Technical Note PR-TN 2006/00302

Issued: 04/2006

From BSIM3/4 to PSP

Translation of flicker noise and junction parameters

The PSP model is a joint development of The Pennsylvania State University and Philips Research

A.J. Scholten; G.D.J. Smit; R. van Langevelde; D.B.M. Klaassen; G. Gildenblat (Penn.State Univ.); X. Li (Penn.State Univ.); H. Wang (Penn.State Univ.); W. Wu (Penn.State Univ.)

Philips Research Europe

Unclassified

Authors’ address data: A.J. Scholten WAY41; Andries.Scholten@philips.com
G.D.J. Smit WAY41; Gert-Jan.Smit@philips.com
R. van Langevelde WAY51; Ronald.van.Langevelde@philips.com
D.B.M. Klaassen WAY41; D.B.M.Klaassen@philips.com
G. Gildenblat; Gildenblat@psu.edu

Unclassified Report:	NL-TN 2006/00302
Title:	From BSIM3/4 to PSP Translation of flicker noise and junction parameters
Author(s):	G.D.J. Smit, R. van Langevelde, A.J. Scholten, and D.B.M. Klaassen (Philips Research) G. Gildenblat, X. Li, H. Wang, and W. Wu (The Pennsylvania State University)

Part of project:	Compact modelling
Customer:	Philips Semiconductors

Keywords: PSP Model, JUNCAP2 model, compact modelling, MOSFET, CMOS, circuit simulation, integrated circuits

Abstract: In December 2005, the Compact Model Council (CMC) elected PSP to become the new industrial standard model for compact MOSFET modeling. This document provides BSIM3/4-to-PSP translation schemes for flicker noise and junction parameters, that may be useful for those who want to switch over from BSIM3/4 to PSP.

Contents

1 Introduction

This document is intended to provide a quick start with *(i)* the PSP flicker noise model and *(ii)* the JUNCAP2 junction model for those who are familiar with their BSIM3 or BSIM4 equivalents. Translations from BSIM3 and BSIM4 flicker noise and junction parameters to PSP and JUNCAP2 parameters are provided. The reader should be warned, however, that a full one-to-one translation is in general not possible. These translations are merely intended to provide BSIM users that are switching over to PSP with initial parameter sets. In Section 2 we will treat the translation of flicker noise parameters, and in Section 3 we will treat junction parameters. The translation schemes provided will be verified using examples run in a circuit simulator.

2 From BSIM to PSP flicker noise parameters

2.1 Introduction

The PSP flicker noise model has the same physical background [1] as that of the unified noise models in BSIM3v3 (**noimod** $=$ 2 or 3) and BSIM4 (**fnoimod**$=$ 1). Therefore, an approximate translation of the BSIM noise parameters into the corresponding PSP parameters is possible and will be outlined in this section. For other flicker noise models selected in BSIM3/4, no straightforward translation is possible.

2.2 BSIM3

2.2.1 Translation scheme

In BSIM3v3 the so-called unified flicker noise model is selected by setting the switch **noimod** to 2 or 3. In that case, the flicker noise is calculated using the parameters listed in Table 2.1.

BSIM3v3 parameter	**Description**
$NOIA$	noise parameter A
$NOIB$	noise parameter B
$NOIC$	noise parameter C
EF	flicker exponent
$LINTNOI$	length reduction parameter offset

Table 2.1: Overview of BSIM3v3 unified flicker noise model parameters

The PSP flicker noise model has the following differences w.r.t the BSIM3v3 model:

- There is no equivalent of the parameter EF. Its value is fixed to 1 in PSP.
- There is no equivalent of the parameter $LINTNOI$. Its value is fixed to 0 in PSP.
- In PSP the calculations are done in a surface-potential based framework instead of a threshold-voltage-based framework. Therefore, the transition between weak and strong inversion is smoother and more physical in PSP.

When in BSIM3v3 $EF = 1$ and $LINTNOI = 0$, one can translate the parameters $NOIA$, $NOIB$, and $NOIC$ into the corresponding PSP parameters (see also [2]) using Table 2.2.

PSP parameter	**Calculated from BSIM3v3 parameters as follows:**
local model parameters	
NFA	$\frac{NOIA}{10^8 \cdot W_{\mathrm{eff}} \cdot L_{\mathrm{eff}}}$
NFB	$\frac{NOIB}{10^8 \cdot W_{\mathrm{eff}} \cdot L_{\mathrm{eff}}}$
NFC	$\frac{NOIC}{10^8 \cdot W_{\mathrm{eff}} \cdot L_{\mathrm{eff}}}$
global model parameters	
NFALW	$NOIA \cdot 10^4$
NFBLW	$NOIB \cdot 10^4$
NFCLW	$NOIC \cdot 10^4$
binning model parameters	
PONFA	0
PONFB	0
PONFC	0
PLNFA	0
PLNFB	0
PLNFC	0
PWNFA	0
PWNFB	0
PWNFC	0
PLWNFA	$NOIA \cdot 10^4$

continued on next page

continued from previous page

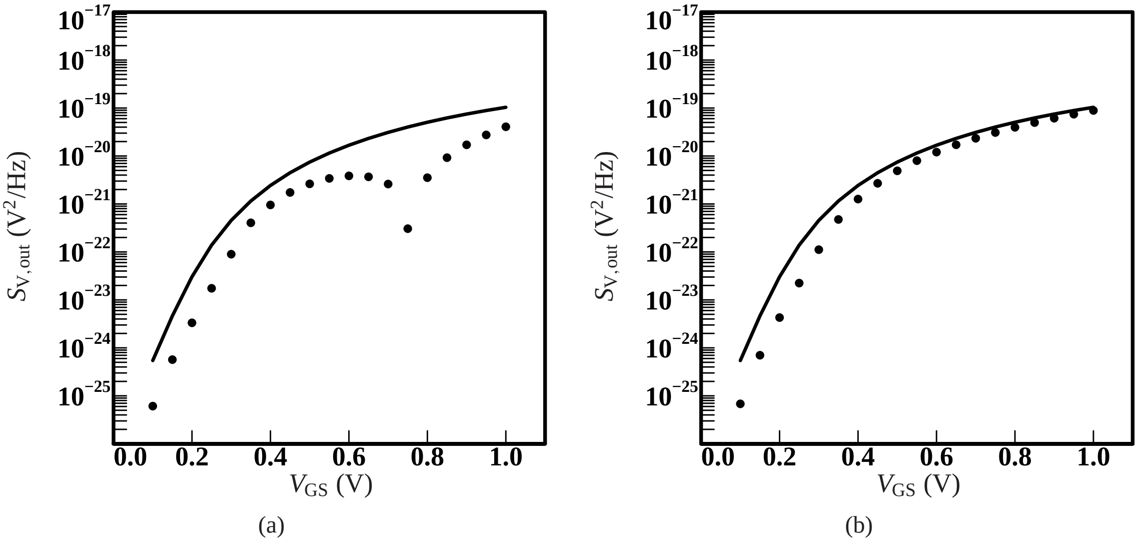
PSP parameter	**Calculated from BSIM3v3 parameters as follows:**
PLWNFB	$NOIB \cdot 10^4$
PLWNFC	$NOIC \cdot 10^4$

Table 2.2: Translation of BSIM3v3 to PSP flicker noise parameters

2.2.2 Verification

The BSIM3v3-to-PSP translation scheme for flicker noise has been tested using the Spectre simulator. With BSIM3v3, IV and CV simulations have been performed for a 10/10 μm n-channel device from a 90-nm CMOS technology. A PSP local parameter set has been generated which fits to the resulting IV and CV curves. In the BSIM3v3 the flicker noise parameters $NOIA$, $NOIB$, and $NOIC$ have been set to their default values. The corresponding PSP parameters have been found using the translation scheme of Table 2.2. The noise of the BSIM3v3 and PSP models has been compared using a two-port noise analysis in Spectre. The flicker noise voltage spectral density on the 50-Ω output port is compared in Fig. 2.1(a) for BSIM3v3 and PSP. BSIM3v3 shows behavior which cannot be reproduced in PSP (which has a smoother and more realistic shape). The BSIM3v3 behavior is related to the parameter $NOIC$. When $NOIC$, and thus **NFC** in PSP, is set to zero, the agreement between BSIM3v3 and PSP is much better, as shown in Fig. 2.1(b).

In conclusion, the BSIM3v3-to-PSP translation scheme for flicker noise gives reasonable results, but a full one-to-one agreement is evidently not possible due to fundamental differences in the core model.



(a) (b)

Figure 2.1: (a) Comparison of BSIM3v3 (markers) and PSP (line) flicker noise simulation in Spectre for a 10/10 μm n-channel device at a frequency of $f = 1$ kHz. The drain-source voltage is 1 V. BSIM3v3 parameters were set to their default values $NOIA = 1 \times 10^{20}$, $NOIB = 5 \times 10^4$, and $NOIC = -1.4 \times 10^{-12}$. The corresponding PSP parameters were $\mathbf{NFA} = 1 \times 10^{22}$, $\mathbf{NFB} = 5 \times 10^6$, and $\mathbf{NFC} = -1.4 \times 10^{-10}$. (b) Same, but now with $NOIC = 0$ and $\mathbf{NFC} = 0$.

2.3 BSIM4

2.3.1 Translation scheme

In BSIM4 the unified flicker noise model is selected by setting the switch **fnoimod** to 1. In that case, the flicker noise is calculated using the parameters listed in Table 2.3.

BSIM4 parameter	**description**
$NOIA$	Flicker noise parameter A
$NOIB$	Flicker noise parameter B
$NOIC$	Flicker noise parameter C
EF	Flicker noise frequency exponent
$LINTNOI$	length reduction parameter offset

Table 2.3: Overview of BSIM4 unified flicker noise model parameters

The BSIM4 unified flicker noise model is very similar to its BSIM3v3 equivalent. Therefore, just as in the BSIM3v3 case, one can translate the parameters $NOIA$, $NOIB$, and $NOIC$ into the corresponding PSP parameters provided that $EF = 1$ and $LINTNOI = 0$ in BSIM4. Note however that the BSIM4 parametrization is slightly different:

- In BSIM3v3, the value of γ_{ox}, i.e., the attenuation coefficient of the electron wave function in the gate oxide, was fixed to 10^8 (which is the correct value when expressed in cm^{-1}). In BSIM4, however, this value is fixed to 10^{10} (which is the correct value when expressed in m^{-1}).

- In BSIM4, an additional factor q (i.e., elementary charge) has been included in the pre-factor of the flicker noise equation.

As a consequence, the values of the BSIM4 flicker noise parameters need to be $100/q$ times larger than their BSIM3v3 counterparts to get the same amount of flicker noise. Similarly, when we translate BSIM4 flicker noise parameters into PSP flicker noise parameters, we need to include an additional factor of $q/100$ as compared to the BSIM3v3 translation scheme of Table 2.2. This leads to the translation scheme as given in Table 2.4.

PSP parameter	**calculated from BSIM4 parameters as follows:**
local model parameters	
NFA	$\frac{q \cdot NOIA}{10^{10} \cdot W_{\mathrm{eff}} \cdot L_{\mathrm{eff}}}$
NFB	$\frac{q \cdot NOIB}{10^{10} \cdot W_{\mathrm{eff}} \cdot L_{\mathrm{eff}}}$
NFC	$\frac{q \cdot NOIC}{10^{10} \cdot W_{\mathrm{eff}} \cdot L_{\mathrm{eff}}}$
global model parameters	
NFALW	$q \cdot NOIA \cdot 10^2$
NFBLW	$q \cdot NOIB \cdot 10^2$
NFCLW	$q \cdot NOIC \cdot 10^2$
binning model parameters	
PONFA	0
PONFB	0
PONFC	0
PLNFA	0
PLNFB	0
PLNFC	0
PWNFA	0
PWNFB	0
PWNFC	0
PLWNFA	$q \cdot NOIA \cdot 10^2$

continued on next page

continued from previous page

PSP parameter	**calculated from BSIM4 parameters as follows:**
PLWNFB	$q \cdot NOIB \cdot 10^2$
PLWNFC	$q \cdot NOIC \cdot 10^2$

Table 2.4: Translation of BSIM4 to PSP flicker noise parameters. The symbol q denotes the elementary charge.

2.3.2 Verification

The BSIM4-to-PSP translation scheme for flicker noise has been tested using the Spectre simulator. With BSIM4, IV and CV simulations have been performed for a 10/10 μm n-channel device from a 90-nm CMOS technology. A PSP local parameter set has been generated which fits to these IV and CV curves. In the BSIM4 the flicker noise parameters $NOIA$, $NOIB$, and $NOIC$ have been set to their default values. The corresponding PSP parameters have been found using the translation scheme of Table 2.4. The noise of the BSIM3v3 and PSP models has been compared using a two-port noise analysis in Spectre. The flicker noise voltage spectral density on the 50-Ω output port is compared in Fig. 2.2 for BSIM4 and PSP. Excellent agreement is observed, much better than in the BSIM3v3 case.

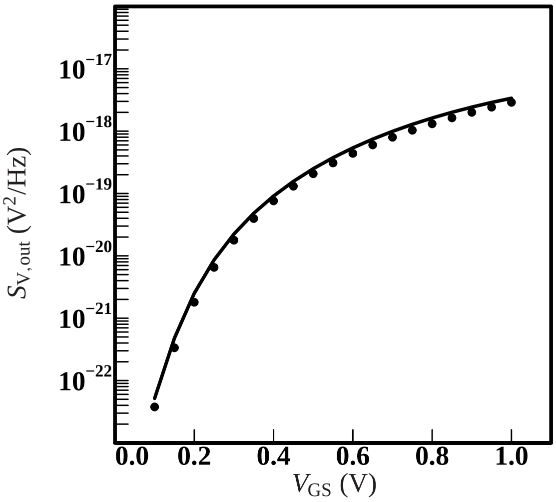


Figure 2.2: Comparison of BSIM4 (markers) and PSP (line) flicker noise simulation in Spectre for a 10/10 μm n-channel device at a frequency of $f = 1$ kHz. The drain-source voltage is 1 V. BSIM4 parameters were set to their default values $NOIA = 6.25 \times 10^{41}$, $NOIB = 3.125 \times 10^{26}$, and $NOIC = 8.75 \times 10^{9}$. The corresponding PSP parameters were $NFA = 1 \times 10^{23}$, $NFB = 5 \times 10^{7}$, and $NFC = 1.4 \times 10^{-9}$.

3 From BSIM junction parameters to JUNCAP2 parameters

3.1 Introduction

This chapter is intended to provide a quick start with the JUNCAP2 junction model for those who are familiar with the BSIM3 or BSIM4 junction models. Translations from BSIM3 and BSIM4 junction parameters to JUNCAP2 parameters are provided.

3.2 BSIM3

3.2.1 Introduction

We will base ourselves on the documentation of BSIM3v3.3, as found on the BSIM website [3]. The junction parameters taken from this document are listed in Table 3.5. It was found that the junction parameter list in the Spectre simulator was extended w.r.t. the Berkeley documentation (e.g., parameters CBS, CBD). Thus, readers should be careful in applying the information in this chapter to their own situation, because their BSIM3v3.3 version/implementation may also deviate from the description in the BSIM3v3.3 manual.

BSIM3v3.3 parameter name	**BSIM3v3.3 parameter description**	**unit**
AS	source junction area	m^2
PS	source junction perimeter	m
AD	drain junction area	m^2
PD	drain junction perimeter	m
$TNOM$	temperature at which parameters are extracted	K
CJ	bottom junction capacitance per unit area at zero bias	F/m^2
MJ	bottom junction capacitance grading coefficient	-
PB	bottom junction built-in potential	V
$CJSW$	source/drain sidewall junction capacitance per unit length at zero bias	F/m
$MJSW$	source/drain sidewall junction capacitance grading coefficient	-

continued on next page

continued from previous page

BSIM3v3.3 parameter name	**BSIM3v3.3 parameter description**	**unit**
$PBSW$	source/drain sidewall junction built-in potential	V
$CJSWG$	source/drain gate side wall junction capacitance per unit length at zero bias	F/m
$MJSWG$	source/drain gate side wall junction capacitance grading coefficient	-
$PBSWG$	source/drain gate side wall junction built-in potential	V
TPB	temperature coefficient of PB	V/K
$TPBSW$	temperature coefficient of $PBSW$	V/K
$TPBSWG$	temperature coefficient of $PBSWG$	V/K
TCJ	temperature coefficient of CJ	1/K
$TCJSW$	temperature coefficient of $CJSW$	1/K
$TCJSWG$	temperature coefficient of $CJSWG$	1/K
JS	saturation current density	A/m^2
$JSSW$	side wall saturation current density	A/m
NJ	emission coefficient	-
XTI	junction current temperature exponent coefficient	-
$IJTH$	limiting current	A

Table 3.5: Overview of BSIM3v3.3 junction capacitance parameters.

3.2.2 Instance parameters

The JUNCAP2 stand-alone model has inherited its instance parameters $\mathbf{AB}$, $\mathbf{LS}$, and $\mathbf{LG}$ from the JUNCAP (level=1) model. Here $\mathbf{AB}$ is the junction area, $\mathbf{LS}$ the junction isolation sidewall perimeter, and $\mathbf{LG}$ the junction gate edge sidewall perimeter. It is important to realize that the instance parameters in BSIM3 are defined somewhat differently. In BSIM3, the instance parameters AS and AD represent the junction area of source and drain, respectively[1]. The instance parameters PS and PD represent the *total* junction perimeter (isolation sidewall plus gate sidewall). In table 3.6, the translation from BSIM3 to JUNCAP2 instance parameters is given. Here, W_{eff} represents the BSIM3 effective width of the MOSFET.

For JUNCAP2 as embedded in the PSP MOSFET model, the junction dimensions can be specified in different ways, depending on the value of the switch $\mathbf{SWJUNCAP}$. For all details on this, please refer to [4].

JUNCAP2 instance parameter	**calculated from BSIM3 quantities as follows:**	
	source	drain
AB	AS	AD
LS	$PS - W_{\text{eff}}$	$PD - W_{\text{eff}}$
LG	W_{eff}	W_{eff}

Table 3.6: Translation of BSIM3 junction instance parameters to JUNCAP2 instance parameters.

3.2.3 Junction capacitance parameters

Just like JUNCAP2, the BSIM3v3.3 junction capacitance model distinguishes bottom, isolation sidewall, and gate sidewall components of the capacitances.

Moreover, the BSIM3v3.3 junction capacitance model is parametrized in terms of a built-in voltage, grading coefficient, and zero-bias capacitance, just as JUNCAP2.

Nevertheless, the JUNCAP2 capacitance model is not fully compatible with the BSIM3v3.3 junction capacitance model. The reason for this is that the BSIM3v3.3 junction capacitance model, as compared to JUNCAP2, has additional temperature scaling parameters for built-in voltages (TPB, $TPBSW$, and $TPBSWG$), and zero-bias capacitances (TCJ, $TCJSW$, $TCJSWG$). For JUNCAP2, these effects are incorporated in the underlying physics and therefore these BSIM3v3 parameters have no JUNCAP2 equivalents. In addition, the BSIM3v3 handles the junction capacitance under forward bias differently than JUNCAP2.

Assuming that the above-mentioned additional temperature scaling parameters are zero or at a physically reasonable value, one can use Table 3.7 to translate BSIM3v3.3 junction capacitance parameters into JUNCAP2 parameters. An example comparison of a BSIM3v3.3 simulation of the junction ca-

---

[1] Note that BSIM3, in contrast to BSIM4, does not have the **permod** switch, discussed in section 3.3.2.

pacitance with a JUNCAP2 simulation is shown in Figure 3.3. Good agreement is observed. For practical situations the temperature dependence of junction capacitance is fairly small, and the different treatment of this in BSIM3v3 and JUNCAP2 only gives minor deviations in the junction capacitance.

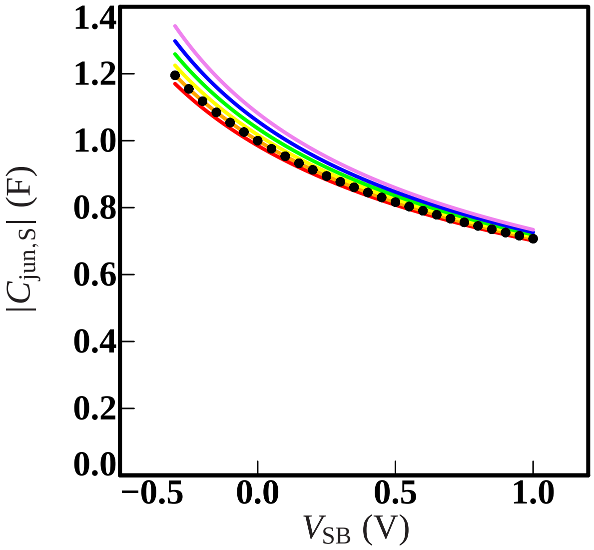


Figure 3.3: Comparison of BSIM3v3.3 simulation of junction capacitance with a JUNCAP2 simulation. The BSIM3v3.3 simulations showed no temperature dependence and are indicated with black markers. The JUNCAP2 simulations are indicated by colored lines, where the colors red, orange, yellow, green, blue, and violet indicate temperatures of -40, 0, 40, 80, 120, and 160 °C, respectively. The relevant BSIM3v3.3 parameters are $TNOM = 40$, $CJ = 1000$, $MJ = 0.5$, $PB = 1$, $TCJ = 0$, and $TPB = 0$. The corresponding JUNCAP2 parameters are $\mathbf{TRJ} = 40$, $\mathbf{CJORBOT} = 1000$, $\mathbf{PBOT} = 0.5$, $\mathbf{VBIRBOT} = 1$, $\mathbf{PHIGBOT} = 1.16$.

3.2.4 Junction leakage current parameters

The BSIM3v3.3 junction leakage model is quite different from the JUNCAP2 model. Some of the major differences are:

- For junction currents, BSIM3v3.3 makes no distinction between isolation sidewall and gate sidewall. (N.B. for junction capacitances this distinction *is* made in BSIM3v3.3.)
- BSIM3v3.3 has no models for Shockley-Read-Hall, trap-assisted tunneling, band-to-band tunneling, and avalanche breakdown. In reverse bias, only ideal diode current is modeled by BSIM3v3.3.
- BSIM3v3.3 models non-ideality in the forward mode of operation using an emission coefficient (or “non-ideality factor”). In JUNCAP2 this is modeled by physical models for Shockley-Read-Hall and trap-assisted tunneling.
- In JUNCAP2 the temperature dependence of the ideal current can be tuned using the $\mathbf{PHIG}$ parameters, which represent the band gap voltage. In BSIM3v3 the band gap is fixed to 1.16 eV and a non-physical parameter XTI is used to tune the temperature dependence. These two different descriptions are not fully compatible.

Let us first discuss the special case that the emission coefficient NJ in BSIM3v3.3 is equal to 1. Now we can make an (approximate) translation to JUNCAP2, which is valid both in forward and reverse mode of operation. In this case, we can write the BSIM3v3.3 expression for the bottom component of the junction as:

$$I_{\mathrm{bs}} = A_{\mathrm{s}} \cdot J_{\mathrm{s}} \cdot \left[\exp\left(\frac{q \cdot V_{\mathrm{bs}}}{k_{\mathrm{B}} \cdot T} \right) - 1 \right] \ , \tag{3.1}$$

with

$$J_{\mathrm{s}} = J_{\mathrm{s0}} \cdot \exp\left[\frac{E_{\mathrm{g0}}}{V_{\mathrm{tm0}}} - \frac{E_{\mathrm{g}}}{V_{\mathrm{tm}}} + XTI \cdot \ln\left(\frac{T}{T_{\mathrm{nom}}} \right) \right] \ . \tag{3.2}$$

Here E_{g} and E_{g0} represent the band gap in eV at the device temperature and at T_{nom}, respectively. The BSIM3v3.3 formulas for $E_{\mathrm{g}}(T)$ are the same as those for JUNCAP2, with the exception that the extrapolated zero-temperature band gap is fixed to 1.16 eV in BSIM3v3.3, while it is an adjustable parameter in JUNCAP2. Equating the BSIM3v3.3 and JUNCAP expressions leads to

$$3 \cdot \ln\left(\frac{T_{\mathrm{KD}}}{T_{\mathrm{KR}}} \right) + \frac{\mathbf{PHIGBOT} - 1.16}{\phi_{\mathrm{TR}}} \cdot \left(1 - \frac{\phi_{\mathrm{TR}}}{\phi_{\mathrm{TD}}} \right) = XTI \cdot \ln\left(\frac{T}{T_{\mathrm{nom}}} \right) \ . \tag{3.3}$$

Now we approximate

$$1 - \frac{\phi_{\mathrm{TR}}}{\phi_{\mathrm{TD}}} \approx \ln\left(\frac{T_{\mathrm{KD}}}{T_{\mathrm{KR}}} \right) \ . \tag{3.4}$$

Identifying T_{KD} with T and T_{KR} with T_{nom} we get

$$XTI \approx 3 + \frac{\mathbf{PHIGBOT} - 1.16}{\phi_{\mathrm{TR}}} \ . \tag{3.5}$$

Solving for $\mathbf{PHIGBOT}$ yields

$$\mathbf{PHIGBOT} \approx 1.16 + \frac{k_{\mathrm{B}} \cdot T_{\mathrm{nom}}}{q} \cdot (XTI - 3) \ . \tag{3.6}$$

For the more general case that NJ is not equal to 1, there is no straightforward translation from BSIM3v3 to JUNCAP2 in the forward mode of junction operation. Moreover, Eq. (3.6) has to be modified since in BSIM3v3.3 the emission coefficient NJ also influences the temperature dependence of the junction saturation current

$$J_{\mathrm{s}} = J_{\mathrm{s0}} \cdot \exp\left[\frac{\frac{E_{\mathrm{g0}}}{V_{\mathrm{tm0}}} - \frac{E_{\mathrm{g}}}{V_{\mathrm{tm}}} + XTI \cdot \ln\left(\frac{T}{T_{\mathrm{nom}}} \right)}{NJ} \right] \ . \tag{3.7}$$

If we neglect the T-dependence of E_{g} equating Eq. (3.7) to the JUNCAP2 ideal current equation leads to the following generalization of Eq. (3.6):

$$\mathbf{PHIGBOT} \approx \frac{1.16}{NJ} + \frac{k_{\mathrm{B}} \cdot T_{\mathrm{nom}}}{q} \cdot \left(\frac{XTI}{NJ} - 3 \right) \ . \tag{3.8}$$

In Figs. 3.4(a), 3.4(b), and 3.5(a), the IV results of the BSIM3v3.3 junction model with $NJ = 1$ are compared with those of JUNCAP2. Here, we have used Eq. (3.8) to calculate the required value for $\mathbf{PHIGBOT}$ from the given value for XTI. The full translation of junction IV-parameters is summarized in Table 3.7. As expected, a close match between BSIM3v3.3 and JUNCAP2 is observed for the reverse behavior in the case that $XTI = 3$, which corresponds to $\mathbf{PHIGBOT} = 1.16$. But also for $XTI = -3$, corresponding to $\mathbf{PHIGBOT} = 1.0$, the match is very good (note that this is already a somewhat unrealistic case, since such a big deviation from 1.16 eV is not found in practice). Only in extremely unrealistic cases, such as $XTI = -20$, corresponding to an unrealistic bandgap voltage $\mathbf{PHIGBOT} = 0.54$, the approximate nature of Eq. (3.8) becomes apparent (Fig. 3.5(a)). In the forward mode of operation, the agreement is also very good, except for some deviations at high currents due to the limiting behavior of the forward current in the Spectre simulator which was used for this test.

In Figs. 3.5(b), a similar comparison is done for non-unity emission coefficient in BSIM3v3.3. Now the slope of the forward IV-curves differs in JUNCAP2, but the temperature scaling of the reverse current is still well fit due to the use of Eq. (3.8).

JUNCAP2 parameter	**calculated from BSIM3v3.3 parameters as follows:**
General parameters	
$\mathbf{TRJ}$	$TNOM$
$\mathbf{IMAX}$	$IJTH$
Capacitance parameters	
$\mathbf{CJORBOT}$	CJ
$\mathbf{CJORSTI}$	$CJSW$
$\mathbf{CJORGAT}$	$CJSWG$
$\mathbf{VBIRBOT}$	PB
$\mathbf{VBIRSTI}$	$PBSW$
$\mathbf{VBIRGAT}$	$PBSWG$
$\mathbf{PBOT}$	MJ
$\mathbf{PSTI}$	$MJSW$
$\mathbf{PGAT}$	$MJSWG$

continued on next page

continued from previous page

JUNCAP2 parameter	**calculated from BSIM3v3.3 parameters as follows:**
Ideal-current parameters	
PHIGBOT	$\frac{1.16}{NJ} + \frac{k_{\mathrm{B}} \cdot T_{\mathrm{nom}}}{q} \cdot \left(\frac{XTI}{NJ} - 3\right)$
PHIGSTI	$\frac{1.16}{NJ} + \frac{k_{\mathrm{B}} \cdot T_{\mathrm{nom}}}{q} \cdot \left(\frac{XTI}{NJ} - 3\right)$
PHIGGAT	$\frac{1.16}{NJ} + \frac{k_{\mathrm{B}} \cdot T_{\mathrm{nom}}}{q} \cdot \left(\frac{XTI}{NJ} - 3\right)$
IDSATRBOT	JS
IDSATRSTI	$JSSW$
IDSATRGAT	$JSSW$
Shockley-Read-Hall parameters	
CSRHBOT	0
CSRHSTI	0
CSRHGAT	0
XJUNSTI	10^{-7}
XJUNGAT	10^{-7}
Trap-assisted tunneling parameters	
CTATBOT	0
CTATSTI	0
CTATGAT	0
MEFFTATBOT	0.25

continued on next page

continued from previous page

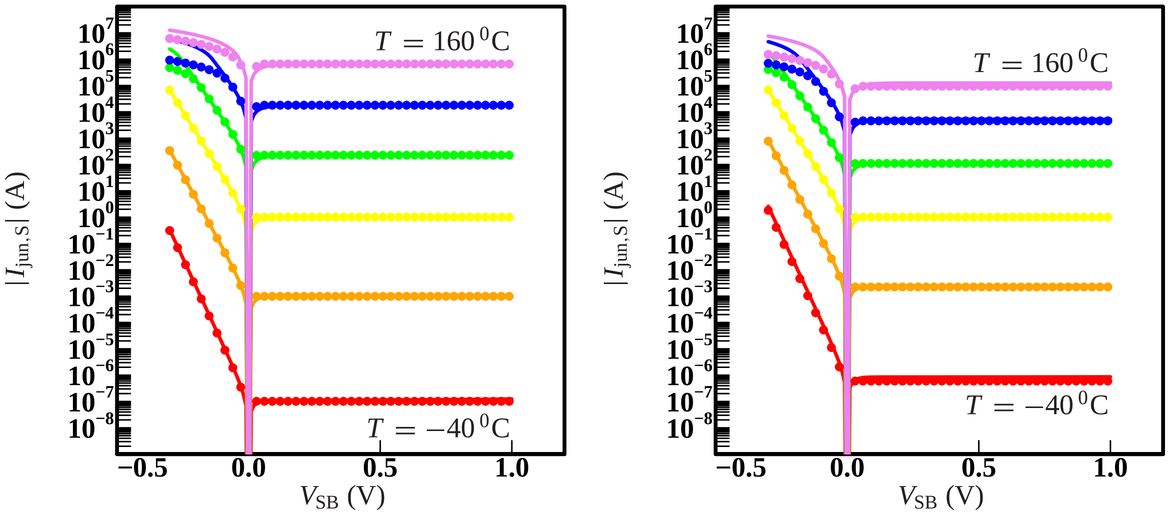
JUNCAP2 parameter	**calculated from BSIM3v3.3 parameters as follows:**
MEFFTATSTI	0.25
MEFFTATGAT	0.25
Band-to-band tunneling parameters	
CBBTBOT	0
CBBTSTI	0
CBBTGAT	0
FBBTRBOT	1×10^9
FBBTRSTI	1×10^9
FBBTRGAT	1×10^9
STFBBTBOT	0
STFBBTSTI	0
STFBBTGAT	0
Avalanche breakdown parameters	
VBRBOT	1001
VBRSTI	1001
VBRGAT	1001
PBRBOT	4
PBRSTI	4

continued on next page

continued from previous page

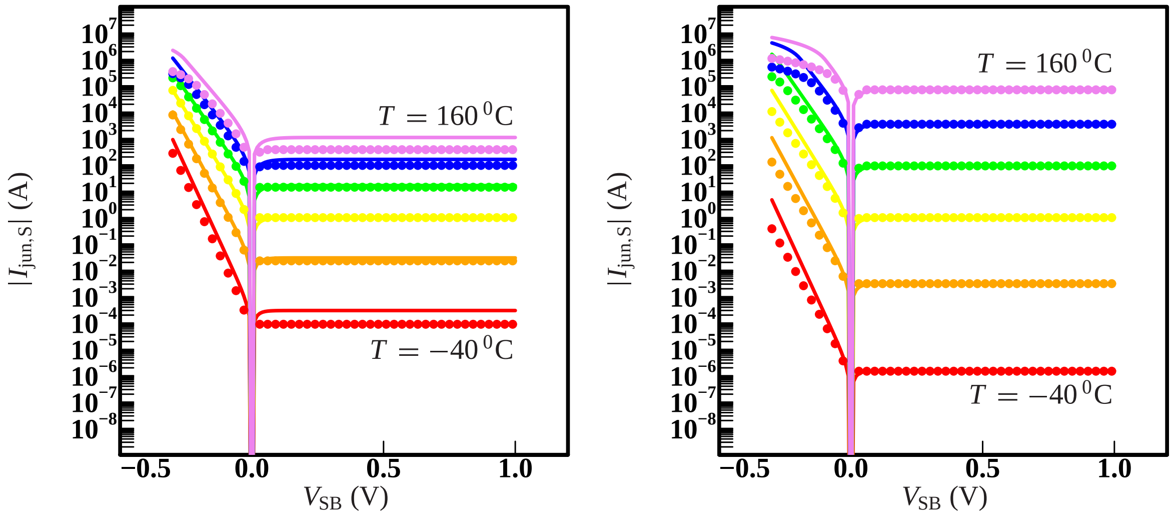
JUNCAP2 parameter	**calculated from BSIM3v3.3 parameters as follows:**
$\mathbf{PBRGAT}$	4

Table 3.7: BSIM3v3.3-to-JUNCAP2 junction parameter translation scheme.



(a) (b)

Figure 3.4: (a) Comparison of BSIM3v3.3 simulation with $NJ = 1$ and $XTI = 3$ (markers) with JUNCAP2 simulation with $\mathbf{PHIGBOT} = 1.16$ (lines). (b) Comparison of BSIM3v3.3 simulation with $NJ = 1$ and $XTI = -3$ (markers) with JUNCAP2 simulation with $\mathbf{PHIGBOT} = 1.0$ (lines). Temperatures are -40, 0, 40, 80, 120, and 160 $^{\mathrm{o}}$C, and are indicated by colors red, orange, yellow, green, blue, and violet, respectively.



(a) (b)

Figure 3.5: (a) Comparison of BSIM3v3.3 simulation with $NJ = 1$ and $XTI = -20$ (markers) with JUNCAP2 simulation with $\mathbf{PHIGBOT} = 0.54$ (lines). (b) Comparison of BSIM3v3.3 simulation with $NJ = 1.2$ and $XTI = 3$ (markers) with JUNCAP2 simulation with $\mathbf{PHIGBOT} = 0.953$ (lines). Temperatures are -40, 0, 40, 80, 120, and 160 °C, and are indicated by colors red, orange, yellow, green, blue, and violet, respectively.

3.3 BSIM4

3.3.1 Introduction

We will base ourselves on the documentation of BSIM4.5.0, as found on the BSIM website [3]. The junction parameters taken from this documentation are listed in Table 3.8.

BSIM4.5.0 parameter name		**BSIM4.5.0 parameter description**	unit
source	**drain**		
$TNOM$		temperature at which parameters are extracted	°C
CJS	CJD	bottom junction capacitance per unit area at zero bias	F/m^2
MJS	MJD	bottom junction capacitance grading coefficient	-
PBS	PBD	bottom junction built-in potential	V
$CJSWS$	$CJSWD$	isolation-edge sidewall junction capacitance per unit length	F/m
$MJSWS$	$MJSWD$	isolation-edge sidewall junction capacitance grading coefficient	-
$PBSWS$	$PBSWD$	isolation-edge sidewall junction built-in potential	V
$CJSWGS$	$CJSWGD$	gate-edge sidewall junction capacitance per unit length	F/m
$MJSWGS$	$MJSWGD$	gate-edge sidewall junction capacitance grading coefficient	-
$PBSWGS$	$PBSWGD$	gate-edge sidewall junction built-in potential	V
TPB		temperature coefficient of PBS, PBD	V/K
$TPBSW$		temperature coefficient of $PBSWS$, $PBSWD$	V/K
$TPBSWG$		temperature coefficient of $PBSWGS$, $PBSWGD$	V/K
TCJ		temperature coefficient of CJS, CJD	1/K

continued on next page

continued from previous page

BSIM4.5.0 parameter name		**BSIM4.5.0 parameter description**	unit
source	**drain**		
$TCJSW$		temperature coefficient of $CJSWS$, $CJSWD$	1/K
$TCJSWG$		temperature coefficient of $CJSWGS$, $CJSWGD$	1/K
JSS	JSD	bottom junction reverse saturation current density	A/m^2
$JSWS$	$JSWD$	isolation-edge sidewall reverse saturation current density	A/m
$JSWGS$	$JSWGD$	gate-edge sidewall reverse saturation current density	A/m
NJS	NJD	emission coefficient of junction	-
$XTIS$	$XTID$	junction current temperature exponent	-
$IJTHSREV$	$IJTHDREV$	limiting current in reverse bias region	A
$IJTHSFWD$	$IJTHDFWD$	limiting current in forward bias region	A
$XJVBS$	$XJVBD$	fitting parameter for diode breakdown	-
BVS	BVD	breakdown voltage	V
$JTSS$	$JTSD$	bottom trap-assisted saturation current density	A/m^2
$JTSSWS$	$JTSSWD$	STI sidewall trap-assisted saturation current density	A/m
$JTSSWGS$	$JTSSWGD$	gate-edge sidewall trap-assisted saturation current density	A/m
$VTSS$	$VTSD$	bottom trap-assisted voltage dependent parameter	V
$VTSSWS$	$VTSSWD$	STI sidewall trap-assisted voltage dependent parameter	V

continued on next page

continued from previous page

BSIM4.5.0 parameter name		**BSIM4.5.0 parameter description**	unit
source	**drain**		
$VTSSWGS$	$VTSSWGD$	gate-edge sidewall trap-assisted voltage dependent parameter	V
$NJTS$		non-ideality factor for $JTSS$, $JTSD$	-
$NJTSSW$		non-ideality factor for $JTSSWS$, $JTSSWD$	-
$NJTSSWG$		non-ideality factor for $JTSSWGS$, $JTSSWGD$	-
$XTSS$	$XTSD$	power dependence of $JTSS$, $JTSD$ on temperature	-
$XTSSWS$	$XTSSWD$	power dependence of $JTSSWS$, $JTSSWD$ on temperature	-
$XTSSWGS$	$XTSSWGD$	power dependence of $JTSSWGS$, $JTSSWGD$ on temperature	-
$TNJTS$		temperature coefficient for $NJTS$	-
$TNJTSSW$		temperature coefficient for $NJTSSW$	-
$TNJTSSWG$		temperature coefficient for $NJTSSWG$	-

Table 3.8: Overview of BSIM4.5.0 junction parameters.

3.3.2 Instance parameters

The meaning of the BSIM4 junction instance parameters depends on the value of the switch `permod`. When `permod`=1 (default), the instance parameters have the same meaning as in BSIM3, and the translation scheme is similar to Table 3.6 for BSIM3. When `permod`$= 0$ however the parameters PS and PD only refer to the isolation-edge part of the junction perimeter. In table 3.9, the translation from BSIM4 to JUNCAP2 instance parameters is given. Here, W_{effcj} represents the BSIM4 effective junction width.

For JUNCAP2 as embedded in the PSP MOSFET model, the junction dimensions can be specified in different ways, depending on the value of the switch $\mathbf{SWJUNCAP}$. For all details on this, please refer to [4].

JUNCAP2 instance parameter	**calculated from BSIM4 quantities as follows:**			
	`permod`$= 1$ (default)		`permod`$= 0$	
	source	**drain**	**source**	**drain**
AB	AS	AD	AS	AD
LS	$PS - W_{\mathrm{effcj}}$	$PD - W_{\mathrm{effcj}}$	PS	PD
LG	W_{effcj}	W_{effcj}	W_{effcj}	W_{effcj}

Table 3.9: Translation of BSIM4 junction instance parameters to JUNCAP2 instance parameters.

3.3.3 Junction capacitance and leakage current parameters

The translation of BSIM4 to JUNCAP2 junction parameters is very similar to the BSIM3-to-JUNCAP2 translation, discussed in Section 3.2.3. The discussion here will be limited to the items that are specific for BSIM4:

- A large part, but not all of the parameters can now be set separately for source and drain. This construction does not exist for JUNCAP2 as embedded in the PSP model; but in the exceptional cases that this feature is needed, one can easily generate a compound model (AKA subcircuit model) consisting of a junction-less PSP model ($\mathbf{SWJUNCAP} = 0$) and two instances of the stand-alone JUNCAP2 model between source/bulk and drain/bulk terminals, see Fig. 3.6. (N.B. This compound model has *no* internal nodes and thus adds no computational complexity as compared to PSP with built-in junctions.)

- Not only the junction capacitance, but also the junction currents now distinguish a STI sidewall and a gate-edge sidewall contribution. This feature can be translated directly to JUNCAP2.

- A simple junction breakdown model has been added. This feature can be translated directly to JUNCAP2.

- A fit-function based trap-assisted tunneling model has been added. This model is incompatible with the physics-based model for trap-assisted tunneling in JUNCAP2. A straightforward translation is not possible.

- An addition to limiting of forward current, limiting of reverse current is introduced. A similar feature does not exist in JUNCAP2.

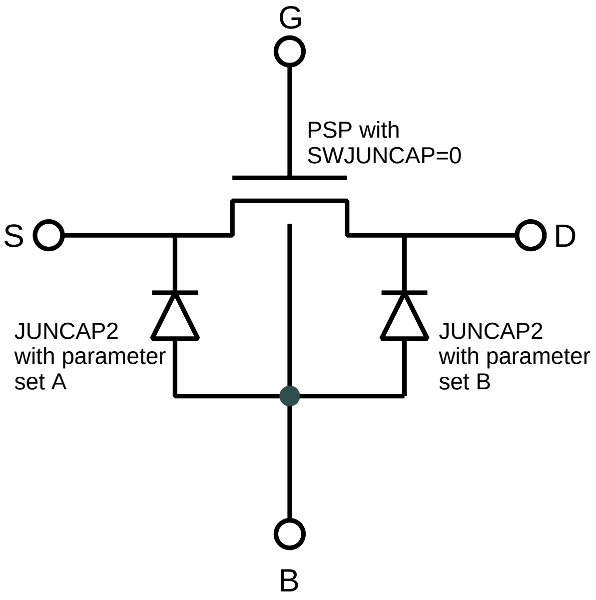


Figure 3.6: Compound model of junction-less PSP and two instances of the stand-alone JUNCAP2 model.

JUNCAP2 parameter	**calculated from BSIM4.5.0 parameters as follows:**	
	source	**drain**
General parameters		
TRJ	$TNOM$	
IMAX	$IJTHSFWD$	$IJTHDFWD$
Capacitance parameters		
CJORBOT	CJS	CJD
CJORSTI	$CJSWS$	$CJSWD$
CJORGAT	$CJSWGS$	$CJSWGD$
VBIRBOT	PBS	PBD
VBIRSTI	$PBSWS$	$PBSWD$

continued on next page

continued from previous page

JUNCAP2 parameter	**calculated from BSIM4.5.0 parameters as follows:**	
	source	**drain**
VBIRGAT	$PBSWGS$	$PBSWGD$
PBOT	MJS	MJD
PSTI	$MJSWS$	$MJSWD$
PGAT	$MJSWGS$	$MJSWGD$
Ideal-current parameters		
PHIGBOT	$\frac{1.16}{NJS} + \frac{k_\mathrm{B} \cdot T_\mathrm{nom}}{q} \cdot \left(\frac{XTIS}{NJS} - 3\right)$	$\frac{1.16}{NJD} + \frac{k_\mathrm{B} \cdot T_\mathrm{nom}}{q} \cdot \left(\frac{XTID}{NJD} - 3\right)$
PHIGSTI	$\frac{1.16}{NJS} + \frac{k_\mathrm{B} \cdot T_\mathrm{nom}}{q} \cdot \left(\frac{XTIS}{NJS} - 3\right)$	$\frac{1.16}{NJD} + \frac{k_\mathrm{B} \cdot T_\mathrm{nom}}{q} \cdot \left(\frac{XTID}{NJD} - 3\right)$
PHIGGAT	$\frac{1.16}{NJS} + \frac{k_\mathrm{B} \cdot T_\mathrm{nom}}{q} \cdot \left(\frac{XTIS}{NJS} - 3\right)$	$\frac{1.16}{NJD} + \frac{k_\mathrm{B} \cdot T_\mathrm{nom}}{q} \cdot \left(\frac{XTID}{NJD} - 3\right)$
IDSATRBOT	JSS	JSD
IDSATRSTI	$JSWS$	$JSWD$
IDSATRGAT	$JSWGS$	$JSWGD$
Shockley-Read-Hall parameters		
CSRHBOT	0	0
CSRHSTI	0	0
CSRHGAT	0	0
XJUNSTI	10^{-7}	10^{-7}
XJUNGAT	10^{-7}	10^{-7}

continued on next page

continued from previous page

JUNCAP2 parameter	**calculated from BSIM4.5.0 parameters as follows:**	
	source	**drain**
Trap-assisted tunneling parameters		
CTATBOT	0	0
CTATSTI	0	0
CTATGAT	0	0
MEFFTATBOT	0.25	0.25
MEFFTATSTI	0.25	0.25
MEFFTATGAT	0.25	0.25
Band-to-band tunneling parameters		
CBBTBOT	0	0
CBBTSTI	0	0
CBBTGAT	0	0
FBBTRBOT	1×10^9	1×10^9
FBBTRSTI	1×10^9	1×10^9
FBBTRGAT	1×10^9	1×10^9
STFBBTBOT	0	0
STFBBTSTI	0	0
STFBBTGAT	0	0

continued on next page

continued from previous page

JUNCAP2 parameter	**calculated from BSIM4.5.0 parameters as follows:**	
	source	**drain**
Avalanche breakdown parameters		
VBRBOT	BVS	BVD
VBRSTI	BVS	BVD
VBRGAT	BVS	BVD
PBRBOT	4	4
PBRSTI	4	4
PBRGAT	4	4

Table 3.10: BSIM4.5.0-to-JUNCAP2 junction parameter translation scheme.

3.3.4 Verification

In this section we verify the BSIM4-to-JUNCAP2 translation scheme for junction parameters. Because of the similarity between BSIM3 and BSIM4 junction models the same kind of agreement is expected as for the BSIM3 case discussed before.

In Fig. 3.7, we compare the junction capacitances of BSIM4 with their JUNCAP2 counterparts. As expected, the plot is very similar to Fig. 3.3, and the same comments apply.

In Fig. 3.8, we show some comparisons between BSIM4 junction currents and the JUNCAP2 currents derived from that using the translation scheme. Again, the plots are very similar to their BSIM3 counterparts Fig. 3.4(a) and 3.5(b), discussed previously.

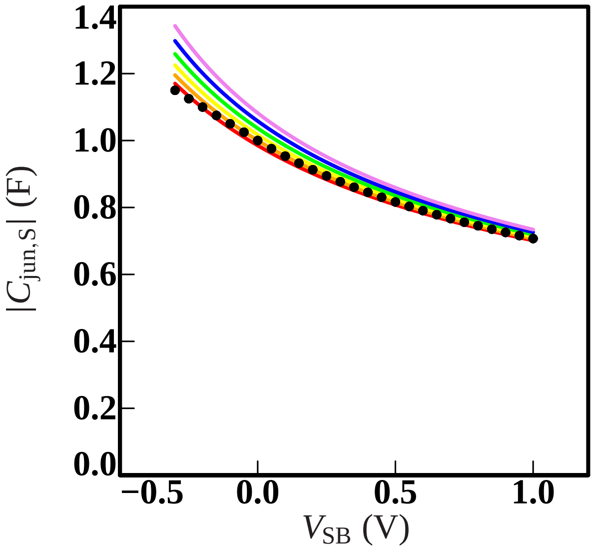
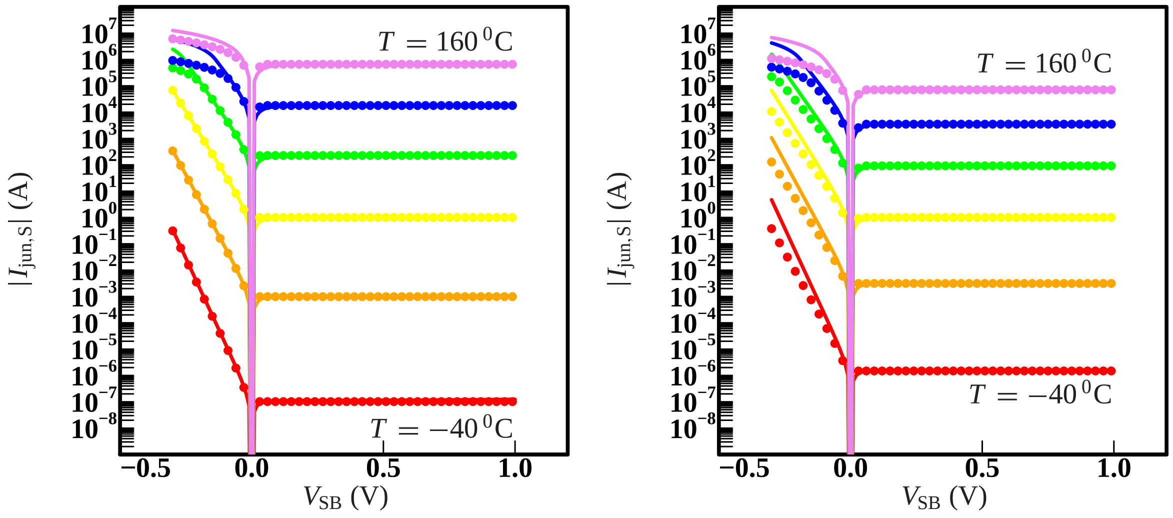


Figure 3.7: Comparison of BSIM4 simulation of junction capacitance with a JUNCAP2 simulation. The BSIM4 simulations showed no temperature dependence and are indicated with black markers. The JUNCAP2 simulations are indicated by colored lines, where the colors red, orange, yellow, green, blue, and violet indicate temperatures of -40, 0, 40, 80, 120, and 160 °C, respectively. The relevant BSIM4 parameters are $TNOM = 40$, $CJ = 1000$, $MJ = 0.5$, $PB = 1$, $TCJ = 0$, and $TPB = 0$. The corresponding JUNCAP2 parameters are $\mathbf{TRJ} = 40$, $\mathbf{CJORBOT} = 1000$, $\mathbf{PBOT} = 0.5$, $\mathbf{VBIRBOT} = 1$, $\mathbf{PHIGBOT} = 1.16$.



(a) (b)

Figure 3.8: (a) Comparison of BSIM4 simulation with $NJ = 1$ and $XTI = 3$ (markers) with JUNCAP2 simulation with $\mathbf{PHIGBOT} = 1.16$ (lines). (b) Comparison of BSIM4 simulation with $NJ = 1.2$ and $XTI = 3$ (markers) with JUNCAP2 simulation with $\mathbf{PHIGBOT} = 0.953$ (lines). Temperatures are -40, 0, 40, 80, 120, and 160 °C, and are indicated by colors red, orange, yellow, green, blue, and violet, respectively.

References

[1] K.K. Hung *et al.*, IEEE Trans. El. Dev., Vol. 37, pp. 654–665 (1990); ibid., pp. 1323-1332 (1990).

[2] A.J. Scholten and D.B.M. Klaassen, *New 1/f noise model in MOS Model 9, level 903*, Nat.Lab. NL-UR 816/98, available on `http://www.semiconductors.philips.com/Philips_Models/mos_models/model9/`.

[3] `http://www-device.eecs.berkeley.edu/˜bsim3/`

[4] G.D.J. Smit, R. van Langevelde, A.J. Scholten, D.B.M. Klaassen, G. Gildenblat, X. Li, H. Wang, and W. Wu, *PSP 101.0*, Philips Research Technical Note TN-2006-00192, available on `http://www.semiconductors.philips.com/Philips_Models/`.