系所組別：微電子工程研究所

考試科目：固態電子元件

※ 考生請注意：本試題可使用計算機

1. Consider two energy levels E_1 and E_2 of a material, where E_1 corresponds to the ground state and E_2 corresponds to the excited state. Einstein identified three radiative processes as spontaneous emission, absorption and stimulated emission, expressed by

$$\frac{dn_2}{dt} = -A_{21}n_2 + B_{12}n_1\rho(v) - B_{21}n_2\rho(v) = -\frac{dn_1}{dt}$$

, where n_2 and n_1 are the populations on the energy states of E_2 and E_1. The coefficients of A_{21}, B_{12}, B_{21} correspond to the radiative rates of spontaneous emission, absorption and stimulated emission. In a cavity filled with the material, the electromagnetic energy density at the central frequency of interest ν is

$$\rho(v) = \left(\frac{8\pi n^3 v^2}{c^3}\right)\frac{hv}{e^{hv/kT}-1},$$

where $hv=E_2-E_1$. Using classic Boltzmann statistics $n_2/n_1=exp(-hv/kT)$, find out

(5%) (a) A_{21}/B_{21},

(5%) (b) B_{12}/B_{21}

(10%) (c) Assuming that $\rho(v)$ is provided by an external source, how much is $\rho(v)$ in order to achieve $n_2/n_1=0.5$?

2. (15%) An intrinsic Si sample is doped with doners from one side such that $N_d = N_o \exp(-ax)$
   (a) Find an expression for the build in electric field $\mathcal{E}(x)$ at equilibrium over the range for which $N_d >> n_i$
   (b) Evaluate the $\mathcal{E}(x)$ when $a = 1\ \mu m^{-1}$. (kT = 0.0259 eV at 300 K)

3. (10%) Consider silicon, at T=300 K, doped with boron, we assume that the limit of the Boltzmann approximation occurs when $E_F - E_a = 3$ kT. For boron in Si, the impurity ionization energy is 0.045 eV. If we assume that $E_{Fi} \approx E_{midgap}$, Find the maximum doping at which the Boltzmann approximation is still valid. (For Si, $E_g = 1.12$ eV, use $n_i = 1.5 \times 10^{10}$ cm^{-3} and kT = 0.0259 eV at 300 K)

4. (15%) Please compare the difference of current transport and switching characteristics between Schottky diode and pn junction diode.

5. (15%) Please draw the typical current-voltage characteristics of a p-n-p-n thyristor and explain its operation in forward-blocking, forward-conducting, reverse-blocking, and reverse-breakdown states.

6. (15%) Please describe the possible charges in the oxide and traps at the SiO_2-Si interface in a MOSFET. How do the charges and traps affect the characteristics of a MOSFET?

7. (10%) Please explain the formation of the two-dimensional electron gas in a normally-off modulation doped field-effect transistor (MODFET) when the gate bias is larger than the threshold voltage.