Light Emitting Diodes
lites.asia Workshop

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Kathryn M. Conway, LED Consulting
Nassau, New York, USA

Agenda & References

- **2:00 LED Basics**
- **2:45 LED Systems**
- **3:30 Afternoon Tea**
- **4:00 LED Challenges**
- **5:00 Discussion**
- **5:30 Adjourn**

- *Some references are made to items available only to onsite participants:*
- *Articles in distributor magazine*
- *USAID draft white paper on LEDs*

mag p.# **paper p.#**

Workshop Goals

- Consider various policy objectives within your authority that might be met by addressing LED systems.
- Learn more about LED technology, applications, manufacturing, resources & ongoing standards activities.
- Discuss ways to collaborate and make a unique contribution to Asia and the world!

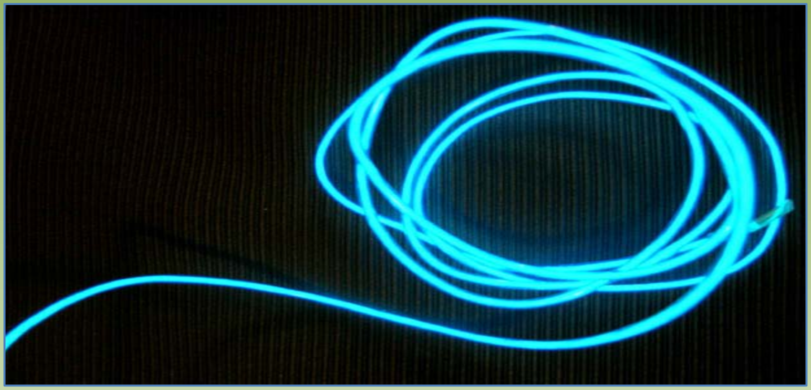
Many Types of Standards Pertain to LEDs

- Bidding & procurement
- Building & appliance codes
- Business (accounting, human resources, transparency, best practices)
- Certification
- Communications
- Consumer label
- Electrical
- Electrical safety
- Energy and environmental
- Human occupational health & safety
- Industrial process and facilities
- Intellectual property
- Mechanical, material and chemical
- Nomenclature (definitions & specs)
- Photometric & radiometric
- Quality Assurance
- Testing and equipment
- Trade

I. LED BASICS

Solid-State Lighting (SSL) includes:

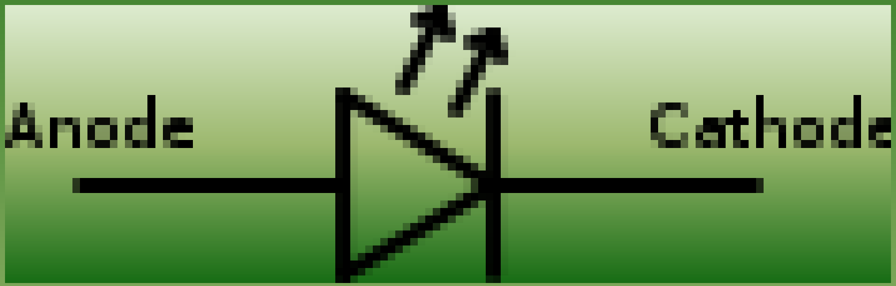
- **Light-emitting diodes (LEDs)**
- **<u>Organic</u>* light-emitting diodes (OLEDs)**
- **Electroluminescent panels, wires (EL)**



EL wire

**Substance that contains carbon atoms, but may not taste good in salad ☹ !*

What is a Light Emitting Diode (LED)?



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It is…

- An electronic device that allows current to flow in one direction only.
- Made of compound semiconductor materials, in alternating, crystalline layers of conductors and insulators.
- Transforming electrical energy (electrons) into light energy (photons) and thermal energy (heat). ***The more light, the less heat!***
- Used individually, or grouped together.
- Most useful as part of an application-dedicated electronic system.
- NOT like a conventional light source: it does not incandesce or fluoresce, nor does it need a gas atmosphere in a glass bulb to operate.

Light from LEDs

Color of light

- Each LED emits light in only one color per diode. The color is specified by wavelength, in nanometers (nm). This is a universally recognized way to signify color, without words.
- Emissions are possible in nearly every wavelength from ultraviolet (UV) to visible to infrared (IR).

"White" light is created several ways:

- RGB: red+green+blue chips
- Phosphor conversion (PC): blue (or UV) chips + yellow phosphors (or, +red+green phosphors)
- The human visual system combines these colors to "see white."

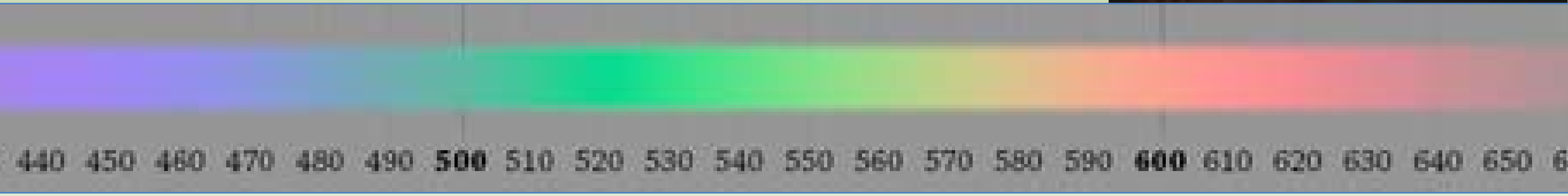

Image source, top & bottom: *Wikipedia/Wikimedia Foundation*

LEDs: Mid-Evolution & Improving Rapidly

- Commercialized in 1960s, for indicators, in a few colors. Blue LEDs not commercialized until mid-1990s; they enabled "white LEDs."
- For visible light, luminous efficacy is expressed in photometric units, as lumens per watt (lm/W or LPW). Radiometric units are used outside the visible range.
- Many factors determine LED LPW, including chemistry, chip architecture, packaging, optics, thermal management and electrical controls. The theoretical maximum LPW (of white LEDs) is near 250.
- LED companies fiercely protect their intellectual property. They build up a portfolio to preserve their competitive position, and to have IP assets that they can use to leverage deals with each other. Lawsuits, licensing & cross-licensing are very common.
- LEDs are not standardized, interchangeable, commodities: Each application has different performance requirements, so manufacturers offer many product solutions. Catalogs include thousands of SKUs!

Global LED Industry Structure: In Flux

Tier I: Strongest R&D, often supported by government grants; fundamental, large & diverse IP portfolios for white LEDs; best-in-class lighting-grade products; recognized brand names; high volume production and global sales. Strong vertical integration, some are legacy lighting & chemical businesses, founded in early-mid 1900s (*).

- Cree, Inc. (USA)
- Nichia Corp.* (Japan)
- Osram Optosemiconductors/Osram GmbH*/Siemens (Germany)
- Philips Lumileds*/Philips NV (Netherlands)
- Toyoda Gosei Co., Ltd.* (Japan)

Tier II: R&D & IP portfolios growing rapidly; good quality products for BLU & lighting; global sales; mainly in Taiwan, Korea and Japan, with many JVs in China. Avago (Singapore); Epistar (Taiwan); Samsung (Korea); Seoul Semi (Korea).

Tier III: Limited R&D and IP; high volume, mid-grade to low-grade LEDs, especially single colors; little to no brand recognition.

Start-ups: R&D focus on innovation at materials and chips; associated with universities; supported by governments; worldwide; limited number of novel products at low-volume production; limited marketing, sales & distribution.

LED Manufacturing

- **Intersection of three established industries:**

Semiconductors :: Consumer Electronics :: Lighting

- **Some companies vertically integrate, to capture value.**
- **Materials, components, vocabulary, metrology, standards, marketing, distribution, sales & customers are *not harmonized*.**
- **Close cooperation between customers & manufacturers leads to new products for their specific applications.**

LED Supply Chain Requires Many Specifications, Standards and Tools

Intensive testing is required at every step of manufacturing.

	Front-end Processes		
Equipment	Industrial chemistry	Furnaces; polishing machines; metrology	MOCVD reactors; scanning electron microscopes; metrology
Materials & processes	Feedstock materials, chemicals & gases; rare earth phosphors	Crystal Growth; Cut & Polished Wafers	Compound semiconductor epitaxy
Products	Precursors	Substrate (sapphire; silicon carbide; silicon	"Epi" Wafers

LED Supply Chain

	Back-end Processes			
Equipment	Photolithography; chemical & mechanical treatments; diamond saws; lasers; chemical lift-off	In-situ test equipment; microscopes; vacuum pickers	W/B & soldering tools; high-speed pick & place tools	Environmental test chambers; aging racks; metrology
Materials & processes	Chip fabrication (layers, roughening, patterning, metallization); wafer-bonding; thinning; flip-chip; thin-film; contact formation; die separation	Binning	Lead-frame; wire-bonding; single chip, multi-chip or chip-on-board; soldering; phosphor application	Binning
Products	LED chips	LED chips, in bins	LED packages	LED packages, on reels

LED Supply Chain

	Assembly & Finishing Processes		
Equipment	Environmental test chambers; racks; metrology; automated & hand assembly lines	Automated & hand assembly lines; photometric, thermal & electrical test instruments.	
Materials & processes	Secondary optic; thermal heat sink; circuit drivers.	Lamp housing; end-cap; lens; photometric & life testing.	Luminaire housing; supports; controls; photometric & life testing.
Products	LED modules or arrays; LED backlighting units	LED lamps	LED luminaires; LED video displays; signs; signals.

LED Packages

- One or more chips are placed in a small reflector cup or mounted on a circuit board. Fine wires are attached to each chip to conduct electricity.
- Direct current flows through the chip in only one direction. Electrons moving through the layers transform to photons.
- Within the layers of the chip are optical features that direct the photons out of the chip. Usually the package has a protective encapsulant that also helps to direct the light out of the chip.

LED Lamps

- **Self-contained systems that typically include one or more packaged LED chips; a circuit driver; a thermal heat sink to cool the chips; a housing to hold the other components in place; and, a base (also called an endcap) that fits into a socket. Often a plastic lens (optic) or frosted bulb is used to shape the lamp's light distribution.**
- <u>**If the LED chip gets hot inside, *it emits less light,* so thermal management is crucial for good performance.**</u>

Lamp: Directional, or, Omnidirectional

II. LED SYSTEMS

Already, LED systems can displace:

- Any single-color light source (except LPS).
- White: CCFL backlight units (BLUs); I & HI (directional)

Soon, white LEDs will compete with:

- Low-wattage linear fluorescent (FL) and compact fluorescent (CFL) light sources; I & HI (omnidirectional)

Eventually, LEDs may compete with:

- HID (except LPS)

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LED Systems, Efficiency & Reliability

- **Common components: Lamps ("bulbs") contain one or more LEDs and are inserted in luminaires (fixtures). A thermal heat sink manages the junction temperature inside the LED chip. A circuit driver provides correct voltage & current. Controls turn power on/off and can dim the lights (via pulse-width modulation) or mix colors or create dynamic effects.**
- **The efficiency of the system is (generally) determined by multiplying the efficiencies of each of the components.**
- **The system reliability is limited by the least reliable component(s). The potential lifetime of the system is determined by the component(s) with the shortest rated lifetime, operating conditions, and many other factors.**
- **Using components that are short-lived or not appropriate for lighting can ruin an otherwise promising LED system!**

Comparing Light Sources

Light Source	CCT: Correlated Color Temp	CRI*: Color rendering index	Efficacy (lumens/ watt)	Weight (oz.) PAR 20 lamp
I	2700-2800	100	5-11	0.9
HI	2775-3000	98-100	10-13	1.2
HIR	3800-4400	98-100	10-14	--
CF**	2400-6500+	65-92	35-65	3.4
LED***	2400-6500+	65-98	15-70	6.7

** CRI may be replaced by a new metric, "color quality scale" (CQS)*
*** Requires special handling: contains mercury.*
**** LED packages have much higher luminous efficacy integral lamps do.*




Let’s Be More Specific about “Lighting”

Luminance or Illuminance…

direct view of light source or, light reflected from a surface

- Each has different nomenclature, practices, equipment & measurement methods.
- Likewise, there are differences when we describe and quantify light energy as a non-visual physiological stimulus.
- Examples: photosynthetically active radiation (PAR) determines plant growth and fruiting; infrared (IR) can promote wound healing in animals & humans; blue light establishes circadian rhythms in all organisms. Blue and UV can damage living tissue, including human eyes and skin.
- We have much to learn about using LEDs beyond “general lighting” !

Applications: Luminance
Light goes directly to viewers’ eyes.

- Backlighting units: portable devices; notebooks; monitors; TVs.
- Indicators (on equipment & control panels)
- Signals: traffic, transport, infrastructure
- Signs: guidance (“exit”), information & advertising
- Full-color video signs/billboards

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Applications: Illuminance

Light reflects off a surface, → viewers' eyes.

Exterior

- Roadway, street pathway, parking pedestrian areas
- Building facades
- Infrastructure

Interior

- Ceilings, walls, other surfaces
- Task lighting

Specialty

- Camera flash
- Handheld (torches)
- Off-grid (with PV, dynamo or hydro)
- Medical and healthcare
- Automotive
- Machine vision

Applications: Illuminance

Zhaga Consortium for the standardization of LED light engines

Creating new lighting systems for illumination applications requires industry collaborations, like “Zhaga.”

Outdoor Lighting: Cool & Controllable

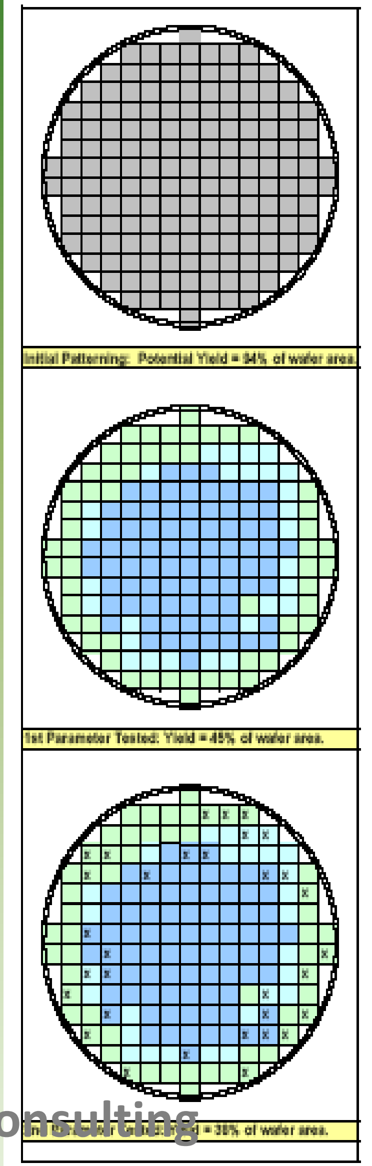
Well-designed LED luminaires put light only where you need it, when you need it, with minimal input power.

III. A FEW LED CHALLENGES

Why is the "color of white light" so difficult to describe, achieve, maintain & measure? Why are high quality white LEDs so expensive?

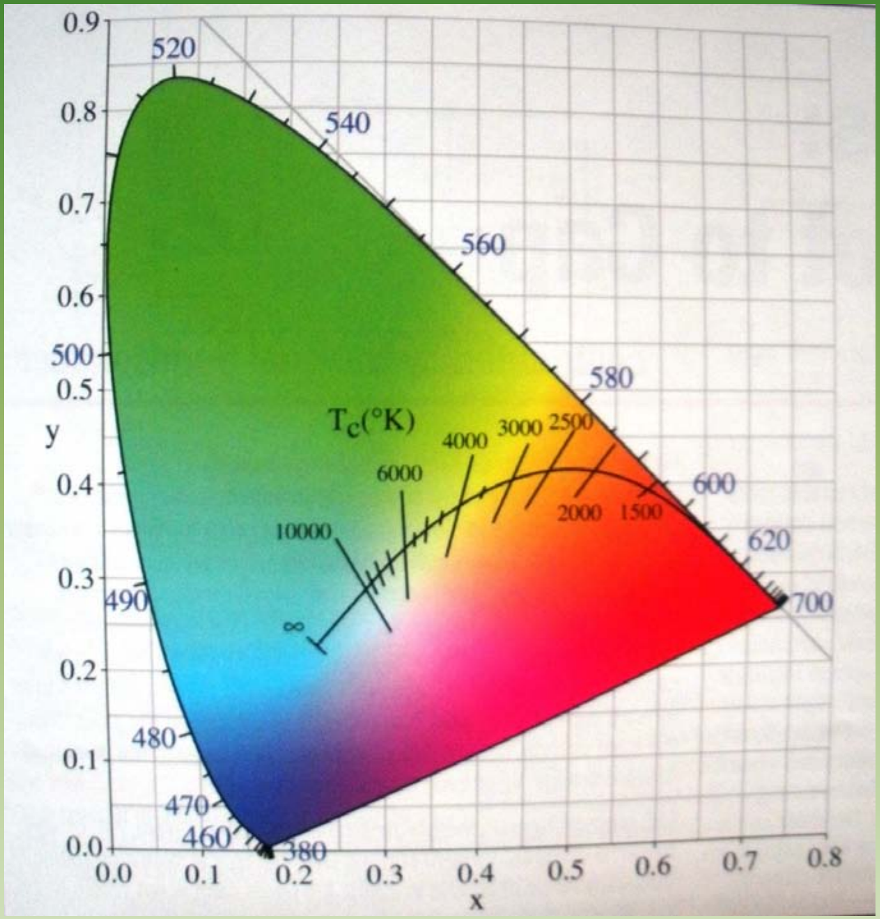
- **CIE color coordinates** mag p.55
- **Article on binning** mag p.58
- **Color Rendering Index (CRI), or, Color Quality Scale(CQS)? See NIST article:**

http://www.nist.gov/pml/div685/grp05/ssl.cfm



Binning: Each Manufacturer Differs

but most refer to CIE 1936 x,y color coordinates



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Inaccurate Performance Claims

How Can Regulators Address This Problem?

- Require a label or tech data sheet with standardized test info for lamps and luminaires (not just for LEDs).
- Conduct outreach to help inform manufacturers and distributors. Offer recognition for best performance.
- Conduct random testing. Publish the results. Institute a third-party appeal procedure, but also reserve the right to impose reasonable penalties for violations of the law.
- Require "no-questions-asked" return or warranty terms from manufacturers, distributors or retailers. Inform buyers of their legal recourse if the warranty is not honored. (Consumer watchdog agency, attorney general, etc.)

- What's the average rated lamp life for LEDs?
- Do LEDs really operate for 100,000 hours?
- How do we predict lumen maintenance?
- Will I pass these LEDs on to my grandchildren?!

Sorry, we don't know, or just can't agree! ☹

What you CAN evaluate—informally—with a watt-meter, an illuminance meter, and a digital camera:

- Initial illuminance (relative to a system you are replacing)
- Input power demand (watts)
- Light distribution (intensity) pattern

Such measures can give you a rough idea of whether the new LED system could be a candidate for replacing your previous system. They are not a substitute for standardized testing, but they can save you time and effort if you are in the early stages of a project.

IV. What Could *lites.asia* Do?

- **Evaluate the system, not “the LED.”**
- **Focus on performance, not on technology. Leave the technical solutions to manufacturers, but give them a clear signal of what you require as minimum performance.**
- **Demonstrate and evaluate in real-world conditions, not only in the lab. If you are a standards organization, team up with others who can take risks to invent new, practical test methods.**

What Could *lites.asia* Do?

- **Asia is doing great things with LEDs! However, the best and the worst LED systems come from Asia. Communication between "makers," "users," and "regulators" could help establish appropriate expectations and benchmarks.**
- **The clamor to lower prices for LEDs inevitably will eventually compromise quality and/or service life. What are your constituents willing to trade-off?**
- **For discussion: Does anyone really need 50,000-hour LED packages in lamps that look "like the old ones"? Or, is it a better use of effort and budgets to transition to new luminaires that are designed to optimize 50,000-hour LEDs?**
- **Regulators and manufacturers (particularly end-of-the-supply chain assemblers) would benefit from frank discussions about reliability factors.**

What Could *lites.asia* Do?

Human resources: Encourage manufacturers to: improve assembly-line worker education and management training opportunities; provide appropriate precision tools; improve plant conditions for workers' health, safety & productivity; institute state-of-the-art quality assurance programs; reward employees for reducing defects and other problems.

Environment: Conduct and share lifecycle cost analyses for various applications. Require lead-free solder. Encourage design engineers to make separable heat sinks, optics and housings that could be re-used or recycled. Institute "take-back" programs (as with printer/toner cartridges). Create & enforce environmental standards for facilities, storage areas and factory discharges.

Economic development: vendor "ecosystems" develop to support chip fabs or packaging plants. Institutional and private investors are very interested in the LED industry, but they demand: strong business plans; realistic revenue projections based on target market data; experienced semiconductor management teams; environmental compliance; intellectual property diligence; and, world-class accounting and legal practices.

"But I thought all LEDs were energy efficient! We don't have the time, expertise or money to do all this measurement—we just want to do something simple!"

JUST DO IT; OTHERS HAVE (or will soon)!

- **Lighting publications offer many well-documented case studies of LED lighting systems.**
- **Consider setting absolute input power demand standards for: exit signs, traffic signals, decorative lights and single-color, luminous signs.**
- **Phase out some types of incandescent lamps.**
- **Request permission to use others' specs for procurement, or participate in a bulk order.**

Free LED Resources

- LEDs Magazine: www.ledsmagazine.com
- Lighting Africa: www.lightingafrica.org
- Lighting Research Center, Rensselaer Polytechnic Institute:
  www.lrc.rpi.edu
- The Lumina Project: http://light.lbl.gov/
- Manufacturer & distributor websites & e-seminars.
- Trade shows (most in Asia offer free passes to exhibits)
- U.S. Dept. of Energy: http://www1.eere.energy.gov/buildings/ssl/
- U.S. Nat'l Institute of Standards, SSL Metrology:
  http://www.nist.gov/pml/div685/grp05/ssl.cfm
- Wikipedia
- Your local lighting community… designers, professors, sales reps...

Examples of Global Groups

- Annex 4 E, Solid State Lighting, International Energy Agency (IEA)
- HB-LED Standards Committee, SEMI International Standards Program
- International Commission on Illumination (CIE)
- Climate Initiative, William J. Clinton Foundation
- Global Lighting Forum, National Electrical Manufacturers Association (NEMA, USA)
- LED University (Cree)
- Zhaga Consortium

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