

LED照明产品品鉴暨光环境设计创造价值论坛，成都，2013/11/22日
中国照明网主办 / 雷士照明 四川运营中心承办

LED照明技术 现状与展望

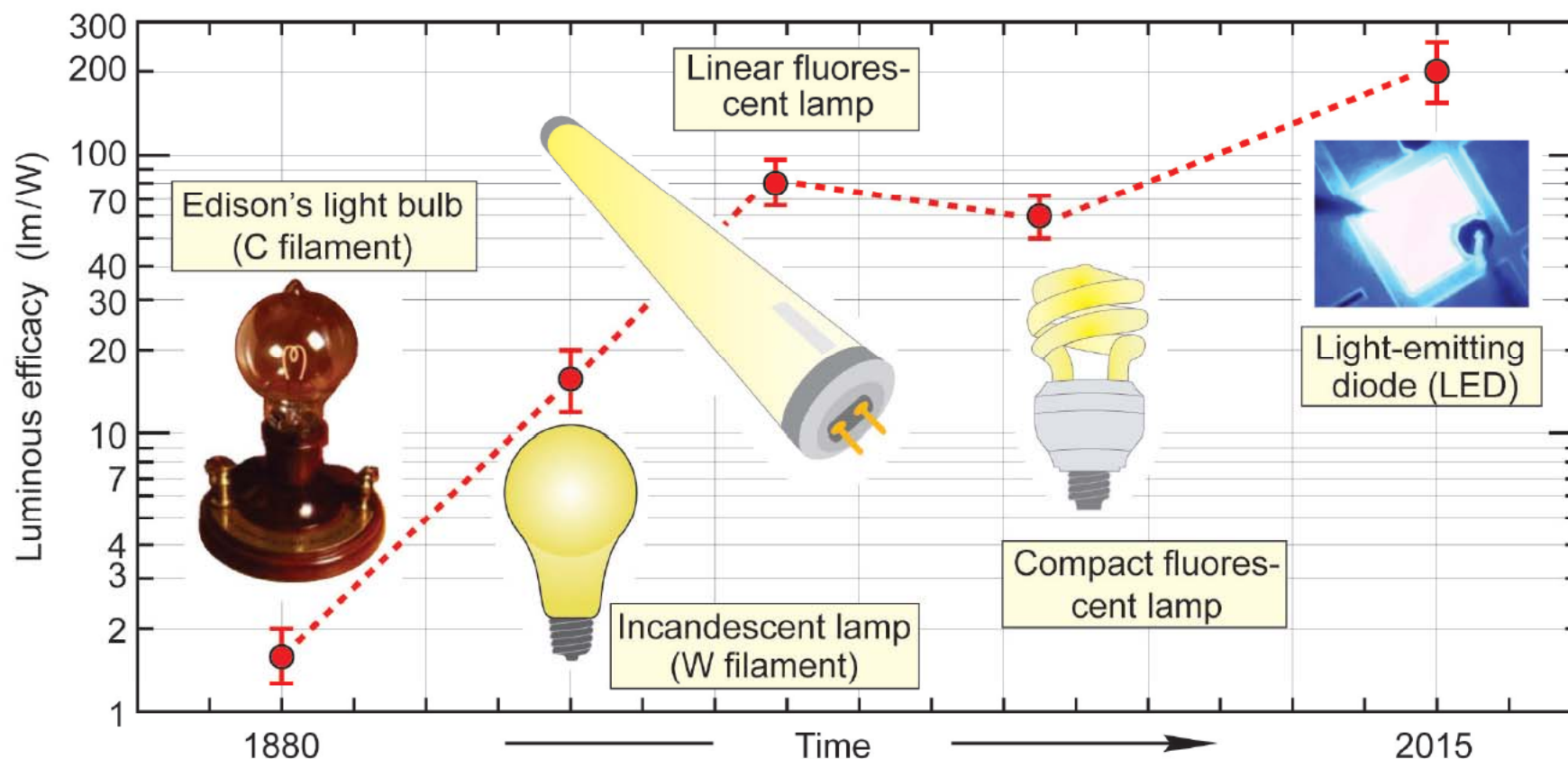


复旦大学电光源研究所

梁荣庆

电光源效率的演变及LED的优势

- 传统光源（如白炽灯、荧光灯等）效率提高受到基本物理规律制约
- **LED**以其极高的电光转换效率（现有纪录已达到**276 lm/W**）正在迅速取代传统光源
- **LED**具有超长使用寿命、有助环保、光学和电学性能可控性高等优点

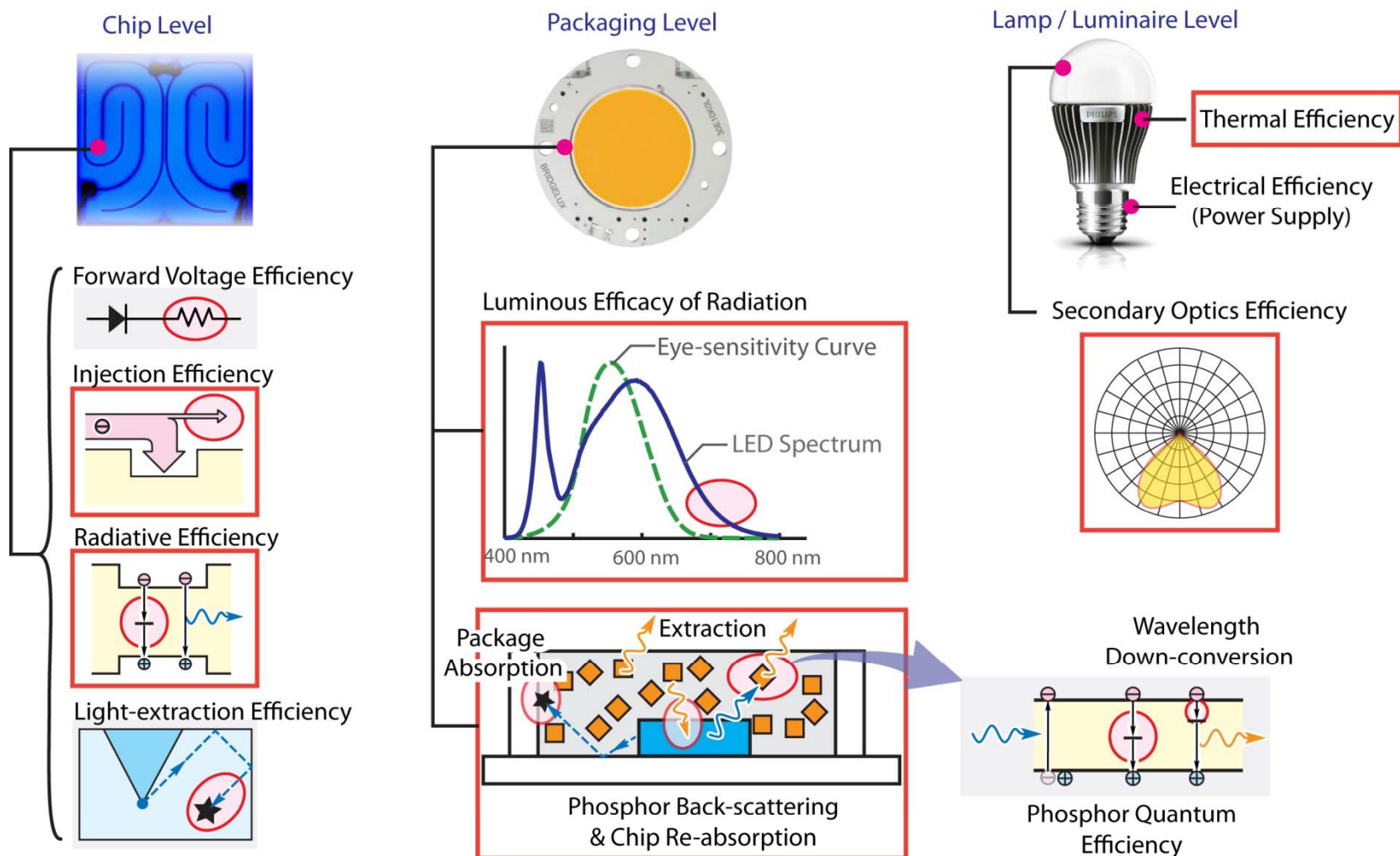


LED有哪些重要的技术正在突破进程中

- LED的“**Efficiency Droop**”(效率下降)问题的突破可大大提高流明/单价
新结构、衬底、生长技术
- 通过**Color mixed LEDs** 技术，性能上可超过荧光粉LED，“**green gap**”问题将被解决
- 新衬底的广泛应用
Al₂O₃, SiC, Si, GaN, ZnO
- 量子点LED的应用
窄带红光，其他单色光，器件结构
- 光子晶体结构和纳米线，以及其他纳米结构进入实用阶段
- 新的热沉技术出现
尺寸，形状，材料（例如石墨烯）

LED及固态照明主要能量损耗机制

○ Efficiency Loss Mechanisms



LED技术上游---LED 外延和芯片

- 目前在 350 mA/mm² 电流密度下，主流公司量产LED 的wall-plug efficiency (WPE) 已超过60%，在小电流密度下（减少efficiency droop 的影响）WPE 已超过70%（已考虑encapsulation gain 的数值）。

$$\text{WPE} = \text{Internal Quantum Efficiency} \times \text{Light Extraction Efficiency} \times \text{Voltage Efficiency}$$

因此LED内量子效率、光取出效率和电压效率都已接近90%

Cree 宣布其白光LED 效率已可达到 276 lm/W (@4401 K, 350 mA, LED 芯片面积未知；实验室结果)。

- 目前，国际主流LED 公司如Osram, Philips Lumileds 等都已实现在6" Sapphire 衬底上GaN-based LED 外延片的量产。Patterned Sapphire Substrate (PSS) 因在提高外延片晶体质量，提高芯片light extraction efficiency 等方面的优势已被广泛采用（特别是2"和4"的PSS）。Sapphire 衬底目前仍然是LED 衬底主流。许多公司在8" 衬底上的外延生长研发也取得了突破。

LED技术上游---LED 外延和芯片

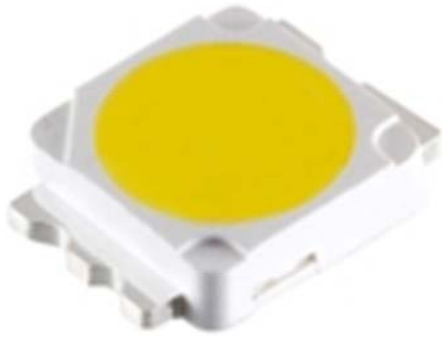
➤ 除了 Sapphire 衬底外，Silicon，GaN，以及SiC 等衬底具有各自的优势：

1) GaN-on-Si 技术具有低成本8” Silicon 衬底，可以很好地利用传统半导体加工工艺和生产线等优点，有望较大幅度降低LED 芯片的成本。美国Bridgelux公司于2011 年取得了GaN-on-Si 技术很大的突破，成功开发出和GaN-on-sapphire 性能接近的GaN-on-Si LED；日本的Toshiba 公司于2012 年初购得Bridgelux的GaN-on-Si 技术，并宣布于2012 年底实现了基于GaN-on-Si 技术的LED产品量产。Toshiba 公司于2013 年进一步购得Bridgelux 的GaN-on-Si 外延和芯片部门。Osram 也于2012 年初宣布在GaN-on-Si 技术上取得突破。虽然目前已有一些公司宣布实现量产GaN-on-Si LED，并且产品性能和GaN-on-Sapphire LED 的差距可达到小于10%，但还没有证据显示此技术的良品率和产品的reliability 已得到了完全解决。

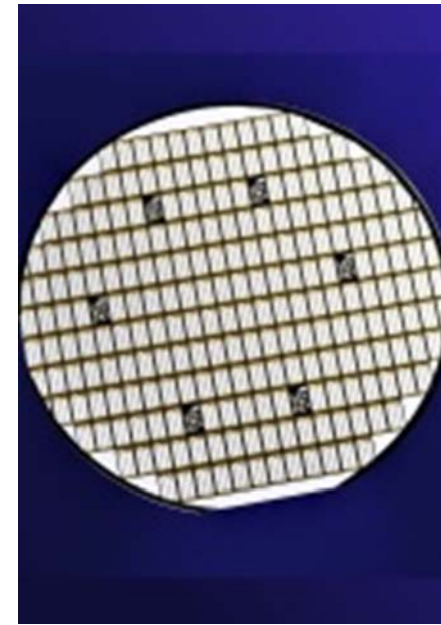
LED技术上游---LED 外延和芯片

2) GaN-on-GaN 技术采用bulk GaN 衬底，由于没有使用Sapphire, Si 等衬底所产生的衬底和外延片之间的lattice mismatch 和thermal expansion mismatch，外延的dislocation 大大降低，因此大大提高了晶体的质量。美国Soraa 公司是GaN-on-GaN 技术的大力创导者。Soraa 的GaN-on-GaN 方案可能存在bulk GaN 衬底成本过高，LED 芯片主波长较短（约为410 ~ 430 nm，相对于通常450 ~ 460 nm的蓝光LED 在通过荧光粉转化为白光的过程中会有更多因stocks shift 造成的能量损耗）等问题。

3) Cree 公司拥有其独特的SiC 衬底技术；并已将150 mm SiC 衬底推向市场。



GaN LEDs on 6-inch silicon. Bridgelux



Cree's 150mm(almost 6 inches) n-type SiC wafers on the market

Toshiba will begin mass production of white LEDs on 200-mm silicon wafers. 1.1mm² LED chip fabricated on an 8" GaN on silicon (GaN-on-Si) wafer

These LEDs have extremely low operating voltages, requiring just 2.90V at 350mA and <3.25V at 1 Amp. 135lm/W, CCT of 4730K.

LED技术上游---氮化镓 LED 的” efficiency droop”

- 1、美国Philips Lumileds 公司的YC Shen et al., 支持Auger Recombination 作为efficiency droop 的原因;
- 2、美国Rensselaer Polytechnic Institute 的Schubert 教授组和韩国 Samsung LED 公司MH Kim et al., 支持carrier overflow from MQWs 作为efficiency droop 的原因。
- 3、美国的University of California, Santa Barbara 和法国的Ecole Polytechnique 2013 年4 月底宣称直接测量到LED 中的Auger recombination, 认为Auger recombination 是产生efficiency droop 的主要原因 。

efficiency droop 的原因目前仍有较大的争议。产生机制和解决方案仍然是LED 研究领域最重要的课题之一，并且持续成为学术界和工业界争论的焦点。

LED技术中游—封装

小功率LED vs. 大功率LED

- LED封装产品主要有基于plastic carrier的中小功率surface-mounting device (SMD)；基于陶瓷基底的大功率SMD；以及chip-on-board (COB)类型大功率产品。
- 针对不同应用: Outdoor / Directional / Linear / BLU / Indirect 及不同的光学、热学设计要求、lm/\$要求等有不同的选择
- 一般来说大功率产品主要用于室外路灯、停车场等照明产品；或者是一些directional lighting 产品。

小功率产品主要用于linear, area 类型的luminaire （小功率产品具有最好的lm/\$优势，并且使用多个小功率LED 更有利于实现source hiding, thermal spreading 等目标。



LED技术中游—封装

- 总体而言，Nichia 公司极力倡导小功率LED 封装产品；而 Cree 公司则认为并没有明显的理由认为小功率封装产品有更广的应用和价格优势。
- 目前主流 LED 公司的封装产品在3000 K, 80 CRI 的情况下效率一般为110 ~ 140 lm/W。在5000 ~ 6000 K, 70 CRI 的情况下效率大约可以再提高30%。

LED封装技术上的挑战和机遇

- 不同的LED芯片架构和不同的LED封装平台设计之间优化 chip – phosphor / package 以达到最高的系统效率
- Phosphor的back-scattering和LED芯片的self-absorption目前是LED封装层面能量损耗的一个重要来源
- 超高Luminance（如20 Mcd/m²）的LED chip-on-board封装设计: chip architecture, thermal management
- LED封装层面光学设计（primary optics）以提高LED产品的附加值（如batwing distribution, wide beam angle distribution）
- 光谱优化：高光谱效率，高CRI
- Tight color binning
- Wafer-level packaging
- Phosphor development
-

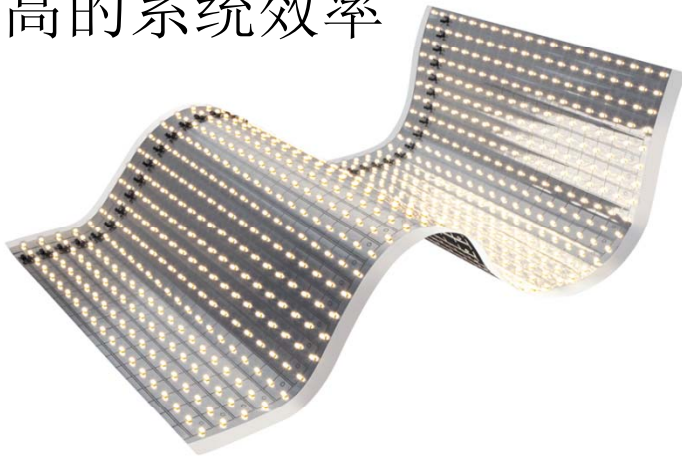
LED技术下游—照明灯具的新概念设计

- 通过光学设计，根据LED 点光源及lambertian source 的特点，针对不同应用设计不同的beam distribution：如bat-wing distribution（如Philips 的ArcForm），asymmetric distribution 等。
- 通过 edge-lit 技术，可以实现照明灯具的超薄设计，实现source hiding，并且可以通过控制light guide 的micro pattern 控制beam distribution。
- 利用 indirect lighting 光学设计可以在使用大功率LED 的情况下达到source hiding的效果。
- 基于 flexible substrate 的低成本flexible light engine。

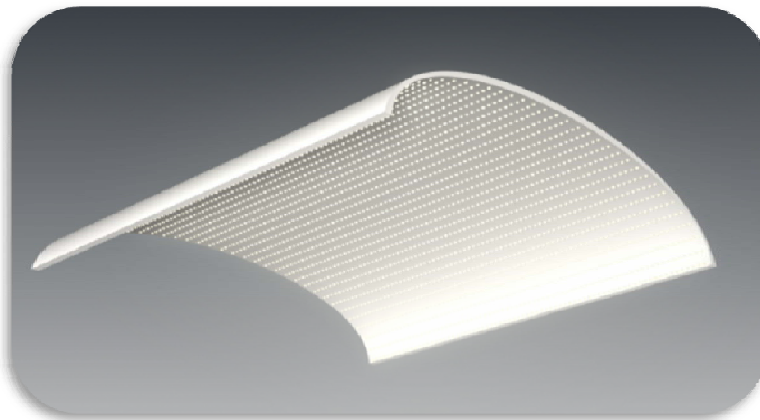
Flexible LED light engine

■ 下一代 LED light engine

- 低成本flexible衬底 – 极高效率, 新功能集成
- 独特的散热设计, 实现很低的LED半导体结温, 由此得到很高的系统效率



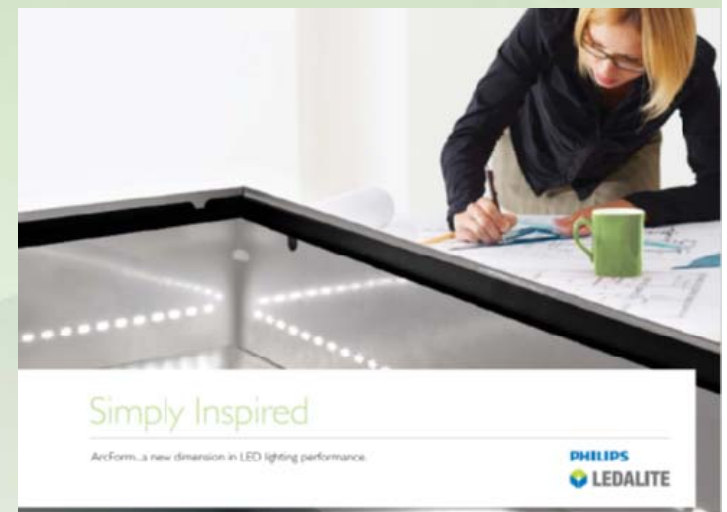
GE; Osram; Coolidge Lighting
正在研发



- ✓ 面发光强度20lm /平方英寸;
- ✓ 发光效率大于100lm/ W,
- ✓ 寿命50,000 小时.
- ✓ 无需散热部件.
- ✓ 尺寸宽度1" (28mm) to 11" (280mm), 长度可达8' (2.4m).

ArcForm

Soft. Subtle. Sophisticated.



Simply Inspired

ArcForm...a new dimension in LED lighting performance.

PHILIPS
LEDALITE

HOW IT WORKS

Light emitted from highly efficacious LED arrays is reflected by 98% efficient upper reflectors and microcellular PET perimeter reflectors. The light then mixes inside the optical cavity, passes through MesoOptics film and emerges from the ArcForm concave lens in a precisely controlled 3D symmetrical batwing distribution.

UPPER REFLECTOR

98% efficient Miro Silver reflects light out of the fixture.

PERIMETER REFLECTORS

Highly efficient microcellular PET material mixes light within the optical cavity.

ARCFORM DOOR

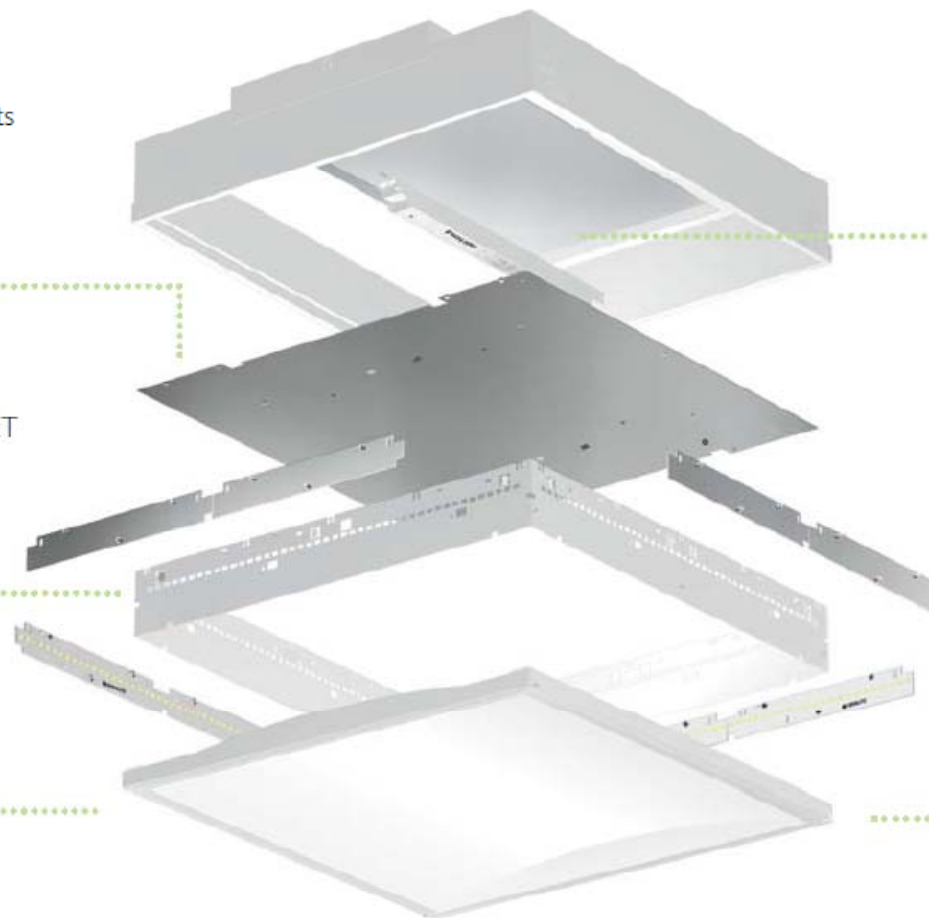
Elegant architectural aesthetic provides easy access to the inside of the fixture.

LED DRIVER

Multiple lumen packages, 0-10V dimming, battery pack options, and accessible from below for easy maintenance.

LED ARRAYS

Highly efficacious Philips platform LED arrays are available in 3 color temperatures.

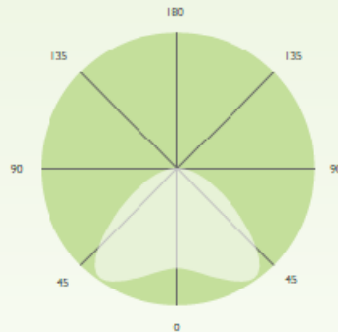


mesoOptics

Controls light to create a precise 3D batwing distribution.

Exceptional Control & Efficiency

MesoOptics technology provides the best possible combination of control and luminance.

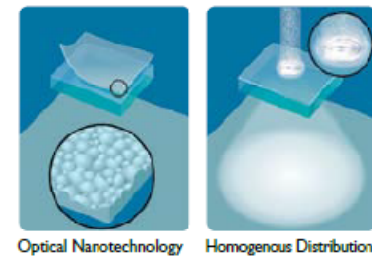


Higher transmission efficiencies than traditional optical and control methods mean lower energy consumption. Small amounts of controlled brightness are introduced to the vertical surfaces, creating a brighter and more visually comfortable environment without unwanted glare.



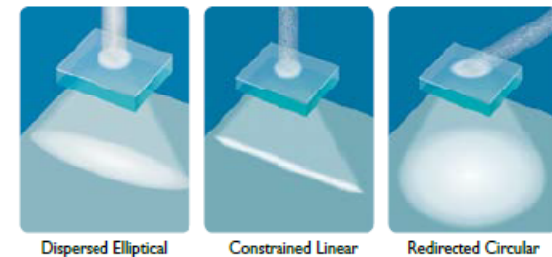
PURIFY

MesoOptics material purifies and controls the LED light passing through. It homogenizes color, and removes striations and hot spots, creating smooth gradients of pure, white light free from color shifts.



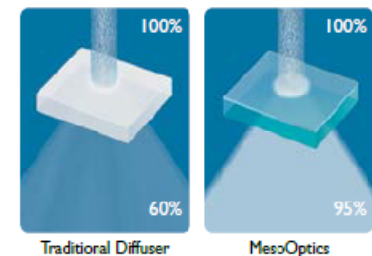
CONTROL

MesoOptics disperses light uniformly and creates precisely controlled beam patterns to redirect light into a 3D batwing distribution.



SUSTAIN

MesoOptics' highly efficient material allows up to 95% of the light to pass through, resulting in a highly efficacious lighting system that is environmentally sound and visually healthy.



3D Symmetrical Batwing Distribution

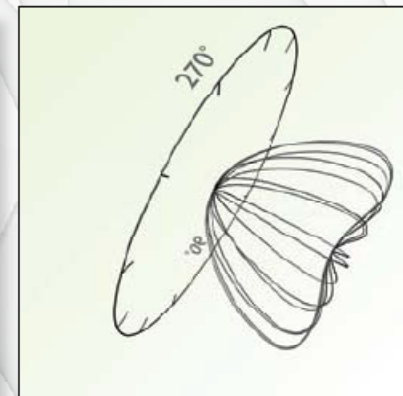
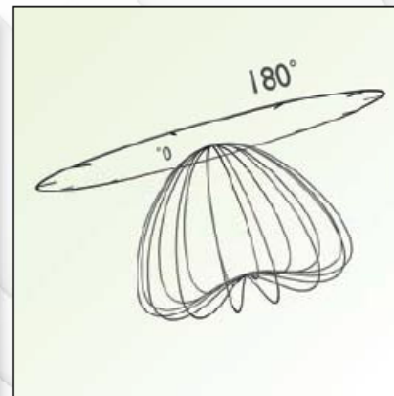
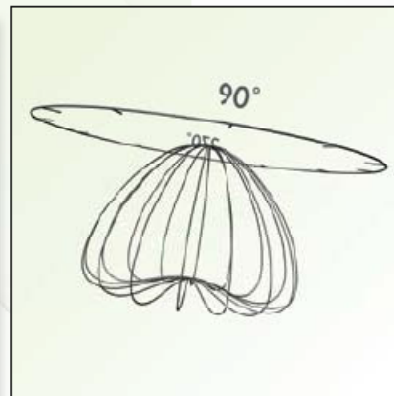
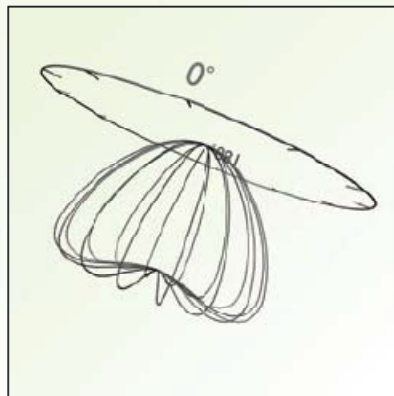
ArcForm is a highly efficacious, fully luminous fixture with brilliant color rendering and an innovative 3D symmetrical batwing lighting distribution. It delivers pure, white light—free of glare, color shifts, hotspots or striations, with unparalleled uniformity, maximizing visual comfort and energy savings.

A New Dimension In Lighting Performance

Advanced LED optical design and patented MesoOptics technology combine to deliver wider fixture spacing while ensuring optimal light levels, perfect uniformity, and maximum energy savings.



Scan to view ArcForm video
or visit arcform3d.com



ArcForm 灯具系列



































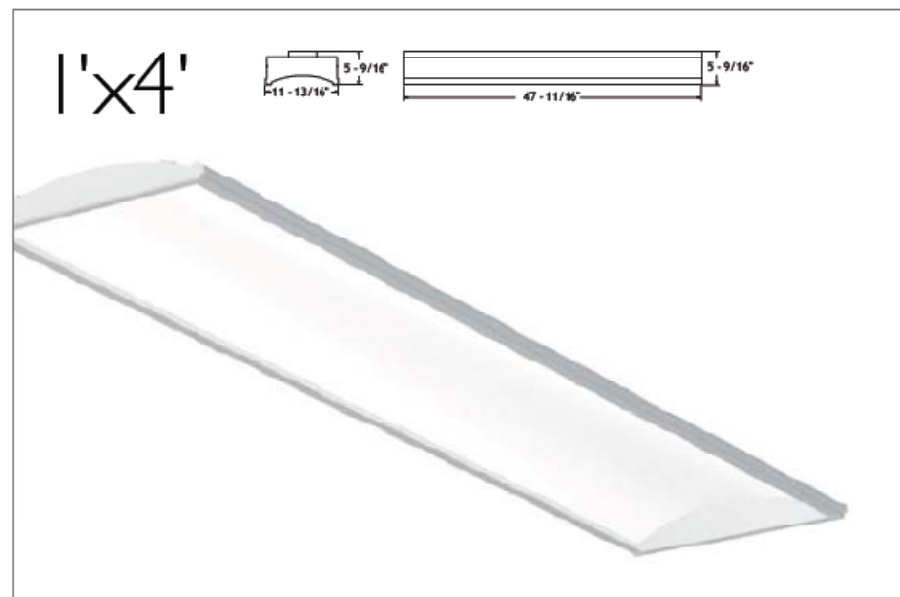
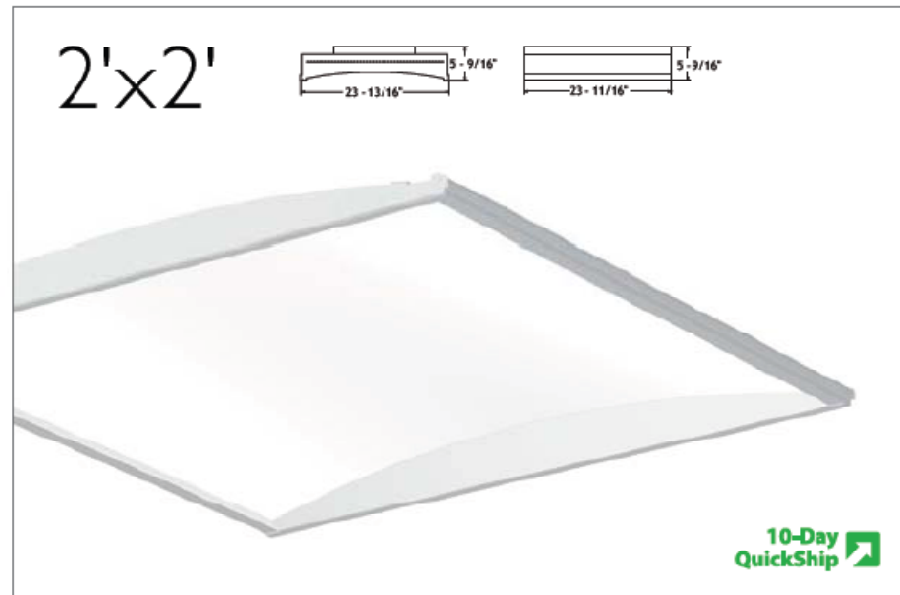
Product Options

FUTUREPROOF OPTICS

LEDLOGIQ solutions are field upgradable to stay current with the latest advancements in solid state lighting technology. ArcForm is designed with a simple plug and play platform so that field replacement and maintenance are quick and hassle-free. As a partner with the world's leading LED component suppliers, Philips Ledalite provides high quality, top performing products, and a commitment to ongoing research and development.

LUMEN PACKAGES

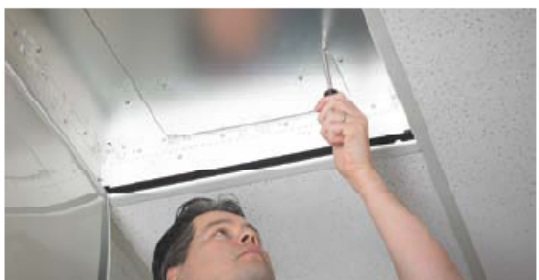
Color Temp	Lumens
A 4000K	36 3600 lumens
B 3500K	44 4400 lumens
C 3000K	



MAINTENANCE MADE EASY



1. Push in the end corners of the fixture where the hinges are located.



2. To access the driver compartment, remove the screws on the upper reflector.



3. Gently lower the upper reflector and remove the LED driver.

5 YEAR TOTAL SYSTEM WARRANTY

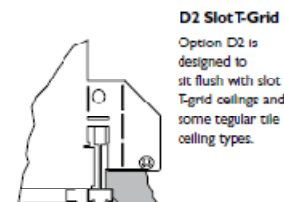
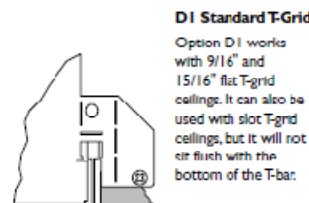
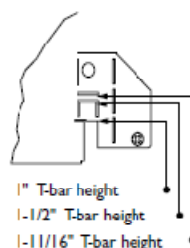
ArcForm comes with a 5 year total system warranty, that covers the entire luminaire—including the LED board, driver and all fixture components—with world class support backed by Philips Ledalite.



5 YEAR
SYSTEM
WARRANTY
Fixture + LED + Driver

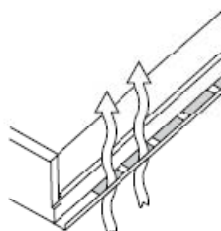
CEILING INTEGRATION

All ArcForm products feature integrated mounting tabs that can be field-adjusted to various T-bar ceiling heights. Fixtures can be fastened directly to the T-bar grid and/or tied-off to the building structure.



AIR RETURN

Air return is available with the ArcForm 2'x2' option.



Gree 公司LED 平板灯
摄于复旦大学光学楼
2013年5月29日上午

aim at fluorescent office lighting
with flat-screen LED fixtures that
are thinner and last longer than
traditional fixtures



LED技术下游 - Color Mixed LED

在固态照明领域，除了简单地替代传统光源外，LED 光源为照明设计提供了更多的应用。一些热门的研发方向有：

- 通过 LED multi-color mixing，可以实现LED 照明产品的最高效率（color mixing 大大减少了stocks shift 产生的不可避免的能量损耗），并且用户可以控制光源的色温。较高的Color rendering（一般CRI 为90 以上）也是color mixing 的一个优势。目前已出现具有基本色温调节功能的LED 照明产品。

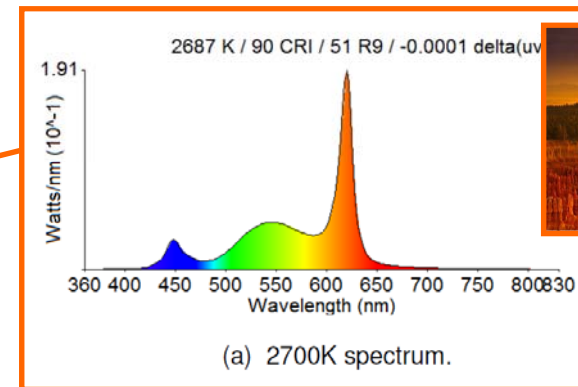
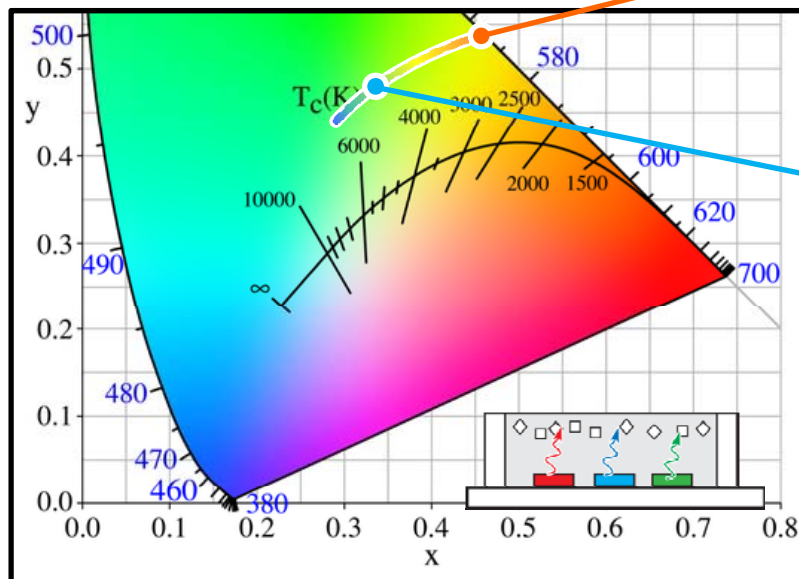
LED Color-mixing light engine 方面的主要工作

- Color mixing light engine 解决方案和产品原型：具有高效率（比普通LED高25%），高显色性（90 CRI），用户可调色温（2700 K ~ 7000 K）等优点
- 在10~80 °C环境温度范围测量色彩和设定色彩小于2 MacAdam ellipses的极高颜色准确性
- PWM和Current sharing(使用single-channel power supply)两种控制方式解决方案
- 优化LED的色坐标选择以达到efficacy, CRI等参数的最优化，并且降低对power supply的dynamic range的要求

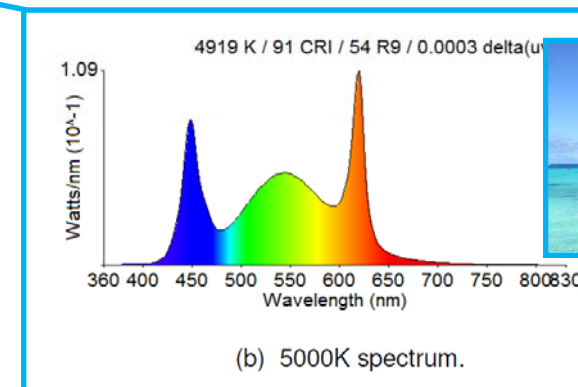
LED color mixing and tuning

■ Color mixing的优点

- 消除了phosphor conversion过程中不可避免的能量损耗(quantum efficiency, scattering, Stokes' loss)
- AlGaInP红光LED具有较狭的光谱, 减少红外波段能量损耗
- 更好的照明品质: CRI > 90
- 用户可调色温
- 对单个LED color binning要求很低



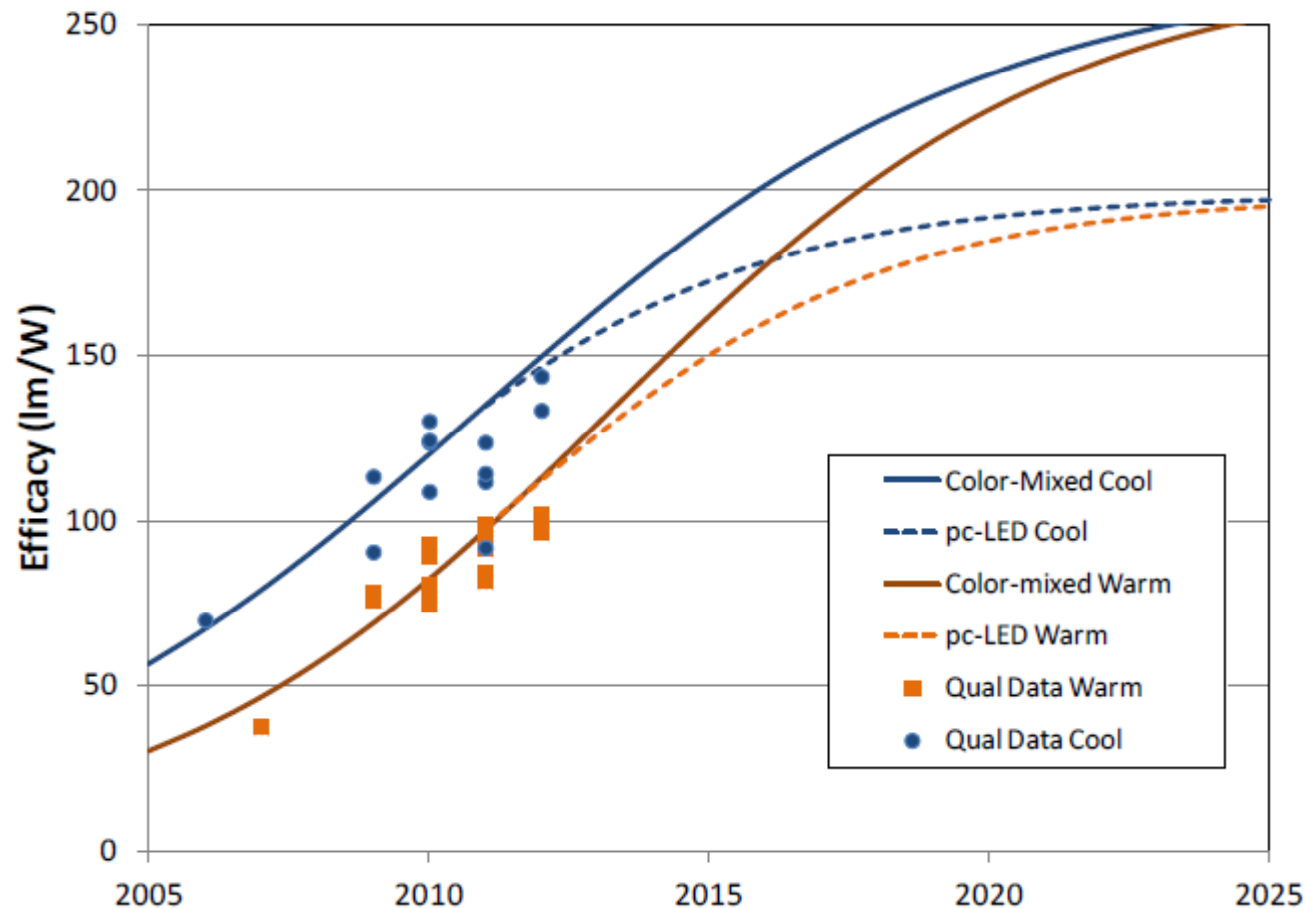
日出: 2000 K
日出后一小时: 3500 K



正午: 5500 K
午后: 6500 K

Color mixing vs. phosphor conversion

- Color mixing相对phosphor conversion保持效率优势



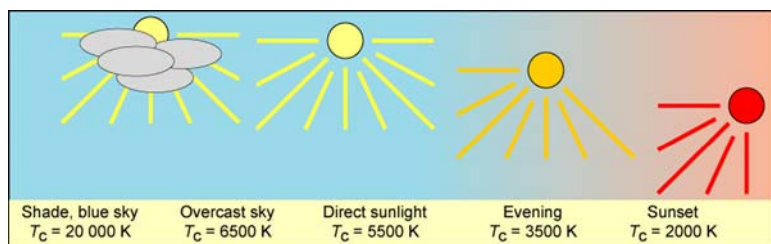
White light LED package efficacy projection for commercial product

(US Department of Energy, Solid-State Lighting Research and Development Multi-Year Program Plan, April 2012)

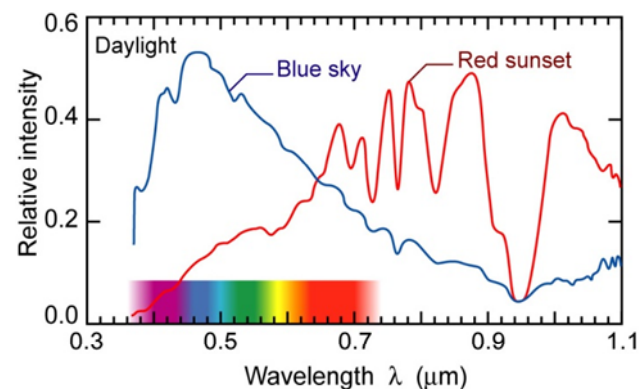
LED技术下游—健康照明、智能照明

- 光线的不同可影响人的生理变化和人的生理节律

Circadian lighting – healthcare applications



- CCT tuning, circadian light



- 使用 proximity sensor 和 lighting control 得到节能的效果；利用因特网、物联网技术可使LED技术更加有效，并使得光源也融入信息社会

Wireless Controls

Airwave wireless controls represent a quantum leap forward in flexibility and sustainability.

Using organic sources of renewable kinetic and solar energy, Airwave delivers wireless individual personal control, daylight harvesting, occupancy sensing, and full range dimming for spaces where the ability to control energy and lighting are essential. The simple flick of a batteryless, wireless switch creates enough kinetic energy for simple ON/OFF control or dimming. Solar powered Airwave sensors monitor ambient daylight levels or occupancy and wirelessly signal luminaires to adjust output and save energy.

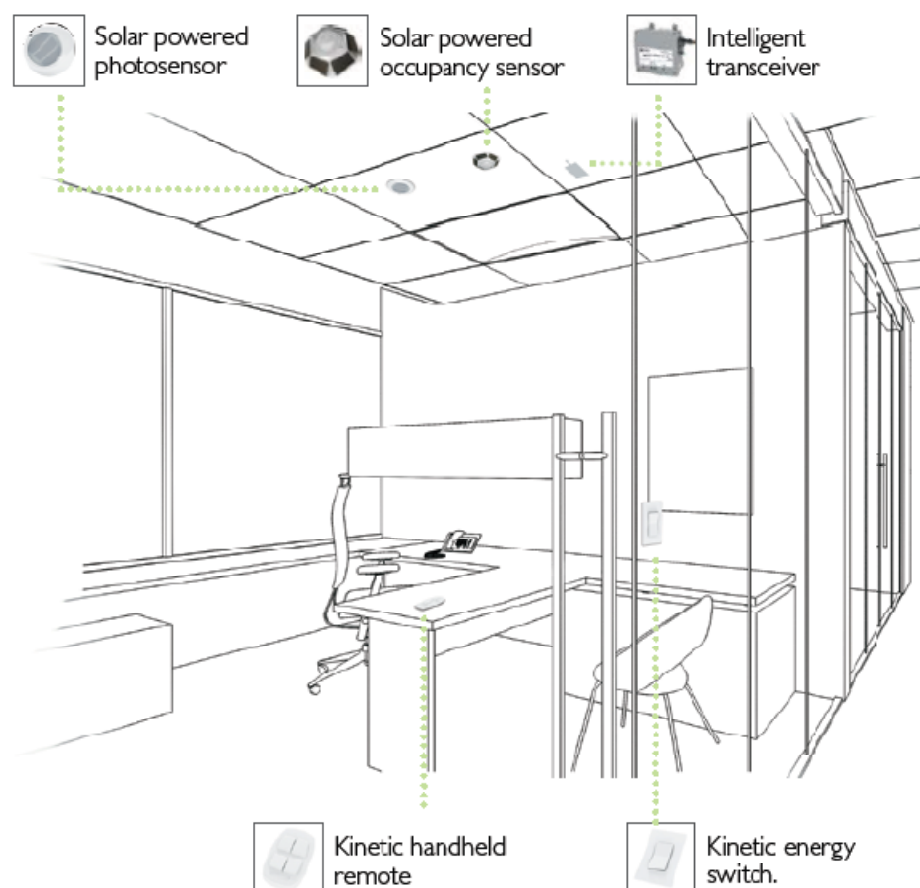
ledalite.com/airwave



智能控制

—调节光色达到舒适、
节电的目的

Wireless. Batteryless. Limitless.



Daylight Harvesting

Response daylight harvesting sensors can provide 30-35% energy savings in window adjacent locations—helping to reduce operating expenses and comply with new energy codes.

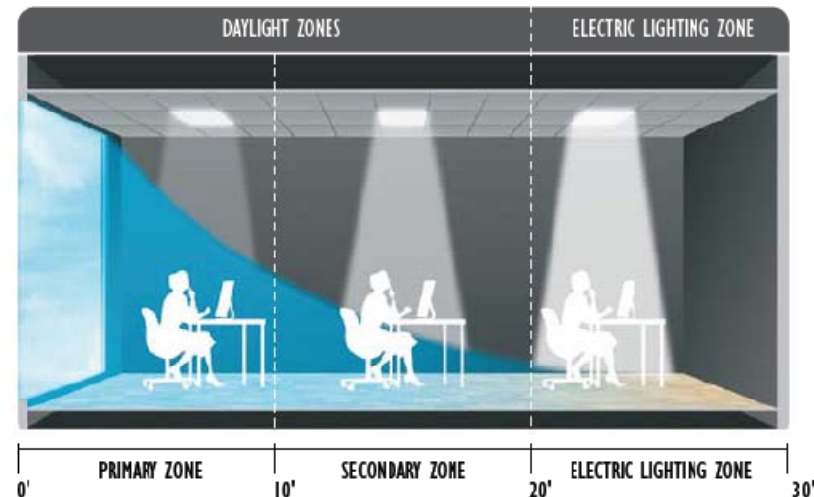
ledalite.com/response



RESPONSE

NO WIRING. NO COMMISSIONING.

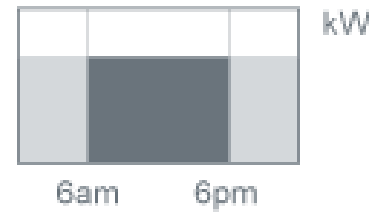
Response Daylight sensors are factory pre-calibrated and ready to use right out of the box. Just plug in the fixture—no power packs, standalone sensors or low-voltage wiring schemes required. The sensors adjust light output gradually with minimal distraction for occupants. A built-in delay prevents disruptions from passing clouds and shadows.



In this example, two control zones have been created where there is ample daylight contribution, and one uncontrolled zone where daylight is minimal. As daylight contribution increases, sensors automatically and gradually reduce electric light output to save energy.



Smart Time Scheduling



10-40%



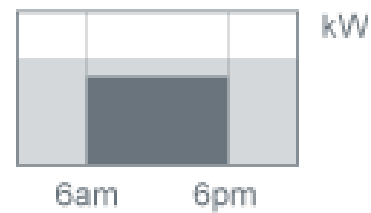
Daylight Harvesting



5-15%



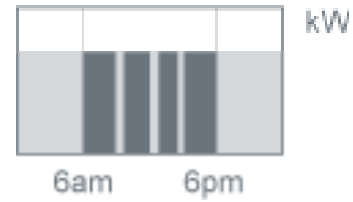
Task Tuning



5-20%



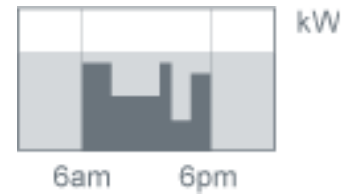
Occupancy Control



25-50%



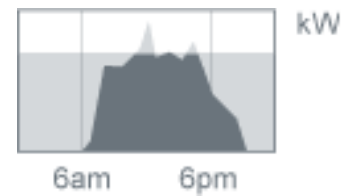
Personal Control



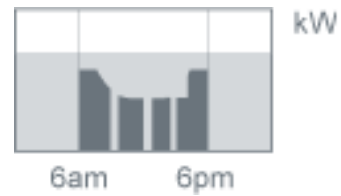
10%



Variable Load Shedding



5-15%

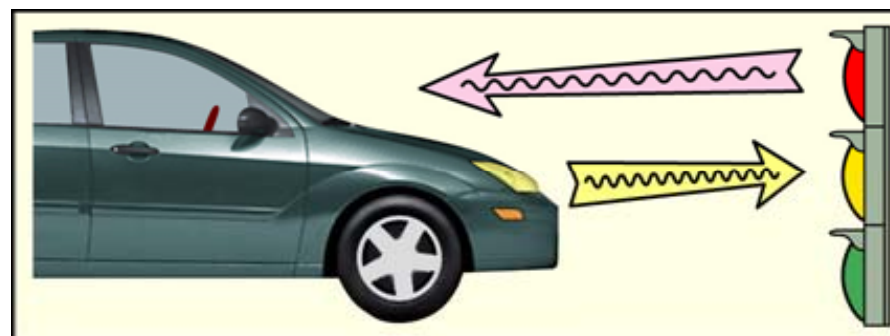


Up to 50 - 75%

LED照明在作为“替换传统产品”之后发展

- “数码照明革命”的兴起
色彩、色温可控调节，运动传感，通信等
- 顶灯照明从格栅灯和泡灯走向大面积的平板灯（skylight），色温、亮度可控制调节
- 通过深入了解人的生理与光的关系，发展更有利于身体健康的光源与照明方式
- 太阳能与LED结合的形式从分离式照明到联网太阳能储能的照明
- 在衣服、家具和表演道具等各种用具中镶嵌LED的广泛应用
- 完全创新的设计出现。

LED可见光通信



LED非视觉应用-植物补光



LED非视觉应用-杀菌、诱虫



诱虫、杀菌LED
紫外光源

大田诱虫
光电池—LED光源



LED非视觉应用-美容



LED美容



LED美牙

LED技术在下一个十年将会有哪些变化？

- 流明/瓦数、流明/单价（Lumens/Watt、Lumens/Dollar）将会进一步提高；光的品质会通过现存以及新出现的技术得到不断优化。
- 技术的进步和不断的创新会推动SSL持续的发展，但很难说哪一方面是最重要的
- 照明灯具系统将走出替换阶段，显示SSL特点与优势的新设计与新应用正在不断涌现。

总 结

- 近十年来**LED**技术得到持续、快速的发展
- **Lumens/Watt**和**Lumens/Dollar**的不断提升促进了**LED**在普通照明中的广泛应用
- 由于**LED**技术的突破并导致照明系统的演变，下一个十年将在我们面前呈现出一个非常不同的照明世界（**World of Lighting**）



Thank You!

