Final Exam, Spring Semester 2007

ECSE-6961, Light-emitting diodes and solid-state lighting, Prof. Schubert

Note: Put your name on paper. Show all your work. Always show units. All materials are allowed (books, manuscripts, excerpts, calculators, etc.). Use ball-point pen, no pencil.

1. Consider a white-light source consisting of a blue LED (λ = 460 nm) and a yellow phosphor (λ = 560 nm). Assume that for every blue photon emitted by the white-light emitter, one yellow photon is being emitted, i.e. 50% of the blue photons are converted to yellow photons.
   (a) Identify a fundamental energy loss mechanism in this device.
   (b) What is the maximum attainable power efficiency ($\eta_{power} = P_{optical} / P_{electrical}$) of the device?
   (c) What is the maximum attainable luminous efficiency of the device?
   (d) Assume that the blue LED and the yellow phosphor have the following quantum efficiencies: $\eta_{internal} = \eta_{external} = 1.0$. Assume further that the device is injected with 1 mA. How many yellow photons are being emitted per second?

2. Consider a white-light source consisting of a UV LED (λ = 400 nm) and a blue, a green, and a red phosphor emitting at λ = 450 nm, 550 nm, λ = 650 nm, respectively. Assume that for every 3 UV photons emitted by the LED, one blue, one green, and one red photon is being emitted.
   (a) What is the maximum attainable power efficiency of the device?
   (b) What is the maximum attainable luminous efficiency of the device?
   (c) Compare the following approaches:
      (i) White LED made from blue LED and yellow phosphor.
      (ii) White LED made from UV LED and a blue, green, and red phosphor combination.
      Which of the two has the higher power efficiency? Explain the reason in words.
   (d) Which of the two has the higher luminous efficiency? Explain the reason in words.

3. Consider a 10 km long multimode step-index fiber with a core refractive index of n = 1.50 and a cladding refractive index of n = 1.45. Assume that the fiber input comes from an LED emitting at 850 nm.
   (a) Calculate the numerical aperture of the fiber.
   (b) What is the solid angle of a light source that can be coupled into the fiber?
   (c) Assume that the LED emits 1 mW of optical power isotropically into a hemisphere (solid angle 2π). What is the optical power that can be coupled into the fiber?
   (d) What optical power exits the fiber?

4. This question concerns the design a Distributed Bragg Reflector optimized for a wavelength of 300 nm.

Dielectric Material	Refractive Index	Transparency range
SiO_2 (silica)	1.45	> 0.15 um
Al_2O_3 (alumina)	1.76	> 0.15 um
TiO_2 (Titania)	2.50	> 0.35 um
Si_3N_4 (silicon nitride)	2.00	> 0.25 um
ZnS (zinc sulphide)	2.29	> 0.34 um
CaF_2 (calcium fluoride)	1.43	> 0.12 um

(a) Select two materials from the table above which would form the DBR with highest reflectivity and least number of periods for 300 nm.
(b) Calculate the layer thickness of each material.
(c) Which material layer should form the top layer if the ambient is air?

5. This question concerns colorimetry.
   (a) Deduce the temperature of a black body whose Planckian spectrum has a maximum intensity at 443 nm.
   (b) Schematically draw a chromaticity diagram and mark the location of the above Planckian black-body radiator. (Hint: Appendix 18.1 on page 312 of textbook *Light-Emitting Diodes*, second edition)
   (c) Can we obtain a light source with the same location on chromaticity diagram as the above Planckian black-body radiator by mixing the blue and yellow sources marked on the chromaticity diagram below?
   (d) Can we obtain a light source with the same location on chromaticity diagram as the above Planckian black-body radiator by mixing the Blue, Green and Red sources marked on the chromaticity diagram below?
   (e) Which of the following properties will be the same for the three light sources obtained in (b), (c) and (d)? (i) Spectrum (ii) CRI (iii) *x*, *y* chromaticity coordinates (iv) *u*, *v* chromaticity coordinates (v) luminous efficacy.