**Learning Outcomes in Semiconductor Device Modeling (EE5132)**

Please check if you learned the following items in this course. These are the minimum knowledge that you must gain through this course. If you feel any difficulty to understand any of the items below while attending the lectures, please ask questions and get clarified.

PART-I

1. How does the resistivity/conductivity of conductor or semiconductor or insulator vary with the conduction electron density?
2. From the analogy of periodically arranged traffic signal, did you get a feeling that there can be a pass-band and a forbidden gap for electrons in the crystal?
3. Why is the concentration of electron (/$cm^3$) calculated in energy domain?
4. What is the density of (energy) states?
5. How is the Fermi-Energy level ($E_F$) defined? What is Fermi-Dirac occupation factor, f(E)? How is it used in computing the electron concentration?
6. How to compute the electron and hole concentration of a 3D lattice? What is the effective density of states? How to estimate the maxima of the integrand D(E)f(E) in the conduction band or D(E)(1-f(E)) in the valence band?
7. How to find out the position of $E_F$ of an intrinsic semiconductor ($E_{Fi}$) in energy-domain? How does it depend on the effective mass of electron and hole?
8. How to estimate the intrinsic carrier density, $n_i$? How does it depend on various material and temperature? How to express the electron or hole concentration in terms of $n_i$ and $E_{Fi}$?

PART-II

9. How to calculate the donor or acceptor level for extrinsic semiconductors? Where do they appear in the energy-band diagram?
10. What is the mass-action law? When is the mass-action law valid?
11. What is the charge-neutrality principle? How is it used along with the mass-action law to estimate the carrier density?
12. Why do the carriers move with a drift velocity within a semiconductor under an electrostatic field and not accelerate? How to obtain the maximum thermal velocity at room temperature? Can the drift velocity be more than the maximum thermal velocity (or saturation velocity)?
13. What are the major scattering mechanisms present in a semiconductor and how to obtain the expression for mobility of carriers? What is the effective mobility if more than one type of scattering is present?
14. What is the relation for conductivity of a semiconductor sample?
15. How does the radiative recombination occur for a direct and an indirect bandgap semiconductor? How are the energy and momentum conservation principles satisfied in this process?

16. Can the free carriers linearly increase with the doping concentration? What is the relation to find out the fraction of the donor or acceptor atoms ionized to yield free carriers?
17. How to obtain the current density equation for electrons and holes? Are you confident about the signs of the different terms? How to obtain the Einstein's relation from the equilibrium condition?
18. What is the quasi-Fermi energy level? If both drift and diffusion processes are present, how to obtain a more compact expression for the current density in terms of the gradient of the quasi-Fermi energy level of electron and that of hole? In which case, does the quasi-Fermi field is same as the electro-static field?
19. When does the energy band bend?
20. How do the following quantity change with temperature: $n_i$, $E_F$-$E_I$, $\mu$?

PART-III

21. What is the relation between electro-static potential and electron energy? How are the quasi-Fermi electric field of electron and that of hole related to the corresponding energy levels? When the quasi-Fermi fields are identical with the electro-static field?
22. How do the energy bands bend in equilibrium as well as in non-equilibrium situations? When is there no drift current even if the energy band appears bent? When is there no diffusion current even with a non-zero slope of electron concentration?
23. What happens to the band diagram of a (uniformly or non-uniformly doped) silicon sample if a steady light is shone on one side?
24. When does the excess carrier density appear in a semiconductor? How to obtain the excess carrier concentration when a steady-state light is shone on a semiconductor sample? How are the minority carrier recombination life times defined?
25. How do the excess carriers (created due to photo-absorption) decay with time?
26. What is photoconductivity? How to estimate the change in conductivity due to the exposure of light on a semiconductor sample?
27. How to obtain the continuity equation?
28. How does the excess carrier density change with position in a diffusion-recombination steady-state process? What is diffusion length? How are the recombination life-time and diffusion length related?

PART-IV

29. What is an abrupt p/n junction and its doping profile? How does the concept of contact potential appear in a p/n junction? How is the concept of work function related with the contact potential? How does the contact potential appear in the band diagram?

30. What is depletion approximation? How to solve Poisson's equation in a p/n junction? How do the space-dependent charge-density and field appear in a p/n junction? How does the electro-static potential vary in a p/n junction? How to calculate the depletion width in a p/n junction?
31. How to obtain the band diagrams and carrier density profiles of a p/n junction under forward/reverse biased conditions? Where do you apply depletion approximation? What about the space-dependent charge density, field and potential profile in the biased conditions?
32. Why is the static current in a forward biased p/n junction diode spatially constant? How to derive the static current? How to obtain the space-dependent electron and hole components of static current? Can you discuss the phenomena with a flow diagram? How are the recombination life time and transit time used in various situations?
33. How to estimate the depletion and diffusion charges, depletion and diffusion capacitances, and the diode conductance? What is the equivalent circuit?
34. When is the injection across a forward biased p/n junction low or high?
35. What is the Zener and Avalanche breakdown? How to estimate the avalanche multiplication factor?
36. What is a transient effect? What is the reverse recovery of a diode? How to obtain the time-dependent junction voltage in a transient situation?
37. What are operation principles of the zener diode, photo-detector, solar cell, varactor?
38. How to analyze the metal-semiconductor junctions (Schottky) under equilibrium and biased conditions? Why is the Schottky diode advantageous in some situations?

PART-V

39. How to explain the operation of a BJT using a flow diagram?
40. What are the emitter injection efficiency, base transport factor and current gain in a BJT? How to relate the gain of a BJT with the minority carrier life time and transit time within the base region? What are the important design-factors affecting the gain of a BJT?
41. How to obtain the base and collector currents from the information of the minority carriers in a BJT?
42. What is the Early effect in a BJT?
43. How to obtain the large-signal and small-signal equivalent circuit of a BJT? How to obtain the expressions of admittance parameters of a BJT?
44. How does a BJT behave under a large-signal transient (e.g. in switching application)?

PART-VI

45. What is an ideal MOS capacitor? How does its energy band appear under accumulation, depletion and inversion conditions? What is the condition for strong inversion? How do the charge density, electric field and electro-static potential look for an ideal MOS capacitor in strong inversion?
46. How is the threshold voltage of a MOS capacitor defined? How to calculate the maximum depletion width, depletion charge, and threshold voltage for an ideal MOS capacitor?
47. How does the capacitance of an ideal MOS capacitor vary with voltage? How to obtain the maximum and minimum capacitance of an ideal MOS capacitor?
48. How does a real MOS capacitor differ from an ideal MOS capacitor? What is a flat band voltage and how to obtain it? How is the calculation of threshold voltage modified for a real MOS capacitor compared to its ideal counterpart? How does the threshold voltage vary with substrate doping?
49. What is the operation principle of a MOSFET and how to obtain its drain current? How does the drain current expression vary in different bias regimes?
50. How to obtain the output conductance and trans-conductance of a MOSFET? How is the threshold voltage of a MOSFET controlled using substrate bias?