Exercise Sheet 4

MBE provides some interesting applications of the kinetic theory of gases. Some of the standard formulas will be given here and applied to MBE. The flux of molecules onto a surface (the number of molecules striking unit area in unit time) is given by $F = \frac{1}{4}n\bar{c}$, where n is the number density of molecules (number per unit volume) and $\bar{c}$ is their mean velocity. Pressure, number density, and temperature are related by the ideal gas law, which in microscopic terms reads $p = nk_BT$. The average velocity is related to the thermal energy by $\frac{1}{2}mc_{rms}^2 = \frac{3}{2}k_BT$, where c_{rms} is the root-mean-square velocity. This is related to the mean velocity by $\bar{c} = \sqrt{\frac{8}{3\pi}}c_{rms}$. Combining these equations gives the familiar result $p = \frac{1}{3}nmc_{rms}^2$.

Use these results to find out how long a surface in UHV remains clean, before a monolayer is deposited on it from the background gas. first, calculate the flux F_{bg} of background gas onto the substrate, assuming that H_2 is the dominant species. Only a fraction ζ, the sticking coefficient, of the incident atoms adhere to the surface. Estimate t_{bg}, the time taken to coat the surface with a monolayer. Assume that $\zeta = 1$ (a very pessimistic assumption) and that the background gas is at a pressure of $5 * 10^{-11}$ mbar and room temperature $T_{bg} = 300$ K.

Estimate the growth rate, assuming that growth is limited by the supply of Ga, whose pressure in the K-cell is about $5 * 10^{-4}$ mbar at $T_{Ga} = 900$ C. The preceding formulas can be used to find the flux F_{Ga} of Ga atoms at the mouth of the K-cell, whose radius A≈ 10 mm. If the substrate is at a distance R≈ 200 mm from the K-cell, the flux is spread over a hemisphere of area $2\pi R^2$ but is double the average value in the forward direction. Hence find the time t_{ML} to grow a monolayer. It is also instructive to convert this to the time to grow a thickness of 1 μm.

Estimate the degree of contamination in the grown material simply as $\frac{t_{ML}}{t_{bg}}$ (although hydrogen is not a realistic material to consider as a contaminant). Good material needs this fraction of impurities to be well below 10^{-6}, so it is as well that the assumption $\zeta = 1$ is pessimistic!

Verify that the mean free path L is much greater than the size of the apparatus. If the molecules have diameter d, they will hit all other molecules in a volume $\pi d^2 x$ while travelling a distance x. On average they hit one other molecule when travelling one mean free path, so $\pi d^2 Ln = 1$. Estimate L both for the background gas and for the molecular beams, using the foregoing conditions.

Hydrogen atomic radius(r_H) $= 25 * 10^{-12}$ m.
Gallium atomic radius(r_{Ga}) $= 135 * 10^{-12}$ m.
Atomic mass unit(amu) $= 1.66 * 10^{-27}$ kg.
Hydrogen atomic mass(m_H) $= 1$ amu.
Gallium atomic mass(m_{Ga}) $= 70$ amu.
Boltzmann Constant (k_B) $= 1.38 * 10^{-23}\ JK^{-1}$.