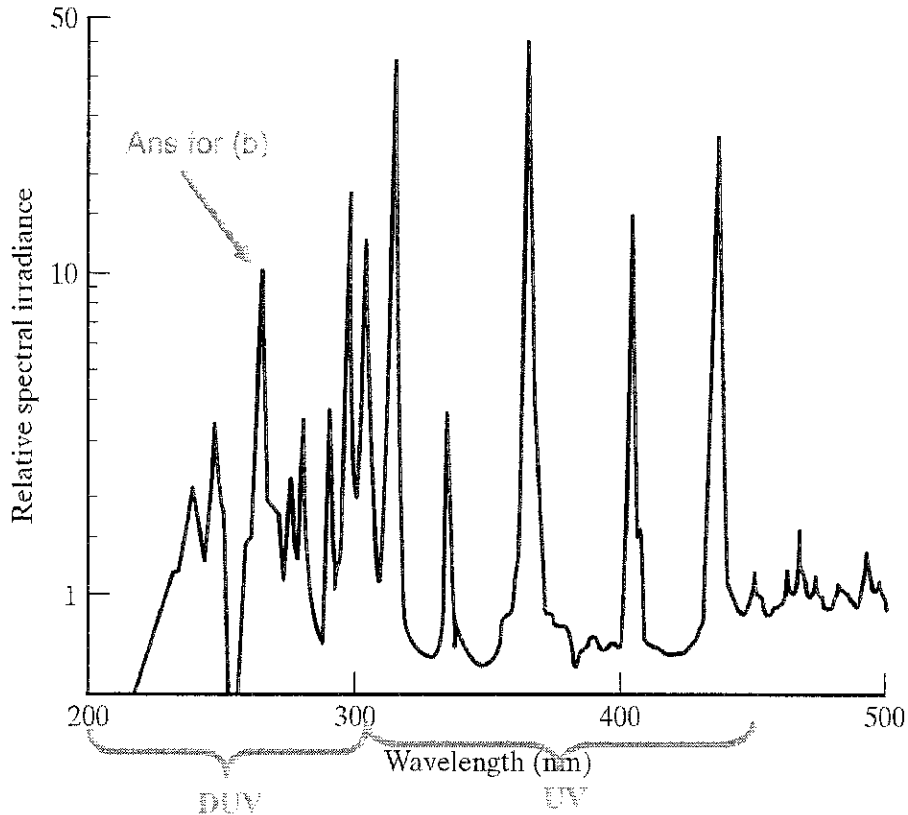


Sol<sup>n</sup> 1 Samir Iqbal

1. Following plot shows a typical spectral content of a lamp used for optical lithography.



- (a) Identify the DUV and UV regions on the plot? (10 points)  
 (b) What wavelength of the lamp output should be most suitable for the 250 nm technology and below? (10 points)

Ans:  $\approx 265$  nm

- (c) Considering  $NA \geq 0.5$  and using phase-shifting mask, what minimum feature size can be achieved with the wavelength of question (b)? (15 points)

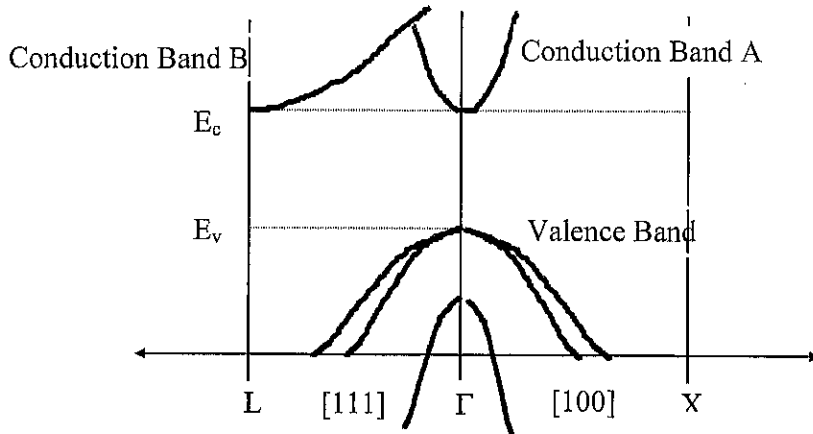
Ans:  $265 \times 0.5 = 132.5$  nm

- (d) What would be expected depth of field for this system? (15 points)

Ans:  $DF = 0.6 \frac{\lambda}{NA^2} = 0.6 \times \frac{265}{0.5^2} = 0.6 \times \frac{265}{0.25} = 6 \times \frac{265}{2.5} = 6 \times \frac{53}{0.5} = 12 \times \frac{53}{1} = 636$  nm

sol<sup>n</sup> 2 Don Butler

2. Congratulations, you have just discovered a new semiconductor, "utaium" which has a cubic crystal structure. The E-k relationship is shown in the figure below. The conduction bands "A" and "B" have the same energy minima  $E_c$ .



- Draw the constant energy surface(s) for electrons near the conduction band minima in k-space.
- Given the following inverse effective mass tensor data measured by cyclotron resonance at 4 K. Calculate the density of states effective mass for the conduction band,  $m_n^*$ .

Conduction Band A

$$\frac{m_o}{m^*} = \begin{bmatrix} 5 & 0 & 0 \\ 0 & 5 & 0 \\ 0 & 0 & 5 \end{bmatrix}$$

$$m_o = 9.1 \times 10^{-31} \text{ kg}$$

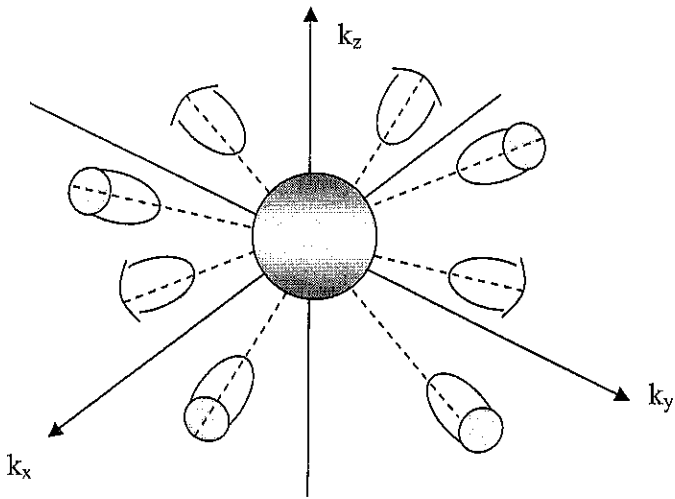
Conduction Band B

$$\frac{m_o}{m^*} = \begin{bmatrix} 0.05 & 0 & 0 \\ 0 & 0.2 & 0 \\ 0 & 0 & 0.2 \end{bmatrix}$$

- Given the effective mass data for the valence bands are  $m_{hh} = 0.347m_o$ ,  $m_{lh} = 0.0429m_o$ , and  $m_{so} = 0.077m_o$ ; determine the density of states effective mass for holes in the valence band  $m_p^*$ .

Assume parabolic constant energy surfaces at the band minima.

Note: The volume of a prolate spheroid is  $\frac{4 \pi a b^2}{3}$  where 2a and 2b are the lengths of the major and minor axes respectively of the rotated ellipse.



a) 8 half ellipsoids along  $\langle 111 \rangle$  and one sphere centered at  $k=0$

b)

Conduction Band B - ellipsoidal constant energy surface, anisotropic effective mass

$$m_l := \frac{1}{0.05} \cdot m_0 \quad \frac{m_l}{m_0} = 20$$

$$m_t := \frac{1}{0.2} \cdot m_0 \quad \frac{m_t}{m_0} = 5$$

$$N_{el} := 8 \cdot \frac{1}{2} \quad N_{el} = 4$$

$$m_B := N_{el}^{\frac{2}{3}} \cdot \left( m_l m_t^2 \right)^{\frac{1}{3}} \quad \frac{m_B}{m_0} = 20 \quad m_B = 1.82 \times 10^{-29} \text{ kg}$$

Conduction Band A - spherical constant energy surface with minima along [111] direction, half in the first Brillouin zone.

$$m_A := 0.2 m_0 \quad m_A = 1.82 \times 10^{-31} \text{ kg}$$

$$m_n := \left( m_A^{\frac{3}{2}} + m_B^{\frac{3}{2}} \right)^{\frac{2}{3}} \quad \frac{m_n}{m_0} = 20.013 \quad m_n = 1.821 \times 10^{-29} \text{ kg}$$

c)

$$m_{hh} := 0.347m_0$$

$$m_{lh} := 0.0429m_0$$

$$m_{so} := 0.077m_0$$

Ignore the splitt-off band

$$m_p := \left( m_{hh}^{\frac{3}{2}} + m_{lh}^{\frac{3}{2}} \right)^{\frac{2}{3}} \quad \frac{m_p}{m_0} = 0.357$$

$$m_p = 3.249 \times 10^{-31} \text{ kg}$$

Sol<sup>n</sup> 3

Don Butler

3. Crystalline silicon has a lattice constant of 5.43095 Å and an atomic weight of 28.09 gm/mole.
- a) What is the Bravais lattice of Si? **Face-centered cubic**
  - b) What is the crystal structure of Si? **Diamond Lattice**
  - c) What is the crystal system of Si? **Cubic**
  - d) What are the symmetry properties of Si? **Four 3-fold rotation axes**
  - e) How many atoms are there per unit cell? **8**
  - f) What is the mass density of Si?

$a := 5.43095 \cdot 10^{-8} \text{ cm}$  lattice constant

$m_{\text{Si}} := 28.09 \frac{\text{g}}{\text{mole}}$  atomic weight

Avagadros number  $N_A := 6.022 \cdot 10^{23} \frac{1}{\text{mole}}$

Volume  $\text{Vol} := a^3$  Vol =

8 atoms/unit cell, therefore the number density  $N := \frac{8}{\text{Vol}}$   $N = \text{cm}^{-3}$

Mass density  $\rho := \frac{N \cdot m_{\text{Si}}}{N_A}$   $\rho = \frac{\text{g}}{\text{cm}^3}$