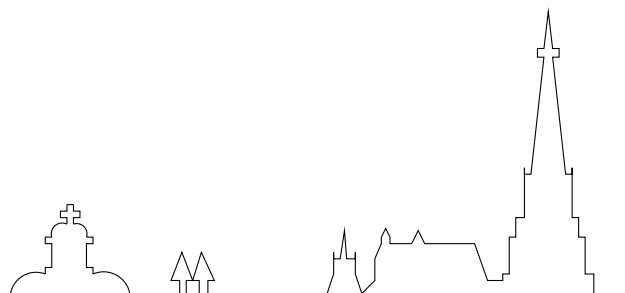# MINIMOS 4.0/PC

USER'S GUIDE

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CONTENTS

Introduction

MINIMOS is a highly user oriented software tool for the two-dimensional numerical simulation of planar MOS-transistors. The fundamental semiconductor equations are solved with sophisticated programming techniques to allow very low computer costs. Great efforts have been made to ensure up-to-date modeling of the relevant physical parameters such as doping profile, carrier mobility, and carrier generation/recombination.

MINIMOS 3 is upward-compatible to all previous versions of MINIMOS and will work with any input file legal for a previous version. Some modifications of the format of the external files, however, have been performed.

For further introductory information refer to:

S.SELBERHERR, A.SCHÜTZ, H.PÖTZL; MINIMOS – A Two-Dimensional MOS Transistor Analyzer, *IEEE ED-27*, pp.1770-1780, (1980).

S.SELBERHERR; Zweidimensionale Simulation von MOS-Transistoren, *Dissertation, Technical University Vienna*, (1981).

A.SCHÜTZ, S.SELBERHERR, H.PÖTZL; A Numerical Model of the Avalanche Effect in MOS-Transistors, *Solid-State Electron. 25*, pp.177-183, (1982).

A.SCHÜTZ, S.SELBERHERR, H.PÖTZL; Analysis of Breakdown Phenomena in MOS-FET's, *IEEE CAD-1*, pp.77-85, (1982).

A.SCHÜTZ; Simulation des Lawinendurchbruchs in MOS-Transistoren, *Dissertation, Technical University Vienna*, (1982).

S.SELBERHERR, A.SCHÜTZ, H.PÖTZL; Two-Dimensional MOS-Transistor Modeling, *in: Process and Device Simulation for MOS-VLSI Circuits, edited by: P.Antogentti, D.A.Antoniadis, R.W.Dutton, W.G.Oldham*, ISBN 90-247-2824-X, pp.490-581, (1983).

S.SELBERHERR; Analysis and Simulation of Semiconductor Devices, *Springer-Verlag Wien New York*, ISBN 3-211-81800-6, (1984).

S.SELBERHERR; The Status of MINIMOS, *in: Simulation of Semiconductor Devices and Processes, edited by: K.Board, D.R.J.Owen*, ISBN 0-906674-59-X, pp.2-15, (1986).

W.HÄNSCH, S.SELBERHERR; MINIMOS 3: A MOSFET Simulator that Includes Energy Balance, *IEEE ED-34*, pp.1074-1078, (1987).

The MINIMOS Input Format

The input parameters for MINIMOS are specified by a sequence of lines (directives) in a data file. The first 72 characters are used to parse information and 80 characters are read and written to the output file to offer the user the possibility of sequencing his/her statements. The first line in the data file is interpreted as a title statement. All text on this line is used to identify the printout pages. This title line must not be omitted.

All the other statements conform to a simple syntax, namely:

DIRECTIVE, KEY1=VALUE1, ..., KEYi=VALUEi, ...

DIRECTIVE may be any character string of the following group:

BIAS, DEVICE, END, IMPLANT, INTERFACE, MOBILITY, OPTION, OUTPUT, PROFILE, RECOMBINATION, STEP

For any directive only the first two characters are significant. The directive is delimited by either a blank, a comma, or an asterisk. Any directive can be continued in the next line. In this case the continuation line has to start with a plus (+) in the first column. Comment information can be placed anywhere in the input stream. Start of comment is indicated by an asterisk. Thus, a line starting with an asterisk is totally interpreted as a comment line and an asterisk in any column of a directive indicates that the remainder of this line is comment. Comment is allowed within continuation lines. All blank lines are ignored but not allowed within a continued directive. Blanks in front of a directive are ignored.

The BIAS, DEVICE and PROFILE directive with appropriate keys are required in any MINIMOS input file. The END, IMPLANT, MOBILITY, INTERFACE, OPTION, OUTPUT, RECOMBINATION and STEP directives are optional. The directives may appear in arbitrary order in the input file, except the END directive which has to be the last statement to indicate the end of the input stream.

The individual directives with their associated parameters are described on the following pages.

The BIAS Directive

The BIAS directive is used to specify the operating point for which the simulation should be performed. The following keys are possible:

BIAS, **UB**=*num*, **UD**=*num*, **UG**=*num*, **US**=*num*

The first two characters are significant for any of these keys.

UB

This key specifies the applied bulk voltage in Volts. *num* can be any value in the range of -20 to 20. If this key is omitted, UB=US is assumed. This key has to be omitted for SOI simulations.

UD

This key specifies the applied drain voltage in Volts. *num* can be any value in the range of -20 to 20. This key must not be omitted.

UG

This key specifies the applied gate voltage in Volts. *num* can be any value in the range of -20 to 20. This key must not be omitted unless the MODEL=THRES option is used (cf. OPTION directive).

US

This key specifies the applied source voltage in Volts. *num* can be any value in the range of -20 to 20. If this key is omitted, zero is assumed as source voltage.

<div align="center">NOTE</div>

The input data will be checked for physical plausibility. Therefore UD$-$US and US$-$UB must not be negative for n-channel devices and positive for p-channel devices. This plausibility check can be suppressed by the PHYSCK key (cf. OPTION directive).

The DEVICE Directive

The DEVICE directive is used to specify the principal physical device parameters. The following keys are possible:

DEVICE, BULK=*num*, CHANNEL=*type*, **DGAP**=*num*, **FILM**=*num*, **GATE**=*mat*
+ **INS**=*mat*, **KBULK**=*num*, **L**=*num*, **SGAP**=*num*, **TINS**=*num*, **W**=*num*

Only the first character is significant for any of these keys.

BULK

This key specifies the thickness of the insulating substrate in centimeters for the simulation of SOI transistors. *num* can be any value within the range of 10^{-4} to $2 \cdot 10^{-3}$. If this key is given, the FILM and the KBULK key have also to be given and the UB key (cf. BIAS directive) and the DB and NB keys (cf. STEP directive) have to be omitted.

CHANNEL

This key specifies the type of device. *type* can be N or P for n-channel or p-channel devices, respectively. Only the first character is significant. The CHANNEL key must not be omitted.

DGAP

This key specifies the gap between the gate edge and the drain contact in centimeters. *num* can be any value within the range of 10^{-6} to 10^{-2}. The default setting of this key is SGAP.

FILM

This key specifies the thickness of the semiconductor film in centimeters for the simulation of SOI transistors. *num* can be any value within the range of 10^{-5} to $5 \cdot 10^{-4}$. If this key is given, the BULK and the KBULK key have also to be given and the UB key (cf. BIAS directive) and the DB and NB keys (cf. STEP directive) have to be omitted.

GATE

This key specifies the work function of the gate material. *mat* can be either a characterstring or a real number. In case of a characterstring, AL, NPOLY or PPOLY indicate aluminium, n-doped polysilicon or p-doped polysilicon as gate material, which results in a workfunction of $-0.59V$, $-0.55V$ or $0.55V$, respectively. Only the first character is significant. If *mat* is a real number, it specifies the workfunction in Volts explicitly and it must be in the range of -0.6 to 0.6. The GATE key must not be omitted, unless the UFB key is given on the OPTION directive. In this case the GATE key has to be omitted.

INS

This key specifies the relative permittivity of the gate insulator. *mat* can be either a characterstring or a real number. In case of a characterstring, NITRIDE (Si_3N_4) or OXIDE (SiO_2)indicate a relative permittivity of 3.9 or 7.2 respectively. Only the first character is significant. If *mat* is a real number, it specifies the relative permittivity explicitly and it must be in the range of 1 to 20. On default a relative permittivity of 3.9 (SiO_2) is assumed for the gate insulator.

KBULK

This key specifies the relative permittivity of the insulating substrate for the simulation of SOI transistors. *num* can be any value within the range of 1 to 20. If this key is given, the BULK and the FILM key have also to be given and the UB key (cf. BIAS directive) and the DB and NB keys (cf. STEP directive) have to be omitted.

L

This key specifies the channel length in centimeters. *num* can be any value within the range of $2 \cdot 10^{-5}$ to 10^{-2}. The L key must not be omitted.

SGAP

This key specifies the gap between the gate edge and the source contact in centimeters. *num* can be any value within the range of 10^{-6} to 10^{-2}. The default setting of this key is 10·TINS.

TINS

This key specifies the thickness of the gate insulator in centimeters. *num* can be any value within the range of 10^{-6} to 10^{-3}. The TINS key must not be omitted.

W

This key specifies the channel width in centimeters. *num* can be any value within the range of 10^{-4} to 1. The W key must not be omitted.

The END Directive

The END directive is used to signal the end of the input file. This directive may be omitted; if present, however, it must be the last directive. The following keys are possible:

END, **BIN**=*log*, **ERROR**=*num*, **TCERR**=*num*

The first character is significant for these keys.

BIN

This key specifies if the simulation results are to be saved on an external file. *log* can be YES or NO. The first character is significant only. This key can be omitted. The default setting is NO. The format of the external file is given in Appendix B.

ERROR

This key specifies the desired final error of the simulation in terms of maximum relative error in space charge. If MODEL=THRES is given, ERROR specifies additionally the final error of the threshold voltage in Volts. *num* can be any value within the range of 10^{-5} to 0.5. This key can be omitted. The default setting for this key is 10^{-2}.

TCERR

This key specifies the desired final relative error of the carrier temperatures. TCERR may only be given if MODEL=HOT is specified (cf. OPTION directive). *num* can be any value within the range of 10^{-5} to 0.5. This key can be omitted. The default setting for this key is 10^{-2}.

The IMPLANT Directive

The IMPLANT directive is used to specify a channel implantation. This directive can be omitted if a homogeneous doped channel area is desired. One IMPLANT directive is necessary for a single channel-implanted device, and two IMPLANT statements are required for a double channel-implanted device. However, only one set of anneal parameters is allowed, as both implants are always annealed together. The channel and the source-drain temperature treatments are totally independent and do not at all affect each other. The channel anneal parameters can be specified on the first or the second IMPLANT directive. If FILE=2-D or FILE=1-D is specified on the PROFILE directive, no IMPLANT directive at all is allowed.

The following keys are possible:

IMPLANT, **AK**EV=*num*, **DO**SE=*num*, **EL**EM=*dop*, **TEMP**=*num*, **TIME**=*num*

The first two characters are significant for any of these keys.

AKEV

This key specifies the channel implantation energy in keV. *num* can be any value between 10 and 300. The AKEV key must not be omitted, if any of the IMPLANT keys is specified.

DOSE

This key specifies the channel implantation dose in cm^{-2}. *num* can be any value between 10^9 and 10^{14}. The DOSE key must not be omitted, if any of the IMPLANT keys is specified.

ELEM

This key specifies the channel implantation element. *dop* can be B,P,SB and AS denoting boron, phosphorus, antimony and arsenic. Only the first character is significant. The ELEM key must not be omitted, if any of the IMPLANT keys is specified.

TEMP

This key specifies the channel implantation anneal temperature in centigrades. *num* can be any value between 800 and 1300. The TEMP key must not be omitted, if any of the IMPLANT keys is specified. In case of a double implanted channel, however, it may only be specified once.

TIME

This key specifies the channel implantation anneal time in seconds. *num* can be any value between 60 and $48 \cdot 3600$. The TIME key must not be omitted, if any of the IMPLANT keys is specified. In case of a double implanted channel, however, it may only be specified once.

<div align="center">NOTE</div>

The channel implantation is assumed to be performed through an insulator of material INS with thickness TINS (cf. DEVICE directive). If a permittivity number is explicitly given with the INS key, SiO_2 is assumed for the insulator if INS=3.9 and Si_3N_4 is assumed for any other value of INS.

The INTERFACE Directive

The INTERFACE directive is used to specify semiconductor-insulator interface parameters. This directive can be omitted. No key of this directive is required. Default values are existing as outlined in the description of each individual key. The following keys are possible:

INTERFACE, **CI**SS=*num*, **FS**S=*num*, **NS**S=*num*

+ **PS**S=*num*, **SI**SS=*num*, **XI**SS=*num*

The first two characters are significant for any of these keys.

CISS

This key specifies the peak concentration of a Gaussian slow-surface-state density profile at the gate-insulator interface in $cm^{-2} \cdot V^{-1}$. *num* can be any value in the range of -10^{13} to 10^{13}. If this key is omitted, no slow-surface-state density profile is taken into account. If the CISS key is given, the XISS key must also be given.

FSS

This key specifies the fast chargeable surface-state density at the gate-insulator interface in cm^{-2}. *num* can be any value in the range of -10^{15} to 10^{15}. If this key is omitted, a fast chargeable surface-state density of zero is assumed.

NSS

This key specifies the slow-surface-state density at the gate-insulator interface in cm^{-2}. *num* can be any value in the range of -10^{13} to 10^{13}. If this key is omitted, a slow-surface-state density of zero is assumed. This key must not be specified, if the UFB key on the OPTION directive is given.

PSS

This key specifies the slow-surface-state density at the bulk-insulator interface in cm^{-2}. *num* can be any value in the range of -10^{13} to 10^{13}. If this key is omitted, a slow-surface-state density of zero is assumed. This key is only active for SOI simulations.

SISS

This key specifies the standard deviation of a Gaussian slow-surface-state density profile at the gate-insulator interface in cm. *num* can be any value in the range of 10^{-6} to 10^{-3}. This key can be omitted. The default setting for this key is 10^{-5}.

XISS

This key specifies the peak position of a Gaussian slow-surface-state density profile at the gate-insulator interface in cm. *num* can be any value in the range of -10^{-2} to 10^{-2}. If this key is omitted, no slow-surface-state density profile is taken into account. If the XISS key is given, the CISS key must also be given.

The MOBILITY Directive

The MOBILITY directive is used to specify various physical device parameters. This directive can be omitted. No key of this directive is required. Default values are existing as outlined in the description of each individual key. The following keys are possible:

MOBILITY, **MB**=*num*, **MI**=*num*, **ML**=*num*, **MR**=*num*, **MS**=*num*, **MT**=*num*

+ **MV**=*num*

The first two characters are significant for any of these keys.

MB

This key specifies the weight of the Mathiessens coefficient for combining the zero-field mobility with velocity saturation. *num* can be any value within the range of 0.1 to 10. If this key is omitted, the weight is set to 1. MB greater than one leads to velocity saturation at higher fields and vice-versa.

MI

This key specifies the weight for the critical concentration of impurity scattering. *num* can have any value within the range of 10^{-4} to 10^{6}. If this key is omitted, the weight is set to 1. MI greater than one leads to less impurity scattering and vice-versa.

ML

This key specifies the weight for the zero-field lattice mobility. *num* can have any value within the range of 0.5 to 2. If this key is omitted, the weight is set to 1. ML greater than one leads to a higher mobility and vice-versa.

MR

This key specifies the weight for the surface reference mobility. *num* can have any value within the range of 0.5 to 2. If this key is omitted, the weight is set to 1. MR greater than one leads to a higher mobility and vice-versa.

MS

This key specifies the weight of the characteristic distance for surface scattering. *num* can be any value within the range of 10^{-2} to 10^{2}. If this key is omitted, the weight is set to 1. MS greater than one leads to less surface scattering and vice-versa.

MT

This key specifies the weight of the prefactor for surface scattering. *num* can be any value within the range of 10^{-2} to 10^{2}. If this key is omitted, the weight is set to 1. MT greater than one leads to less surface scattering and vice-versa.

MV

This key specifies the weight of the saturation velocity due to carrier heating. *num* can be any value within the range of 10^{-2} to 10^{6}. If this key is omitted, this weight is set to 1. MV greater than one leads to a higher saturation velocity, thus to less hot electron scattering and vice-versa.

The OPTION Directive

The OPTION directive is used to specify various physical device parameters. This directive can be omitted. No key of this directive is required. Default values are existing as outlined in the description of each individual key. The following keys are possible:

OPTION, **CURRENT**=*num*, **EA**=*num*, **ED**=*num*, **GRIDFREEZE**=*log*

+ **INTRINSIC**=*num*, **MODEL**=*mod*, **PHYSCK**=*log*, **RBULK**=*num*

+ **RD**RAIN=*num*, **RS**OURCE=*num*, **TE**MP=*num*, **UFB**=*num*, **UN**=*num*, **UP**=*num*

The first two characters are significant for any of these keys.

CURRENT

This key is active only if the MODEL key is given with *mod*=THRES. In that case the CURRENT key determines the drain current in Amperes for threshold condition. The magnitude of *num* may be any value between 10^{-10} and $2 \cdot 10^{-3}$. Default setting is $10^{-7} \cdot W/L$ for n-channel devices and $-10^{-7} \cdot W/L$ for p-channel devices.

EA

This key specifies the difference between the activation energy of acceptors and the valence band edge in volts. *num* can be any value within the range of 10^{-3} to 10^{-1}. There is no default setting of this key. If EA is not specified total ionization of acceptors is assumed. A typical value for EA is 0.045 (boron).

ED

This key specifies the difference between the conduction band edge and the activation energy of donors. *num* can be any value within the range of 10^{-3} to 10^{-1}. There is no default setting of this key. If ED is not specified total ionization of donors is assumed. Typical values for ED are 0.039 (antimony), 0.045 (phosphorus) and 0.054 (arsenic).

GRIDFREEZE

This key is active only if any of the step parameters (cf. STEP directive) has been chosen. This key may be used to determine whether grid modifications should be performed between any voltage steps or not. *log* may be YES or NO. Default setting of this key is NO.

INTRINSIC

This key specifies the intrinsic concentration at the simulation temperature in cm^{-3}. *num* can be any value within the range of 10^{-20} to 10^{15}. If this key is omitted, a built-in temperature dependent model for the intrinsic concentration will be used.

MODEL

This key specifies which mode of calculation MINIMOS should perform. The user may choose between five models, therefore, *mod* may be one of the following character strings: 1-D, THRES, 2-D, AVAL, HOT (default value is 2-D). Only the first character is significant.

MODEL=1-D: This is the simplest model that can be selected and offers very fast execution. Poisson's equation is solved in two dimensions whereas the minority-carrier continuity equation is solved only in the channel region and carrier recombination/generation is neglected. However, for many applications MODEL=1-D will give sufficiently accurate results.

MODEL=THRES: Same as MODEL=1-D; instead of calculating currents, however, an internal iterative procedure is activated to calculate the threshold voltage. If this model is selected, neither the NG key nor the DG key may appear with the STEP directive. If the UG key is present (cf. BIAS directive), the specified gate voltage is used as initial value for the threshold voltage, otherwise, the long-channel threshold voltage will be used. The definition of the threshold voltage may be influenced by the CURRENT key.

MODEL=2-D: Both Poisson's equation and the minority-carrier continuity equation are solved in two dimensions. Recombination/generation is neglected.

MODEL=AVAL: This is the only model for accurate calculation in the avalanche breakdown region. The full set of semiconductor equations (Poisson's equation and both continuity equations) is solved in two dimensions. Recombination/generation as well as impact ionization is taken into account in the inhomogeneity term of the carrier continuity equation and, therefore, substrate currents can also be calculated.

MODEL=HOT: This is the most complex and also most expensive model which is presently available with MINIMOS. The simulation is performed in the same manner as with MODEL=AVAL and, additionally, a position dependent carrier temperature is introduced to account more sophisticatedly for carrier heating.

PHYSCK

This key specifies whether 'physical' errors should be processed. 'Physical' errors are 'out-of-range' errors of any *num* value as well as sign errors within the BIAS directive. Another meaning of this key is to decide whether execution should be terminated if any iteration seems to diverge (e.g. threshold voltage infinite due to punch-through). *log* may be YES or NO; only the first character is significant. If 'physical' errors are detected by MINIMOS with PHYSCK=NO, a warning message will be issued. If this key is omitted, 'physical' errors will be processed. For instance, if a positive bulk voltage should be specified for an n-channel device PHYSCK= NO has to be given. Since any guarantee of regular execution is lost with PHYSCK=NO, use of this statement is not recommended.

RBULK

This key specifies an effective bulk resistor in Ohms. *num* may be any value between 0 and 10^5. The default setting of this key is 0. When this key is given, the effective substrate bias is calculated as UB−RBULK·Isub (for UB see BIAS directive). As a large value of *num* may affect the computation time in an undesirable manner it is recommended to determine the effective substrate bias by the UB key directly, provided

that Isub is known (not applicable if the STEP directive is given). This key is active only if MODEL=AVAL or MODEL=HOT is specified.

RDRAIN

This key specifies an effective drain resistor in Ohms. *num* may be any value between 0 and 10^2. The default setting of this key is 0. When this key is given, the effective drain bias is calculated as UD−RDRAIN·Idrain (for UD see BIAS directive). As a large value of *num* may affect the computation time in an undesirable manner it is recommended to determine the effective drain bias by the UD key directly, provided that Idrain is known (not applicable if the STEP directive is given).

RSOURCE

This key specifies an effective source resistor in Ohms. *num* may be any value between 0 and 10^2. The default setting of this key is 0. When this key is given, the effective source bias is calculated as US−RSOURCE·Isource (for US see BIAS directive). As a large value of *num* may affect the computation time in an undesirable manner it is recommended to determine the effective source bias by the UD key directly, provided that Isource is known (not applicable if the STEP directive is given).

TEMP

This key specifies the simulation temperature in Kelvin. *num* can be any value within the range of 77 to 450. If this key is omitted, the simulation is performed at 300 Kelvin.

UFB

This key specifies the flatband voltage in Volts. *num* can be any value within the range of −3 to 3. If this key is omitted, the flatband voltage will be calculated from the workfunction difference of the gate material (GATE key on the DEVICE directive) and the slow-surface-state density (NSS key on the INTERFACE directive). If UFB is specified, the GATE key on the DEVICE directive and the NSS key must be omitted.

UN, UP

These keys specify weights for the energy relaxation times for electrons and holes in seconds, respectively. *num* may be any value between 0 and 1. Default settings for UN and UP are 0.8. These keys are active only if MODEL=HOT is specified.

The OUTPUT Directive

The OUTPUT directive is used to specify the physical quantities which are to be printed after the simulation has terminated successfully. All keys possible on this directive are logical items. Thus the only decision requested is if some physical quantity is to be printed or not. The following keys are possible:

OUTPUT, **ALL**=*log*, **AV**AL=*log*, **CC**=*log*, **DC**=*log*, **EL**AT=*log*, **ET**RAN=*log*

+ **IN**SULATOR=*log*, **JL**AT=*log*, **JT**RAN=*log*, **MAJ**=*log*, **MIN**=*log*, **MO**B=*log*

+ **NO**NE=*log*, **OX**IDE=*log*, **PH**I=*log*, **PS**I=*log*, **RH**O=*log*, **TC**=*log*

The first two characters are significant for any of these keys. *log* can be YES or NO. The first character is significant only. All keys have a default setting.

ALL

This key specifies the printing of all available quantities regardless of the specifications for the individual keys. The default setting of this key is NO.

AVAL

This key specifies the printing of the avalanche generation rate. The default setting of this key is NO. The avalanche generation rate is available only if MODEL=AVAL or MODEL=HOT is given (cf. OPTION directive).

CC

This key specifies the printing of the carrier concentrations. The default setting of this key is YES.

DC

This key specifies the printing of the doping profile. The default setting of this key is NO.

ELAT

This key specifies the printing of the lateral electric field component. The default setting of this key is YES.

ETRAN

This key specifies the printing of the transversal electric field component. The default setting of this key is YES.

JLAT

This key specifies the printing of the lateral current density components. The default setting of this key is NO.

JTRAN

This key specifies the printing of the transversal current density components. The default setting of this key is NO.

MAJ

This key specifies if majority quantities should be printed. The default setting of this key is NO. Majority quantities are available only if MODEL=AVAL or MODEL=HOT is given (cf. OPTION directive).

MIN

This key specifies if minority quantities should be printed. The default setting of this key is YES.

MOB

This key specifies the printing of the mobility distributions. The default setting of this key is NO.

NONE

This key supresses the printing of all available quantities regardless of the specifications for the individual keys. The default setting of this key is NO. If both, NONE=YES and ALL=YES, are specified, no distributions will be printed.

OXIDE or **IN**SULATOR

This key specifies the printing of the electrostatic potential and the electric field components within the insulator. The default setting of this key is NO.

PHI

This key specifies the printing of the quasi-Fermi levels. The default setting of this key is NO. This quantity is not available if MODEL=HOT is given (cf. OPTION directive).

PSI

This key specifies the printing of the electrostatic potential. The default setting of this key is YES.

RHO

This key specifies the printing of the space charge. The default setting of this key is NO.

TC

This key specifies the printing of the carrier temperature distribution. The default setting of this key is NO. This quantity is available only if MODEL=HOT is given (cf. OPTION directive).

The PROFILE Directive

The PROFILE directive is used to specify the source-drain doping profile and the bulk doping, or an external file from which the doping profile for source-drain and the channel is to be read. The following keys are possible:

PROFILE, **AK**EV=*num*, **AS**YM=*log*, **DO**SE=*num*, **EL**EM=*dop*, **FI**LE=*fil*

+ **LF**IT=*num*, **NB**=*num*, **NS**=*num*, **TE**MP=*num*, **TI**ME=*num*, **TO**X=*num*

+ **XO**FF=*num*, **YO**FF=*num*

The first two characters are significant for any of these keys.

There exist four possibilities to define a source-drain profile. Once the user has chosen one of them, the associated keys must appear (keys in brackets may be omitted).

1. **FILE=2**-D
2. **FILE=1**-D [, **AS**YM=*log*] [, **LF**IT=*num*] [, **XO**FF=*num*] [, **YO**FF=*num*]
3. [**FI**LE=NO,] [**AS**YM=*log*,] **NB**=*num*, **NS**=*num*, **TE**MP=*num*, **TI**ME=*num* [, **XO**FF=*num*] [, **YO**FF=*num*]
4. [**FI**LE=NO,] [**AS**YM=*log*,] **AK**EV=*num*, **DO**SE=*num*, **EL**EM=*dop*, **NB**=*num*, **TE**MP=*num*, **TI**ME=*num*[, **TO**X=*num*] [, **XO**FF=*num*] [, **YO**FF=*num*]

If FILE=NO and ASYM=YES, or FILE=NO and XOFF is given, two PROFILE directives must be used.

AKEV

This key specifies the source-drain implantation energy in keV. *num* can be any value within the range of 10 to 300. If the AKEV key is specified with a particular PROFILE directive, the ELEM and DOSE keys have also to be specified and the NS key must be omitted on this PROFILE directive (NS may appear on another PROFILE directive if two PROFILE directives are required). This key must be omitted if FILE=2-D or FILE=1-D is specified.

ASYM

This key specifies a non-symmetric source-drain profile. *log* may be YES or NO; only the first character is significant. Default setting of this key is NO. If ASYM=YES and FILE=NO is specified, two PROFILE directives must appear. The profile given with the first PROFILE directive will be used for the source region and the profile given with the second PROFILE directive will be used for the drain region. If XOFF is also specified, the profile given with the first PROFILE directive will be used for source and drain, whereas the profile given with the second PROFILE directive will be superimposed at offset XOFF at the drain only. If FILE=1-D is specified, there have to be two profile slices on the external doping file (cf. Appendix A). The data of the first slice are then used for the source region and the data from the second slice are used for the drain region. Similarly, if XOFF is also specified, the data of the first slice will be used for source and drain, whereas the data from the second slice will be superimposed at offset XOFF at the drain only. The ASYM key must be omitted if FILE=2-D is specified. The ASYM key has to be specified if XOFF is negative.

DOSE

This key specifies the source-drain implantation dose in cm^{-2}. *num* can be any value between 10^{10} and 10^{17}. If the DOSE key is specified with a particular PROFILE directive, the ELEM and AKEV keys have also to be specified and the NS key must be omitted on this PROFILE directive. This key must be omitted if FILE=2-D or FILE=1-D is specified.

ELEM

This key specifies the source-drain implantation element. *dop* can be B,P,SB and AS denoting boron, phosphorus, antimony and arsenic. Only the first character is significant. If the ELEM key is specified with a particular PROFILE directive, the DOSE and AKEV keys have also to be specified and the NS key must be omitted. For n-channel devices only P,SB and AS is allowed, for p-channel devices just B can be given as a value for dop. This key must be omitted if FILE=2-D or FILE=1-D is specified.

FILE

This key specifies if doping data are to be read from an external file. The format of the external file is given in Appendix A. *fil* can be 2-D, 1-D, YES or NO. 1-D and YES are treated synonymously for the *fil* value. The first character is significant only. If FILE=2-D (two-dimensional external doping data) is specified, no other key must be given. If FILE=1-D (one-dimensional external doping data) is specified, only the ASYM, LFIT, XOFF or YOFF key may additionally be specified.

LFIT

This key specifies the fitting parameter for the subdiffusion in case of using doping data from an external file. *num* can be any value in the range of 0.1 and 2. The LFIT key can be omitted but, if specified, FILE=1-D must have been given too. 0.7 is assumed for LFIT by default.

NB

This key specifies the bulk doping in cm^{-3}. *num* can be any value between $5 \cdot 10^{13}$ and $5 \cdot 10^{17}$. The NB key has to be specified unless FILE=2-D or FILE=1-D has been given. In this case the NB key must be omitted.

NS

This key specifies the surface concentration for a source-drain predeposition in cm^{-3}. *num* can be any value within the range of 10^{17} to 10^{21}. If the NS key is specified with a particular PROFILE directive, the ELEM, DOSE, AKEV and TOX keys must not be specified. Phosphorus and boron dopants are assumed for n-channel and p-channel devices, respectively. The specified value must be at least 100 times larger than the bulk doping. The NS key must be omitted, if FILE=2-D or FILE=1-D is specified or the ELEM, DOSE and AKEV keys are given.

TEMP

This key specifies the source-drain profile diffusion temperature in centigrades. *num* can be any value in the range of 800 to 1300. The TEMP key has to be specified unless FILE=2-D or FILE=1-D has been given. In this case the TEMP key must be omitted. If two PROFILE directives are required, the TEMP key may appear only once with either the first or the second PROFILE directive.

TIME

This key specifies the source-drain profile diffusion time in seconds. *num* can be any value within the range of 60 to $48 \cdot 3600$. The TIME key has to be specified unless FILE=2-D or FILE=1-D has been given. In this case the TIME key must be omitted. If two PROFILE directives are required, the TIME key may appear only once with either the first or the second PROFILE directive.

TOX

This key specifies the source-drain implantation isolation oxide in cm. *num* can be any value within the range of 0 to 10^{-3}. The TOX key can be omitted. If it is specified, the ELEM, DOSE and AKEV keys have also to be specified and the NS key must be omitted. If it is not specified and the ELEM, DOSE and AKEV keys are given, a default value of 0 is assumed, that means implantation into the bare surface. If two PROFILE directives with implantation data are given and required, the TOX key may appear only once with either the first or the second PROFILE directive. This key must be omitted if FILE=2-D or FILE=1-D is specified.

XOFF

This key specifies an offset for superposition of two source and/or drain profiles in *cm*. *num* can be any value within the range of $-2 \cdot 10^{-4}$ to $2 \cdot 10^{-4}$. If XOFF is specified, either two PROFILE directives have to be given (FILE=NO) or two slices for a source-drain profile have to be given with the external doping file (FILE=1-D). This key must be omitted if FILE=2-D is specified. If *num* is negative, the ASYM key must be specified.

YOFF

This key specifies a distance in *cm* for shifting the source-drain profile into the bulk. Used cleverly, the YOFF key allows to account to some extent for non-planar source-drain surfaces. *num* can be any value within the range of 0 to 10^{-4}. If this key is omitted, the default value 0 is assumed which means no vertical shift. This key must be omitted if FILE=2-D is specified.

The RECOMBINATION Directive

The RECOMBINATION directive is used to specify recombination and generation parameters. This directive can be omitted. No key of this directive is required. Default values are existing as outlined in the description of each individual key. The following keys are possible:

RECOMBINATION, **AN**=*num*, **AP**=*num*, **BN**=*num*, **BP**=*num*, **CN**=*num*

+ **CP**=*num*, **SN**=*num*, **SP**=*num*, **TN**=*num*, **TP**=*num*, **VN**=*num*, **VP**=*num*

The first two characters are significant for any of these keys.

AN, AP, BN, BP

These keys are used for the calculation of the impact ionization rates. The calculation is given by: $\alpha_n(E) = AN * EXP(-BN/E)$ and $\alpha_p(E) = AP * EXP(-BP/E))$ with E denoting the electric field. AN and AP are given in cm^{-1}, BN and BP are given in V/cm. Default setting is AN=$7 \cdot 10^5$, AP=$1.58 \cdot 10^6$, BN=$1.23 \cdot 10^6$, BP=$2.036 \cdot 10^6$ (Van Overstraeten; Solid State Electron. 13, pp.583-608). Owing to the dark space effect of the impact ionization, the parameters given above may overestimate the ionization rates especially at small drain voltages and/or steep drain junctions. Hence the calculated bulk current will be too large. In that situation the above parameters should be increased - e.g. AN=$1.7 \cdot 10^7$, AP=$1.7 \cdot 10^7$, BN=$2.9 \cdot 10^6$, BP=$3.2 \cdot 10^6$. AN and AP have to be in the range 0 to 10^9. BN and BP have to be in the range $5 \cdot 10^5$ to 10^7. These keys are active only if MODEL=AVAL or MODEL=HOT is specified.

CN, CP

These keys specify the Auger recombination parameters for electrons and holes in cm^6, respectively. *num* may be any value between 0 and 10^{-28}. Default setting for CN is $1.4 \cdot 10^{-31}$ and default setting for CP is $9.9 \cdot 10^{-32}$. These keys are active only if MODEL=AVAL or MODEL=HOT is specified.

SN, SP

These keys specify the surface recombination velocities (at the gate insulator interface) for electrons and holes in cm/sec, respectively. *num* may be any value between 1 and 10^7. Default setting for SN and SP is 100. These keys are active only if MODEL=AVAL or MODEL=HOT is specified.

TN, TP

These keys specify the lifetimes of electrons and holes in seconds, respectively. *num* can be any value within the range of 10^{-9} to 10^6. The default value for TN and TP is 10^{-6}. These keys are active only if MODEL=AVAL or MODEL=HOT is specified.

VN, VP

These keys specify the interface recombination velocities (at the bulk-insulator interface) for electrons and holes in cm/sec, respectively. *num* may be any value between 1 and 10^7. Default setting for VN and VP is 100. These keys are active only for SOI simulations and if MODEL=AVAL or MODEL=HOT is specified.

The STEP Directive

The STEP directive is used to specify a step sequence for any applied voltage. The following keys are possible:

STEP, **DB**=*num*, **DD**=*num*, **DG**=*num*, **NB**=*num*, **ND**=*num*, **NG**=*num*

Both characters are significant for any of these keys.

DB

This key specifies the incremental bulk voltage in Volts. *num* can be any value within -5 to 5. The absolute value must be greater than or equal to 0.1. The DB key can be omitted but, if specified, the NB key must also be given.

DD

This key specifies the incremental drain voltage in Volts. *num* can be any value within -5 to 5. The absolute value must be greater than or equal to 0.1. The DD key can be omitted but, if specified, the ND key must also be given.

DG

This key specifies the incremental gate voltage in Volts. *num* can be any value within -5 to 5. The absolute value must be greater than or equal to 0.1. The DG key can be omitted but, if specified, the NG key must also be given. However, if the MODEL=THRES option (cf. OPTION directive) is used, neither the DG key nor the NG key may appear.

NB

This key specifies the number of bulk voltage steps to be performed. *num* can be any value between 1 and 20. A fractional number will be truncated. The NB key can be omitted but, if specified, the DB key must also be given.

ND

This key specifies the number of drain voltage steps to be performed. *num* can be any value between 1 and 20. A fractional number will be truncated. The ND key can be omitted but, if specified, the DD key must also be given.

NG

This key specifies the number of gate voltage steps to be performed. *num* can be any value between 1 and 20. A fractional number will be truncated. The NG key can be omitted but, if specified, the DG key must also be given.

NOTE

The input data will be checked for physical plausibility unless the PHYSCK key is set to NO (cf. OPTION directive). Therefore $UD+i \cdot DD - US$ i=1,ND and $US - UB - i \cdot DB$ i=1,NB have to be within 0 to 20. and within 0 to -20 for n-channel and p-channel devices, respectively.

Appendix A. The Format of the DOPING File

The doping file is read in Fortran binary mode. The format of the doping file depends on the setting of three parameters (ASYM, FILE, XOFF) on the PROFILE directive.

If FILE=1-D is specified with the PROFILE directive, the doping profile has to be given in one-dimensional profile slices which are artificially extended to two dimensions. The format of the doping file is required to be as follows. The first record is expected the following way:

```
READ (NUMDOP) DUMMY,YINC
```

YINC is the distance increment for the doping table.

The next 100 records of the doping file are interpreted as the acceptor and donor concentration and their derivatives for a source-drain profile slice, a channel profile slice and, if required, a second source-drain profile slice. If ASYM=YES and/or XOFF is given on the PROFILE directive, three profile slices are required on the doping file (NSLICE=3). If ASYM=NO and XOFF is not given on the profile directive, only two profile slices are required (NSLICE=2).

```
      DO 1 I=1,100
   1    READ (NUMDOP) (AC(I,J),DACDY(I,J),DC(I,J),DDCDY(I,J),J=1,NSLICE)
```

AC(I,J) is the acceptor concentration in cm^{-3} at location I for slice J.

DACDY(I,J) is the spatial derivative of the acceptor concentration in cm^{-4} at location I for slice J.

DC(I,J) is the donor concentration in cm^{-3} at location I for slice J.

DDCDY(I,J) is the spatial derivative of the donor concentration in cm^{-4} at location I for slice J.

I=1 denotes the surface. I=100 denotes the depth 99·YINC. If MINIMOS needs the doping at a deeper distance, the bulk value will be assumed. J=1 denotes the first slice from which the source (and drain) doping is formed. If ASYM=YES and XOFF is not given, J=1 denotes only the source profile. J=2 is the channel profile which is extended homogenously all over the device. J=3 denotes the second (source and) drain profile slice. IF ASYM=YES and XOFF is not specified, J=3 gives only the drain profile. If ASYM=NO and XOFF is given J=1 denotes the inner source and drain profile and J=3 is the outer source and drain profile which is assumed to be shifted with the distance XOFF. For an LDD application J=1 gives the profile in the lowly doped region and J=3 is the profile slice for the heavily doped region at offset XOFF. If ASYM=YES and XOFF is specified, the source profile is comprised from the J=1 profile slice and the drain profile is comprised from the J=1 profile slice and the J=3 profile slice with an offset XOFF.

If FILE=2-D is specified with the profile directive, the external doping file must give a fully two-dimensional doping profile in the following manner.

```
          READ (NUMDOP) NPIECE
          READ (NUMDOP) NHS,NVS
          READ (NUMDOP) (ZHS(I),I=1,NHS)
          READ (NUMDOP) (ZVS(J),J=1,NVS)
          DO 1 J=1,NVS
    1     READ (NUMDOP) (CDS(I,J),I=1,NHS)
          IF (NPIECE.GT.0) THEN
             DO 2 J=1,NVS
    2        READ (NUMDOP) (DCDDHS(I,J),I=1,NHS)
             DO 3 J=1,NVS
    3        READ (NUMDOP) (DCDDVS(I,J),I=1,NHS)
          ENDIF
          DO 4 J=1,NVS
    4     READ (NUMDOP) (CAS(I,J),I=1,NHS)
          IF (NPIECE.GT.0) THEN
             DO 5 J=1,NVS
    5        READ (NUMDOP) (DCADHS(I,J),I=1,NHS)
             DO 6 J=1,NVS
    6        READ (NUMDOP) (DCADVS(I,J),I=1,NHS)
          ENDIF
          IF (ABS(NPIECE).EQ.1) THEN
             REWIND NUMDOP
             READ (NUMDOP) NPIECE
          ENDIF
          READ (NUMDOP) NHD,NVD
          READ (NUMDOP) (ZHD(I),I=1,NHD)
          READ (NUMDOP) (ZVD(J),J=1,NVD)
          DO 7 J=1,NVD
    7     READ (NUMDOP) (CDD(I,J),I=1,NHD)
          IF (NPIECE.GT.0) THEN
             DO 8 J=1,NVD
    8        READ (NUMDOP) (DCDDH(I,J),I=1,NHD)
             DO 9 J=1,NVD
    9        READ (NUMDOP) (DCDDV(I,J),I=1,NHD)
          ENDIF
          DO 10 J=1,NVD
   10     READ (NUMDOP) (CA(I,J),I=1,NHD)
          IF (NPIECE.GT.0) THEN
             DO 11 J=1,NVD
   11        READ (NUMDOP) (DCADH(I,J),I=1,NHD)
             DO 12 J=1,NVD
   12        READ (NUMDOP) (DCADV(I,J),I=1,NHD)
          ENDIF
```

ABS(NPIECE)=1 denotes that the same two-dimensional profile piece should be used for source and drain. ABS(NPIECE)=2 denotes that different but matching profile pieces are used for the source region and the drain region.

NHS and NVS are the number of points of the external profile array in horizontal

(parallel to the interface) and vertical (perpendicular to the interface) direction for the source profile. NHS and NVS have to be greater equal 10 and less equal 50. ZHS(I) and ZVS(J) are the coordinates (ZHS(I) in horizontal and ZVS(J) in vertical direction) of the point (I,J) for the source profile in centimeters. There has to be an index K between 1 and NHS so that ZHS(K)=0. This location is interpreted as the mask edge of the two-dimensional profile. ZHS(I) less than zero is the free surface and ZHS(I) greater than zero denotes the masked surface. There must also be an index L between 1 and NVS so that ZVS(L)=0. This location is interpreted as the gate insulator to semiconductor interface. Positive ZVS denotes the semiconductor area. Values at negative ZVS are ignored. CDS(I,J) is the donor concentration at location (I,J) for the source profile in cm^{-3}. DCDSDH(I,J) is the partial derivative of the donor concentration at location (I,J) with respect to the horizontal direction for the source profile in cm^{-4}. DCDSDV(I,J) is the partial derivative of the acceptor concentration at location (I,J) with respect to the vertical direction for the source profile in cm^{-4}. CAS(I,J) is the acceptor concentration at location (I,J) for the source profile in cm^{-3}. DCASDH(I,J) is the partial derivative of the acceptor concentration at location (I,J) with respect to the horizontal direction for the source profile in cm^{-4}. DCASDV(I,J) is the partial derivative of the acceptor concentration at location (I,J) with respect to the vertical direction for the source profile in cm^{-4}. The derivatives are only required if NPIECE > 0.

NHD and NVD are the number of points of the external profile array in horizontal (parallel to the interface) and vertical (perpendicular to the interface) direction for the drain profile. NHD and NVD have to be greater equal 10 and less equal 50. ZHD(I) and ZVD(J) are the coordinates (ZHD(I) in horizontal and ZVD(J) in vertical direction) of the point (I,J) for the drain profile in centimeters. There has to be an index K between 1 and NHD so that ZHD(K)=0. This location is interpreted as the mask edge of the two-dimensional profile. ZHD(I) less than zero is the free surface and ZHD(I) greater than zero denotes the masked surface. There must also be an index L between 1 and NVD so that ZVD(L)=0. This location is interpreted as the gate insulator to semiconductor interface. Positive ZVD denotes the semiconductor area. Values at negative ZVD are ignored. CDD(I,J) is the donor concentration at location (I,J) for the drain profile in cm^{-3}. DCDDDH(I,J) is the partial derivative of the donor concentration at location (I,J) with respect to the horizontal direction for the drain profile in cm^{-4}. DCDDDV(I,J) is the partial derivative of the acceptor concentration at location (I,J) with respect to the vertical direction for the drain profile in cm^{-4}. CAD(I,J) is the acceptor concentration at location (I,J) for the drain profile in cm^{-3}. DCADDH(I,J) is the partial derivative of the acceptor concentration at location (I,J) with respect to the horizontal direction for the drain profile in cm^{-4}. DCADDV(I,J) is the partial derivative of the acceptor concentration at location (I,J) with respect to the vertical direction for the drain profile in cm^{-4}. The derivatives are only required if NPIECE > 0.

If two separate profile pieces for source and drain are given (ABS(NPIECE)=2), the profiles have to match for the middle of the channel. If the simulation domain generated by MINIMOS is larger than the domains described by the external doping arrays, the profile is simply extended in the respective direction.

The doping data read from file are not physically verified.

Appendix B. The Format of the BINARY File

The BINARY file is written in Fortran binary mode by subroutine BINAER. The main purpose of this file is to store the output data for subsequent postprocessing (e.g. plotting). The length of this file depends on the specification of the MODEL key (cf. OPTION directive). The various quantities are given in modified S.I. units (cm, sec, Volts, Amps). The data are written in the following order:

1. TITLE. (80 characters)

   The first line of the input file.

2. CHANNEL,UFB,TINS,L,W. (1 character + 4 floating point words)

   For CHANNEL, TINS, L, W see DEVICE directive, for UFB see OPTION directive.

3. US,UG,UD,UB,ID,IS,IB. (7 floating point words)

   For US, UG, UD, UB see BIAS directive, ID, IS, IB are the drain-, source-, and bulk current, respectively.

4. LI,UT,NI. (3 floating point words)

   LI is the intrinsic Debye length, UT is the thermal voltage and NI is the intrinsic concentration.

5. NX,NT,NY,NYOXM,NYTOT,NXS,NXSOX. (7 integer words)

   NX is the number of mesh lines in x-direction. NT is the number of mesh lines of the active semiconductor in y-direction. NY is the number of mesh lines of the semiconductor in y-direction. NYOXM is the number of mesh lines of the gate insulator in y-direction. NYTOT is the total number of mesh lines in y-direction. NXS is the x-index of the first gate point (source side) and NXSOX is the x-index of the last gate point (drain side).

6. X(I), I=1,NX. (NX floating point words)

   X are the x-coordinates.

7. Y(J), J=1,NYTOT. (NYTOT floating point words)

   Y are the y-coordinates. Note, NYOXM+1 denotes the gate-insulator to semiconductor interface.

8. CDOP(I,J), I=1,NX, J=NYOXM+1,NYOXM+NY.

   Doping concentration.

9. PSI(I,J), I=1,NX, J=1,NYTOT.

   Electrostatic Potential.

10. CMIN(I,J), I=1,NX, J=NYOXM+1,NYOXM+NT.

Minority carrier concentration.

11. MOMINL(I,J), I=1,NX, J=NYOXM+1,NYOXM+NT.

Minority carrier mobility parallel to the gate insulator interface.

12. MOMINT(I,J), I=1,NX, J=NYOXM+1,NYOXM+NT.

Minority carrier mobility perpendicular to the gate insulator interface.

13. JLMIN(I,J), I=1,NX, J=NYOXM+1,NYOXM+NT.

Minority carrier current density (x-component).

14. JTMIN(I,J), I=1,NX, J=NYOXM+1,NYOXM+NT.

Minority carrier current density (y-component).

End-of-file for MODEL=1-D, MODEL=THRES and MODEL=2-D

15. CMAJ(I,J), I=1,NX, J=NYOXM+1,NYOXM+NT.

Majority carrier concentration.

16. MOMAJL(I,J), I=1,NX, J=NYOXM+1,NYOXM+NT.

Majority carrier mobility parallel to the gate insulator interface.

17. MOMAJT(I,J), I=1,NX, J=NYOXM+1,NYOXM+NT.

Majority carrier mobility perpendicular to the gate insulator interface.

18. JLMAJ(I,J), I=1,NX, J=NYOXM+1,NYOXM+NT.

Majority carrier current density (x-component).

19. JTMAJ(I,J), I=1,NX, J=NYOXM+1,NYOXM+NT.

Majority carrier current density (y-component).

20. AVAL(I,J), I=1,NX, J=NYOXM+1,NYOXM+NT.

Avalanche (impact ionization) generation rate.

End-of-file for MODEL=AVAL

21. TCMIN(I,J), I=1,NX, J=NYOXM+1,NYOXM+NT.

Minority carrier temperature.

22. TCMAJ(I,J), I=1,NX, J=NYOXM+1,NYOXM+NT.

Majority carrier temperature.

End-of-File for MODEL=HOT