MATERIALS ENGINEERING 153
STUDENT LEARNING OBJECTIVES

After successfully completing all course assignments including reviewing lecture notes, participating in class discussions and bluesheets, homework assignments and examinations, the student should be able to:

Bonding between atoms
1. **Calculate** equilibrium bond distance and bond energy from potential energy function.
2. **Distinguish** between metallic, covalent, and ionic bonding.

Crystal structure
3. **Calculate** lattice parameter from atomic radius and vice versa for cubic structures.
4. **Calculate** atomic density of a crystal using either the mass density or the lattice parameter.
5. **Identify** important low-index planes and directions in cubic crystals.
6. **Identify** families of planes and directions.
7. **Label** planes and directions in a cubic system using Miller's indices.
8. **Demonstrate** the correct number of nearest neighbors for cubic crystals.
9. **Construct** and **sketch** unit cells of simple, face-centered, body-centered and diamond cubic crystals.
10. **Utilize** Bragg's law to relate the lattice parameter of a crystal to its wave scattering behavior.

Defects in crystals
11. **Distinguish** between defects of different dimensionality.
12. **Identify** vacancies and different types of impurities (substitutional and interstitial)
13. **Explain** movement of dislocations.
14. **Distinguish** between n-type and p-type impurities in semiconductors.
15. **Convert** between weight fraction and atomic fraction of a solid solution.

Wave and particle properties of a photon
16. **Calculate** the energy of a photon from its wavelength or wave number and vice versa.
17. **Calculate** the flux of photons in an electromagnetic wave.
18. **Relate** the intensity of light to the E-field.

Photon interactions with electrons in bound system
19. **Describe** the photoelectric effect.
20. **Determine** cut-off frequency and threshold wavelength for photoemission from data plot.
21. **Calculate** work function from photoemission data.
22. **Calculate** energy and wavelengths of photons emitted in electron transitions in bound systems.

Properties of a free electron
23. **Write** the one-dimensional time-independent Schroedinger wave equation (SWE).
24. **Identify** the form of the SWE for a free electron.

25. **Identify** the wave properties and the particle properties of an electron.
26. **Identify** the allowed energies and wave numbers for a free electron.
27. **Utilize** relationships between momentum, velocity and energy of a free electron (particle properties).
28. **Calculate** the momentum and energy of an electron from its wavelength or wave number utilizing the deBroglie relation.

Properties of an electron confined by an infinite square well potential (electron-in-a-box).

29. **Identify** the form of the SWE for the electron-in-a-box model.
30. **Identify** the constraints and boundary conditions on the forms of the wave function.
31. **Identify** the allowed energies and wave numbers for an electron confined by an infinite square well potential (electron-in-a-box).
32. **Derive** the wave function and energy for the first three states.
33. **Calculate** the degeneracy and the number of electrons at each energy level.
34. **Calculate** the transition energies between various states.
35. **Utilize** the dispersion relationship to find the allowed energies.

Properties of an electron in a hydrogen-like atom

36. **Identify** the form of the SWE for an electron in an H atom.
37. **Distinguish** between situations requiring SWE for a free electron, an electron in a box, and the H atom.
38. **Differentiate** between energy states relative to a free electron for the electron in a box model versus the hydrogen atom.
39. **Describe** and **enumerate** the atomic orbitals in an atom using the quantum numbers and describe their filling by Hund's rule.
40. **Calculate** the electron transitions in absorption and emission of energy for a H atom.
41. **Plot** the radial wave functions and the first three spherical harmonics (s,p,d).
42. **Determine** the Bohr radius from plots of the radial probability function.
43. **Calculate** the first ionization energy of a valence electron using various types of nuclear screening models.
44. **Calculate** total orbital angular momentum (L) and total angular momentum (J) of an atom.

Spin of an electron (m_s)

45. **Utilize** Hund's rules for distributing electrons in atomic orbitals with correct spin.
46. **Calculate** spin angular momentum (S) for an isolated atom.

Scattering of electrons by defects in crystals.

47. **Estimate** scattering time and mobility from defect concentration.
48. **Utilize** relationships between mobility, conductivity, scattering time, and drift velocity.
49. **Explain** temperature dependence of lattice scattering for metals.
50. **Explain** temperature dependence of lattice scattering for semiconductors.

Conductivity in metals

51. **Distinguish** between resistance, resistivity and conductivity, and **convert** between them.

52. **Calculate** free electron concentration for a metal from its atomic structure and density.
53. **Distinguish** between drift velocity and current.
54. **Determine** temperature coefficient of resistivity (α) for a metal from measured data.
55. **Calculate** $\rho(T)$ for metal using α.
56. **Explain** Matthiesen's rule.
57. **Explain** effect of impurities on metal resistivity.
58. **Calculate** the resistivity using Nordheim's rule.

Density of states function, Fermi function, density of occupied states

59. **Derive** density of states function.
60. **Distinguish** between density of states and probability of occupancy
61. **Calculate** density of states at selected energies.
62. **Calculate** probability of occupation for selected energies and temperatures, using both Fermi-Dirac and Maxwell-Boltzmann functions.
63. **Compare** probabilities obtained by the two functions (F-D and M-B) and **determine** when each is appropriate.
64. **Calculate** the Fermi energy for a metal and for a semiconductor.

Band Structure

65. **Describe** splitting of energy levels due to bonding
66. **Distinguish** between band diagrams for a metal, semiconductor or insulator.
67. **Utilize** the sp3 hybridization process to explain the bonding of atoms seen in a Si crystal.
68. **Calculate** electron concentration in an energy interval in the band, as well as total electron concentration in the band.

Free carrier concentration

69. **Calculate** the intrinsic carrier concentration in a semiconductor.
70. **Distinguish** between the meaning of free electrons in a metal and a semiconductor.

Influence of impurities on free carrier concentration (semiconductors)

71. **Define** relationship between doping concentration and carrier concentration in semiconductors.
72. **Describe** effect of freeze-out on free carrier concentration and conductivity
73. **Distinguish** between n-type and p-type dopants.
74. **Calculate** majority and minority carrier concentrations from doping concentration at any temperature.
75. **Calculate** the Fermi energy in an extrinsic semiconductor as a function of doping and temperature.

Conductivity in semiconductors

76. **Determine** doping type using a Hall voltage measurement.
77. **Calculate** the mobility from a Hall voltage measurement.
78. **Determine** semiconductor electron and hole mobility at different temperatures and doping levels.
79. **Distinguish** between various types of carrier velocity (thermal, drift, Fermi).
80. **Utilize** relationship between mobility, field and drift velocity.

81. **Calculate** semiconductor conductivity from carrier concentration and mobility.
82. **Calculate** electron concentration in intrinsic semiconductor at any temperature.
83. **Calculate** electron concentration in extrinsic semiconductor, at any temperature.
84. **Determine** intrinsic and saturation temperatures of a doped semiconductor.
85. **Determine** semiconductor mobility at any temperature for both intrinsic and extrinsic semiconductors.
86. **Determine** semiconductor bandgap energy from measured conductivity data.
87. **Define** and **calculate** the intrinsic carrier concentration as a function of temperature and band gap energy.
88. **Compare** the electrical conductivity as a function of temperature for metals and semiconductors.

Photoconductivity in semiconductors

89. **Define** generation and recombination time for electrons and holes.
90. **Calculate** photogenerated current in an illuminated sample.
91. **Determine** minority carrier recombination time from photoconductivity data.

Drift and Diffusion

92. **Calculate** drift current in a sample under electric field.
93. **Calculate** diffusion current and built-in field in a non-homogeneous sample.

Optical absorption and emission

94. **Determine** semiconductor bandgap energy from optical absorption data.
95. **Calculate** absorption coefficient and absorption edge in a semiconductor sample from experimental data.
96. **Determine** the bandgap of an LED from its emission spectrum.

Junction Diodes

97. **Explain** how a pn junction diode works.
98. **Explain** how a solar cell works.
99. **Determine** the turn-on voltage of a diode from experimental data.
100. **Recognize** forward and reverse bias regions of a diode IV curve.

Magnetic properties of an atom

101. **Calculate** total spin magnetic moment for an isolated atom.
102. **Derive** value of Bohr magneton and **explain** origin of it.
103. **Calculate** the total orbital moment of an isolated atom
104. **Calculate** the net magnetic moment of an isolated atom.

Magnetic properties of a solid

105. **Calculate** the ideal saturation magnetization of a solid.
106. **Compare** and **distinguish** between the actual and ideal magnetization of a solid.

Electromagnetic radiation, H-component

107. **Explain** the relationship between current and magnetism.
108. **Demonstrate** relationship between B and H fields.

109. **Calculate** B and H for a solenoid.

Magnetization vector

110. **Distinguish** between dia-, para- and ferro-magnetic materials based on their magnetization curves.
111. **Explain** the Meissner effect.
112. **Distinguish** between BH and MH loops
113. **Utilize** functional relationships between μ, χ, M and B.

Magnetic anisotropy in ferro-and ferri-magnets

114. **Distinguish** between ferromagnets and ferrimagnets.
115. **Define** the properties that affect domain formation: exchange energies, magnetostatic energy, magnetocrystalline energy, shape anisotropy.

Characteristics of hysteresis loop

116. **Identify** coercivity (H_c), remanence, remanent magnetization, saturation field, saturation magnetization on a hysteresis curve for a specific material
117. **Describe** and **sketch** the magnetization of the domains along a magnetization curve.

General Learning objectives applicable to laboratory and lecture activities

118. **Perform** linear regression on appropriate data.
119. **Perform** dimensional analysis.
120. **Utilize** Excel spreadsheets for manipulating data and for plotting and fitting curves.
121. **Write** an effective report documenting laboratory activities and demonstrating analysis of experimental data.
122. **Deliver** an effective oral report documenting project planning and results.
123. **Demonstrate** ability to function in a small group by performing various job functions.
124. **Express** answers to problems using proper number of significant figures.