dünner Film optisch aktiver Moleküle wird mit zwei Elektroden verbunden, so dass ein elektrischer Strom aus positiven und negativen Ladungen fließt. Treffen diese Ladungen aufeinander, so rekombinieren sie unter Emission von Lichtquanten. Dies läuft allerdings weniger effizient ab, obwohl sich entgegengesetzte elektrische Ladungen anziehen, da sie zusätzlich noch einen Spin besitzen – ein magnetisches Moment. Ladungen mit gleichem Spin stoßen sich wie zwei gleichartige Magnetpole ab, und dieser Effekt überwiegt die Anziehung zwischen den positiven und negativen Ladungen. Da drei Viertel aller Ladungen denselben Spin tragen, geben sie ihre Energie überwiegend in Form von Wärme ab, statt zu verstrahlen. Entsprechend gering ist die Lichtausbeute.

Die erwähnte Dotierung mit schweren Metallen wie Platin oder Iridium dient dazu, die Spins mit noch stärkeren Magneten durcheinander zu wirbeln. So kann in „metallorganischen OLEDs" fast die gesamte elektrische Energie zur Erzeugung von Licht verwendet werden, nur leider zu einem hohen Preis.

Die neuartigen OLEDs erhöhen ihre Ausbeute dagegen mit einem ganz anderen Mechanismus. Ladungen können die Richtung ihres Spins nämlich auch spontan ändern, wenn man nur lange genug wartet. Herkömmliche OLEDs können die Ladungen allerdings nicht hinreichend lange speichern, um diese Wartezeit zu überbrücken, und wandeln die Energie stattdessen in Wärme um.

Die von den Forschern mit neuartigen Stoffen konstruierten OLEDs können nun offenbar gerade dies, sie speichern die elektrische Energie augenscheinlich deutlich länger, so zumindest die bisher angenommene Erklärung. Daher können sie die spontanen Sprünge der Spins nutzen, um zusätzliche Lichtquanten statt Verlustwärme zu erzeugen. Die eingesetzte elektrische Energie wird somit sehr effizient in Licht umgewandelt.

Die Arbeiten wurden von der Volkswagen-Stiftung und der Deutschen Forschungsgemeinschaft (DFG) gefördert.

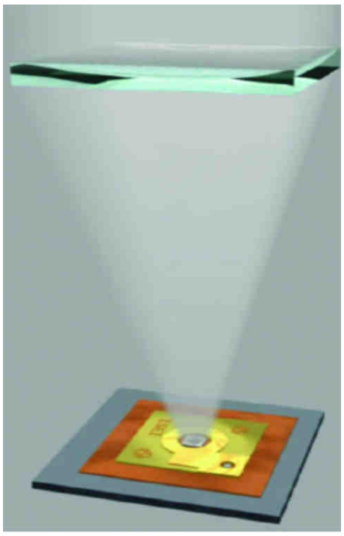
D. Chaudhuri, E. Sigmund, A. Meyer, L. Röck, P. Klemm, S. Lautenschlager, A. Schmid, S.R. Yost, T. Van Voorhis, S. Bange, S. Höger, J.M. Lupton, Metal-free OLED triplet emitters by side-stepping Kasha's rule, Angewandte Chemie (DOI: 10.1002/anie.201307601)

Dec 17, 2013

8. Wafer bonding creates record-breaking four-junction cell

To prevent the formation of efficiency sapping defects, conventional multi-junction cells are built with lattice-matched materials. But this restriction can be lifted with wafer-bonding, which enables the fabrication of a four-junction cell with record-breaking efficiency, say Rainer Krause and Bruno Ghyselen from Soitec and Frank Dimroth from the Fraunhofer Institute for Solar Energy Systems.

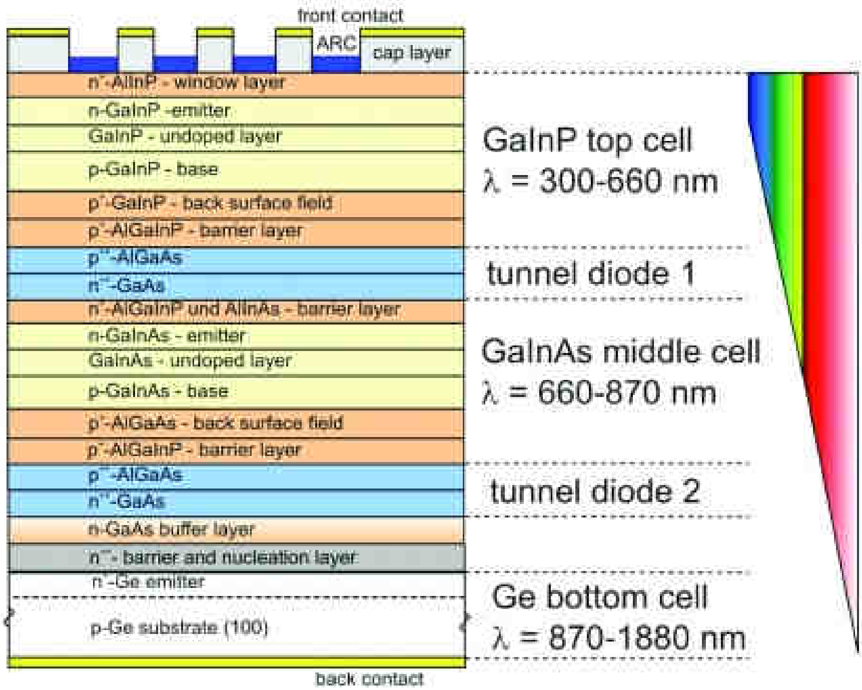
At Soitec of Bernin, France, we are one of the world's leading manufacturers of this class of solar system. We manufacture modules that use Fresnel lenses to focus sunlight onto cells at a concentration of over 500 suns and we are analysing optical concentrators that would allow us to increase further the concentration level with the same degree of reliability (see Figure 1). To ensure that these modules generate as much energy as possible, they are mounted on tracking systems that follow the sun's position in the sky from dawn to dusk. Such systems are deployed on solar farms, and deliver their best returns in locations with bright sunshine (regions said to have a high value for Direct Normal Irradiation, or DNI).



We are currently making our systems more competitive by working on different elements of the system. On the solar cell side, by teaming up with researchers from Fraunhofer ISE and CEA-Leti, we are running a programme to take cell efficiency to a new level. Our new devices feature four junctions – one more than the traditional multi-junction cell – bringing the achievable maximum efficiency to around 50 percent. Onthe way to hitting this level of performance, in 2013 we raised the world record for efficiency to 44.7 percent by uniting a top tandem cell of GaInP and GaAs with a bottom tandem cell made from GaInAsP and GaInAs.

We are by no means the only multi-junction cell manufacturer or developer that has devoted a great deal of effort to improving device efficiency. That's because gains in efficiency can lead to significant reductions in the levelised cost of energy.

Before we unveiled our ground-breaking device, increases in the record for efficiency – which have recently increased by about one percent a year – resulted from refinements to the conventional triple-junction cell. In its standard form (see Figure 2), it comprises a germanium (0.7 eV) bottom junction and middle and top junctions of GaAs (1.4 eV) and GaInP (1.9 eV).



Several firms, including AZUR-Space in Germany, and Boeing-Spectrolab and Emcore in the United States, manufacture this incumbent design using mature, high-yield industrial production processes. Such devices are deployed in commercial systems, where they can reach efficiencies of 41 percent [1, 2].

Features of the standard device include two terminals – a front contact and a backside contact – and the connection of the three cells in series, so that a single voltage is delivered at the cell level. The epitaxial structure of the multi-junction cell is usually formed by MOCVD. There are limits to what is possible with this approach, due to epitaxy and lattice matching, and if the material quality is not high, charge carrier recombination can impair device performance. So, to optimise the efficiency of the cell, it is crucial to carefully balance the characteristics of every junction, so that they work well together.

Increasing efficiency

Two well-known routes exist for improving the efficiency of multi-junction cells. One is to fine-tune its absorption profile, so that the contribution from every junction combines to propel the overall efficiency to a new high. And there is also a more ambitious approach: To add additional junctions, starting with a move from three to four.
We are not alone in targeting a four-junction device with cells operating at the optimum bandgap energies of 1.9 eV, 1.4 eV, 1.1 eV and 0.7 eV. It has been demonstrated that it is possible to reach these energies by introducing dilute nitrides, such as GaInNAs, into the conventional GaInP/GaAs/Ge stack [3]. Meanwhile, researchers at NREL followed by other industrial groups, have proposed the use of an inverted metamorphic four-junction solar cell [4].

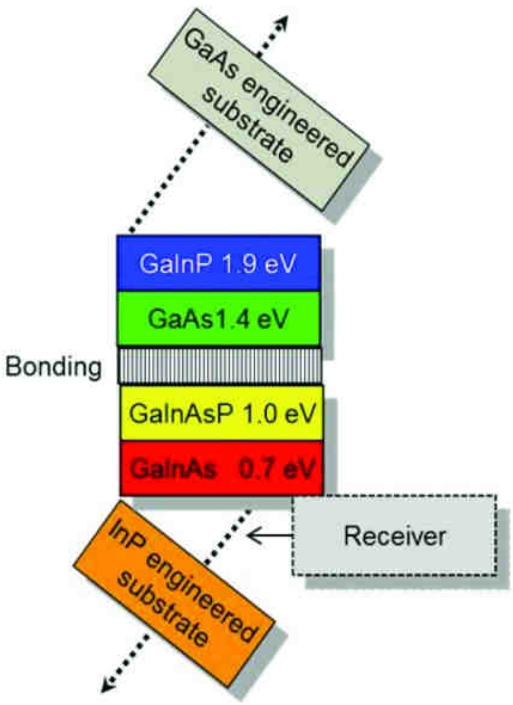
Our approach is different. While the number of junctions and the choice for their energies remain basically the same, a totally different and key technological step is added to the epitaxy tool box: wafer-bonding. The concept of applying wafer bonding in this arena is not completely new [5, 6]. However, we are the first to use this to form, at full wafer level, cells with an efficiency that exceeds every triple-junction device. Introducing wafer bonding has enabled the marriage of lattice-mismatched materials without the creation of dislocations, so GaAs and InP can be united.

To join materials such as these, two crystal structures must be brought together to form covalent bonds at the interface. Success demands that materials are carefully prepared, and their surface roughness is low. Once these conditions are met, it is possible to yield multi-junction solar cells based on defect-free material.

Wafer bonding

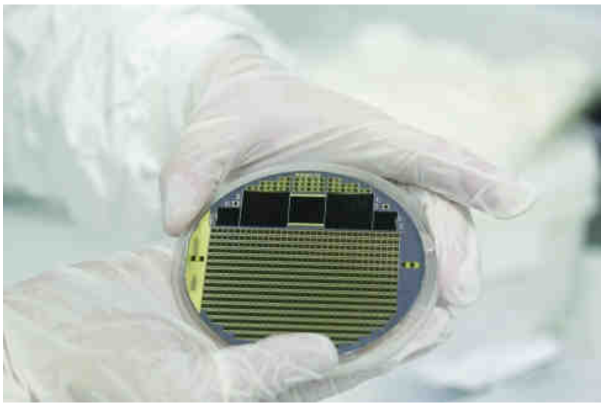
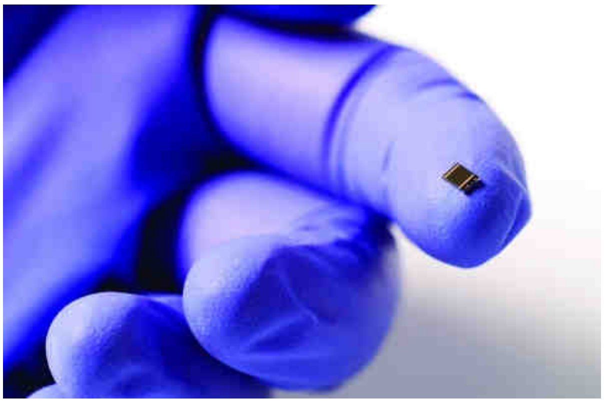
We have developed a specific wafer-bonding process for uniting InP- and GaAs-based materials to form a transparent, electrically conductive design. In our case, bonding is not restricted to bulk wafers, but includes ternary and quaternary epilayers, thereby enabling an incredibly wide choice of optimum materials.

InP bulk material is more expensive than GaAs or germanium wafers, but this is not a stumbling block for us, because we can leverage our Smart Cut technology, which we have used in volume manufacturing for more than a decade. Armed with this, we use only a very thin layer of initial material, and can consequently re-use the InP substrate many times. Once a thin layer of InP has been extracted from the substrate, it can be transferred to many different types of carrier. This led us to introduce the acronym ‘InPOX’ as a generic name for ‘InP-on-X’, where X can include silicon, GaAs, germanium and sapphire. An example of this is the transfer of a 0.5 µm-thick layer of InP to 100 mm sapphire. Working with partners at Fraunhofer ISE and CEA-Leti, we have used our Smart Cut technology in conjunction with direct wafer bonding and III-V epitaxial growth to produce a record-breaking four-junction cell. Our collaborators contribute expertise associated with III-V material growth, fabrication of engineered substrates and epitaxial lift-off and bonding techniques.



The device that resulted features a bottom GaInAs junction with a bandgap of 0.7 eV, overlaid with GaInAsP, GaAs and GaInP cells with bandgaps of 1.0 eV, 1.4 eV and 1.9 eV, respectively (see Figure 3). Features of this photovoltaic include low shading losses, which results from front metal contacts with a finger width of 5 µm, and a double layer anti-reflection coating that ensures minimal reflection.

Using 100 mm substrates, cells with an area of 5.2 mm^2 have been processed and characterised to form four active junctions. Development of the fabrication process revealed approaches for dramatically increasing the yield of good solar cells, and this helped us to produce wafers with a yield of functional devices in excess of 95 percent (see Figure 4 for images of finished cells, at wafer level and after die separation).

Our partners at the Fraunhofer ISE CalLab measured our cell's quantum efficiencies and current-voltage characteristics under one-sun AM1.5d (1000 W/m^2, 25 °C) standard test conditions using a spectrally adjustable solar simulator. To determine performance under concentration, a Xenon Flash simulator with adjustable distance between the flash bulb and the measurement plane illuminated the devices.

A three-dimensional laser microscope enabled an accurate measurement for mesa edge, and thus an accurate value for the efficiency of these small area concentrator solar cells [7].

Measurements revealed that the peak quantum efficiency for all four cells is well above 85 percent, and that device efficiency hits 44.7 percent at 297 suns. Even at 1000 suns there is no indication of a breakdown in peak tunnel current density, while the high fill-factor of 86.5 percent at this concentration indicates a moderate resistance of the bond interface, which operates well up to current densities of several A cm^{-2}.

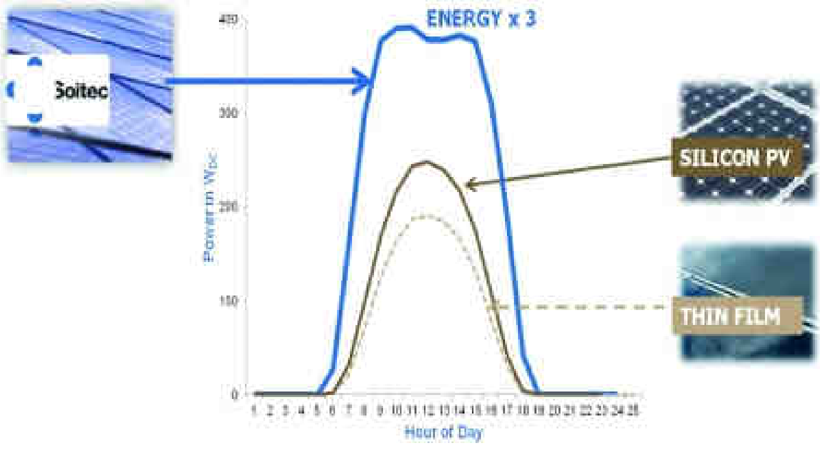
We know that it is possible to deliver even higher efficiencies from our four-junction cell. Our plan is to realise this, and efforts at improving device structures are already underway, directed at the optimisation of sub-cell characteristics and further material quality improvement. In the longer term, this will help to trim the generating costs associated with concentrating photovoltaics and empower this technology to displace other types of cell.

The authors acknowledge the contributing work from the CEA Leti team in Grenoble France and the laboratory work of the Fraunhofer ISE team in Freiburg. Also acknowledged is the contributing work from Helmotltz-Zentrum in Berlin. This program is supported by the French Environment and Energy Management Agency (ADEME) through the "Investissements d'Avenir", pending European Commission notification agreement.

The strengths of CPV

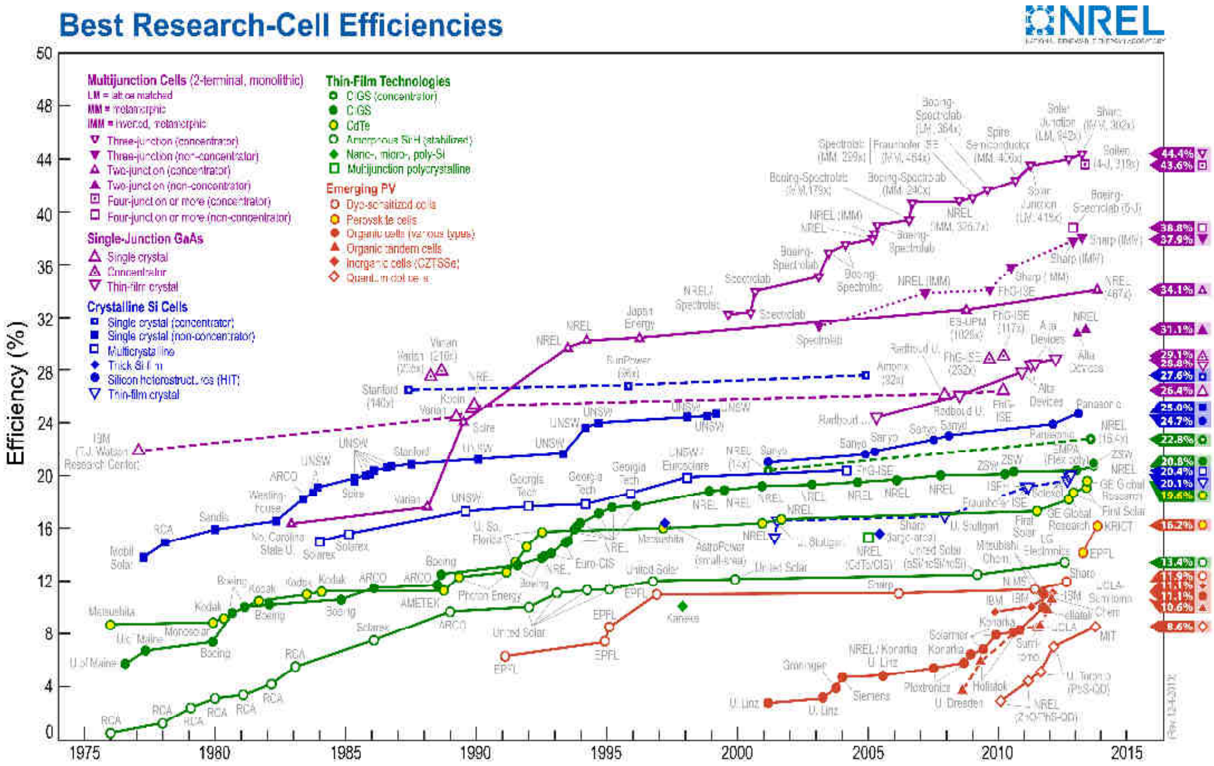
Concentrating photovoltaic systems are already cost-competitive in very sunny climes, and in these locations there are several reasons for turning to this form of energy generation. For example, aside from the tiny solar cells located at the focal points of the lenses, the production of a CPV system generally employs low-cost materials, such as glass or silicone, and involves fully automated mass-production conditions.

Electricity production per module m²



Daily average power production in a sunny area (based on annual calculation)

Another attribute of CPV is that the record-breaking cells not only outperform their rivals at room temperature, but exhibit a far slower decline in efficiency with temperature, as well as much less aging degradation. What's more, mounting of these cells in tracker systems leads to a more constant power output curve throughout the day (see figure), resulting in not only more energy harvested, but also a higher energy production during peak hours – when it is most valuable. On top of all these arguments, which are associated with the levelised cost-of-energy, there are environmental considerations, such as the small physical footprint of CPV, its absence of water consumption, high levels of recycling, and the opportunity for dual land use with agriculture or animals.



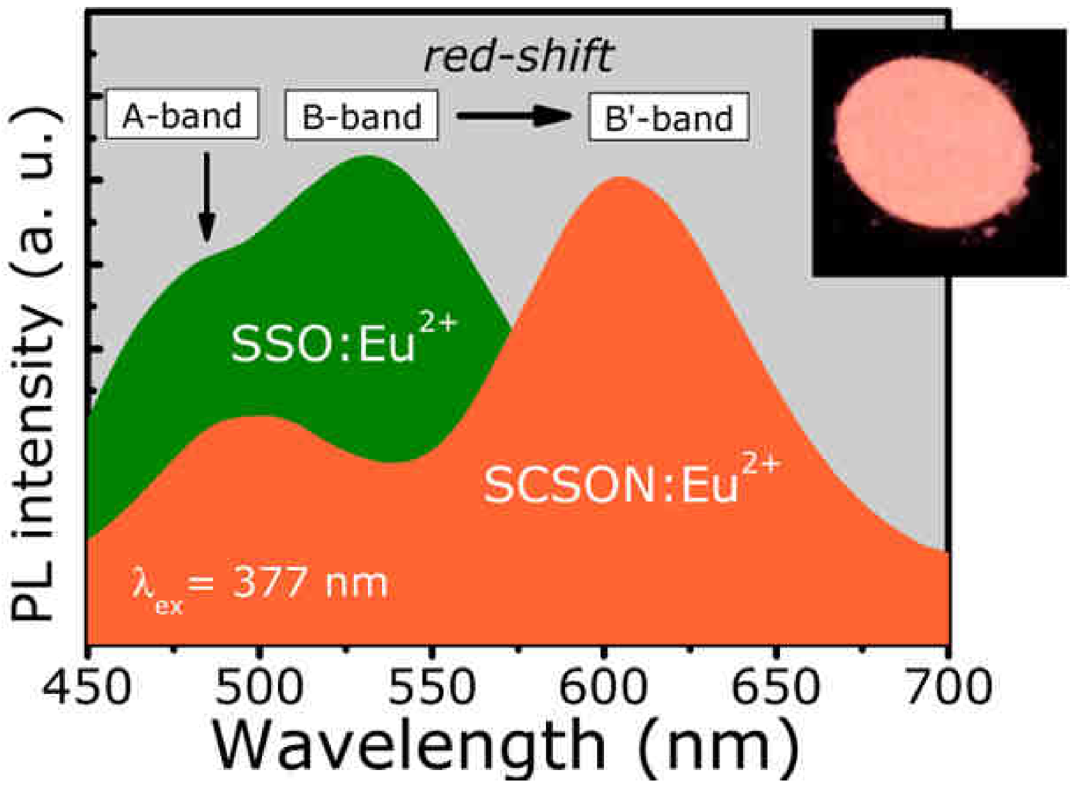
Journals

1. Evolution of Luminescence of Sr2-y-zCazSi(O1-xNx)4:yEu2+ with N3-, Eu2+, and Ca2+ Substitutions

By Park, Jungkyu; Lee, Seung Jae; Kim, Young Jin

Crystal Growth & Design, Volume 13, Issue 12, Pages 5204-5210, 2013
DOI:10.1021/cg400751n

$Sr_{2-y-z}Ca_zSi$-$(O_{1-x}N_x)_4$-:yEu^{2+} (SCSON:Eu^{2+}) solid solns. were prepd. by substituting N^{3-}, Eu^{2+}, and Ca^{2+} ions into Sr_2SiO_4 (SSO). These ions contributed differently to the evolution of luminescence of SCSON:Eu^{2+}. SSON:Eu^{2+} (z = 0) has two activation centers: Eu-(I) and Eu-(II). The nitridation effects led to a dramatic change in the crystal field surrounding the Eu-(II) site but rarely affected the Eu-(I) site. Accordingly, SSON:Eu^{2+} exhibited broad excitation spectra from UV to visible wavelengths. In comparison with the Eu-(II) green emissions of SSO:Eu^{2+}, the dominant peak wavelengths (DPWs) of the Eu-(II) emissions were at red emission regions (605-630 nm), depending on the amt. of Eu^{2+} ions. The Ca^{2+} ions of SCSON:Eu^{2+} preferentially changed the emission wavelength assigned to Eu-(I) and affected the Eu-(II) emission intensity. In addn. to the spectral properties, the chromaticity coordinates and a low thermal quenching behavior of SCSON:Eu^{2+} powders demonstrated that they can be a novel red phosphors for use in white light emitting diodes.



2. New Yellow-Emitting Nitride Phosphor SrAlSi4N7:Ce3+ and Important Role of Excessive AlN in Material Synthesis

By Zhang, Liangliang; Zhang, Jiahua; Zhang, Xia; Hao, Zhendong; Zhao, Haifeng; Luo, Yongshi

ACS Applied Materials & Interfaces, PagesAhead of Print ,Journal, 2013
DOI:10.1021/am402612n

Synthesis and luminescent properties of Ce^{3+}-doped $SrAlSi_4N_7$ yellow-emitting phosphor are reported. In comparison with YAG: Ce^{3+}, the phosphor exhibits smaller thermal quenching and a broader emission band centering at 555 nm with a bandwidth as large as 115 nm, being suitable for fabricating high color rendering white LED. It is obsd. in material synthesis that intense luminescence can be achieved only in case of excessive AlN in the raw materials. The role of the excessive AlN is studied. The mechanism for existence of edge-sharing [AlN_4] tetrahedral, which is unreasonable according to the aluminum avoidance principle, is discussed in detail.

3. Luminescent properties of Dy3+ or/and Tm3+ co-doped in La3PO7 for white LEDs

By Wang, Jiyou; Wang, Jianbo; Duan, Ping

Optical Materials (Amsterdam, Netherlands), Volume 36, Issue 2, Pages 572-574, 2013
DOI:10.1016/j.optmat.2013.10.0

Dy^{3+}/Tm^{3+} single doped and co-doped La_3PO_7 phosphors were synthesized by solid state reaction method. The single doped Dy^{3+}/Tm^{3+} ions showed their characteristic emissions yellow and blue. The luminescence intensity of this phosphor firstly increased and then decreased with increasing concn. of Dy^{3+} ions. The exptl. results and the theor. calcn. indicate that the concn. quenching mechanism of Dy^{3+} ions in La_3PO_7 is the dipole-dipole interaction. By changing the doping concn. of Dy^{3+} and Tm^{3+} in La_3PO_7, their corresponding color coordinates are very close to the white color chromaticity coordinates (x = 0.33, y = 0.33). These results indicate that the $La_{3-x-y}PO_7$:xDy^{3+}-yTm^{3+} phosphors exhibit great potential for use as single-component phosphors for w-LEDs.

Patents

1. Narrow spectral line-width emission phosphors with broad band excitation edge up to and including the blue wavelength region based on rare earth-doped alkaline earth molybdates, tungstates, vanadates, niobates and tantalates

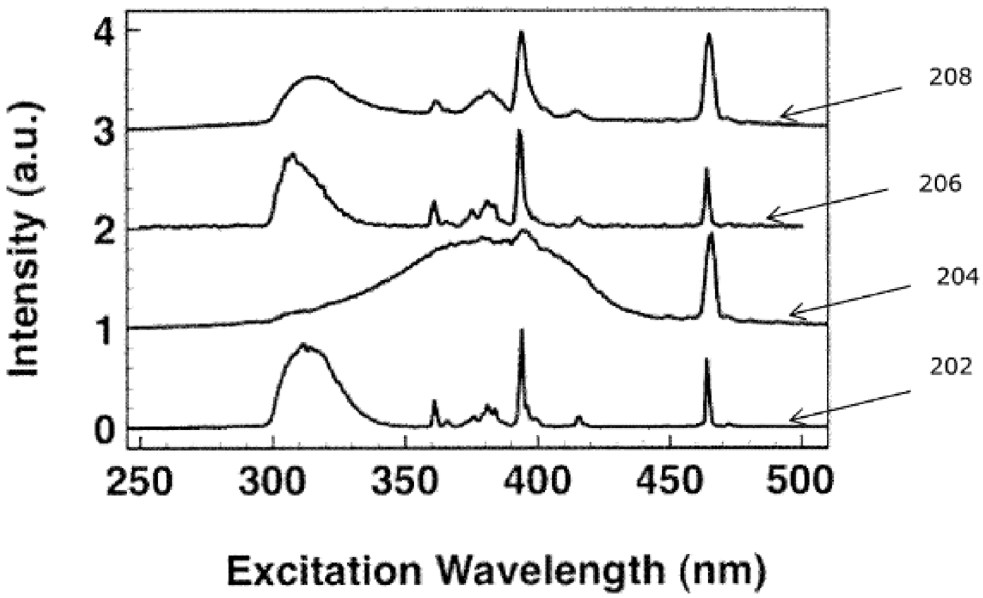
By Dutta, Partha S.; Khanna, Aloka

Assignee: Rensselaer Polytechnic Institute, USA

Narrow spectral line-width emission phosphor compns. having crystal structures and chem. bond arrangements that enable broad band absorption and excitation using radiation up to and including the blue wavelength region are described which may have a general formula $(A_xA_y...A_z)_{3-(1+q)m}(W_{1-r}Mo_r)O_6$: Ln_m, D_{qm} or $(A_xA_y...A_z)_{1-(1+q)m}(W_{1-r}Mo_r)O_3$: Ln_m, D_{qm}, where $x + y +......+ z =1$; $0 \leq r \leq 1$; $0 \leq q \leq 1$; $0 < m \leq 0.12$; and A = one or more divalent element from group IIA and/or IIB (e.g., Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, Zn^{2+}, etc.), W = tungsten with 6+ or 4+ charge state, Mo = molybdenum with 6+ or 4+ charge state, Ln = one or more trivalent rare earth lanthanide element (e.g., Ce^{3+} to Lu^{3+}), D = one or more monovalent element from group IA and/or IB (e.g., Li^{1+}, Na^{1+}, Cu^{1+}, etc.), and O = Oxygen (O^{2-}).

Patent Information

Patent No.	**Kind**	**Date**	**Application No.**	**Date**
WO 2013158993	A1	Oct 24, 2013	WO 2013-US37366	Apr 19, 2013
Priority Application				
US 2012-61687238	P	Apr 20, 2012		



2. Hybrid light bulbs using combinations of remote phosphor leds and direct emitting leds

By Ouderkirk, Andrew J.; Binder, Erin A.

Assignee: 3M Innovative Properties Company, USA

A light source suitable for general lighting applications combines at least one remote phosphor LED and at least one direct emitting LED in a single unit. Both the remote phosphor LED and the direct emitting LED are carried by a base and covered by a bulb or other suitable cover member, which may be light-diffusing. The remote phosphor LED includes a first LED, a phosphor layer, and a first dichroic reflector. Excitation light from the first LED is reflected by the first dichroic reflector onto the phosphor layer to generate phosphor light, which is substantially transmitted by the first dichroic reflector. At least some light from the direct emitting LED propagates to the cover member without passing through any dichroic reflector, including the first dichroic reflector. The light source may provide white light output using relatively small amounts of phosphor material.

Patent Information

Patent No.	**Kind**	**Date**	**Application No.**	**Date**
WO 2013180890	A1	Dec 5, 2013	WO 2013-US39272	May 2, 2013
Priority Application				
US 2012-61654278	P	Jun 1, 2012		