Electronic Materials

1. Please explain qualitatively the enormous variation in electrical conductivity of metals, semiconductors, and insulators in terms of their energy band structures. (10 points)

2. Please derive the expression for the resistivity of the semiconductor, ρ, in terms of electron mobility μ_n, hole mobility μ_p, charge q, electron concentration n, and hole concentration p. (10 points)

3. Please prove that at thermal equilibrium, the Fermi level E_F must be constant (i.e., independent of x) at the p-n junction. The expression for hole concentration is:

$$p = n_i e^{(E_i - E_F)/kT}$$

. (10 points)

4. According to Fig. 1, please prove that the total depletion layer width W can be expressed as a function of the built-in potential V_{bi},

$$W = \sqrt{\frac{2\varepsilon_s}{q}\left[\frac{N_A + N_D}{N_A N_D}\right] V_{bi}}$$

for an abrupt junction. (10 points)

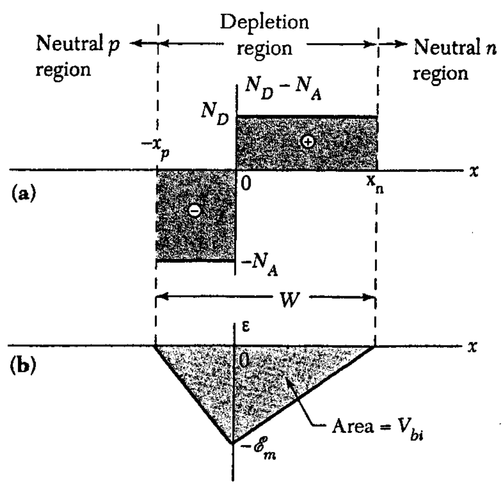


Fig. 1 (*a*) Space charge distribution in the depletion region at thermal equilibrium. (*b*) Electric-field distribution. The shaded area corresponds to the built-in potential.

5. According to Fig. 2, please derive the ideal diode equation for a forward biased p-n junction. (10 points)

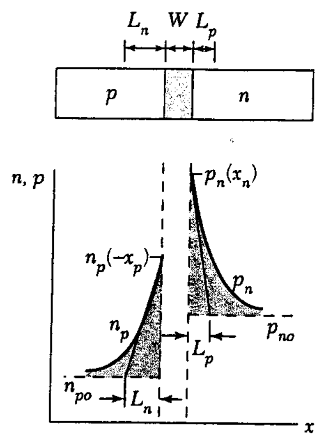


Fig. 2 Injected minority carrier distribution : Forward bias.

Electronic Materials

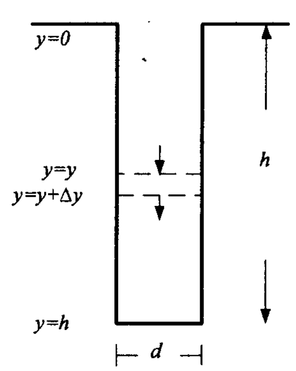
6. · Via is a cylindrical hole of micron or submicron size on semiconductor substrate. Filling a via is a part of back-end engineering in Silicon VLSI technology. One way of filling a via is to use film-forming species in a fluid phase and deposit a conducting film, as illustrated in Fig. 1.

Assume the deposition process is in steady state, first-order surface reaction (reaction constant k_s), diffusion coefficient D, concentration of film-forming species C, and the one-dimensional problem is subject to the following two boundary conditions. Please formulate the diffusion-reaction problem (15%) and solve for the concentration along the via (15%). (Neglect the thickness of depositing mass.)

BC1 $y = 0, C = C_h$

BC2 $y = h, D(dC/dy) = k_sC$

Diffusion and chemical reaction in filling a via



7. When the dopant concentration (As) exceeds the intrinsic carrier concentration, the internal electric field set up by fast-moving electrons can affect the diffusion process. In other words, diffusion of dopant As^{5+} in a Si crystal is driven by both chemical potential and electric field. Therefore, the flux of dopant F_{total} is a combination of the flux driven by a concentration gradient F and the flux driven by the electric field F'.

$$F = -D\frac{\partial C}{\partial x} \qquad (2.1)$$

$$F' = -DC\frac{\partial}{\partial x}\ln\frac{n}{n_i} \qquad (2.2)$$

$$F_{total} = F + F' \qquad , \qquad (2.3)$$

where D is diffusion coefficient, C the dopant concentration, n the electron concentration, n_i the intrinsic electron concentration. Please derive the following equation (2.4). (10%)

$$F_{total} = -DC\frac{\partial}{\partial x}\ln(C\frac{n}{n_i}) \quad (2.4)$$

Furthermore, if charge neutrality and Boltzmann statistics apply, then

$$N_D + p = n \quad (2.5)$$

$$n \times p = n_i^2 \quad (2.6)$$

n, p are electron, hole concentration. N_D is the donor dopant concentration.

Assume that only one donor species exists and completely ionized, so that $N_D = C$. Please derive the following equation. (10%)

$$F_{total} = -hD\frac{\partial C}{\partial x}, \quad h = 1 + \frac{C}{\sqrt{C^2 + 4n_i^2}} \quad (2.7)$$

n_i = constant.

九十五學年度資格考

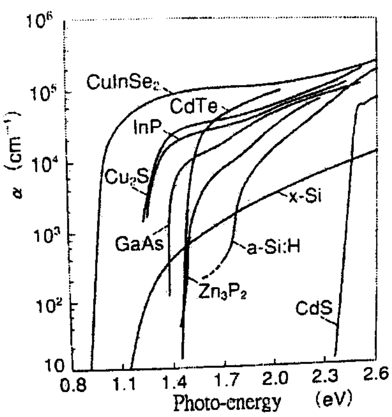
電子材料

1. 試舉出五種常用的電子材料，並說明其功能及應用 （20%）

2. 近年來隨著油價的持續上揚，替代能源的重要性日益增加，其中太陽能電池十分受矚目。而以矽(silicon)為材質的太陽能電池又可分為單晶(single crystalline)矽、多晶(polycrystalline)矽、以及非晶(amorphous)矽三種。

問題一： 試以材料的微結構觀點圖示並說明單晶矽、多晶矽、以及非晶矽的差異。

問題二： 半導體結晶中電子的能量與其動量相關，請由能帶的觀點說明為何結晶矽的光吸收係數(α (cm^{-1}), photo-adsorption coefficient)比砷化鎵(GaAs)晶體的值來得小？又為何非晶矽的光吸收係數會比結晶矽來得大？



問題三：標準的單晶矽太陽能電池常使用 p 型 Si (電洞濃度約 1.5×10^{15} cm^{-3}, resistivity = 1 $\Omega \cdot cm$)為基材，並於其上摻入磷製作一層薄的 n 型層(電子濃度約 1×10^{19} cm^{-3}) ，即形成一 pn 接合(p-n junction)。求此一 pn 接合的內建電位(build-in potential)V_{bi} = ?

問題四：有一單晶矽太陽能電池採用的矽晶片厚度約為 300 μm，其型態為 p 型 Si (電洞濃度約 1.5×10^{15} cm^{-3})。已知少數載子電子的擴散係數 D_n 約為 40 cm^2/sec、擴散長度(diffusion length)為 $L_n = \sqrt{D_n \tau_n}$ ，其中 τ_n 為載子電子的壽命。若此一 p 型 Si 的 τ_n = 100 μsec 時，請問在此一矽晶片內因照光激發產生的電子載子與電洞的再結合(recombination)，是否會嚴重地影響發電效率？為什麼？

問題五：近年由於供需的變化，作為太陽能電池原料使用的多晶矽(solar cell grade Si, SOG-Si)價格急遽上升。現極需於短期內籌畫一生產高純度多晶矽

的工廠。以傳統的製備方法而言，可以價格便宜的冶金級矽砂（純度 98%）為原料，將其在 300℃下與鹽酸氣體(HCl)反應為 $SiHCl_3$，再經純化後，於 1000℃附近的高溫下與氫氣還原而產生多晶矽的析出。請畫出此一生產程序的可能流程圖。（40%）

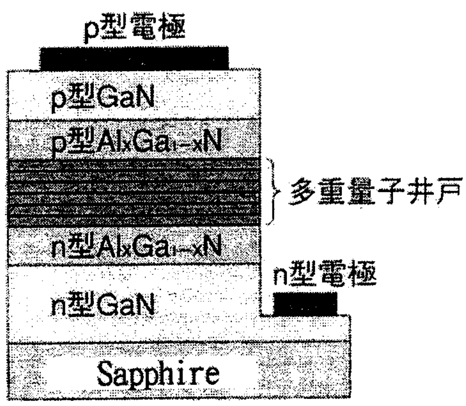
3. 已知 Si 的電子移動度(electron mobility)為 1450 $cm^2V^{-1}s^{-1}$, 而 GaAs 為 8500 $cm^2V^{-1}s^{-1}$ 。請問半導體的載子移動度與什麼物理量相關？又上述的兩個材質何者適合高頻元件的使用？為什麼？又在製作液晶螢幕時，產業的趨勢是要將非晶矽改為多晶矽，其理由為何？（15%）

4. 台灣在發光二極體(LED)的產能已經居世界領導地位，特別是以氮化鎵(GaN)為基礎材質的藍光 LED（結構圖參考圖一）再搭配黃光螢光劑變成發白光，為未來省能源照明的一重要選擇。請就材料觀點解釋下述問題：

問題一： 氮化鎵晶體採纖鋅礦(wurtzite)結晶結構，請問為何可以使用藍寶石(sapphire, α-Al_2O_3) 作為基材(substrate)？

問題二： 美國的 CREE 公司乃採用 SiC 為成長 GaN 的基材。由於 SiC 的熱傳導係數較 sapphire 大許多，請問在 LED 應用上，它的有利點為何？又另又一研發方向是將 SiC 先長在矽基材上，請問在 Si(100)晶面上要磊晶長出 SiC 時，要注意所謂晶格不整合(lattice mismatch)的問題，試解釋之。

問題三： 在 P 型電極與 p-type GaN 層之間，之前是藉一 Ni-Au 的合金薄層來形成歐姆接觸，但最近大都改使用 ITO($InSnO_x$，氧化銦錫)或 ZnO。請問這些氧化物為何會擁有不錯的導電特性？（25%）



圖一、藍光LED發光元件的結構剖面圖