Solid-State Lighting: Toward Smart & Ultra-Efficient

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Smart, ultra-efficient SSL: likely characteristics

- 3.5%-efficient Incandescent
  - CCT 3,000K 14 lm/W
  - (Courtesy Lauren Rohwer)
- 21%-efficient Fluorescent
  - CCT 3,090K 85 lm/W
- 16%-efficient PC SSL (0.7A)
  - CCT 3,100K 66 lm/W SSL
- 100%-efficient RYGB SSL
  - CCT 3,800K 400 lm/W
- Spiky Spectra
  - -- High CRI
  - -- High LER
- All Electroluminescence
  - (no 0.2=0.8x0.25 Stokes loss)
Spiky spectra have excellent color rendering: e.g., a 4-color laser illuminant

Reference sources
Incandescent (o)
PC SSL Warm (o)
PC SSL Neutral (-)
PC SSL Cool (-)

Spiky spectra have highest LERs: unconstrained SPD simulations

\[
MAXLER_{MAXLER_o, CCT_o, n, m}(CCT) = \frac{MAXLER_o \cdot n \cdot CCT_o^{n-m} \cdot CCT^m}{(n-m) \cdot CCT_o^n + m \cdot CCT^n}
\]

Smart, ultra-efficient SSL: is it worth pursuing?

Light ISN’T an economic factor of production; consumption is saturated

\[ gdp = gdp_{2011} \]

Light IS an economic factor of production; consumption ISN’T saturated

\[ gdp = gdp_{2011} \cdot \left( \frac{\varepsilon}{\varepsilon_{2011}} \right)^{0.01} \]

Profit maximization in a Cobb-Douglas economy

\[ \pi(\chi, \varphi) = [A \cdot \chi^{\alpha} \varphi^{\beta}] \]

\[ -[\chi \cdot CoX + \varphi \cdot CoL] \]

Profit  Production (gdp)  Cost

**Profit**

**Production (gdp)**

**Cost**

A qualified yes:
more light = more productivity


Smart Lighting: It isn’t just Kool-Aid

“2nd Wave Lighting: Smart and Feature Rich

Integrated Illumination and Displays

Human Health, Well Being and Productivity

Agriculture

Communication

Light-Field Mapping


Courtesy of E.F. Schubert

Courtesy of NEONNY Technologies

Courtesy of Dan Picasso and the Wall Street Journal

Courtesy of SOA architects

Courtesy of pureVLC Ltd.

Courtesy of Shuntaro Yamazaki, AIST
Ultra-efficient SSL light emitters: two approaches

1. Efficiency, and its valley of death

   \[ \varepsilon_B (Blue\ Emitter\ Efficiency) \]

2. Chip areal cost necessary for \( \text{CoL}_{\text{cap}} < \text{CoL}_{\text{ope}} / 6 \)

   \[ c_{\text{chip}} = \frac{L \cdot \text{CoE}}{6 \alpha} \left( \frac{P_{\text{in}}}{A_{\text{chip}}} \right) \]

3. Heat-sink-limited chip area

   \[ A_{\text{hsl}} = \left[ \frac{2 \kappa T \sqrt{4 / \pi} \cdot \Delta T_{\text{max}}}{(1 - \varepsilon_B \varepsilon_{pp}) \cdot \left( \frac{P_{\text{in}}}{A_{\text{chip}}} \right)} \right]^2 \]

4. Heat-sink-limited white light flux

   \[ \Phi_{\text{hsl}} = \frac{\text{MWLER} \cdot \varepsilon_B \varepsilon_{pp}}{\left( \frac{P_{\text{in}}}{A_{\text{chip}}} \right)} \cdot \left[ \frac{2 \kappa T \sqrt{4 / \pi} \cdot \Delta T_{\text{max}}}{(1 - \varepsilon_B \varepsilon_{pp})} \right]^2 \]

RYGB lasers: the ultimate smart, ultra-efficient SSL source

Wide color gamut and easy integration with optics for directing light

- 459 nm
- 535 nm
- 573 nm
- 614 nm

Courtesy of BMW Group
Extreme nano: convergence of routes to filling the RYG Gap and the Valley of Droop

1 Fill the Valley of Droop

2 Fill the RYG Gap

Wavelength (nm)

Efficiency

Input Power Density (W/cm²)

Threshold current density (A/cm²)

Year

GaAs pn

Miller et al.

Quantum Well

Alferov et al.

Double Hetero Structure

Alferov et al.

Tsang

Alferov et al.

Liu et al.

Alferov et al.

Grundmann et al. (Theory)

Quantum Dot

Kirstaedter et al.

Ledentsov et al.

Ribbat, Sellin

Room Temperature
