6.730 PHYSICS FOR SOLID STATE APPLICATIONS

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PROBLEM SET 3

Issued: 2-22-02 Due: 3-01-02, at the beginning of class.

Readings: PSSA Chapter 4 and 5

Problem 3.1 *Lattice Mismatched Epitaxy*

An epitaxial layer of a cubic semiconductor with lattice constant a_{epi} is grown on a substrate that has a lattice constant a_S. If the two lattice constants are near each other, the strain can be coherent. Then the lattice constant of the epitaxial layer along the interface is equal to the lattice constant of the substrate as shown below.
The epitaxial layer is biaxially strained $E_{xx} = E_{yy}$ in the plane of the substrate by an amount $E_\parallel$ and uniaxially strained in the growth direction along the z axis by $E_{zz} = E_\perp$.

(a) Argue why $E_\parallel \approx \frac{a_S}{a_{\text{epi}}} - 1$ for the [001] growth.

(b)Explain why there is not any stress in the growth direction. Find E_{xx}, E_{yy}, E_{zz}, E_{yz}, E_{zx}, E_{xy} in terms of $E_\parallel$ and $E_\perp$.

If $E_\perp = -E_\parallel/\nu$, what is the Poisson ratio ν in terms of the material's elastic Lame constants?

(c) Find e the volume contraction in terms of $E_\parallel$ and the Lame constants.

(d) The elastic energy is given by

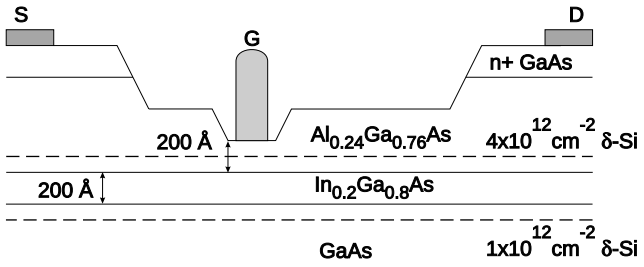
$$W = \int dv\ (E_{xx}T_{xx} + E_{yy}T_{yy} + E_{zz}T_{zz} + E_{xy}T_{xy} + E_{zx}T_{zx} + E_{yz}T_{yz})$$

Show that

$$W = V\frac{\mu(3\lambda + 2\mu)}{\lambda + 2\mu}E_\parallel^2 = V\frac{E_Y}{1-\nu}E_\parallel^2$$

where V is the volume, and E_Y is Young's modulus.

(d) One application of lattice mismatched epitaxy is the fabrication of pseudomorphic high electron mobility transistors (pHEMTs). In these devices, a thin channel of strained $In_{0.2}Ga_{0.8}As$ is grown on a GaAs substrate, as shown in the cross-section below. $In_{0.2}Ga_{0.8}As$ has a relaxed lattice constant of 5.7254 Å. If the stiffness coefficients of $In_{0.2}Ga_{0.8}As$ are the same as for GaAs, what is the elastic strain energy per bond in the channel layer? (Hint: Take the volume to be the a cubic unit cell and count the bonds.) Also, assume that $E_Y \approx C_{11}$ and $\nu \approx C_{12}/C_{11}$.



Typical pHEMT cross-section.

(e) Do the same calculation for Ge grown on a Si substrate. Why doesn't one make Si/Ge pHEMTs?

	a[Å]	C_{11}	C_{12}	C_{44}
GaAs	5.6419	118	54	60
Si	5.4309	166	64	80
Ge	5.6461	129	48	67

The elastic constants are in units of GPa.

Problem 3.2 *2D Crystal Structure Former Quiz Problem*

There is a two-dimensional array of idenitical atoms (see plot on the last page). Using various sections of the drawing on the last page, indicate the following:

(a) The primitive translations of the lattice.

(b) The basis for the periodic structure.

(c) The Wigner-Seitz unit cell.

(d) The primitive translations of the reciprocal lattice.

(e) The first Brillouin Zone.

Turn in the attached page with your homework.