JUNCAP model (Philips JUNCAP Device) capacitorJn

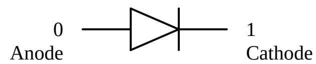


Figure 1: capacitorJn —— Juncap Element

Description:

This element implements a junction capacitor model that is used to model the source-bulk and drain-bulk junction diode behavior of the Philips MOS Model 9 model..

Form:

capacitorJn :(instance name) n_1 n_2 <parameter list>

n_1 is the positive(anode) diode voltage.

n_2 is the negative(cathode) diode voltage.

Parameters:

Parameters	Type	Default value	Required ?
level: Level of this model. Must be set to 1	Double	1	no
ab: Diffusion area(m^2)	Double	1e-12	no
ls: Length of side-wall of diffusion area AB which is not under gate(m)	Double	1.0e-6	no
lg: Length of side-wall of diffusion area AB which is under gate(m)	Double	1.0e-6	no
dta: Temperature offset of capjn element with respect to TA(C)	Double	0.0	no
tr: Temperature at which parameters have been determined(C)	Double	25	no
vr: Voltage at which parameters have been determined(V)	Double	0.0	no
jsgbr: Bottom saturation-current density due to electron-hole gene ration at V=VR(Am-2)	Double	1.0E-3	no
jsdbr: Bottom saturation-current density due to diffusion from back contact(Am-2)	Double	1.0E-3	no
jsgsr: Sidewall saturation-current density due to electron-hole generation at V=VR(Am-1)	Double	1.0E-3	no
jsdsr: Sidewall saturation-current density due to diffusion from back contact(Am-1)	Double	1.0E-3	no
jsggr: Gate edge saturation current density due to electron-hole generation at V=VR(Am-1)	Double	1.0E-3	no

jsdgr: Gate edge saturation current density due to diffusion from back contact(Am-1)	Double	1.0E-3	no
jsggr: Gate edge saturation current density due to electron-hole generation at V=VR(Am-1)	Double	1.0E-3	no
jsdgr: Gate edge saturation current density due to diffusion from back contact(Am-1)	Double	1.0E-3	no
nb: Emission coefficient of the bottom forward current	Double	1.0	no
ns: Emission coefficient of the sidewall forward current	Double	1.0	no
ng: Emission coefficient of the gate edge forward current	Double	1.0	no
vb: Reverse breakdown voltage(V)	Double	0.9	no
cjbr: Bottom junction capacitance at V=VR(Fm-2)	Double	1.0E-12	no
cjsr: Sidewall junction capacitance at V=VR(Fm-1)	Double	1.0E-12	no
cjgr: Gate edge junction capacitance at V=VR(Fm-1)	Double	1.0E-12	no
vdbr: Diffusion voltage of the bottom junction at T=TR(V)	Double	1.00	no
vdsr: Diffusion voltage of the sidewall junction at T=TR(V)	Double	1.00	no
vdgr: Diffusion voltage of the gate edge junction(V)	Double	1.00	no
pb: Bottom junction grading coefficient	Double	0.40	no
ps: Sidewall junction grading coefficient	Double	0.40	no
pg: Gate edge junction grading coefficient	Double	0.40	no

Example:

capacitorJn: j1 0 0.07 level=1 jsggr=1e-9

Model Documentation:

Theory

This section summarizes the elementary physics of a junction diode. Refer to semiconductor textbooks for additional information.Generally, the current voltage characteristics can be represented as follows:

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

$$ni \sim T^{\frac{3}{2}} \cdot \exp\left(\frac{-E_g}{2kT}\right)$$

Table 1-1: Current Voltage Characteristics		
Quantity	**Units**	**Description**
J	Am -2	Total reverse current density
Jd	Am -2	Diffusion saturation current density
Jg	Am -2	Generation current density
ni	m -3	Intrinsic carrier concentration
V	V	Voltage across the diode
Eg	J	Energy gap
k	JK -1	Boltzmann constant
T	K	Temperature

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

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

Table 1-2: Junction Capacitance Charge		
Quantity	**Units**	**Description**
Q	C	Total diode junction charge
Q j	C	Junction charge at built-in voltage
V	V	Voltage across the diode
Vd	V	Junction diffusion voltage
P		Junction grading coefficient

CAPJN Model

The CAPJN model is intended to describe formed by the source, drain or well-to-bulk junction devices, limited to the case of reverse biasing of these junctions. Similar 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 CAPJN model. Both the diffusion and the generation currents are treated in the model, each with individual temperature and voltage dependence.

In the CAPJN 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 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, which are described in the section on implementation. Any fixed capacitance that is present on a node (e.g., metal-1-to-substrate capacitance) must appear in a fixed capacitor statement or must be included in INTCAP. They no longer form the CAPJN model in contrast to the old NODCAP model.

Nomenclature

Table 1-3: List of Electrical Variable Parameters

No	**Variable**	**Programming Name**	**Units**	**Description**
1	Va	VA	V	Potential applied to the anode
2	Vk	VK	V	Potential applied to the cathode
3	Ia	IA	A	DC current into the anode
4	Ik	IK	A	DC current into the cathode
5	Qa	QA	C	Charge in the device attributed to the anode
6	Qk	QK	C	Charge in the device attributed to the cathode

List of Internal Variables and Parameters

Table 1-4: Internal Variables and Parameters

No	**Parameter**	**Programming Name**	**Units**	**Description**
1	Vdb	VDB	V	Diffusion voltage of bottom area AB
2	Vds	VDS	V	Diffusion voltage of Locos-edge LS
3	Vdg	VDG	V	Diffusion voltage of gate-edge LG
4	Cjb	CJB	F	Capacitance of bottom area AB
5	Cjs	CJS	F	Capacitance of Locos-edge LS
6	Cjg	CJG	F	Capacitance of gate-edge LG
7	Isdb	ISDB	A	Diffusion saturation current of bottom area AB
8	Isds	ISDS	A	Diffusion saturation current of Locos-edge LS
9	Isdg	ISDG	A	Diffusion saturation current of gate-edge LG
10	Isgb	ISGB	A	Generation saturation current of bottom area AB
11	Isgs	ISGS	A	Generation saturation current of Locos-edge LS
12	Isgg	ISGG	A	Generation saturation current of gate-edge LG
13	Ta	TA	C	Ambient circuit temperature

14	Tkd	TKD	K	Absolute temperature of the junction/device
15	V	V	V	Diode bias voltage (V=VA - VK)
16	I	I	A	Total DC current from anode to cathode (I = IA = -IK)
17	Q	Q	C	Total junction charge(Q = QA = - QK)

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. The devices start in the default state.

JUNCAP	Default	ON	OFF
V_D	-0.1	0.7	-0.1

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, Gmin, is connectedvalue of the conductance Gmin is $10^{-15}[1/\Omega]$.
Remark**:** The conductance G min is connected in parallel to the conductance G. This conductance influences the DC operating output.

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

CAPJN Model Equations
Temperature, Geometry and Voltage Dependence
The general scaling rules, which apply to all three components of the CAPJN model, are:

$$T_{KR} = T_0 + T_R$$

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

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

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

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

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

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

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

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

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

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

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

Similar formulations hold for the locos-edge and the gate-edge components. Replace the index *B* by *S* and *G* , and the area *AB* by *LS* and *LG*
In subsequent sections, we will show the equations only for the bottom component.

CAPJN Capacitor and Leakage Current Model
Charge
In the charge description, the following internal parameter is defined:

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

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

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

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

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

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

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

Similar expressions exist for the locos-edge and gate-edge charges, *Qjsv* and *Qjgv* .
The total charge characteristic can be described by:

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

Capacitance
Using elementary mathematics, simple equations for the capacitance of the bottom area:

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

and similar expressions exist for *Cjsv* and *Cjgv* .
The total capacitance can be described by:

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

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

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

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

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. 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 :

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

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

The generation current voltage characteristic in the forward region becomes:

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

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

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

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

Similar expressions exist for the locos-edge and gate-edge components.
The total junction current can be expressed as:

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

References:

http://www.semiconductors.philips.com/Philips_Models/additional/juncap/

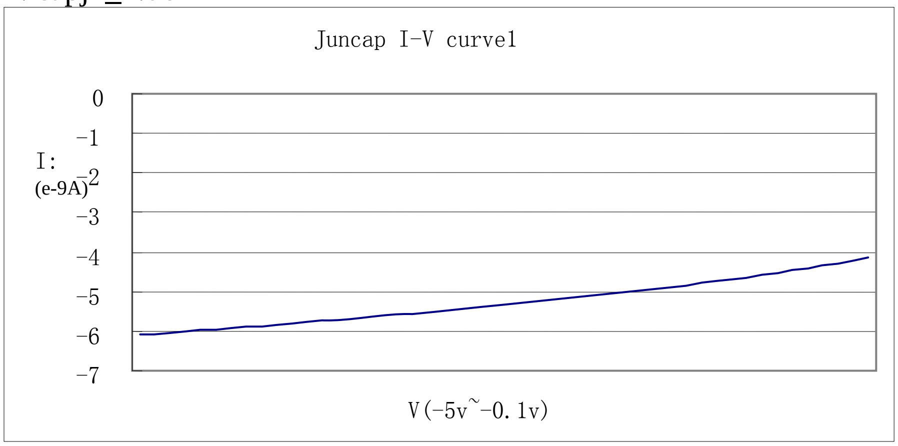
Sample Netlist:

```
*****Test netlist for capacitoJn(mos9)mosfet model*****
*.dc sweep="vsource:v1" start=-5 stop=-0.1 step=0.1
*.dc sweep="vsource:v1" start=-1 stop=-0.01 step=0.01
.dc sweep="vsource:v1" start=-1 stop=0.1 step=0.01
capacitorJn:j1 1 0

vsource:v1 1 0
*res:rd 1 0 r=1e15

*.out plot element "capacitorjn:j1" 0 it in "capjn_1.dc"
*.out plot element " capacitorjn:j1" 0 it in "capjn_2.dc"
.out plot element " capacitorjn:j1" 0 it in "capjn_3.dc"
.end
```

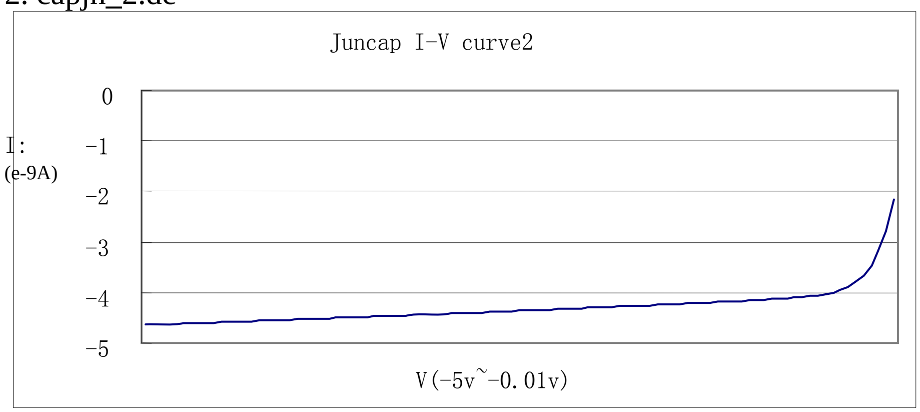
Validation:

The results of runs.

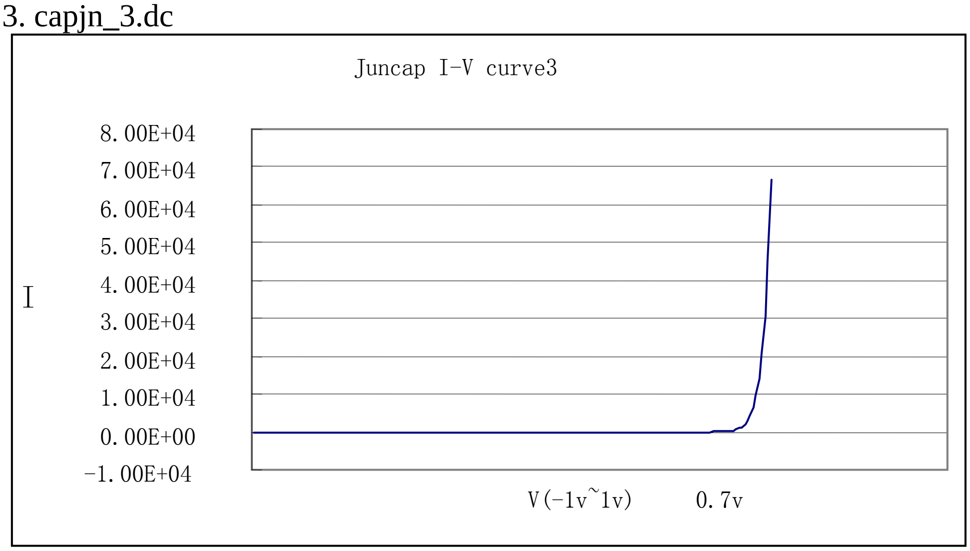
1. capjn_1.dc



2. capjn_2.dc



3. capjn_3.dc



Known Bugs:

When the input voltage is zero, the derivative of zero turn out to be extremely small but not zero.

Credits:

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