Here is some basic information and procedural instructions. You may not need to use all of this information.

1. This Help Sheet (2 pages) and anything you may want to write on it may be used on Test 1.
2. Where possible, calculate all needed parameters.
3. Do all work in the spaces provided on this exam paper. If you write on the back of a sheet, make the notation "PTO" in your solution in order to assure that material written on the back of the page is evaluated for a grade.
4. You may use a calculator.
5. Show all calculations, making numerical substitutions and giving numerical results where possible.
6. Write answers in space given.
7. Unless stated otherwise, $T = 300K$, $V_t = kT/q = 25.852 mV$,
   $\varepsilon_o = 8.85E-14 Fd/cm$, $q = 1.602E-19 Coul$.
8. Unless otherwise stated, the material is silicon with
   $n_i = 1.05E10 cm^{-3}$, $N_c = 2.84E19 cm^{-3}$,
   $N_v = 3.08E19 cm^{-3}$, $q_{\varepsilon_{Si}} = 4.05 eV$,
   $E_{g, Si} = 1.125 eV$, $\varepsilon_{Si} = 11.7$.
9. The law of mass action is: $n p = N_c N_v e^{-E_g/kT} = n_i^2$, (note $N_c$ and $N_v$ are $\propto T^{3/2}$).
10. Local charge neutrality is given by
   $[coul/cm^3] = q(N_d + - N_a - + p - n)$, where $N_d^+$ is the density of ionized donors,
   $N_a^-$ is the density of ionized acceptors, and $p$ and $n$ are the densities of holes and electrons.
11. For $n$ or $p >> n_i$, and defining $N \equiv (N_d^+ - N_a^-)$, and that $n_0$ and $p_0$ are the equilibrium concentrations,
   a. we have n-type material for $N > 0$, where $n_0 = N$, and $p_0 = n_i^2/N$,
   b. we have p-type material for $N < 0$, where $p_0 = -N = |N|$, and $n_0 = n_i^2/|N|$.
12. The law of the junction applies as a boundary condition at the depletion region boundary and the non-equilibrium concentrations satisfy the equation:
   \[ n p = n_i^2 e^{V_A/V_t} = N_c N_v e^{-E_{g,Si}/V_A} \], where $V_A$ is the potential applied across the junction.
13. The depletion width at a junction is given by
   $W = \left[2\varepsilon_o\varepsilon_{Si}(V_{bi}-V_A)/(q N_{eff})\right]^{1/2}$, where $N_{eff} = N_a N_d/(N_a + N_d)$, and $V_{bi} = V_t \ln[N_d N_v (n_i^2)^3]$, the lever rule applies where $N_d x_n = N_a x_p$, and $n_0$ and $p_0$ are the widths of the depletion region on the n-side and p-side respectively.
14. The depletion capacitance per unit area [Fd/cm$^2$] of a junction is given by $C'_j = \varepsilon_{Si}/W$.
15. The conductivity of a semiconductor is given by $\sigma = q(n \mu_n + p \mu_p) = 1/\rho$, where $\rho$ is the resistivity.
16. For silicon, assume the hole and electron mobilities are given by:
   a. $\mu_p = \{418.3+{[1+(N_i^{1.6E17})^{0.7}]}+49.7, \text{ in cm}^2/\text{V-sec}, \text{ and}$
   b. $\mu_n = \{1268+{[1+(N_i^{1.3E17})^{0.91}]}+92, \text{ in cm}^2/\text{V-sec}, \text{ (where } N_i = \text{ the total impurity concentration in n- or p-type material whether compensated or not)}.$
17. The x-component drift current is given by $J_{x, \text{drift}} = \sigma E_x$, $E_x = -dV/dx$ is the electric field x-component.
18. The end-to-end resistance of a bar of material of length L, width w, and height t, is: $R = \rho L/(wt)$.
19. The x-component diffusion current is given by $J_{x, \text{diffusion}} = q(D_n dn/dx - D_p dp/dx)$.
20. The diffusion coefficients are given by $D_n = V_d \mu_n$ and $D_p = V_d \mu_p$.
21. The total current density $J_{x, \text{total}} = J_{x, \text{drift}} = J_{x, \text{diffusion}}$, in Ampere/cm$^2$. 

You may use only this Help Sheet and a calculator on the exam. You may write any additional material you desire on this sheet.
22. For minority carriers in silicon, the minority carrier lifetime is modeled by the relationship:
\[ \tau_{\text{min}} = (45E-6 \text{ sec}) + [1 + 7.7E-18 \cdot N_i + 4.5E-36 \cdot N_i^2], \] (where N_i = the total impurity concentration).
23. The minority carrier diffusion length is L_{\text{min}} = \left[ D_{\text{min}} \tau_{\text{min}} \right]^{1/2}.
24. A diode has a current i_D = IS[e^{v_D} - 1], where v_D = V_a is the potential across the depletion region.
25. For a diode, the charge neutral region is the region between the contact and the depletion region edge.
26. IS = (J_{n0} + J_{p0})A = qn_n^2 A [D_n/(N_n X_n) + D_p/(N_p X_p)], where the appropriate parameters and a good approximation of X is defined below (see notes).
27. The small-signal diffusion resistance of the diode is \( r = (dV/dx)^{-1} \).
28. For silicon dioxide, SiO_2, the electron affinity is \( \chi_{\text{SiO}_2} = 0.95 \text{ V} \), the relative permittivity is \( \varepsilon_{\text{SiO}_2} = 3.9 \).

The following are based on the G-P bipolar junction transistor (BJT) model in the mid-current range:

29. For the work function of n+ poly silicon, use \( \phi_{n+} = \chi_{\text{Si}} = 4.05 \text{ V} \), and for the work function of p+ poly silicon, use \( \phi_{p+} = \chi_{\text{Si}} + E_{g,Si}/q = 5.175 \text{ V} \).
30. Metal gate work functions should be assumed to be (gold) \( \phi_{Au} = 4.75 \text{ V} \), (aluminum) \( \phi_{Al} = 4.1 \text{ V} \).
31. For silicon dioxide, SiO_2, the electron affinity is \( \chi_{\text{SiO}_2} = 0.95 \text{ V} \), the relative permittivity is \( \varepsilon_{\text{SiO}_2} = 3.9 \).

In the active mode,
\[ i_{C,\text{active}} = \pm IS \exp(\pm v_{BE}/(NF*V_t))/(1 \pm v_{BE}/VAR \pm v_{BC}/VAF), \]
\[ i_{B,\text{active}} = \pm IS \exp(\pm v_{BE}/(NF*V_t))/BF, \]
for the BJT (+ for npn, - for pnp throughout), where \( i_C \) is the current INTO the collector, and \( v_{BE} = v_B - v_E \), etc. The active mode is generally defined by \( \pm v_{BE} > \pm v_{BE,\text{turn-on}} \) and \( \pm v_{BC} < \pm v_{BC,\text{turn-on}} \). Typical values are \( \pm v_{BE,\text{turn-on}} \approx 0.7 \text{ V} \) and \( \pm v_{BC,\text{turn-on}} \approx 0.5 \text{ V} \). The base circuit has a small-signal dynamic resistance of \( r_B = NF*V_t/i_B \).

32. In the saturation mode,
\[ i_{C,\text{sat}} = (v_{CE} - v_{CE,\text{sat}})/r_{CE,\text{sat}}, \]
\[ i_{B,\text{sat}} \geq i_{C,\text{sat}}/BF \]
Typically this is when \( \pm v_{BE} > \pm v_{BE,\text{turn-on}} \) and \( \pm v_{BC} > \pm v_{BC,\text{turn-on}} \). The base circuit has a small-signal dynamic resistance of \( r_B = NF*V_t/i_C \). Note that in the saturation mode, for a given \( (v_{BE},v_{BC}) \), the formally calculated values for \( i_{C,\text{active}} > i_{C,\text{sat}} \). \( v_{CE,\text{sat}} \approx v_{BE,\text{turn-on}} - v_{BC,\text{turn-on}} \) and \( r_{CE,\text{sat}} \approx NF*V_t/i_{C,\text{sat}} \).
33. For purposes of this exam, we will assume that in the cutoff mode, \( i_{C,\text{cut-off}} \approx 0 \). Typically this is when \( \pm v_{BE} < \pm v_{BE,\text{turn-on}} \) and \( \pm v_{BC} < \pm v_{BC,\text{turn-on}} \).