11.8 JUNCAP Model

11.8.1 Syntax

The syntax (or "insertion statement") is:

juncap_n (A, K) <parameters>

n	:	occurrence indicator
<parameters>	:	list of model parameters

Example:
juncap_a (0,07) level=1, jsggr=1e-9;
(see also [9] manual for further details.)

11.8.2 Theory

In this section the elementary physics of a junction diode is summarized. An extensive survey can be found in the textbooks about semiconductor devices [1], pp 74-96]. Generally, the current voltage characteristics can be represented as follows:

$$J = \{J_d(n^2{}_i) + J_g(n_i, V)\} \cdot \left[\exp\left(\frac{qV}{kT}\right) - 1\right] \tag{11.36}$$

$$n_i \sim T^{3/2} \cdot \exp\left(\frac{-E_g}{2kT}\right) \tag{11.37}$$

In which:

Quantity	**Units**	**Description**
J	Am^{-2}	Total reverse current density
J_d	Am^{-2}	Diffusion saturation current density
J_g	Am^{-2}	Generation current density
n_i	m^{-3}	Intrinsic carrier concentration

Quantity	Units	Description
V	V	Voltage across the diode
E_g	J	Energy gap
k	JK^{-1}	Boltzmann constant
T	K	Temperature

For $V < V_D$ the charge of the junction capacitance is described by:

$$Q = Q_J \cdot \left[1 - \left(1 - \frac{V}{V_D}\right)^{(1-P)}\right] \tag{11.38}$$

In which:

Quantity	Units	Description
Q	C	Total diode junction charge
Q_J	C	Junction charge at built-in voltage
V	V	Voltage across the diode
V_D	V	Junction diffusion voltage
P	-	Junction grading coefficient

11.8.3 JUNCAP Model Equations

The JUNCAP model is intended to describe the behaviour of the diodes that are formed by the source, drain or well-to-bulk junctions in MOS devices. The model is limited to the case of reverse biasing of these junctions. Similarly to the MOS model, the current equations are formulated and AC effects are modeled via charge equations using the quasi-static approximation. In order to include the effects from differences in the sidewall, bottom and gate-edge-junction profiles, these three contributions are calculated separately in the JUNCAP model. Both the diffusion and the generation currents are treated in the model, each with its own temperature and voltage dependence.

In the JUNCAP model a part of the total charge comes from the gate-edge junction very close to the surface. This charge is also included in the MOS-model charge equations, and is therefore counted twice. However this results in only a very minor error.

In the next section the model equations are presented. Correct operation of the model in a circuit-simulator environment requires some numerical additions, that are described in the section on the implementation. Finally any fixed capacitance that is present on a node - e.g. the metal-1-to-substrate capacitance - must appear in a fixed-capacitor statement or must be included in INTCAP. They no longer form a part of the JUNCAP model in contrast to the old NODCAP model.

11.8.4 Nomenclature

List of Electrical Variables

No.	Variable	Programming Name	Units	Description
1	V_A	VA	V	Potential applied to the anode
2	V_K	VK	V	Potential applied to the cathode
3	I_A	IA	A	DC current into the anode
4	I_K	IK	A	DC current into the cathode
5	Q_A	QA	C	Charge in the device attributed to the anode
6	Q_K	QK	C	Charge in the device attributed to the cathode

Parameter list

No.	Symbol	Programming Name	Units	Description
1	-	LEVEL	--	Level of this model. Must be set to 1
2	A_B	AB	m^2	Diffusion area
3	L_S	LS	m	Length of the side-wall of the diffusion area *AB* which is not under the gate
4	L_G	LG	m	Length of the side-wall of the diffusion area *AB* which is under the gate
5	ΔT_A	DTA	^0C	Temperature offset of the JUNCAP element with respect to T_A
6	T_R	TR	^0C	Temperature at which the parameters have been determined
7	V_R	VR	V	Voltage at which parameters have been determined
8	J_{SGBR}	JSGBR	Am^{-2}	Bottom saturation-current density due to electron-hole generation at $V = V_R$
9	J_{SDBR}	JSDBR	Am^{-2}	Bottom saturation-current density due to diffusion from back contact

No.	Symbol	Programming Name	Units	Description
10	J_{SGSR}	JSGSR	Am^{-1}	Sidewall saturation-current density due to electron-hole generation at $V = V_R$
11	J_{SDSR}	JSDSR	Am^{-1}	Sidewall saturation-current density due to diffusion from back contact
12	J_{SGGR}	JSGGR	Am^{-1}	Gate edge saturation-current density due to electron-hole generation at $V = V_R$
13	J_{SDGR}	JSDGR	Am^{-1}	Gate edge saturation-current density due to diffusion from back contact
14	N_B	NB	-	Emission coefficient of the bottom forward current
15	N_S	NS	-	Emission coefficient of the sidewall forward current
16	N_G	NG	-	Emission coefficient of the gate edge forward current
17	V_B	VB	V	Reverse breakdown voltage
18	C_{JBR}	CJBR	Fm^{-2}	Bottom junction capacitance at $V = V_R$
19	C_{JSR}	CJSR	Fm^{-1}	Sidewall junction capacitance at $V = V_R$
20	C_{JGR}	CJGR	Fm^{-1}	Gate edge junction capacitance at $V= V_R$
21	V_{DBR}	VDBR	V	Diffusion voltage of the bottom junction at $T = T_R$
22	V_{DSR}	VDSR	V	Diffusion voltage of the sidewall junction at $T = T_R$
23	V_{DGR}	VDGR	V	Diffusion voltage of the gate edge junction at $T = T_R$
24	P_B	PB	-	Bottom-junction grading coefficient
25	P_S	PS	-	Sidewall-junction grading coefficient
26	P_G	PG	-	Gate-edge-junction grading coeffcient

List of Internal Variables and Parameters

No.	Parameter	Programming Name	Units	Description
1	V_{DB}	VDB	V	Diffusion voltage of bottom area A_B
2	V_{DS}	VDS	V	Diffusion voltage of Locos-edge L_S
3	V_{DG}	VDG	V	Diffusion voltage of gate-edge L_G
4	C_{JB}	CJB	F	Capacitance of bottom area A_B
5	C_{JS}	CJS	F	Capacitance of Locos-edge L_S
6	C_{JG}	CJG	F	Capacitance of gate-edge L_G
7	I_{SDB}	ISDB	A	Diffusion saturation-current of bottom area A_B
8	I_{SDS}	ISDS	A	Diffusion saturation-current of Locos-edge L_S
9	I_{SDG}	ISDG	A	Diffusion saturation-current of gate-edge L_G
10	I_{SGB}	ISGB	A	Generation saturation-current of bottom area A_B
11	I_{SGS}	ISGS	A	Generation saturation-current of Locos-edge L_S
12	I_{SGG}	ISGG	A	Generation saturation-current of gate-edge L_G
13	T_A	TA	^0C	Ambient circuit temperature
14	T_{KD}	TKD	K	Absolute temperature of the junction/device
15	V	V	V	Diode bias voltage ($V = V_A - V_K$)
16	I	I	A	Total DC current from anode to cathode ($I = I_A = - I_K$)
17	Q	Q	C	Total junction charge ($Q = Q_A = - Q_K$)

11.8.5 Pstar specific values

The default values and clipping values as used by **Pstar** for the juncap model are listed below.

Position in list	Parameter name	Units	Default	Clip low	Clip high
1	*LEVEL*	-	1	-	-
2	*AB*	m^2	1.00×10^{-12}	0.00	-
3	*LS*	m	1.00×10^{-6}	0.00	-
4	*LG*	m	1.00×10^{-6}	0.00	-
5	*DTA*	°C	0.00	-	-
6	*TR*	°C	25.00	-273.15	-
7	*VR*	V	0.00	-	-
8	*JSGBR*	Am^{-2}	1.00×10^{-3}	0.00	-
9	*JSDBR*	Am^{-2}	1.00×10^{-3}	0.00	-
10	*JSGSR*	Am^{-1}	1.00×10^{-3}	0.00	-
11	*JSDSR*	Am^{-1}	1.00×10^{-3}	0.00	-
12	*JSGGR*	Am^{-1}	1.00×10^{-3}	0.00	-
13	*JSDGR*	Am^{-1}	1.00×10^{-3}	0.00	-
14	*NB*	-	1.00	0.1	-
15	*NS*	-	1.00	0.1	-
16	*NG*	-	1.00	0.1	-
17	*VB**	V	0.90	-	-
18	*CJBR*	Fm^{-2}	1.00×10^{-12}	0.00	-
19	*CJSR*	Fm^{-1}	1.00×10^{-12}	0.00	-
20	*CJGR*	Fm^{-1}	1.00×10^{-12}	0.00	-

21	*VDBR*	V	1.00	0.05	-
22	*VDSR*	V	1.00	0.05	-
23	*VDGR*	V	1.00	0.05	-
24	*PB*	-	0.40	0.05	0.99
25	*PS*	-	0.40	0.05	0.99
26	*PG*	-	0.40	0.05	0.99

* The value for *VB* is **(NOT USED)!**

11.8.6 The ON/OFF condition

The solution of a circuit involves a process of successive calculations. The calculations are started from a set of ‘initial guesses’ for the electrical quantities of the non-linear elements. A simplified DCAPPROX mechanism for devices using ON / OFF keywords is mentioned in [9]. By default the devices start in the default state.

JUNCAP			
	Default	ON	OFF
V_D	-0.1	0.7	-0.1

11.8.7 Numerical Adaptation

To implement the model in a circuit simulator, care must be taken of the numerical stability of the simulation program. A small non-physical conductance, G_{min}, is connected parallel to the conductance G. The value of the conductance G_{min} is 10^{-15} [1 / Ω].

11.8.8 DC operating point output

The DC operating point output facility gives information on the state of a device at its operation point.

Quantity	Equation	Description
G		Conductance
C		Capacitance

Remark: The conductance G_{min} is connected parallel to the conductance G. This conductance influences the DC operating output.

11.8.9 Temperature, Geometry and Voltage Dependence

The general scaling rules, which apply to all three components of the JUNCAP model, are:

$$T_{KR} = T_0 + T_R \tag{11.39}$$

$$T_{KD} = T_0 + T_A + \Delta T_A \tag{11.40}$$

$$\phi_{TR} = \frac{k \cdot T_{KR}}{q} \tag{11.41}$$

$$\phi_{TD} = \frac{k \cdot T_{KD}}{q} \tag{11.42}$$

$$\phi_{gR} = 1.16 - \frac{7.02 \cdot 10^{-4} \cdot T_{KR}^2}{1108.0 + T_{KR}} \tag{11.43}$$

$$\phi_{gD} = 1.16 - \frac{7.02 \cdot 10^{-4} \cdot T_{KD}^2}{1108.0 + T_{KD}} \tag{11.44}$$

$$F_{TD} = \left(\frac{T_{KD}}{T_{KR}}\right)^{1.5} \cdot \exp\left(\frac{\phi_{gR}}{2\phi_{TR}} - \frac{\phi_{gD}}{2\phi_{TD}}\right) \tag{11.45}$$

The internal reference parameters for the bottom component are specified by:

$$V_{DB} = V_{DBR} \cdot \frac{T_{KD}}{T_{KR}} - 2 \cdot \phi_{TD} \cdot \ln F_{TD} \tag{11.46}$$

$$C_{JB} = C_{JBR} \cdot A_B \cdot \left(\frac{V_{DBR} - V_R}{V_{DB}}\right)^{P_B} \tag{11.47}$$

$$I_{SGB} = J_{SGBR} \cdot F_{TD} \cdot A_B \cdot \left(\frac{V_{DB}}{V_{DBR} - V_R}\right)^{P_B} \tag{11.48}$$

$$I_{SDB} = J_{SDBR} \cdot F_{TD}^2 \cdot A_B \tag{11.49}$$

Similar formulations hold for the locos-edge and the gate-edge components; one has to replace the index B by S and G, and the area A_{B} by L_{S} and L_{G}, so for the locos-edge:

$$V_{DS} = V_{DSR} \cdot \frac{T_{KD}}{T_{KR}} - 2 \cdot \phi_{TD} \cdot \ln F_{TD} \tag{11.50}$$

$$C_{JS} = C_{JSR} \cdot L_S \cdot \left(\frac{V_{DSR} - V_R}{V_{DS}}\right)^{P_S} \tag{11.51}$$

$$I_{SGS} = J_{SGSR} \cdot F_{TD} \cdot L_S \cdot \left(\frac{V_{DS}}{V_{DSR} - V_R}\right)^{P_S} \tag{11.52}$$

$$I_{SDS} = J_{SDSR} \cdot F_{TD}^2 \cdot L_S \tag{11.53}$$

for the gate-edge:

$$V_{DG} = V_{DGR} \cdot \frac{T_{KD}}{T_{KR}} - 2 \cdot \phi_{TD} \cdot \ln F_{TD} \tag{11.54}$$

$$C_{JG} = C_{JGR} \cdot L_G \cdot \left(\frac{V_{DGR} - V_R}{V_{DG}}\right)^{P_G} \tag{11.55}$$

$$I_{SGG} = J_{SGGR} \cdot F_{TD} \cdot L_G \cdot \left(\frac{V_{DG}}{V_{DGR} - V_R}\right)^{P_G} \tag{11.56}$$

$$I_{SDG} = J_{SDGR} \cdot F_{TD}^2 \cdot L_G \tag{11.57}$$

In subsequent sections we will show the equations only for the bottom component.

11.8.10 JUNCAP - Capacitor and Leakage Current Model

- Junction capacitance of the source or drain diode

In the charge description the following internal parameter is defined:

$$Q_{JDB} = \frac{C_{JB} \cdot V_{DB}}{1 - P_B} \tag{11.58}$$

In order to prevent an unlimited increase of the voltage derivative of the charge, the charge description is divided in two parts: the original power function and a supplemented quadratic function. At the cross-over point between these regions, indicated by $V_L \ldots$, the following parameters are defined:

$$F_{CB} = 1 - \left(\frac{1 + P_B}{3}\right)^{\frac{1}{P_B}} \tag{11.59}$$

$$V_{LB} = F_{CB} \cdot V_{DB} \tag{11.60}$$

$$C_{LB} = C_{JB}(1 - F_{CB})^{-P_B} \tag{11.61}$$

$$Q_{LB} = Q_{JDB}\left\{1 - (1 - F_{CB})^{1 - P_B}\right\} \tag{11.62}$$

$$Q_{JBV} = \begin{cases} Q_{JDB} \cdot \left\{1 - \left(1 - \dfrac{V}{V_{DB}}\right)^{1 - P_B}\right\}, & V < V_{LB} \\ Q_{LB} + C_{LB}(V - V_{LB}) \cdot \left\{1 + \dfrac{P_B(V - V_{LB})}{2 \cdot V_{DB}(1 - F_{CB})}\right\}, & V \ge V_{LB} \end{cases} \tag{11.63}$$

and similar expressions for the locos-edge and gate-edge charges, Q_{JSV} and Q_{JGV}. The total charge characteristic can be described by:

$$Q = Q_{JBV} + Q_{JSV} + Q_{JGV}$$

Using elementary mathematics we can derive from Eqn. (11.63) simple equations for the capacitance of the bottom area:

$$C_{JBV} = \begin{cases} C_{JB} \cdot \dfrac{1}{\left(1 - \dfrac{V}{V_{DB}}\right)^{P_B}}, & V < V_{LB} \\ C_{LB} + \dfrac{C_{LB} \cdot P_B \cdot (V - V_{LB})}{V_{DB} \cdot (1 - F_{CB})}, & V \ge V_{LB} \end{cases} \tag{11.64}$$

and similar expressions for C_{JSV} and C_{JGV}.

The total capacitance can be described by:

$$C = C_{JBV} + C_{JSV} + C_{JGV}$$

- Bulk to source or bulk to drain diode current

  With the scaled parameters of the preceding section, the diffusion and generation current components can be expressed as:

$$I_{DB} = I_{SDB} \cdot \left\{ \exp\left(\frac{V}{N_B \cdot \phi_{TD}}\right) - 1 \right\} \tag{11.65}$$

$$I_{GB} = \begin{cases} I_{SGB} \cdot \left(\frac{V_{DB} - V}{V_{DB}}\right)^{P_B} \cdot \left\{ \exp\left(\frac{V}{N_B \cdot \phi_{TD}}\right) - 1 \right\}, & V \leq V_{DB} \\ 0\,, & V > V_{DB} \end{cases} \tag{11.66}$$

The first relation concerning the diffusion component, is valid over the whole operating range. The second relation, describing the generation current, shows an unlimited increase in the derivative of this function at $V = V_{DB}$. Therefore the power function is merged at $V = 0.0$ with a hyperbolic function in the forward bias range and the exponential part is divided by $\exp\left(\frac{V}{N_B \cdot \phi_{TD}}\right)$. This enables a gradual decrease in the generation current component.

The hyperbolic function: $I_{HYP} = F_{SB}\,(V + V_{AB})^{-B}$ is used. The parameter B controls the decrease of the current for voltages V>0.0 for all generation components. The value of B is fixed and set to 2 in the model. The continuity constraints of function and derivative in the merge point lead to the following relations for F_{SB} and V_{AB}:

$$V_{AB} = \frac{B \cdot V_{DB}}{P_B} \tag{11.67}$$

$$F_{SB} = I_{SGB} \cdot V_{AB}^{B} \tag{11.68}$$

Now the generation current voltage characteristic in the forward region becomes:

$$I_{GB} = \frac{F_{SB}}{(V + V_{AB})^{B}} \cdot \left\{ 1 - \exp\left(\frac{-V}{N_B \cdot \phi_{TD}}\right) \right\} \tag{11.69}$$

and the final model equations for the currents of the bottom area are:

$$I_{DB} = I_{SDB} \cdot \left\{ \exp\left(\frac{V}{N_B \cdot \phi_{TD}}\right) - 1 \right\} \tag{11.70}$$

$$I_{GB} = \begin{cases} I_{SGB} \cdot \left(\dfrac{V_{DB} - V}{V_{DB}}\right)^{\beta_B} \cdot \left\{ \exp\left(\dfrac{V}{N_B \cdot \phi_{TD}}\right) - 1 \right\}, & V \leq 0.0 \\ I_{SGB} \cdot \left(\dfrac{V_{AB}}{V + V_{AB}}\right)^{B} \cdot \left\{ 1 - \exp\left(\dfrac{-V}{N_B \cdot \phi_{TD}}\right) \right\}, & V > 0.0 \end{cases} \tag{11.71}$$

With similar expressions for the locos-edge and gate-edge components, the total junction current can be expressed as:

$$I = (I_{DB} + I_{GB}) + (I_{DS} + I_{GS}) + (I_{DG} + I_{GG}) \tag{11.72}$$