ECE613 / CHE613: Electronic Materials Characterization
Spring 2020
Homework 5
Due at the beginning of class Wednesday June 3rd

Question 1 [12 marks]:

a) Figure 1 shows a schematic diagram of a time resolved microwave conductivity (TRMC) cavity. Consider an experiment carried out on a p-type semiconductor with hole mobility of $\mu_h = 5 \text{ cm}^2/\text{Vs}$, At resonance the standing field has a frequency of $f = 8.0 \text{ GHz}$ and an electric field magnitude of $E_0 = 5 \text{ V/cm}$. Ignoring the effects of thermal diffusion, determine the distance over which you could expect carriers to travel in this experiment, and in what direction. Make a comment on the ability of the TRMC to study charge transport over long distances. [5 marks]

![Figure 1](image1.png)

**Figure 1** Schematic diagram of cavity in time-resolved microwave conductivity experiment. The red line is intended to illustrate the strength of the electric field as a function of position in the cavity.

b) Figure 2(a) shows a cavity sweep from a TRMC experiment, and Figure 2(b) shows the detector voltage measured as a function of time after the sample has been illuminated with light from laser with a fluence of $2 \times 10^{12} \text{ cm}^2$. The data from Figures 2(a) and 2(b) are available to download [here](link) and [here](link) respectively. Assume that the detectors employed in this experiment output a voltage proportional to microwave power. The cavity has a length, width, and depth of $L = 7.62 \text{ cm}$, $W = 2.286 \text{ cm}$, and $D = 1.016 \text{ cm}$ respectively. Assume the cavity is in air, and hence $\varepsilon_r = 1$. The sample absorbs 85% of light that is incident on it at the illumination laser wavelength. From this information determine the representative value of $\phi \Sigma \mu$ for this sample. [7 marks]

![Figure 2](image2.png)

**Figure 2** (a) Cavity reflectivity measured as a function of frequency for the TRMC experiment. (b) Detector voltage as a function of time for a TRMC experiment. The data from Figures 2(a) and 2(b) are available to download [here](link) and [here](link) respectively.
You will need:
- Vacuum permittivity: \( \varepsilon_0 = 8.854 \times 10^{-12} \text{ Fm}^{-1} \).
- Fundamental unit of charge: \( e = 1.602 \times 10^{-19} \text{ C} \).

Question 2 [7 marks]:

a) If a semiconductor has a bandgap of 1.6 eV, what is the longest wavelength of light that can excite a band-to-band transition in this material? Give your answer in nm. [1 mark]

b) We illuminate a 200 nm thick sample with light of optical power density 100 mW/cm\(^2\), and detect a power density of 20 mW/cm\(^2\) transmitted through the sample. If we illuminate another sample of the same material with 100 mW/cm\(^2\) light, but this time detect a transmitted power density of 72.48 mW/cm\(^2\), what is the thickness of this sample? Assume that reflection is negligible in all cases. Give your answer in nm. [2 marks]

c) If we measure a sample of GaAs that is very thick (e.g. 1 \( \mu m \)) we can assume that it exhibits bulk behavior (i.e. band states are not quantized). If we measure a sample of GaAs that is only 5 nm thick however, we expect both the valence and conduction band to become quantized. Using the below equations for the energy of levels in a very thin semiconductor, determine the expected blue-shift in the absorption spectrum when going from a 1 \( \mu m \) thick sample to a 5 nm thick sample. Give your answer in nm. [4 marks]

\[
E_n^{CB} = E_0^{CB} + \frac{n^2 h^2}{8 m_e^* d^2} \\
E_n^{VB} = E_0^{VB} - \frac{n^2 h^2}{8 m_h^* d^2}
\]

Where:
- \( E_n^{CB} \) is the energy of the \( n \)’th quantized energy level in the conduction band.
- \( E_0^{CB} \) is the energy of the conduction band of the bulk semiconductor (i.e. when \( d \to \infty \)).
- \( n \) is the quantum number of the quantized energy state.
- \( h \) is the Planck Constant.
- \( m_e^* \) is the effective mass of electrons in the semiconductor.
- \( d \) is the thickness of the semiconductor.
- \( E_n^{VB} \) is the energy of the \( n \)’th quantized energy level in the valence band.
- \( E_0^{VB} \) is the energy of the valence band of the bulk semiconductor.
- \( m_h^* \) is the effective mass of electrons in the semiconductor.

You will need:
- Planck’s constant is \( h = 6.63 \times 10^{-34} \text{ m}^2\text{kg/s} \).
- The effective mass of electrons in GaAs is \( m_e^* = 0.067 m_0 \).
- The effective mass of holes in GaAs is \( m_h^* = 0.47 m_0 \).
- The rest mass of an electron in a vacuum is \( m_0 = 9.11 \times 10^{-31} \text{ kg} \).
- Band gap of bulk GaAs is \( E_G = 1.424 \text{ eV} \).
- Fundamental unit of charge: \( e = 1.602 \times 10^{-19} \text{ C} \).
- Speed of light in vacuum: \( c = 3.00 \times 10^8 \text{ m/s} \).
Question 3 [6 marks]:
   a) Describe briefly how you could exploit Scanning Electron Microscopy (SEM) to conduct integrated circuit failure analysis. [2 marks]
   b) What use is the information obtained from an electron energy-loss spectroscopy (EELS) experiment? [1 mark]
   c) Imagine you have a very low temperature Auger Electron Spectroscopy (AES) system. With such a system could you carry out an AES experiment on solid hydrogen? Explain why this is the case. [2 marks]
   d) What would be the purpose of including an ion milling gun on a Auger Electron Spectroscopy (AES) system? [1 mark]