Optical Electronics and Photonic Devices

Final Exam

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Thermal-Equilibrium Spontaneous-Emission Spectral Intensity

Final Exam Problem 1

Constants

```
C = 3e8;                         % Speed of Light in m/s
Eg = 1.42;                       % Bandgap Energy in eV
me = (0.511/C^2)/1e6;            % Electron Mass in eV
me_star = 0.07*me;               % Effective Electron Mass
mh_star = 0.50*me;               % Effective Hole Mass
taur = 100e-9;                   % Radiative Recombination Lifetime in s
hbar = 6.58e-16;                 % Reduced Planck Constant in eV*s
h = 4.14e-15;                    % Planck Constant in eV*s
kb = 8.62e-5;                    % Boltzmann Constant in eV/K
lambda = 700e-9:1e-11:900e-9;    % Wavelength in m
f=C./lambda;                     % Frequency 1/s
T = 200:100:400;                 % Temperature in K
```

Calculation

Calculate the reduced mass

$$m_r = \frac{1}{\frac{1}{m_1} + \frac{1}{m_2}} = \frac{m_1 m_2}{m_1 + m_2}$$

```
mr = (me_star*mh_star)/(me_star+mh_star);
```

$$D_0 \equiv \frac{(2m_r)^{3/2}}{\pi \hbar \tau_r} \exp\left[\frac{-E_g}{k_B T}\right]$$

```
for i=1:size(T,2)
    D0(i) = (((2*mr)^(3/2))/(pi*hbar^2*taur))*exp((-Eg)/(kb*T(i)));
end
```

Photon Emission Rate

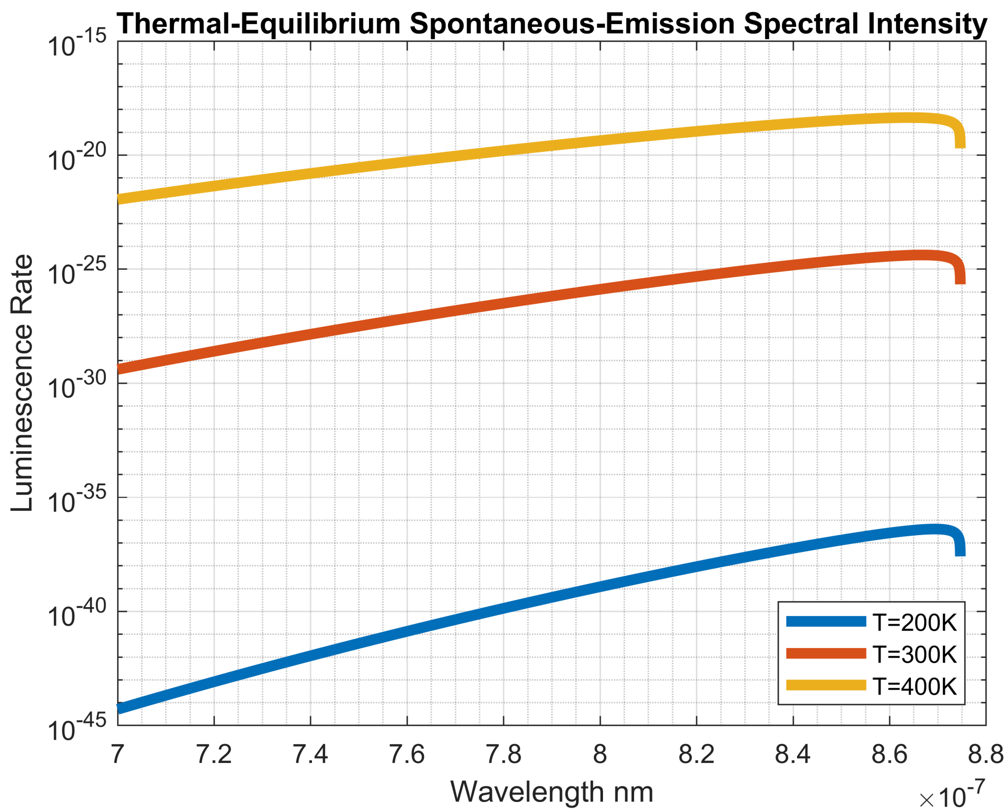
$$r_{\mathrm{sp}}[f] = D_0 \sqrt{\mathrm{hf} - E_g} \exp\left[-\left(\frac{\mathrm{hf} - E_g}{k_B T}\right)\right], \mathrm{hf} \geq E_g$$

```
for i=1:size(T,2)
    for j=1:size(f,2)
        if (h*f(1,j)) >= Eg
            rsp(i,j) = D0(i)*sqrt(h*f(1,j)-Eg)*exp(-((h*f(1,j)-Eg)/(kb.*T(i))));

        end
    end
end
```

Plot the results

```
plot(lambda(1:size(rsp,2)),rsp(1,:),'LineWidth',4)
hold on
plot(lambda(1:size(rsp,2)),rsp(2,:),'LineWidth',4)
plot(lambda(1:size(rsp,2)),rsp(3,:),'LineWidth',4)
legend('T=200K','T=300K','T=400K','Location','southeast')
set(gca, 'YScale', 'log')
grid on
grid minor
title('Thermal-Equilibrium Spontaneous-Emission Spectral Intensity')
ylabel('Luminescence Rate')
xlabel('Wavelength {nm}')
```



Calculate Max and corresponding wavelength

```
for i=1:size(rsp,1)
    [val(i) index(i)] = max(rsp(i,:));
end
fprintf('Peak @ 200K = %g and occurs at lambda = %g\n', val(1), lambda(index(1)));
```

```
Peak @ 200K = 4.08086e-37 and occurs at lambda = 8.6937e-07
```

```
fprintf('Peak @ 300K = %g and occurs at lambda = %g\n', val(2), lambda(index(2)));
```

```
Peak @ 300K = 4.19356e-25 and occurs at lambda = 8.6676e-07
```

```
fprintf('Peak @ 400k = %g and occurs at lambda = %g\n', val(3), lambda(index(3)));
```

```
Peak @ 400k = 4.43552e-19 and occurs at lambda = 8.6416e-07
```

Clear all for problem 2

```
clear all
close all
```

Carrier-Injection Electroluminescence Spectral Intensity

Final Exam Problem 2

Constants

```
C = 3e8;                          % Speed of Light in m/s
Eg = 1.42;                        % Bandgap Energy in eV
me = (0.511/C^2)/1e6;             % Electron Mass in eV
me_star = 0.07*me;                % Effective Electron Mass
mh_star = 0.50*me;                % Effective Hole Mass
taur = 50e-9;                     % Radiative Recombination Lifetime in s
hbar = 6.58e-16;                  % Reduced Planck Constant in eV*s
h = 4.14e-15;                     % Planck Constant in eV*s
kb = 8.62e-5;                     % Boltzmann Constant in eV/K
lambda = 700e-9:1e-12:900e-9;     % Wavelength in m
f=C./lambda;                      % Frequency 1/s
T = 300;                          % Temperature in K
e = 1.602e-19;                    % Fundamental Charge in C
I = [10e-6 100e-6 1e-3];          % Current in A
V = 1;                            % Active Volume in um^3
```

Calculation

Calculate the reduced mass

$$m_r = \frac{1}{\frac{1}{m_1} + \frac{1}{m_2}} = \frac{m_1 m_2}{m_1 + m_2}$$

```
mr = (me_star*mh_star)/(me_star+mh_star);
```

Calculate injected carrier concentration

$$\Delta n = \frac{(I/e)\tau}{V}$$

```
deln = ((I./e).*taur)./V;
```

Estimate difference in quasi-Fermi levels

$$\Delta E_f \approx E_g + (3\pi^2)^{2/3} \frac{\hbar^2}{2m_r} (\Delta n)^{2/3}$$

```
delEf = (3*pi^2)^(2/3)*((hbar^2)/(2*mr));
delEf = delEf.*(deln.^(2/3));
delEf = Eg + delEf;
```

Emission Condition Probability

$$f_e[f] = f_c[E_2](1 - f_v[E_2]) \approx \exp\left[-\left(\frac{\mathrm{hf} - \Delta E_f}{k_B T}\right)\right]$$

```
for i=1:size(delEf,2)
    for j=1:size(f,2)
        if (h*f(j)) >= Eg
            fe(i,j) = exp(-((h*f(j)-delEf(i))/(kb*T)));
        end
    end
end
```

Optical Joint Density of states

$$g[f] = \frac{(2m_r)^{3/2}}{\pi \hbar^2} \sqrt{\mathrm{hf} - E_g}$$

```
for j=1:size(f,2)
    if (h*f(j)) >= Eg
        g(j) = ((2*mr)^(3/2))/(pi*hbar^2)*sqrt(h*f(j)-Eg);
    end
end
```

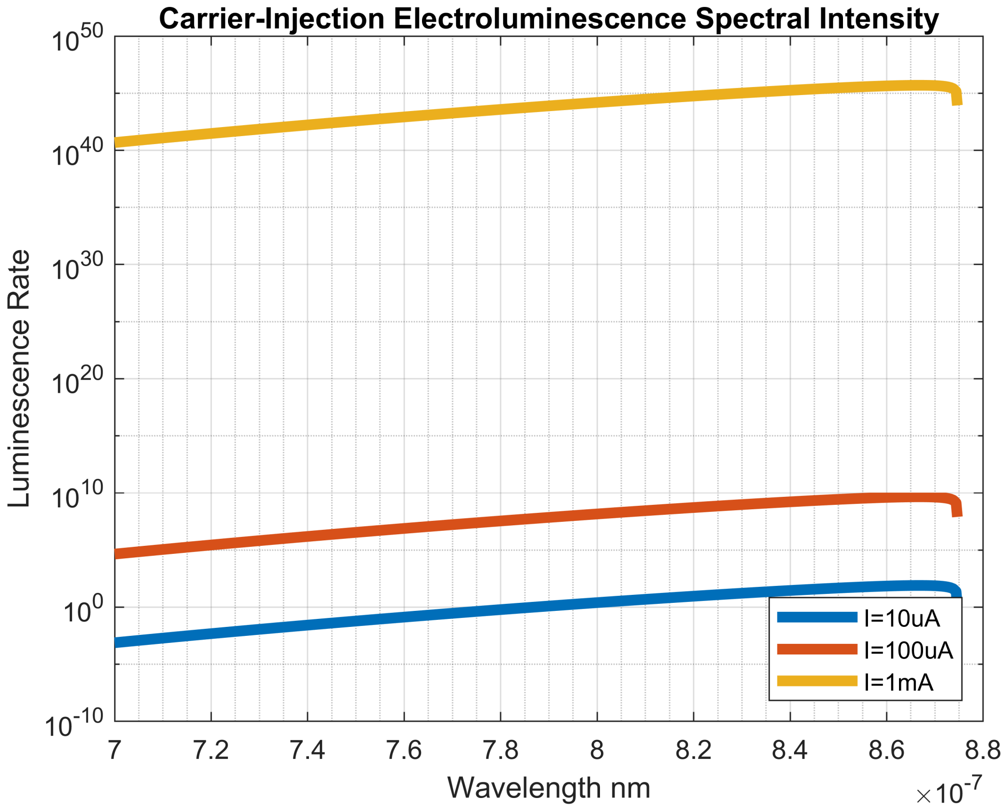
Luminescence

$$r_{\mathrm{sp}}[f] = \frac{1}{\tau_r} g[f] f_e[f]$$

```
rsp = (1/taur).*g.*fe;
```

Plotting Reuslts

```
plot(lambda(1:size(rsp,2)),rsp(1,:),'LineWidth',4)
hold on
plot(lambda(1:size(rsp,2)),rsp(2,:),'LineWidth',4)
plot(lambda(1:size(rsp,2)),rsp(3,:),'LineWidth',4)
legend('I=10uA','I=100uA','I=1mA','Location','southeast')
set(gca, 'YScale', 'log')
grid on
grid minor
title('Carrier-Injection Electroluminescence Spectral Intensity')
ylabel('Luminescence Rate')
xlabel('Wavelength {nm}')
```



Calulate Max and corresponding wavelength

```
for i=1:size(rsp,1)
    [val(i) index(i)] = max(rsp(i,:));
end
fprintf('Peak @ 10uA = %g and occurs at lambda = %g\n', val(1), lambda(index(1)));
```

```
Peak @ 10uA = 79.9307 and occurs at lambda = 8.66756e-07
```

```
fprintf('Peak @ 100uA = %g and occurs at lambda = %g\n', val(2), lambda(index(2)));
```

```
Peak @ 100uA = 4.62246e+09 and occurs at lambda = 8.66756e-07
```

```
fprintf('Peak @ 1mA = %g and occurs at lambda = %g\n', val(3), lambda(index(3)));
```

```
Peak @ 1mA = 4.93887e+45 and occurs at lambda = 8.66756e-07
```