Department of Electrical and Computer Engineering
UNIVERSITY OF BRITISH COLUMBIA

EECE 480 Semiconductor Devices: Physics, Design and Analysis.

FINAL EXAM, December 13, 2010

Time: 3 hours
ALL QUESTIONS MAY BE ATTEMPTED.
All questions carry an equal weight of 12 marks, so a score of greater than 50/50 is possible.
Notes and non-programmable calculators are allowed.
Programmable calculators, telecommunications devices and computers are NOT allowed.
This exam consists of 4 pages; the last two of which show data relevant to the exam.

1. Solar Cell

(a) The photon flux penetrating a solar cell can be written as $\Phi = \Phi_0 e^{-\alpha x}$, where α is the absorption coefficient of the semiconductor.
Use this expression to derive a relation ship between Φ_0 and the optical generation rate of electron-hole pairs in the solar cell. Take the internal quantum efficiency to be unity.

(b) Derive an expression for the photocurrent density generated in the space-charge layer (depletion region) of width W due to the absorption of a photon flux of incident value Φ_0.

(c) The space-charge layer in a particular solar cell has a width of $100\,\mu$m, which can be taken to occupy the entire volume of the cell. The cell is illuminated with a monochromatic incident photon flux of $6.25 \times 10^{20}\,\mathrm{m^{-2}s^{-1}}$. The absorption coefficient at the relevant wavelength is $10^5\,\mathrm{m^{-1}}$. Compute the photocurrent density.

2. LED

Consider a $\mathrm{Ga}_x\mathrm{In}_{1-x}\mathrm{N}$ blue LED of cross-sectional area $5 \times 5\,\mathrm{mm}^2$. The p-type active region has a doping density of $10^{16}\,\mathrm{cm^{-3}}$. The LED draws a current of 10 mA when operated at a forward bias of 2.64 V. The excess electron concentration in the active region under these conditions is $10^{19}\,\mathrm{cm^{-3}}$.

(a) If the luminous efficacy of the LED is about 68.3 lm/W, what is the bandgap of the material in the active region of the device?

(b) Evaluate the voltage efficiency of the LED.

(c) Consider the electrons in the active region to have a Maxwell-Boltzmann distribution, with a mean, unidirectional velocity $v_R = 10^5$ m/s. The conduction-band energy barrier between the active region and the P-type confinement region is 0.3 eV. The corresponding barrier for holes at the N-type confinement layer can be taken to be very large. Evaluate the current efficiency.

(d) Evaluate the radiative recombination lifetime in the active region, given that the radiative recombination coefficient B is $2 \times 10^{-10}\,\mathrm{cm^3s^{-1}}$.

(e) If the non-radiative recombination lifetime is 10^{-9} s, evaluate the radiative recombination efficiency.

(f) If the luminous efficiency of the LED is 40 lm/W, evaluate the extraction efficiency.

3. HBT

(a) Sketch the energy band diagram for the active mode of operation of a Np^+n HBT comprising GaAs base and collector regions and an $In_{0.49}Ga_{0.51}P$ emitter.

The band diagram need not be precisely to scale, but the following features should be obvious: the difference between the hetero- and the homo-junctions, the polarity of the applied biases, the positions of the majority-carrier quasi-Fermi levels in the quasi-neutral regions relative to their respective band edges .

(b) Refer to the band diagram and explain why HBTs are capable of having a large current gain β.

(c) Explain why HBTs are able to achieve significantly higher values of $f_{\max}$ than BJTs.

4. MOSFET

Consider a CMOS65 NFET with a gate length of 65 nm, and a poly-Si gate for which $E_F = E_C$.

(a) Why would the SPICE LEVEL 1 model overestimate the drain saturation current for this device?

(b) When operating with the entire channel in strong inversion and with $V_{DS} = 0.20\,\text{V}$, which is less than V_{DSsat}, a linear-linear plot of I_D *vs.* V_{GS} is a straight line with an intercept on the x-axis of 0.44 V.

Use this information to evaluate the actual threshold voltage of the FET.

(c) Calculate the "long-channel" threshold voltage and commment on why it is different from the value computed above in (b).

(d) Over at least the last 25 years the body doping density in MOSFETs has steadily increased. Why is this?

Why is it likely that this trend may be drastically reversed as FETs are further scaled down in size?

5. FLASH memory

Consider a FLASH memory cell with $Z = L = 100\sqrt{10}$ nm, and a top oxide of thickness 18 nm and relative permittivity 3.9. The cell is read with $V_{GS} = 1.25\,\text{V}$. When there is no charge on the floating gate, the threshold voltage is 0.25 V and the drain saturation current is 1 mA. The device can be modeled by the SPICE LEVEL 1 model, with a body-effect coefficient of unity.

(a) Label the mobility-capacitance product term in the current equation as K, and evaluate it.

(b) The cell is intended to store 2 bits of information.

Evaluate ΔI, the minimum change in I_{Dsat} that the sensing circuitry must be able to detect.

(c) Derive an expression for the change in threshold voltage ΔV_T required to cause a change of ΔI in I_{Dsat}.

(d) Compute the number of electrons that have to be injected onto the floating gate to change the stored binary state of the cell from [11] to [10].

	GaAs	$In_{0.49}Ga_{0.51}P$	Si
Electron affinity (eV)	4.07	4.07	4.01
Bandgap (eV)	1.42	1.89	1.12
Relative permittivity	12.9	11.8	11.9
Intrinsic carrier concentration (cm^{-3})			9.5×10^9

Table 1: Some parameter values

Constant	Symbol	Value	Units
Boltzmann's constant	k_B	1.38×10^{-23}	J/K
Dirac's constant	$\hbar$	1.05×10^{-34}	J s
Elementary charge	q	1.6×10^{-19}	C
Electron rest mass	m_0	9.1×10^{-31}	kg
Electron volt	eV	1.6×10^{-19}	J
Permittivity of free space	ϵ_0	8.85×10^{-12}	F/m
Planck's constant	h	6.63×10^{-34}	J s
Speed of light in vacuum	c	3×10^8	m/s
Thermal energy at 300 K	k_BT	0.0259	eV
Thermal voltage at 300 K	V_{th} or k_BT/q	0.0259	V

Table 2: Physical constants

Information on CMOS65 technology:

$V_{DD} = 1.0\,\text{V}$;

$L = 65\,\text{nm}$;

$t_{ox} = 1.7\,\text{nm}$;

$\epsilon_{ox} = 3.9\epsilon_0$;

$N_A = 2.6 \times 10^{18}\,\text{cm}^{-3}$;

$\mu_{\text{eff}} = 600\,\text{cm}^2(\text{Vs})^{-1}$;

$v_{sat} = 9 \times 10^6\,\text{cm/s}$.

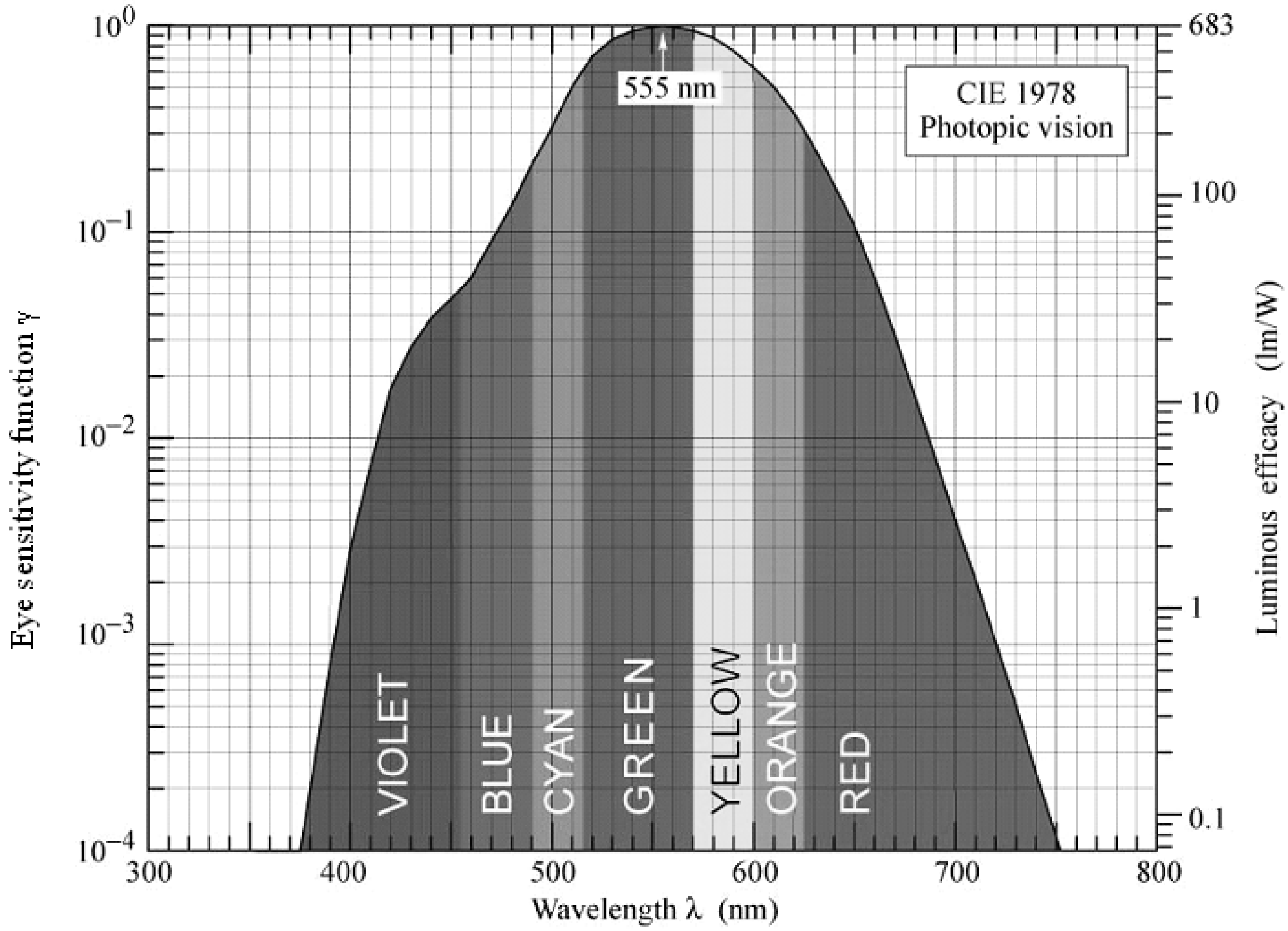

Figure 1: Eye sensitivity function and luminous efficacy. From Schubert, © Cambridge University Press 2006.