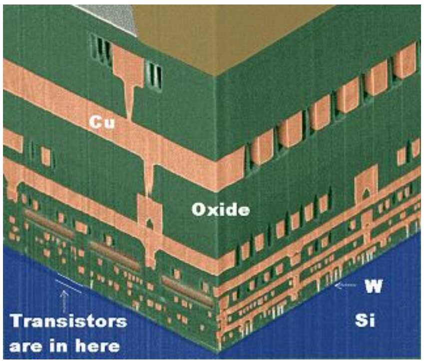
3.6 Summary

3.6.1 Summary to: 3. Thin Films

- Semiconductor technology is almost synonymous with thin film technology.
  - A thin film is always adhering to a substrate and (at least originally) continuous.
  - Thin films may still be found in the product or may have been "sacrificed" during the making of the product.
  - An **IC** is a study of thin films in and on the **Si** substrate.
  - The same is true for pretty much every semiconductor product.



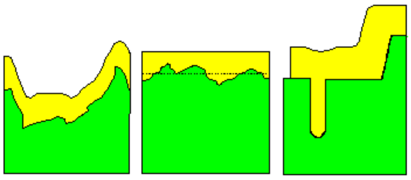
- Thin always means "thin" relative to some intrinsic (internal) length scale. Examples are:
  - Structural length scales.
  - Wavelength and Interaction length scales.
  - Transport parameter length scales.
  - Electrical scales.

- Dimensions $d_{x, y, z}$
- Grain size d_{grain}
- Lattice constants a_0
- λ radiation (light, **IR**, **UV**)
- Absorption depths
- Mean free path lengths.
- Diffusion length

- **SCR** width d_{SCR}
- Debye length d_{Debye}
- Critical thickness d_{crit} for electrical break down
- Critical thickness d_{tu} for tunneling

- There are many thin film applications outside of semiconductor technology:
  - Optical, electrical, chemical, mechanical, magnetic technologies use thin films.

- Thin films have other spatial properties besides their thickness.
  - Interface roughness and surface roughness ***R*** defined by their "root mean square":



$$R = \frac{1}{N}\sum_{i=1}^{N}|z_i|$$

- Thin films adhere to their substrate.
  - A direct measure of adhesion is the interfacial energy γ_{AB} between film **A** and substrate **B**.
  - The phase diagram provides some guideline. Complete miscibility=good adhesion, (eutectic)) decomposition=(?) low adhesion. Calculations of γ are difficult.
  - Full adhesion can only be obtained for films grown on a substrate. Adhesion energies can be measured.

- Generally, there will be stress σ and strain ϵ in a thin film and its substrate.
  - A major source of strain is the difference of the thermal expansion coefficients α.

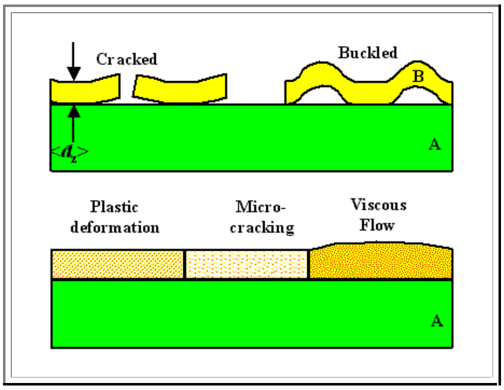
Stress and strain in thin films can be large and problematic!

$$\epsilon_{TF} = \Delta T \cdot \Delta\alpha$$

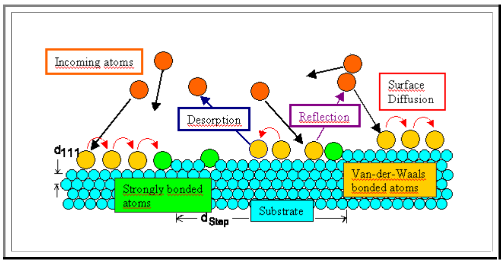
$$\sigma_{TF} = Y \cdot \Delta T \cdot \Delta\alpha$$

- Stress in thin film may relax by many mechanisms, and this might be good or bad:
  - Cracking or buckling.
  - plastic deformation.
  - Viscous flow.
  - Diffusion.
  - Bending of the whole system (Warpage).

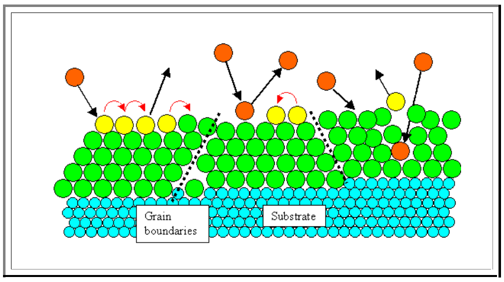
  - Warpage can be a serious problem in semiconductor technology.



- Deposition of a thin layer must start with a "clean" substrate surface on which the first atomic / molecular layer of the film must nucleate.
- There are many possible interactions between the substrate and "first" incoming atoms.
  - As the interaction energy goes up we move from "some" absorption to physisorption (secondary bonds are formed) to chemisorption (full bonding)
  - The sticking coefficient is a measure of the likelihood to find an incoming atom in the thin film forming.
  - Immobilization by some bonding is more likely at defects (=more partners). The initial stage of nucleation is thus very defect sensitive.

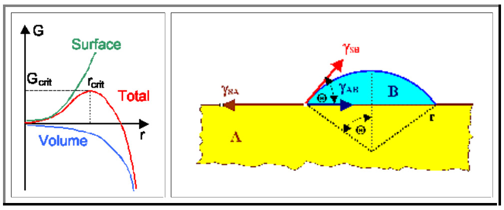


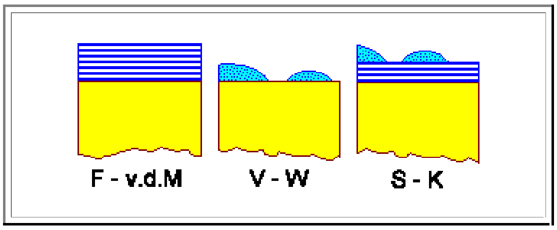
- Simple surface steps qualify as efficient "defects" for nucleation.
  - Small deviations from perfect orientation provide large step densities. Nucleation therefore can be very sensitive to the precise **{hkl}** of the surface
  - Intersections of (screw) dislocation lines with the surface also provide steps.
  - This may cause grain boundaries and other defects in the growing layer.
  - Scanning probe microscopy gives the experimental background



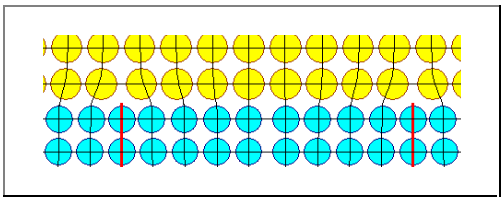
- There is always a nucleation barrier that has to be overcome for the first **B**-clusters" to form on **A**
  - the three involved interface energies, all expressed in the "wetting angle", plus possibly some strain are the decisive inputs for the resulting growth mode.

    - **Frank - van der Merve**: Smooth layer-by-layer growth
    - **Vollmer - Weber**: Island growth
    - **Stranski - Krastonov**: Layer plus island growth





- Epitaxial layers are crucial for semiconductor technology.
  - Misfit of lattice constants will produce strained layers upon epitaxial growth; strain relief happens by the formation of misfit dislocations.
  - Misfit dislocations must be avoided at all costs!
  - Below a usually rather small critical thickness d_{crit} of the the thin layer no misfit dislocations will occur.
  - Rule of thumb:
    0.5 % misfit ⇒ $d_{crit} \approx$ **10 nm**



- The internal structure of thin films can be anything known from bulk materials plus some (important!) specialities.

a-Si: Micro electronics
a-Si:H: Solar cells, **LCD** displays
µc-Si:H: Solar cells

- Properties of thin films can be quite different from that of the bulk material.
  - The reason can be differences in length scales.
  - Semiconductor technology relies to some extent on superior thin film properties.

Much better in thin films

- **Electrical break-down field strength of dielectrics.**
- **Critical current densities in conductors.**

Exercise 3.6-1

All Questions to 3