ME-351 THERMODYNAMICS AND ENERGETICS II

SPRING 2025

QUESTION 1

The equation of state for a Van der Waals gas is

$$\left(p + \frac{a}{V^2}\right)(V - b) = RT$$

where a and b are constants. Derive expressions for $\left(\frac{\partial p}{\partial T}\right)_V$ and $\left(\frac{\partial U}{\partial V}\right)_T$

QUESTION 2

Prove the following relations:

1. $\left(\frac{\partial H}{\partial p}\right)_T = -TV\beta + V$
2. $\left(\frac{\partial H}{\partial T}\right)_p = C_p$
3. $\left(\frac{\partial G}{\partial T}\right)_V = \frac{V\beta}{\kappa} - S$
4. $\left(\frac{\partial S}{\partial p}\right)_V = \frac{C_p\kappa}{T\beta} - V\beta$
5. $T\left(\frac{\partial^2 p}{\partial T^2}\right)_V = \left(\frac{\partial C_V}{\partial V}\right)_T$

You may find the following definitions of response functions useful:

- $C_v = T\left(\frac{\partial S}{\partial T}\right)_V$
- $C_p = T\left(\frac{\partial S}{\partial T}\right)_p$
- $\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_p$
- $\kappa = -\frac{1}{V}\left(\frac{\partial V}{\partial p}\right)_T$

QUESTION 3

Epitaxially grown thin films are extensively used in solid-state electronic devices. Techniques such as physical vapor deposition, chemical vapor deposition etc. can be used to epitaxially grow thin films on large substrates. The epitaxial growth constrains the lattice parameter of the thin film to be equal to the lattice parameter of the substrate. You can think of the epitaxial growth of thin films as one mechanism of experimentally controlling the strain applied to a material along the x and y directions as indicated below in fig. 1. The thin film is kept within an environment that is at constant temperature (T), pressure (p) and electric field ($\vec{E}$).

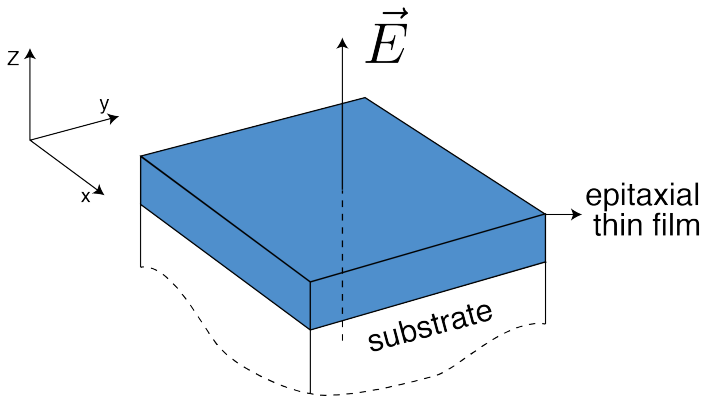

Figure 1

1. What are the thermodynamic state variables of the film that we can experimentally control?

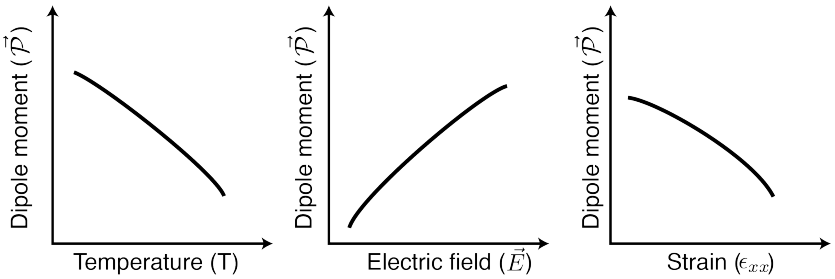

Figure 2

2. Write down an expression for the characteristic potential and equations of state of the film.
3. The thin film is grown such that it is under tensile stress along the x axis. You are worried that as you increase the electric field applied on the film, the internal stress within the film σ_{xx} may increase beyond the critical fracture stress. Based on the measurements shown in fig. 2, should you be worried about the film developing internal cracks?