Solutions EEE402 / EEE6042.

1(a). Sheet resistance of a thin conducting layer $Rs = \rho/t$ **, where**

$\rho = 1/\sigma$ ohm.cm is the resistivity of the material , σ is the conductivity and t is the thickness.

A conducting thin rectangular layer of length (in the direction of current flow) L and width W has a resistance R=Rs(L/W) ohms.

The ratio L/W is termed the number of squares (sq) of width W

Rs units termed ohms/sq. (**2 marks**)

Two methods of measuring sheet resistance are :

(i) Four Point Probe (diagram).

Current I is injected into the outer probes and voltage is measured across the inner probes. Rs=Kp(V/I) where Kp is a constant depending upon the configuration of probes and sample. Kp=π/ln2=4.53 if the film is effectively infinite in all directions. (**1 mark**)

(ii) Van der Pauw 'cross' sample (diagram).

Contacts 1, 2, 3, 4 in sequence around the patterned square

Rs=Kp (V34/I12). (**1mark**)

(b). The optical absorption spectra of the two bandgap materials differ. In the case of direct bandgap, the onset is sharp. In the case of indirect bandgap, the absorption edge is not sharp. Lattice phonons are required for absorption. (**1 mark**)

(Figures). (**2 marks**)

© A semiconductor bar carrying a current (voltage V_x along length L_x) perpendicular to a magnetic field (B_y) develops a voltage (the Hall voltage V_H) at right angles to both across the width of the bar (L_z). (**1 mark**)

(Diagram). (**1 mark**)

(d) Any four of: Monoclinic, triclinic, orthorhombic, cubic, tetragonal, hexagonal, trigonal.

(2 marks)

(e) Consider a unit cell in the diamond cubic lattice.

The unit cell is a cube – 90E internal corners and equal length edges.

The cell edge length a0 – the lattice parameter.

Miller indices relate to an x, y, z coordinate system along the edges of the unit cell.

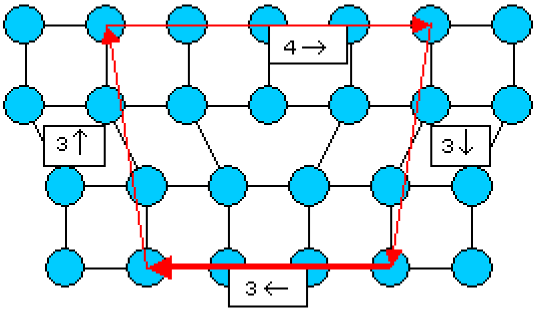
A plane intersects these coordinates at three points: p(x), q(y) and r(z)

The miller indices of the plane are h=1/p,k=1/q and l=1/r.

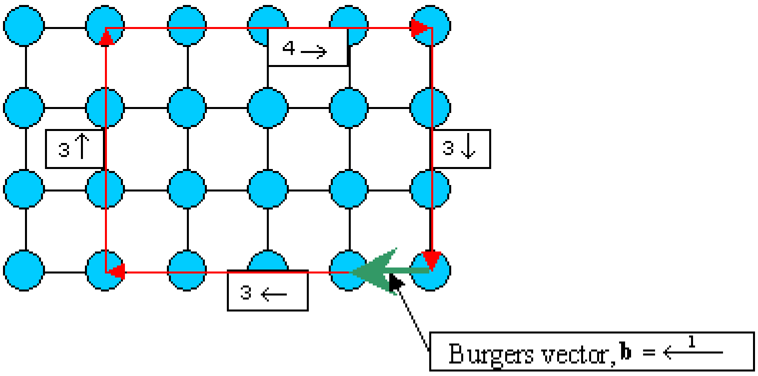
h,k,l must be multiplied upto integers. **(3 marks)**

(f) The Burgers vector of a dislocation is a crystal vector, specified by Miller indices, that quantifies the difference between the distorted lattice around the dislocation and the perfect lattice. Equivalently, the Burgers vector denotes the direction and magnitude of the atomic displacement that occurs when a dislocation moves. (1 mark)

To determine the Burgers vector of a dislocation in a two-dimensional primitive square lattice, trace around the end of the dislocation plane to form a closed loop. Record the number of lattice vectors travelled along each side of the loop (shown here by the numbers in the boxes):



In a perfect lattice, trace out the same path, moving the same number of lattice vectors along each direction as before. This loop will not be complete, and the closure failure is the Burgers vector:



(**2 marks**).

If diagrammatic explanation is consistent without any text, this will also merit 3 marks.

1g). Transition elements Cu, Fe, Ni, Au are unwanted impurities. **(1 mark**)

They introduce deep states in the bandgap, they may lead to unwanted silicide precipitate formation. These lead to device instabilities, deviation of characteristics from design, sometimes failure of device technology. **(1 mark)**

The name of the technique to remove these impurities is called "gettering". **(1 mark)**

Q2(a) The three generic designs of a CVD reactor are (i) radiant barrel (ii) vertical barrel and (iii) horizontal barrel. (DIAGRAMS) (**3 marks)**

The susceptor holds the substrate and is graphite coated with SiC: unreactive to gases and contaminants**.** **(1 mark)**

2(b) Several types of reaction involving Si-containing gases flowing over a heated substrate are possible.

- Most important is the hydrogen reduction of silicon tetrachloride, which takes place on a heated surface

  $SiCl_4 + 2 H_2 \rightarrow Si + 4 HCl$

- Deposited Si atoms run around on a substrate and join steps at the edges of growing crystal planes extending across the surface
- The deposition temperature is generally in the range ~800-1200 C in order to give high quality, single crystal si layers, with good thickness uniformity at deposition rates in the range ~0.01-5 μm/min.
- Prior to deposition, substrates would typeically be given a vapour etch with flowing HCl or a bake in H_2 gas to clean their surfaces.

  Criteria for growth

  - Gas flow in the chamber must be very uniform to give layer thickness uniformity on each of the substrate wafers.
  - Autodoping must be avoided.
  - Residual contamination present on substrate before epitaxy lead to stacking faults or pyramidal hillocks.
  - Non uniform heating leads to slip and dislocations.

MOCVD.

- Growth process involves interaction between group III and group V species on the heated substrate surface after they diffused across a stagnant gas boundary layer.
- Group V precursor present in excess to compensate high volatility of element and to inhibit carbon incorporation.

- Growth characteristics.
- Growth rate is controlled by group III precursor concentration.
- Growth rate is little affected by group V precursor concentration.
- Growth rate depends upon the temperature in three regimes.
    - Increase at low temperatures due to speeding up of reaction kinetics
    - Intermediate regime limited by diffusion across boundary layer
    - Decrease at high temperatures due to desorption of group V elements.

10 marks

2(c) Requirements of reagent materials in MOCVD reactor.

- High volatility makes possible high layer growth rates
- Low tendency to decompose homogeneously
- Should eliminate carbon as completely as possible when cracking upon the substrate surface
- Should be available in high purity. **4 marks**

2(d) Sources: Arsine (AsH_3), phosphine (PH_3), diborane (B_2H_6), Trimethylgallium, trimethylindium, trimethylaluminium. **2 marks**

3(a) Diagrams of compressive and tensile pseudomorphic layers required. **2 marks**

- When the lattice parameters of the deposited layer and the underlying crystal cannot be accurately matched, the interface is then lattice mismatched.
- If the lattice mismatch is relatively small <1.5%), the growing layer can first adopt the in-plane lattice parameter of the crystal substrate.

    - However, the small difference in lattice parameter results in a tetragonal distortion of the unit cells in the growing layer
    - If the growing layer is compressed in-plane, the lattice constant normal to the plane increases slightly.
    - If the growing layer is stretched in-plane, the lattice constant normal to the plane decreases slightly.
- Such epitaxial layers are described as pseudomorphic. **3 marks**

Pseudomorphic layers can be grown only up to a certain thickness, due to the increasing excess energy stored in the distorted lattice.

- Above this critical thickness, defects are introduced into the layer
    - These are often dislocations which may glide into the heterointerface to relieve the misfit and induce relaxation
    - With a certain density of dislocations at the interface, the deposited layer can return to its equilibrium cubic lattice geometry.
- For layers above the critical thickness, dislocations can be introduced into the heterointerface by a number of different mechanisms
    - Pre-existing threading dislocations are forced to bend over into the interface, whereupon they extend across the layer
    - The edge componenets of the Burgers vectors in the interface relax the strain-Matthews and Blakeslee mechanism
    - If there are any inhomogeneities in the layer (precipitates, etc), local strain can produce dislocation loops which expand into the interface
    - –so called secondarysources.
- If the lattice mismatch is relatively large (>1.5%), the sign of the lattice distortion determines the outcome
    - If the grown layer is under tension, it is likely to behave simply as already described.
    - If the grown layer is under compression, it will become morphologically distorted
    - As layer growth proceeds, after a small number of uniform monolayers, there is often a transition to the growth of isolated, small islands (a Stranski-Krastanow transition)

- Islands can be exploited as quantum dots in eg laser cavities
- Further growth leads to island overlap and the formation of undulating, wavy continuous layers
- Islands and undulations are produced because lateral dilatation of the lattice in the growth crests (which are unconstrained) lowers the strain energy of the system.
- Ultimately, for sufficiently thick grown layers, array of misfit-relieving dislocations will be introduced. **(5 marks)**

3b) The initial As concentration in the crystal is : 0.01x0.3%=0.003%.

If C_0 is the initial concentration of the impurity in the melt, C_s is the final concentration of the impurity in the crystal, x is the fraction of melt solidified and k_0 is the impurity segregation coefficient, then,

$C_s=k_0C_0(1-x)^{k_0-1}$.

Therefore, with Cs=0.09

$(1-x)^{k_0-1}=C_s/k_0C_0$

$(1-x)^{-0.7}$=0.09/0.3x0.01

=0.09/0.003=30

1/1-x=128.8757

1-x=0.0077

x=99.22% = required fraction of melt solidified.

3c) Key methods of implementation of a silicon oxide:

1. Thermal oxide, carried out in a furnace 900-1200 C.

   Dry oxidation: Si+ O2 -> SiO2

   Wet oxidation: Si + 2 H2O=SiO2 + H2.

2. Deposition of insulating layers

   Chemical Vapour Deposition of SiO2

   - APCVD with high deposition rates at relatively low temperatures

- LPCVD with larger molecule mean free path giving better layer uniformity and step coverage and purity. This is also higher temperature deposition and lower deposition rates.
- PECVD giving fast deposition rates at low temperatures giving some chemical and particulate contamination.

Films are formed by the pyrolytic oxidation of alkoxysilanes (TEOS)

Or by the ractio of silane with oxygen

$SiH_4 + O_2 \rightarrow SiO_2 + 2H_2$.

Critical issues with oxides:

Gate oxide integrity (should withstand electric field), and is adversely affected by roughness/non-uniformities of oxide thickness and pre-existing particles in oxide.

4a) Operating advantages and disadvantages of CMOS versus bipolar.

CMOS: Greatly reduced power consumption, enhanced Soft error immunity.

Bipolar: Very high speed logic and RF applications in eg telecoms area offer high switching speeds than CMOS but occupy larger si area and consume power. **3 marks**

b) Active Area is defined by the Field Oxide growth, LOCOS (Local oxidation of silicon) is growth of a thick oxide layer for isolation between devices, Threshold adjust implant is needed to raise the threshold of parasitic MOS devices, across the field oxide, so that they do not become active during operation.
3 marks

c) Methods of etching insulating films: Wet chemical etching, dry etching.

Etch characteristics:

Dry etching characterised by high selectivity and pronounced directional etching ability. (Favoured due to dimensional accuracy).

Comparison: wet chemical etch dissolves exposed oxide in an isotropic manner and progressively undercuts the resist.

RIBE is highly anisotropic and produces parallel-walled etched regions with dimensions closely similar to those of the original resist patterns. **4 marks**

d) Salicide process: Self aligned silicide process. Silicidation is the method to reduce contact resistivity of junctions. Typical silicides are Ti and Co. **2 marks**

e) Diffusion coefficient (D) = D_0 exp [-E_A/kT]

At 1000 C (1273K) D=0.76 * exp –[3.46/(8.62x10^{-5}x1273)] cm^2/s

=0.76* exp – [3.46/0.10973]

=0.76 exp (-31.53119) = 1.53x10^{-14} cm^2/s.

For 60 s, the characteristic diffusion length $2\sqrt{Dt}$ =1.9x10^{-6} cm=1.9 µm.

Since the growth rate is 0.5µ/min, this diffusion length is much larger and autodoping would be a serious factor.