MatE 270
Learning Objectives

Vacuum Science

1. **Discuss** why gas kinetics is important to thin film deposition.
2. **Explain** the components of Maxwell-Boltzmann formula for molecular speed.
3. **Calculate** the mean speed, root-mean-speed, and probable speed of a molecule.
4. **Calculate** the molecular concentration and molecular flux at a given pressure and temperature.
5. **Calculate** the film growth rate from molecular flux.
6. **Calculate** the purity of a film based on chamber gases and pressures.
7. **Calculate** the fraction of reactant being utilized for a given deposition rate.
8. **Calculate** the mean free path.
9. **Calculate** the Knudsen number and **utilize** it to determine the flow regime.

Evaporation

10. **Describe** the basic components of an evaporation chamber.
11. **Calculate** the power needed to resistively heat an evaporation filament.
12. **Calculate** the equilibrium vapor pressure using the Clausius-Clapeyron equation from given ΔH_s and integration constants.
13. **Utilize** published charts to determine the equilibrium vapor pressure as a function of temperature and pressure.
14. **Calculate** an evaporation flux.
15. **Calculate** a deposition rate from an evaporation flux using the cosine effusion law.
16. **Analyze** how uniformity of a deposited film varies with location.
17. **Define** an alloy versus a compound.
18. **Discuss** alternative methods needed to evaporate alloys.
19. **Calculate** the relative evaporation fluxes of species in an alloy.
20. **Calculate** film purity based on chamber pressures.

Electroplating

21. **List** the advantages and disadvantages of copper interconnects in integrated circuits.
22. **Draw** the steps of a dual damascene process. **Explain** the purpose of each step and challenges of processing related to that step.
23. **Differentiate** between anodic and cathodic (reduction and oxidation) reactions.
24. **Explain** the major components in an electrochemical cell.
25. **Design** an experiment to determine the Galvanic series.
26. **Determine** which side of a given reaction is the reducer or oxidizer using the Galvanic series.
27. **Write** a given equation in the shorthand notation of a redox cell.
28. **Calculate** the resulting potential in a non-standard cell with the Nernst equation.
29. **Adjust** a given plating or etching process to increase the plating or etching.
30. **List** the major components needed for copper electroplating.
31. **Describe** examples of why additives are used in copper plating baths.
32. **Calculate** the plating rate for a given overpotential or current density.
33. **Determine** i_o and α from experimental data of overpotentials and current densities.
34. **Describe** the controlling kinetic mechanisms in electroplating.

Sputtering

35. **Compare** sputtering and evaporation processes in terms of uniformity, contamination, and deposition of alloys and compounds.
36. **Discuss** ways to optimize the uniformity of a sputtering process.
37. **List** the major components of a sputtering system.
38. **List** the components present in a plasma gas.
39. **Describe** how a plasma is started and maintained.
40. **Describe** the different regions of a plasma in terms of dark spaces and glows.
41. **Define** a striking voltage and explain its dependence on pressure and spacing.
42. **Calculate** the pressure range needed to sustain a plasma in a gas diffuse plasma sputtering system.
43. **Estimate** energy transferred to target based on masses.
44. **Utilize** published data to determine the sputtering yield for given process parameters.
45. **Discuss** factors considered in choosing sputtering ion energies.
46. **Explain** the angular dependence of sputtering yield.
47. **Estimate** the sputtering yield from a given equation (such as Sigmund equation).
48. **Calculate** the rate of sputtered atoms from a measured (given) current of ions in the plasma.
49. **Calculate** the film growth rate from an estimated flux of sputtered atoms.
50. **Discuss** ways to improve the efficiency of a plasma.
51. **Explain** the physics of a magnetron sputtering process.
52. **Describe** rf sputtering process and **give** an example of why it would be used.
53. **Describe** reactive sputtering and **give** an example of why it would be used.
54. **Describe** bias sputtering and **give** an example of why it would be used.
55. **Explain** why non-uniformities results in step coverage from sputtering and **design** a sputtering process to minimize these non-uniformities.

Chemical Vapor Deposition

56. **Describe** the influence of Gibb's free energy on temperature, pressure, phase, and composition.
57. **Calculate** if a CVD deposition reaction from a single chemical reaction is thermodynamically predicted.
58. **Utilize** given tables of partial pressures to calculate whether deposition or etching occurs with a complex set of chemistries in CVD.
59. **Determine** the effect of non-equilibrium partial pressures on the predicted deposition or etching of a process.
60. **Discuss** factors that prevent thermodynamically predicted reactions from occurring.a
61. **Calculate** the critical size nuclei and barrier for nucleation in homogeneous and heterogenous nucleation in a CVD process.
62. **Design** a CVD process to minimize homogeneous nucleation.
63. **Predict** the grain structure of a film (polycrystalline or single crystal) from given processing conditions and chemistries.
64. **Calculate** the Reynold's number from given gas flow properties.
65. **Define** a boundary layer and **explain** why the width of the boundary layer is important to CVD deposition.

66. **Describe** the relationship of gas diffusion on temperature and pressure.
67. **List** factors considered in modeling of gas flow properties in CVD reactors.
68. **Calculate** the flux of gas atoms in a tubular reactor from gas properties.
69. **Calculate** the deposition rate as a function of distance from the gas inlet.
70. **List** the factors that contribute to radial non-uniformities in the deposition rate.
71. **Calculate** whether a deposition reaction is reaction rate or mass transport limited.
72. **Calculate** the film growth rate, reaction rate, and/or diffusion rate from given data.
73. **Describe** the influence of temperature, pressure, and chemistry on the limiting mechanism.
74. **Discuss** different APCVD reactors and why they are designed that way.
75. **State** examples of processes that use APCVD deposition and why APCVD is chosen.
76. **Discuss** different LPCVD reactors and why they are designed that way.
77. **State** examples of processes that use LPCVD deposition and why LPCVD is chosen.
78. **Discuss** different PECVD reactors and why they are designed that way.
79. **State** examples of processes that use PECVD deposition and why PECVD is chosen.
80. **Design** a CVD processes to optimize uniformity based on limiting mechanism and the reactor used.

Thin Film Evolution and Growth

81. **Describe** the possible mechanisms for the incorporation of an impinging atom into a surface.
82. **Describe** why different states have different binding energies.
83. **Determine** the binding energy of a site or the barrier to convert from one site to another (say physisorbed to chemisorbed) from an energy diagram.
84. **Calculate** the reaction rate constant and absorption time for each absorption site.
85. **Describe** why there is a barrier to surface diffusion.
86. **Calculate** the diffusion length on the surface in the time before desorption.
87. **Calculate** the diffusion length on the surface in the time before burial.
88. **Determine** which sites on a surface are more stable for an ad-atom.
89. **Describe** why a critical radius cluster is needed to form a stable nuclei.
90. **Calculate** the critical size radius, using the driving force of evaporation as an example.
91. **Calculate** the free energy needed to create a critical size nucleus.
92. **Explain** the difference between homogeneous and heterogeneous nucleation.
93. **Calculate** the energy needed for homogenous versus heterogeneous nucleation.
94. **Analyze** given deposition process conditions (temperature and deposition rate) to determine if single crystal films will grow.
95. **Describe** the influence of processing conditions (such as substrate type, substrate temperature, and deposition rate) on the nucleation rate.
96. **Explain** Otswald ripening, sintering, and cluster migration.
97. **Draw** the topology of a growing surface with Frank van der Merwe, Volmer-Weber, and Stranski-Krastanov growth mechanisms.
98. **List** the 4 main types of film morphology (Z1, ZT, Z2, and Z3) including the processing conditions they exist in and their general film characteristics.

Materials Analysis

99. **List** the properties of importance to monitor in thin film deposition and **identify** the appropriate metrology tools for each material.
100. **Describe** the difference between a profilometer and an AFM. **State** situations where each is appropriate measurement tool.
101. **Explain** different ways to measure dielectric thickness.
102. **Explain** different ways to measure metal thickness.
103. **Given** a material, determine the best way to measure its film thickness.
104. **Discuss** why chemical composition and impurity levels are critical to monitor.
105. **Explain** the difference between backscattered, secondary, and Auger electrons.
106. **Group** the different chemical composition analysis techniques based on input and output of electrons, ions, and x-rays.
107. **Compare** different analysis techniques based on lateral resolution, depth resolution, sensitivity to specific elements, detection limits, destructiveness of test, and cost.
108. **Identify** the best chemical analysis technique for different situations.