

**Midterm Exam, Spring 2009**  
*ECSE-6962, Light-Emitting Diodes and Solid-State Lighting*

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

1. Consider the semiconductor GaAs, at 300 K, and two types of deep-level traps that are found in this semiconductor. One of these trap levels is located directly at the midgap position; the other one is located 590 meV below the conduction band (CB).
  - (a) What are impurities? What are native defects? Can deep-level traps be caused by (i) impurities, (ii) native defects, or (iii) both?
  - (b) Which of the two traps (midgap or 590 meV below CB) is more deleterious for the operation of the device?
  - (c) Calculate the ratio of the non-radiative recombination lifetimes associated with the two traps (feel free to assume that the Fermi level of intrinsic GaAs is located at midgap).
  - (d) Assume that the midgap trap results in a non-radiative recombination lifetime of 1 ns. What is the lifetime associated with the traps located 590 meV below the conduction band?
  - (e) Assume that the semiconductor contains only one type of trap, namely the one located 590 meV below the conduction band. Assume further that the radiative lifetime is 10 ns. What is the internal quantum efficiency of the material?
  - (f) Assume that the semiconductor is now heated to 450 K. What is the lifetime associated with the 590-meV trap?
  - (g) What is the internal quantum efficiency of the material at 450 K?
  - (h) What is the internal quantum efficiency of the material at 77 K?
  
2. A 460 nm blue LED is tested in a manufacturing environment by measuring the  $V_f = 9.0$  V at 500 mA. Note that the large forward voltage indicates that there is a problem with the series resistance of the device. The device has an external quantum efficiency of 20%.
  - (a) What is the total optical power emitted by the device?
  - (b) What is the power consumed in the series resistance?
  - (c) What the power dissipated in the active region due to non-radiative recombination?
  - (d) What is the total thermal power dissipated in the device?
  - (e) What is the electrical input power of the device?
  - (f) Assume that the device has a package with a thermal resistance of 25 K/W and assume that the ambient temperature is 20°C. What is the junction temperature (= device temperature)?
  
3. A 300 nm AlGaIn LED, a 360 nm GaN LED, and a 450 nm GaInN LED are tested by a photoluminescence measurement, which uses optical excitation of electron-hole pairs to investigate the optical emission properties of devices. Three laser sources are available for excitation: (i) a frequency-quadrupled Nd:YAG laser emitting at 266 nm, (ii) a He-Cd laser emitting at 325 nm, and (iii) a GaInN-based semiconductor laser emitting at 405 nm.
  - (a) Which laser source(s) is/are suitable for excitation of the 300 nm AlGaIn-based LED?
  - (b) Which laser source(s) is/are suitable for excitation of the 360 nm GaN-based LED?
  - (c) Which laser source(s) is/are suitable for excitation of the 450 nm GaInN-based LED?
  - (d) The blue LED has GaInN quantum wells (QW) emitting at 450 nm and GaN quantum barriers. Which laser source(s) is/are suitable to optically excite only the active QW region of the LED? (Explain)
  - (e) Assume that one uses a 405 nm laser with a power of 1 mW to pump the blue LED. What is the number of incident photons per second?
  - (f) The blue LED has five QWs, each QW having a thickness of 3 nm. Assume that the absorption coefficient of the QW is  $\alpha = 5 \times 10^4$  cm<sup>-1</sup> at 405 nm, how much power is absorbed?
  - (g) What is the number of photons absorbed per second?
  - (h) If this LED emits  $1.0 \times 10^{13}$  photons per second, what is its external quantum efficiency?