445.664

Light-Emitting Diodes

Chapter 20.

White-light sources based on LEDs

Euijoon Yoon

Generation of white light with LEDs

- Perception of white
  - Three types of cones located on the retina of the human eye
  - Excitation in a certain ratio (similar intensity)
- Creation of white light out of monochromatic visible-spectrum emitter
  - Fundamental trade-off between the luminous efficacy and color rendering capability of a light source

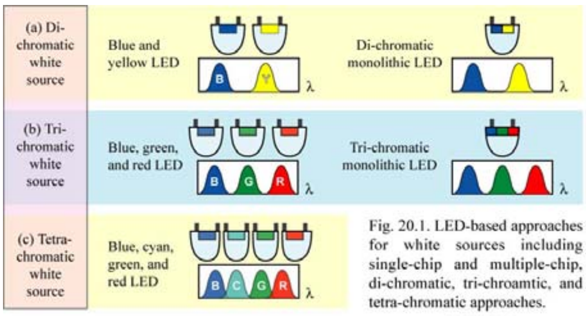
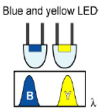


Fig. 20.1. LED-based approaches for white sources including single-chip and multiple-chip, di-chromatic, tri-chroamtic, and tetra-chromatic approaches.

E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

Dichromatic sources

- Two narrow emission bands, called complementary wavelengths



Fundamentally the most efficient way to create white light

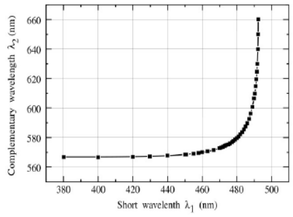


Fig. 12.1. Complementary wavelengths resulting in the perception of white light at a certain power ratio.

- The numerical values for monochromatic complementary wavelengths

Complementary wavelengths		Power ratio
λ1 (nm)	λ2 (nm)	$P(\lambda_2)/P(\lambda_1)$
380	560.9	0.000642
390	560.9	0.00955
400	561.1	0.0785
410	561.3	0.356
420	561.7	0.891
430	562.2	1.42
440	562.9	1.79
450	564.0	1.79

Complementary wavelengths		Power ratio
λ1 (nm)	λ2 (nm)	$P(\lambda_2)/P(\lambda_1)$
460	565.9	1.53
470	570.4	1.09
475	575.5	0.812
480	584.6	0.562
482	591.1	0.482
484	602.1	0.440
485	611.3	0.457
486	629.6	0.668

luminous efficacy of dichromatic light sources

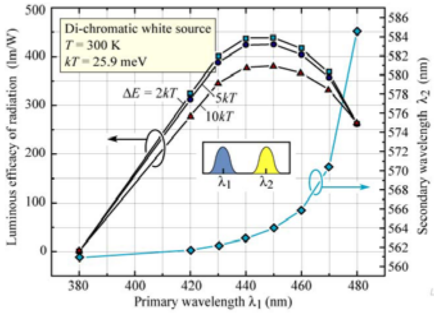


Fig. 20.3. Calculated luminous efficacy of dichromatic white light source (with chromaticity point at D_{65} standard illuminant) for different linewidths ΔE as a function of the primary wavelength. Also shown is the complementary secondary wavelength (after Li *et al.*, 2003).

E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

- Dichromatic source is most efficient way to create white light outstanding.
- Luminous efficacy >400 lm/W for narrow emission lines
- Low CRI : unsuitable for illumination application
- Suitable for display device (e. g. pedestrian traffic signal, display, etc.)
- Fundamental trade-off between CRI and luminous efficacy

LED with two active regions

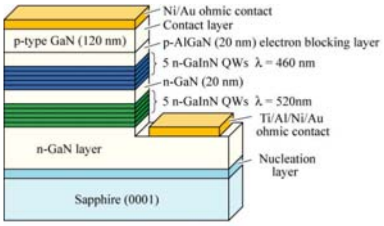


Fig. 20.4. Structure of a monolithic dichromatic LED with two active regions (after Li *et al.*, 2003).

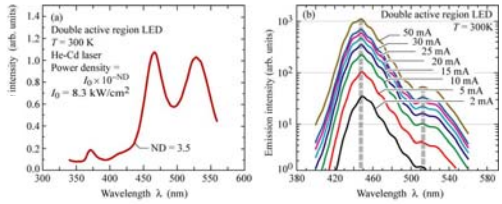


Fig. 20.5. Room temperature (a) photoluminescence and (b) electroluminescence spectra of monolithic dichromatic LED with two active regions (after Li *et al.*, 2003).

- GaInN based LED
  - Two active regions separated by a thin GaN layer
  - Emission at 465 and 525 nm
  - Two peaks at fixed position
  - Change in the ratio of the two peak with excitation power density

Demonstration of trichromatic source

- High quality white light can be generated by mixing of three primary colors.
- Trichromatic emission spectrum of a white-light source
  - 455, 525, 605 nm
  - FWHM at room temperature (20 ^oC)
    - 5.5, 7.9, 2.5 kT where kT=25.25 meV

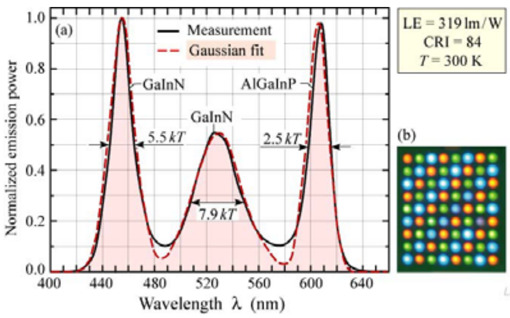


Fig. 20.6. (a) Emission spectrum of tri-chromatic white multi-LED source with color temperature of 6500 K (solid line) and gaussian fit (dashed line). The source has a luminous efficacy of radiation of 319 lm/W and a color rendering index of 84. (b) Photograph of source assembled of 5 mm LEDs (after Chhajed *et al.*, 2004).

Luminous efficacy and CRI for trichromatic source

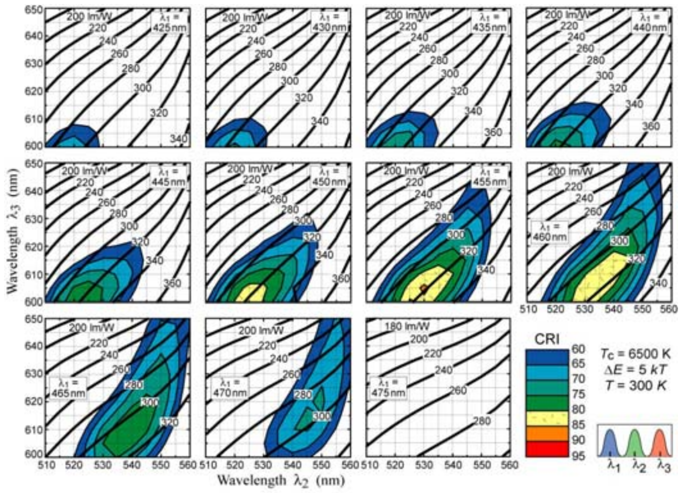


Fig. 20.7. Contour plot of luminous efficacy of radiation and CIE color-rendering index of white trichromatic LED source with color temperature 6500 K as a function of the three wavelengths for a linewidth (FWHM) of 5 kT (after Chhajed *et al.*, 2004).

Luminous efficacy and CRI for trichromatic source

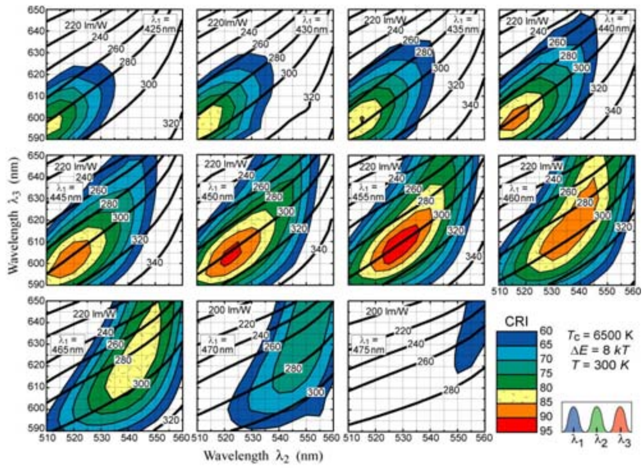


Fig. 20.8. Contour plot of luminous efficacy of radiation and CIE color-rendering index of white trichromatic LED source with color temperature 6500 K as a function of the three wavelengths for a linewidth (FWHM) of 8 kT (after Chhajed *et al.*, 2004).

- **Higher CRI results from the broader emission lines.**

Effects of ambient temperature on chromaticity point

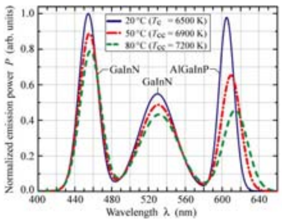


Fig. 20.9. Emission spectrum of trichromatic white LED source for different ambient temperatures (junction heating neglected). Optical power, linewidth, and peak wavelength change with temperature. As a result of these changes, the color temperature of the source increases (after Chhajed *et al.*, 2004).

- As the device temperature increases, the chromaticity point of source changes.
  - Due to the temperature dependences of the emission power, peak wavelength, and spectral width.

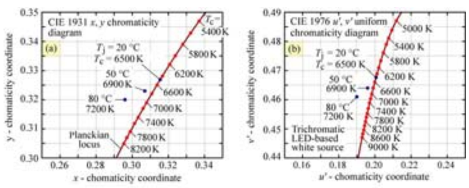


Fig. 20.11. Change in (a) x, y and (b) u', v' chromaticity of trichromatic white LED source. T_c = 6500 K when p-n junctions are at room temperature (after Chhajed *et al.*, 2004).

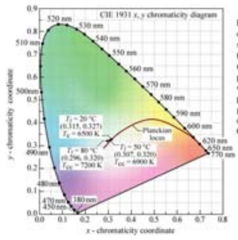


Fig. 20.10. Change in chromaticity of trichromatic white LED-based source. The source color temperature is 6500 K when devices are at room temperature. Due to the dependence of emission power, peak wavelength, and linewidth on temperature, the chromaticity point migrates off the planckian locus as the device temperature increases (after Chhajed *et al.*, 2004).

To solve chromaticity shift problem

- How to eliminate shift in chromaticity
  - Adjusting power ratio of the three LED source
  - Two methods,
    1. Spectrum of the light source is constantly measured.
       - ➢ Feedback control is used to adjust the optical power of the three component.
    2. The device temperature is monitored.
       - ➢ The optical power of the three components is adjusted.
         - Using the known temperature profile of the different types of emitters
       - ➢ Simplicity of a temperature measurement
       - ➢ No compensation for device-aging effect