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BSIM3SOI Version 2.1 (FD, DD and PD) Models Released in SmartSpice

Introduction

The Berkeley BSIM3SOI version 2.1 models, released in September 1999, have been implemented in ***SmartSpice***. The three new models are selected according to LEVEL selector.

- LEVEL = 26 selects the BSIM3SOI2FD (Fully depleted) model
- LEVEL = 27 selects the BSIM3SOI2DD (Dynamic depletion) model
- LEVEL = 29 selects the BSIM3SOI2PD (Partially depleted) model

The ***SmartSpice*** implementation of the three models is close but not identical to the UC Berkeley releases. The ***SmartSpice*** implementation provides a number of improvements and additional parameters currently unsupported in Berkeley's BSIM3SOIv2 models.

In the ***SmartSpice*** implementation of the BSIM3SOIv2 models, enhanced convergence is obtained by properly handling the GMIN and DCGMIN control options during transient and DC analysis.

The GMIN option connects a conductance in parallel with the bulk diodes. This conductance is very useful when the diode model has a very high off-resistance. The conductance DCGMIN is connected between drain and source.

The present section provides all the information needed to understand and use the three models.

BSIM3SOI FD (Fully Depleted) version 2.1 (Model LEVEL = 26)

Major Features

BSIM3SOI FD v2.1 is a suite of BSIM3SOI FD v2.0 released in February 1999. The version 2.0 is a derivative of BSIM3SOI v1.3 (level=25 in ***SmartSpice***). BSIM3SOIFDv2.0 has improved simulation efficiency

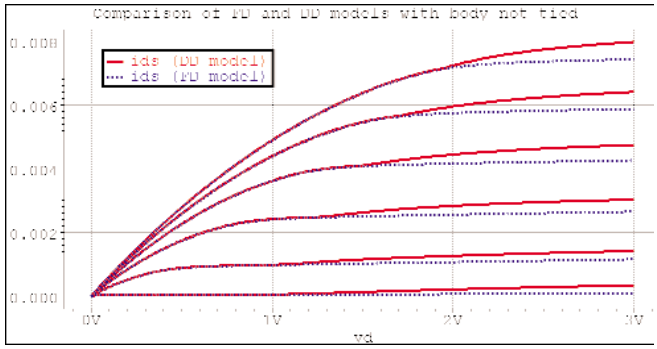

Figure 1 : Example of Id-Vds curves with FD and DD models (default model card from Berkeley)

and noise modeling. The basic IV for this model is modified from BSIM3v3.1 equation set. The major features are summarized as follows [1]:

- Supports external body bias and backgate bias : a total of 5 external nodes;
- Self-heating implementation improved over the alpha version of Berkeley (LEVEL 23 in ***SmartSpice***);
- New depletion charge model (EBCI) introduced for better accuracy in capacitive coupling prediction. An improved BSIM3v3 based model is added as well;
- Single I-V expression as in BSIM3v3.1 to guarantee continuities of Ids, Gm, and Gds and their derivatives for all bias conditions.

New version BSIM3SOI FDv2.1 includes the binning feature to enhance the model flexibility and fixes some bugs found in the previous version 2.0.

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Parameter	Description	Units	Default
SHMOD	Flag for self-heating 0 - no self-heating 1 - self-heating	-	0
TSI	Silicon film thickness	m	1e-7
TBOX	Buried oxide thickness	m	3e-7
VBSA	Transition body voltage offset	V	0
DELP	Constant for limiting Vbseff to Phis	V	0.02
KB1	Coefficient of Vbs0 dependency on Ves	-	1
KB3	Coefficient of Vbs0 dependency on Vgs at subthreshold region	-	1
DVBD0	First coefficient of Vbs0 dependency on Leff	V	0
DVBD1	Second coefficient of Vbs0 dependency on Leff	V	0
MXC	Fitting parameter for Abeff calculation	-	-0.9
ADICE0	DICE bulk charge factor	-	1
ISDIF	Body to source/drain injection saturation current	A/m^2	0.0
ISREC	Recombination in depletion saturation current	A/m^2	1e-5
RBODY	Intrinsic body contact sheet resistance	Ω	0
RBSH	Extrinsic body contact sheet resistance	Ω/m^2	0
CGE0	Gate substrate overlap capacitance per unit channel length	F/m	0.0
VSDFB	Source/drain bottom diffusion capacitance flatband voltage	V	calculated
VSDTH	Source/drain bottom diffusion capacitance threshold voltage	V	calculated
CSDMIN	Source/drain bottom diffusion minimum capacitance	F	calculated
ASD	Source/drain bottom diffusion minimum parameter	-	0.3
CSDESW	Source/drain sidewall fringing capacitance per unit length	F/m	0
CTH0	Normalized thermal capacity	m.°C / (W*s)	0
RTH0	Normalized thermal resistance	m.°C/W	0

Table 1. The additional parameters to BSIM3v3 that correspond to the BSIM3SOI FD Version 2.1 model.

Model Parameters

The additional parameters to BSIM3v3 listed in Table 1 correspond to the BSIM3SOI FD Version 2.1 model.

SilvacoImprovements

Options

The options VZERO and EXPERT are supported in the ***SmartSpice*** BSIM3SOI FD v2.1 model.

The option VZERO=2 allows faster runtime when large circuits are used.

The EXPERT option can be specified to detect possible problems in models, before and during simulation, such as:

- negative conductances GM, GDS and GMBS,
- negative gate capacitances.

New Model Parameters

New model parameters are listed in the following table :

Parameter	Description	Units	Default
VERSION	Version selector	-	2.1
LMIN	Limit for binning	m	0.0
LMAX	Limit for binning	m	1.0
WMIN	Limit for binning	m	0.0
WMAX	Limit for binning	m	1.0

The VERSION model parameter is used to switch between the current versions 2.0 and 2.1. The four others new model parameters are used for binning to select a model. For the binning, Silvaco has also added new binned model parameters that are displayed in Table 2.

BSIM3SOI DD (Dynamic Depletion) version 2.1 Model (LEVEL=27)

Major Features

BSIM3SOI DD v2.1 is a suite of BSIM3SOI DD v2.0 released in February 1999. The version 2.0 is a derivative of BSIM3SOI v1.3 (level=25 in Smartspice). BSIM3SOI DD v2.0 has improved simulation efficiency and noise modeling. The BSIM3SOI DDv2.0 model can be used for both Partially Depleted (PD) and Fully Depleted (FD). The basic IV for this model is modified from BSIM3v3.1 equation set. The major features are summarized as follows [2]:

- Dynamic depletion approach is applied on both I-V and C-V. Charge and drain current are scalable with Tbox and Tsi continuously;
- Supports external body bias and backgate bias : a total of 5 external nodes;
- Real floating body simulation in both I-V and C-V. Body potential is properly bounded by diode and C-V formulation;

AT	GAMMA1	GAMMA2	VBM	VBX	XT	KT1
KT1L	KT2	UA1	UB1	UC1	UTE	RTH0
PRT	CGDL	CGSL	CKAPPA	CF	CLC	CLE
XJ	RBODY	CSDMIN	CTH0	ASD	CSDESW	

Table 2. Silvaco's new binned model parameters.

- Self-heating implementation improved over the alpha version of Berkeley (LEVEL 23 in ***SmartSpice***);
- An improved impact ionization current model;
- Various diode leakage components and parasitic bipolar current included;
- New depletion charge model (EBCI) introduced for better accuracy in capacitive coupling prediction. An improved BSIM3v3 based model is added as well;
- Dynamic depletion can suit different requirements for SOI technologies;
- Single I-V expression as in BSIM3v3.1 to guarantee continuities of Ids, Gm, and Gds and their derivatives for all bias conditions.

New version BSIM3SOI DDv2.1 includes the binning feature to enhance the model flexibility and fixes some bugs found in the previous version 2.0.

Model Parameters

The additional parameters to BSIM3v3 listed below in Table 3 correspond to the BSIM3SOI DD Version 2.1 model.

Parameter	Description	Units	Default
SHMOD	Flag for self-heating 0 - no self-heating 1 - self-heating	-	0
TSI	Silicon film thickness	m	1e-7
TBOX	Buried oxide thickness	m	3e-7
VBSA	Transition body voltage offset	V	0
DELP	Constant for limiting Vbseff to Phis	V	0.02
KB1	Coefficient of Vbs0 dependency on Ves	-	1
KB3	Coefficient of Vbs0 dependency on Vgs at subthreshold region	-	1
DVBD0	First coefficient of Vbs0 dependency on Leff	V	0
DVBD1	Second coefficient of Vbs0 dependency on Leff	V	0
ABP	Coefficient of Abeff dependency on Vgst	-	1
MXC	Fitting parameter for Abeff calculation	-	-0.9
ADICE0	DICE bulk charge factor	-	1
ALPHA1	The second parameter of impact ionization current	m/V	1.0
AII	First Vds dependence Ecrit parameter	-	0
BII	Second Vds dependence Ecrit parameter	m	0
CII	Vgsteff dependence Ecrit parameter	1/m	0
DII	Vbseff dependence Ecrit parameter	1/m	-1.0
AGIDL	GIDL constant	W-1	0
BGIDL	GIDL exponential coefficient	V/m	0
NGIDL	GIDL Vds enhancement coefficent	V	1.2
NTUN	reverse tunneling non-ideality factor	-	10.0
NDIODE	Diode non-ideality factor	-	1.0
ISBJT	BJT injection saturation current	A/m^2	1e-6
ISDIF	Body to source/drain injection saturation current	A/m^2	0.0
ISREC	Recombination in depletion saturation current	A/m^2	1e-5
ISTUN	Reverse tunneling saturation current	A/m2	0
EDL	Electron diffusion length	m	2e-6
KBJT1	Parasitic bipolar early effect coefficient	m/V	0
RBODY	Intrinsic body contact sheet resistance	Ω/m^2	0
RBSH	Extrinsic body contact sheet resistance	Ω/m^2	0
CGE0	Gate substrate overlap capacitance per unit channel length	F/m	0.0
TT	Diffusion capacitance transit time coefficient	s	1e-12
VSDFB	Source/drain bottom diffusion capacitance flatband voltage	V	calculated
VSDTH	Source/drain bottom diffusion capacitance threshold voltage	V	calculated
CSDMIN	Source/drain bottom diffusion minimum capacitance	F	calculated
ASD	Source/drain bottom diffusion minimum parameter	-	0.3
CSDESW	Source/drain sidewall fringing capacitance per unit length	F/m	0
CTH0	Normalized thermal capacity	m.°C / (W*sec)	0
RTH0	Normalized thermal resistance	m.°C/W	0
XBJT	Power dependence of jbjt on temperature	-	2
XDIF	Power dependence of jdif on temperature	-	2
XREC	Power dependence of jrec on temperature	-	20
XTUN	Power dependence of jtun on temperature	-	0
NOIF	Floating body excess noise ideality factor	-	1.0

Table 3. The additional parameters to BSIM3v3 correspond to the BSIM3SOI DD Version 2.1 model.

Silvaco Improvements

Options

The options VZERO and EXPERT are supported in the ***SmartSpice*** BSIM3SOI DD v2.1 model.

The option VZERO=2 allows faster runtime when large circuits are used.

The EXPERT option can be specified to detect possible problems in models, before and during simulation, such as:

- negative conductances GM, GDS and GMBS,
- negative gate capacitances.

New Model Parameters

New model parameters are listed in the following table :

Parameter	Description	Units	Default
VERSION	Version selector	-	2.1
SMART	Improvement selector	-	1
LMIN	Limit for binning	m	0.0
LMAX	Limit for binning	m	1.0
WMIN	Limit for binning	m	0.0
WMAX	Limit for binning	m	1.0

The VERSION model parameter is used to switch between the current version 2.0 and 2.1. The four new model parameters (LMIN, LMAX, WMIN and WMAX) are used for binning to select a model. For the binning, Silvaco has also added the following new binned model parameters shown in Table 4.

The SMART model parameter Silvaco improvements which are not compatible with original Berkeley model allows to switch on . SMART model parameter has been created as follows :

- if SMART = 0: the original Berkeley model is used with its different versions
- if SMART > 0: the Berkeley model is used with the following improvements:
  - problem with RBODY model parameter has been fixed;
  - some derivatives related to body tied have been corrected;
  - the limitation of vb has been modified.

BSIM3SOI PD (Partially depleted) version

AT	GAMMA1	GAMMA2	VBM	VBX	XT	KT1
KT1L	KT2	UA1	UB1	UC1	UTE	RTH0
PRT	CGDL	CGSL	CKAPPA	CF	CLC	CLE
XJ	RBODY	CSDMIN	CTH0	ASD	CSDESW	CJSWG
PBSWG	MJSWG	TT	XBJT	XDIF	XREC	XTUN

Table 4. Silvaco's new binned model parameters.

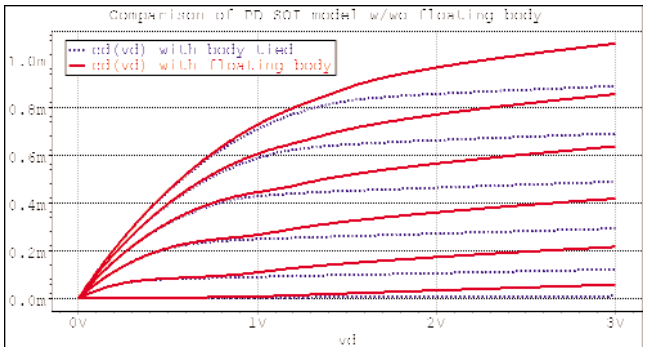

Figure 2 : Example of Id-Vds curves with PD model (default model card from Berkeley)

2.1 Model (LEVEL = 29)

Major Features

BSIM3SOI PD v2.1 is a suite of BSIM3SOI PD v2.01 released in April 1999. The version 2.01 is a derivative of BSIM3SOI v1.3 (level=25 in Smartspice). Many enhanced features are included in BSIM3SOI PD v2.0.1. BSIM3SOI PD v2.0.1 has the following new features relative to BSIM3SOIv1.3 [3]:

- Real floating body simulation in both C-V and I-V. The body potential is determined by the balance of all the body current components;
- Enhancements in the threshold voltage and bulk charge formulation of the high positive body bias regime;
- An improved parasitic bipolar current model. This includes enhancements in the various diode leakage components, second order effects (high-level injection & early effect), diffusion charge equation and temperature dependence of the diode junction capacitance;
- An improved impact ionization current model. The contribution from BJT current is also modeled by the parameter FBJTII;
- Instance parameters (PDBCP, PSBCP, AGBCP, AEBCP, NBC) are provided to model the parasitics of devices with various body-contact and isolation structures.
- An external body node (the 6th node) and other improvements are introduced to facilitate the modeling of distributed body-resistance;
- Self-heating: an external temperature node (the 7th node) is supported to facilitate the simulation of thermal coupling among neighboring devices;
- A unique SOI low frequency noise model, including a new excess noise resulting from the floating body effect;
- Width dependence of the body effect is modeled by parameters (K1, K1W1, K1W2);
- Improved history dependence of the body charges with two new parameters (FBODY, DLCB);

Parameter	Description	Units	Default
SHMOD	Flag for self-heating 0 - no self-heating 1 - self-heating	-	0
TSI	Silicon film thickness	m	1e-7
TBOX	Buried oxide thickness	m	3e-7
KIW1	First body effect with dependent parameter	m	0
KIW2	Second body effect with dependent parameter	m	0
KB1	Coefficient of Vbs0 dependency on Ves	-	1
KETAS	Surface potential adjustment for bulk charge effect	V	0
DWBC	Width offset for body contact isolation edge	m	0.0
FBJTII	Fraction of bipolar current affecting the impact ionization	m/V	0.0
BETA0	First Vds dependence parameter of impact ionization cur-rent	1/V	0
BETA1	Second Vds dependence parameter of impact ionization current	1/V	0
BETA2	Third Vds dependence parameter of impact ionization current	V	0.1
VDSATII0	Nominal drain saturation voltage at threshold for impact ionization current	V	0.9
TII	Temperature dependent parameter for impact ionization current	-	0
LII	Channel length dependent parameter at threshold for impact ionization current	-	0
ESATII	Saturation channel electric field for impact ionization cur-rent	V/m	1e7
SII0	First vgs dependent parameter for impact ionization cur-rent	1/V	0.5
SII1	Second vgs dependent parameter for impact ionization current	1/V	0.1
SII2	Third vgs dependent parameter for impact ionization cur-rent	1/V	0
SIID	vds dependent parameter of drain saturation voltage for impact ionization current	1/V	0
AGIDL	DIDL constant	Ω^{-1}	0
BGIDL	GIDL exponential coefficient	V/m	0
NGIDL	GIDL Vds enhancement coefficent	V	1.2
NTUN	reverse tunneling non-ideality factor	-	10.0
NDIODE	Diode non-ideality factor	-	1.0
NRECF0	Recombination non-ideality factor at forward bias	-	2.0
NRECR0	Recombination non-ideality factor at reversed bias	-	10.0
ISBJT	BJT injection saturation current	A/m^2	1e-6
ISDIF	Body to source/drain injection saturation current	A/m^2	0
ISREC	Recombination in depletion saturation current	A/m^2	1e-5
ISTUN	Reverse tunneling saturation current	A/m^2	0
LN	Electron/hole diffusion length	m	2e-6
VREC0	Voltage dependent parameter for recombination current	V	0
VTUN0	Voltage dependent parameter for tunneling current	V	0
NBJT	Power coefficient of channel length dependency for bipolar current	-	1
LBJT0	Reference channel length for bipolar current	m	0.2 e-6
VABJT	Early voltage for bipolar current	V	10
AELY	Channel length dependency of early voltage bipolar current	V/m	0
AHLI	High level injection parameter for bipolar current	-	0
RBODY	Intrinsic body contact sheet resistance	Ω/m^2	0
RBSH	Extrinsic body contact sheet resistance	Ω/m^2	0
TT	Diffusion capacitance transit time coefficient	s	1e-12
NDIF	Power coefficient of channel length dependency for diffusion capacitance	-	-1
LDIF0	Channel length dependency coefficient of diffusion capacitance	-	1
VSDFB	Source/drain bottom diffusion capacitance flatband voltage	V	calculated
VSDTH	Source/drain bottom diffusion capacitance threshold voltage	V	calculated
CSDMIN	Source/drain bottom diffusion minimum capacitance	-	calculated
ASD	Source/drain bottom diffusion minimum parameter	-	0.3
CSDESW	Source/drain sidewall fringing capacitance per unit length	F/m	0
DLCB	Length offset fitting parameter for body charge	m	0.0
DLBG	Length offset fitting parameter for backgate charge	m	0.0
DELVT	Threshold voltage adjust for C-V	V	0.0
FBODY	Scaling factor for body charge	-	1.0
ACDE	Exponetial coefficient for charge thickness in CAPMOD=3 for accumulation and depletion regions	m/V	1.0
MOIN	Coefficient for the gate-bias dependent surface potential	$V^{0.5}$	15.0
TCJSWG	Temperature coefficient of CJSWG	1/K	0
TPBSWG	Temperature coefficient of PBSWG	V/K	0
CTH0	Normalized thermal capacity	m.°C / (W*sec)	0
RTH0	Normalized thermal resistance	m.°C/W	0
NTRECF	Temperature coefficient for NRECF	-	0
NTRECR	Temperature coefficient for NRECR	-	0
XBJT	Power dependence of jbjt on temperature	-	1
XDIF	Power dependence of jdif on temperature	-	XBJT
XREC	Power dependence of jrec on temperature	-	1
XTUN	Power dependence of jtun on temperature	-	0

Table 5. The additional parameters to BSIM3v3 correspond to the BSIM3SOI PD Version 2.1 model.

- An instance parameter vbsusr is provided for users to set the transient initial condition of the body potential;
- The new-charge thickness capacitance model introduced in BSIM3v3.2, CAPMOD3, is included.

New version BSIM3SOI PD v2.1 includes the binning feature to enhance the model flexibility and fixes some bugs found in the previous version 2.0.1.

Model Parameters

The additional parameters to BSIM3v3 listed in Table 5 correspond to the BSIM3SOI PD Version 2.1 model.

Silvaco Improvements

Options

The options VZERO and EXPERT are supported in the ***SmartSpice*** BSIM3SOI PD v2.1 model.

The option VZERO=2 allows faster runtime when large circuits are used.

The EXPERT option can be specified to detect possible problems in models, before and during simulation, such as:

- negative conductances GM, GDS and GMBS,
- negative gate capacitances.

New model parameters

New model parameters are listed in the following table:

Parameter	Description	Units	Default
VERSION	Version selector	-	2.1
SMART	Improvement selector	-	1
LMIN	Limit for binning	m	0.0
LMAX	Limit for binning	m	1.0
WMIN	Limit for binning	m	0.0
WMAX	Limit for binning	m	1.0

The VERSION model parameter is used to switch between the current versions 2.0.1 and 2.1. The four new model parameters (LMIN, LMAX, WMIN and WMAX) are used for binning to select a model. For the binning, Silvaco has also added the following new binned model parameters shown in Table 6.

The SMART model parameter allows to switch on Silvaco improvements which are not compatible with original Berkeley model. The SMART model parameter has been created as follows :

- if SMART = 0: the original Berkeley model is used with its different versions
- if SMART > 0: the Berkeley model is used with the following improvements:
  - incorrect implementation of model parameter AHLI has been fixed;
  - the limitation of vb has been modified.

Figures 1, 2, 3 and 4 illustrate different models.

AT	GAMMA1	GAMMA2	VBM	VBX	XT	KT1
KT1L	KT2	UA1	UB1	UC1	UTE	RTH0
PRT	CGDL	CGSL	CKAPPA	CF	CLC	CLE
XJ	RBODY	CSDMIN	CTH0	ASD	CSDESW	CJSWG
PBSWG	MJSWG	TT	XBJT	XDIF	XREC	XTUN
LN	NDIF	LDIF0	TCJSWG	TPBSWG	NTRECF	NTRECR

Table 6. Silvaco's new binned model parameters.

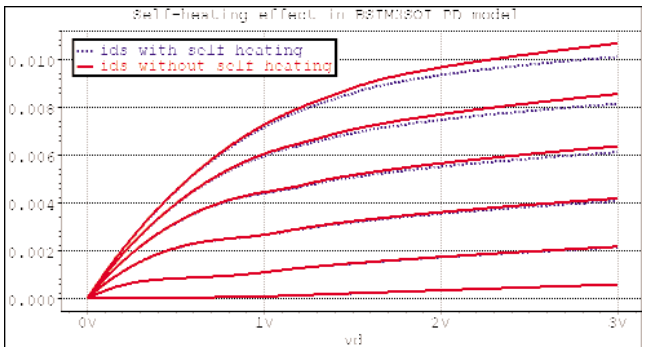

Figure 3 : Self-heating effect with PD model (default model card from Berkeley)

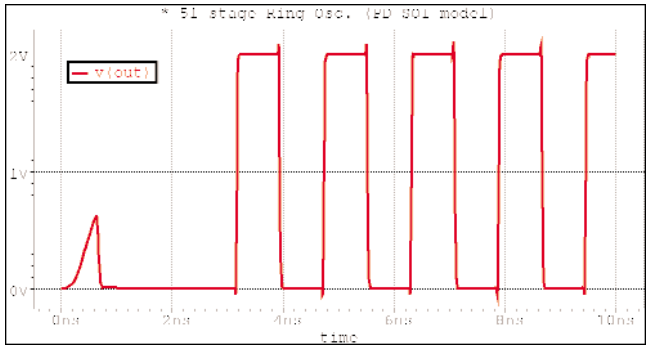

Figure 4 : Example of a ring oscillator with PD model (default model card from Berkeley)

References

[1] BSIM3SOIFDv2.1 User's Manual, 1999, Department of EECS, University of California, Berkeley

[2] BSIM3SOIDDv2.1 User's Manual, 1999, Department of EECS, University of California, Berkeley

[3] BSIM3SOIPDv2.1 User's Manual, 1999, Department of EECS, University of California, Berkeley