

Outline: Thin Film Nucleation, Growth, and Microstructure Evolution

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Chapter 1. The substrate: an introduction to surface structure/processes

- a. surface energies: measurements and role in film growth
- b. surface structure: examples of reconstruction and relaxation
- c. terrace-step-kink structure: examples (STM)
- d. surface diffusion
- e. step-edge barrier and 2D kinetic roughening
- f. corner barrier and 1D kinetic roughening.

Chapter 2. Thin film nucleation

- a. the nanoscience of nuclei and small clusters: reduced cohesive strength, depressed melting point, increased 2D vapor pressures
- b. thermodynamics of nucleation (a simple stability problem): examples
 1. capillarity-based atomic-scale models: examples
 2. wetting angle: examples (TEM, STM)
 3. graphene/fcc(111) moiré superstructure templates (STM, LEED)
- c. kinetics of nucleation: examples (STM)
- d. coalescence and coarsening: examples (TEM, STM videos)
- e. early stages of film growth (experiment and simulation): examples
 1. anisotropic edge diffusion
 2. strain effects.

Chapter 3. 2D step flow and layer-by-layer epitaxial growth

- a. introduction: Si on Si(001), a case study (STM, theory)
- b. 2D step flow
 1. definition and requirements
 2. possible to achieve?
 3. role of buffer layers: examples
 4. experimental observations: He, x-ray, and RHEED scattering
- c. layer-by-layer growth
 1. definition and requirements
 2. possible to achieve?
 3. experimental observations: He, x-ray, and RHEED scattering.

Thin Film, Nucleation, Growth, and Microstructure Evolution (cont.)

Chapter 4. 2D multilayer growth

- a. experimental observations: STM vs. RHEED oscillations
- b. simulations vs. experimental observations: examples
- c. low-temperature epitaxy: fundamental limits
 1. critical epitaxial temperature T_{epi} vs. critical thickness t_{epi}
- d. techniques for increasing t_{epi}
 1. surfactants: examples (STM and RHEED oscillations)
 2. hyperthermal beams: examples (XTEM).

Chapter 5. Heteroepitaxy and the role of misfit strain

- a. elastic strain energy
- b. edge, screw, and mixed dislocations: TEM, XTEM, & LEEM videos
- c. relaxation mechanisms: elastic energy vs. misfit dislocations and surface energy
 1. misfit dislocations, critical thickness, strategies to decrease dislocation density: examples
 2. surface roughening, islanding, S-K growth: examples
- d. quantum dot engineering: examples (STM, XTEM)
- e. quantum wires (STM)
- f. 2D layers: silicene 4×4 /Ag(111), silicene/ZrB₂(0001), MoS₂/Gr (STM, RHEED).

Chapter 6. 3-D polycrystalline growth and nanostructure evolution

- a. nucleation: examples (TEM, AFM, STM)
- b. coalescence: examples (TEM and STM videos)
 1. complete vs. incomplete: examples (STM)
- c. coarsening: examples (TEM and STM videos)
- d. grain boundaries in 2D materials: example Gr/Cu (STM and TEM)
- e. grain boundary energies
- f. grain growth: examples (TEM)
- g. structure-zone models: experiment vs. computer simulations
- h. oblique deposition and atomic shadowing.

Chapter 7. Film stress and texture evolution

- a. thermal stress: examples
- b. stress measurement: examples
- c. tensile stress mechanisms: examples (TEM, XTEM)
- d. ion-induced stress: examples
- e. compressive stress mechanisms: examples (XTEM)
- f. stress in superlattices and multiplayer systems
- g. texture evolution: examples (AFM, XTEM, simulations).