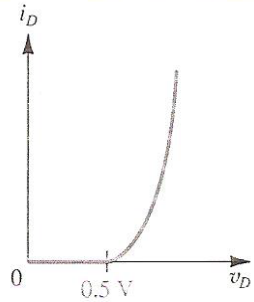
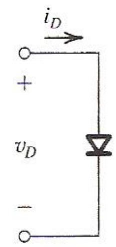
TABLE 3.1 Modeling the Diode Forward Characteristic

Model	Graph	Equations	Circuit	Comments
Exponential		$i_D = I_S e^{v_D/nV_T}$ $v_D = 2.3nV_T \log\left(\frac{i_D}{I_S}\right)$ $V_{D2} - V_{D1} = 2.3nV_T \log\left(\frac{I_{D2}}{I_{D1}}\right)$ $2.3nV_T = 60$ mV for $n = 1$ $2.3nV_T = 120$ mV for $n = 2$		$I_S = 10^{-12}$ A to 10^{-15} A, depending on junction area $V_T \cong 25$ mV $n = 1$ to 2 Physically based and remarkably accurate model Useful when accurate analysis is needed

(Continued)

TABLE 3.1 *(Continued)*

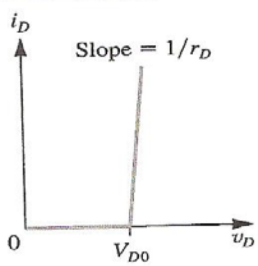
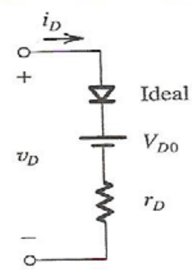
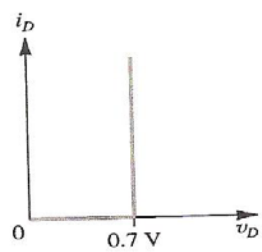
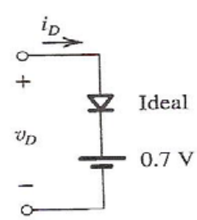
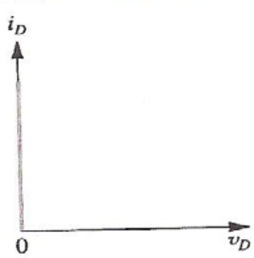
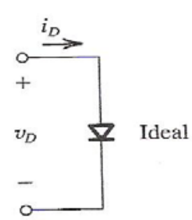
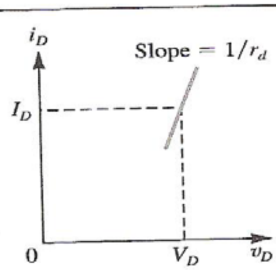
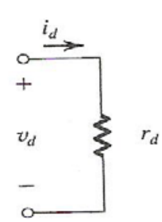
Model	Graph	Equations	Circuit	Comments
Piecewise-linear (battery-plus-resistance)		For $v_D \le V_{D0}$: $i_D = 0$ For $v_D \ge V_{D0}$: $i_D = \frac{1}{r_D}(v_D - V_{D0})$		Choice of V_{D0} and r_D is determined by the current range over which the model is required. For the amount of work involved, not as useful as the constant-voltage-drop model. Used only infrequently.
Constant-voltage-drop (or the "0.7-V model")		For $i_D > 0$: $v_D = 0.7$ V		Easy to use and very popular for the quick, hand analysis that is essential in circuit design.
Ideal-diode		For $i_D > 0$: $v_D = 0$		Good for determining which diodes are conducting and which are cutoff in a multiple-diode circuit. Good for obtaining very approximate values for diode currents, especially when the circuit voltages are much greater than V_D.
Small-signal		For small signals superimposed on V_D and I_D: $i_d = v_d/r_d$ $r_d = nV_T/I_D$ (For $n = 1$, v_d is limited to 5 mV; for $n = 2$, 10 mV)		Useful for finding the signal component of the diode voltage (e.g., in the voltage-regulator application). Serves as the basis for small-signal modeling of transistors (Chapters 4 and 5).

TABLE 3.2 Summary of Important Equations for *pn*-Junction Operation

Quantity	Relationship	Values of Constants and Parameters (for Intrinsic *Si* at $T = 300$ K)
Carrier concentration in intrinsic silicon (/cm^3)	$n_i^2 = BT^3 e^{-E_G/kT}$	$B = 5.4 \times 10^{31}/(\text{K}^3\text{cm}^6)$ $E_G = 1.12$ eV $k = 8.62 \times 10^{-5}$ eV/K $n_i = 1.5 \times 10^{10}/\text{cm}^3$
Diffusion current density (A/cm^2)	$J_p = -qD_p \frac{dp}{dx}$ $J_n = qD_n \frac{dn}{dx}$	$q = 1.60 \times 10^{-19}$ coulomb $D_p = 12$ cm^2/s $D_n = 34$ cm^2/s
Drift current density (A/cm^2)	$J_{drift} = q(p\mu_p + n\mu_n)E$	$\mu_p = 480$ cm^2/V·s $\mu_n = 1350$ cm^2/V·s
Resistivity (Ω·cm)	$\rho = 1/[q(p\mu_p + n\mu_n)]$	μ_p and μ_n decrease with the increase in doping concentration
Relationship between mobility and diffusivity	$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = V_T$	$V_T = kT/q$ $\simeq 25.8$ mV
Carrier concentration in *n*-type silicon (/cm^3)	$n_{n0} \simeq N_D$ $p_{n0} = n_i^2/N_D$	
Carrier concentration in *p*-type silicon (/cm^3)	$p_{p0} \simeq N_A$ $n_{p0} = n_i^2/N_A$	
Junction built-in voltage (V)	$V_0 = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$	
Width of depletion region (cm)	$\frac{x_n}{x_p} = \frac{N_A}{N_D}$ $W_{dep} = x_n + x_p$ $= \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)(V_0 + V_R)}$	$\varepsilon_s = 11.7\varepsilon_0$ $\varepsilon_0 = 8.854 \times 10^{-14}$ F/cm
Charge stored in depletion layer (coulomb)	$q_J = q\frac{N_A N_D}{N_A + N_D} A W_{dep}$	
Depletion capacitance (F)	$C_j = \frac{\varepsilon_s A}{W_{dep}}$, $C_{j0} = \frac{\varepsilon_s A}{W_{dep}\|_{V_R=0}}$ $C_j = C_{j0}\Big/\left(1 + \frac{V_R}{V_0}\right)^m$ $C_j \simeq 2C_{j0}$ (for forward bias)	$m = \frac{1}{3}$ to $\frac{1}{2}$
Forward current (A)	$I = I_p + I_n$ $I_p = Aqn_i^2 \frac{D_p}{L_p N_D}(e^{V/V_T} - 1)$ $I_n = Aqn_i^2 \frac{D_n}{L_n N_A}(e^{V/V_T} - 1)$	
Saturation current (A)	$I_S = Aqn_i^2\left(\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right)$	
Minority-carrier lifetime (s)	$\tau_p = L_p^2/D_p$ $\quad \tau_n = L_n^2/D_n$	$L_p, L_n = 1$ μm to 100 μm $\tau_p, \tau_n = 1$ ns to 10^4 ns
Minority-carrier charge storage (coulomb)	$Q_p = \tau_p I_p$ $\quad Q_n = \tau_n I_n$ $Q = Q_p + Q_n = \tau_T I$	
Diffusion capacitance (F)	$C_d = \left(\frac{\tau_T}{V_T}\right) I$	