Final Exam, Spring 2009

ECSE-6962, Light-Emitting Diodes and Solid-State Lighting

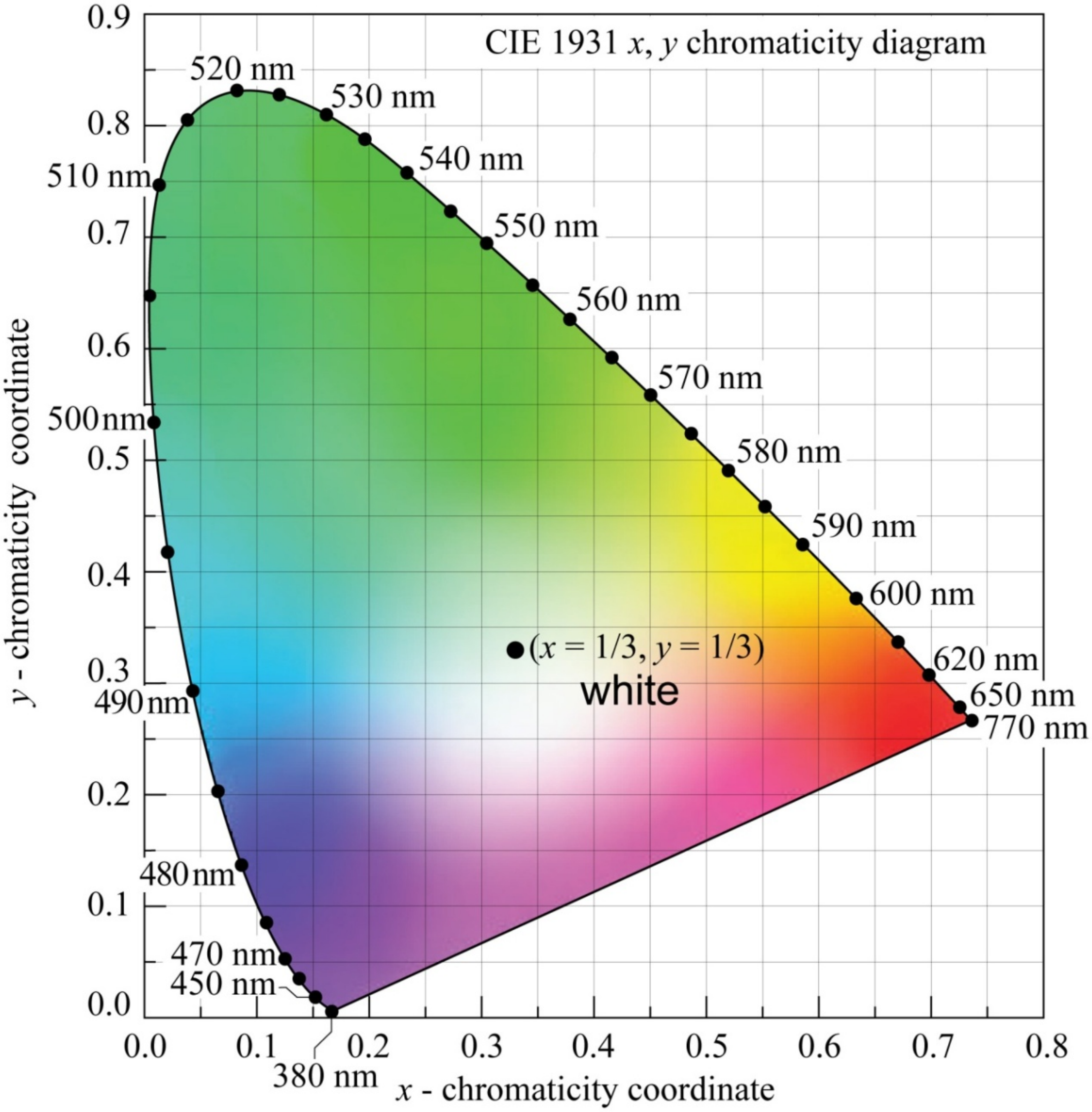
Note: Put your name on paper. Show your work. Underline results. Use appropriate approximations. Show units. All materials are allowed (books, manuscripts, excerpts, calculators, etc.). Use ball-point pen, no pencil.

1. Consider a circuit consisting of an ideal diode (V_{th} = 2.5 V, abrupt turn on, no series resistance, capable of carrying an infinite current for $V > V_{th}$), a series resistance, and a parallel resistance (bypassing the diode and the series resistance). Assume that the series resistance has a value of 25 Ω and the parallel resistance has a value of 2 MΩ.
   (a) Accurately draw the I-V characteristic of the ideal diode.
   (b) Sketch the I-V characteristic of the diode including the series and parallel resistance.
   (c) What is the value of V_{f1}, measured at a total diode current of 100 mA?
   (d) What is the value of V_{f2}, measured at a total diode current of 100 μA?
   (e) What is the value of V_{f3}, measured at a total diode current of 1 μA?
   (f) Assume that one could choose between one diode that has V_{f3} = 1.5 V and another one with V_{f3} = 2.0 V (all other factors are the same). Which diode would you choose, and why?

2. This question is about the design of a white light source that has a white point located at the "equal-energy-point" ($x = y = 0.333$). Given are two blue LEDs one emitting at 460 nm and the other one emitting at 492.5 nm.
   (a) Using the chromaticity diagram, what are the complementary wavelengths of an additional two emitters (two LEDs) that allow one to get white light? (Assume that the complementary emitter is also located on the perimeter of the chromaticity diagram)
   (b) Assume that the intensity needed from each of the emitter is inversely proportional to the distance of the emitter's chromaticity point from the desired white point. Given this, what is the intensity ratio for the two white sources?
   (c) Assuming that the total optical power of each of the white light sources is 1 W, calculate the individual powers of the 4 LEDs.
   (d) Using the eye sensitivity curve $V(\lambda)$, what are the luminous efficacies of radiation for the 4 LEDs.
   (e) Calculate the luminous efficacy of radiation for the 2 white sources.
   (f) One of the two white-light sources probably has a higher efficacy of radiation than the other one. Give an intuitive explanation as to why one of the light sources has a higher efficacy.

3. In an LED display, three different light-emitters are used, emitting monochromatically in the red (620 nm), green (520 nm), and blue (450 nm). Each of them consists of a UV LED (400 nm) and a phosphor. Assume that the external quantum efficiency for each of the three light-emitters (UV LED + phosphor) is 20%.
   (a) Under a forward current of 500 mA (LEDs are in a series circuit), what is the number of photons emitted per second from each of the three light-emitters (UV LED + phosphor)?
   (b) What is the optical power emitted from each of the three light-emitters?
   (c) Given the above discussion, what could be the energy loss mechanisms in these light-emitters?
   (d) Is it possible to reach the "equal-energy-point" in the chromaticity diagram with the three light-emitters?
   (e) What is the entire range of colors that can be created from combinations of the three light-emitters (draw the region in the chromaticity diagram)?
   (f) Light-emitters usually have a spectral broadening. Consider the locations of the three light-emitters in the chromaticity diagram, which chromaticity location (red, green, or blue?) will move more towards the center of the diagram upon spectral broadening, and why?
   (g) Which chromaticity location (red, green, or blue?) will be affected least upon spectral broadening, and why?
   (h) What is the effect of spectral broadening of the light-emitters to the range of colors (area of color gamut) that can be created from combinations of the three light-emitters?
   (i) Give an example as to what kind of color is lost (no longer displayable) because of the spectral broadening of the three light-emitters?

Figure 1: CIE 1931 x, y chromaticity diagram



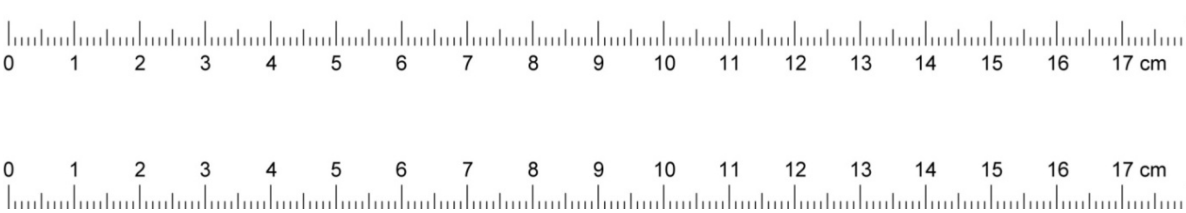


Figure 2: CIE 1978 Photopic vision