

GUIDE TO USING TCAD WITH EXAMPLES

(LINUX AND UNIX VERSION)

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This manual is intended for the first time user of SILVACO TCAD products. Its intention is to enable a new user to have the software up and running within a few minutes of successful installation.

This tutorial will also demonstrate how to navigate the manuals quickly and efficiently to locate explanations and definitions of all parameters used in the simulators. It will cross reference the user to the relevant physics chapters to understand the equations and underlying physics in which these equations are used.

For further reading and references, the reader will be directed to a wealth of technical material and published paper references located in the technical sections of the SILVACO web pages.

Section 2.1: The DeckBuild Runtime Environment Window

The key to rapid familiarization with SILVACO's TCAD software is the versatile and feature laden runtime environment called "DeckBuild." DeckBuild features include: automatic creation of process input files, editing of existing input files, creation of Design Of Experiments (DOE), powerful parameter extraction routines and the ability to make anything in the input file a variable.

Most importantly for the first time user however, DeckBuild includes literally hundreds of examples for many different types of electrical, optical and magnetic technologies.

Getting Started...

Open a console window and create a directory where you Deckbuild V3.38.2.R – (NONE), dir; /home/derekk/manuals/TC want the temporary files that File ∇) View ∇) Edit ⊽) Find ∇) Main Control ∇ Commands ∇) Tools ∇ will be created in this tutorial to reside. For example, to create and relocate to a directory called "tutorial," in the console window type: mkdir tutorial <return> cd tutorial <return> Now invoke the DeckBuild runtime environment by typing: deckbuild <return> You should see the DeckBuild runtime environment appear on your monitor and it should look very similar to that shown in Figure 2.1. next line stop ∇ cont run auit Line: 1 The GUI interface is arranged init kill Stop: None paste clear restart pause in two parts. The upper window OPTOLITH Enabled displays the current input file and ATHENA multicore Enabled the lower window displays the It is now Mon Feb 2 09:58:17 2009 output created when running that Executing on host: sanmateo input file. Loading model file 'athenamod'... done. ATHENA> ATHENA started ATHENA

Figure 2.1 The DeckBuild Runtime Interface GUI

Section 2.2: Loading and Running Examples

The input file can be created by the user or can be loaded from the examples library. Familiarization with the software syntax is best executed by loading an example in the first instance. To load an example from the DeckBuild runtime environment GUI, click:

Main Control... Examples...

A pop up window displays a list of 47 different categories of examples. The first 15 categories are displayed as shown in Figure 2.2. To view the remaining categories, simply scroll down using the slider on the right hand side of the window.

– Deckbuild: Examples	
$(Index \nabla) (Sub-section \nabla)$	(Load exemple)
Index	
1 MOS1 : MOS Application Examples	T
2 MOS2 : Advanced MOS Application Examples	
3 BJT : Bipolar Application Examples	
4 DIODE : Diode Application Examples	
5 SOI : Application Examples	
6 EPROM : Application Examples	
7 LATCHUP : CMOS Latchup Application Examples	
8 ESD : ESD Application Examples	
9 POWER : Power Device Application Examples	
10 ISOLATION : ISOLATION Applications Examples	
11 MESFET : Application Examples	
12 HBT : HBT Application Examples	
13 HEMT: HEMT Application Examples	
14 TFT : TFT Application Examples	
15 QUANTUM : Device Simulation with Quantum Mechanic	s 📗

Figure 2.2 The First 15 DeckBuild Example Categories

To view a listing of the examples in each category, double-click one of the categories. If you double-click the first category entitled "MOS1: MOS Application Examples," you will get the listing shown in Figure 2.3. There are 15 examples in this category.

Deckbuild: Examples
$\underbrace{Index \nabla} \underbrace{Section \nabla} \underbrace{Sub-section \nabla} \underbrace{Lcad example}$
1 MOS1 : MOS Application Examples
1.1 mos1ex01.in : NMOS : Id/Vgs and Threshold Voltage Extraction
1.2 mos1ex02.in : NMOS : Family of Id/Vds Curves
1.3 mos1ex03.in : NMOS : Sub-Threshold Slope Extraction
1.4 mos1ex04.in : NMOS : DIBL Extraction
1.5 mos1ex05.in : NMOS : Body Effect Extraction
1.6 mos1ex06.in : NMOS : Substrate and Gate Current Extraction
1.7 mos1ex07.in : NMOS : Breakdown Voltage Extraction
1.8 mos1ex08.in : PMOS : Id/Vgs and Threshold Voltage Extraction
1.9 mos1ex09.in : PMOS : Family of Id/Vds Curves
1.10 mos1ex10.in : PMOS : Sub-Threshold Slope Extraction
1.11 mos1ex11.in : PMOS : DIBL Extraction
1.12 mos1ex12.in : PMOS : Body Effect Extraction
1.13 mos1ex13.in : PMOS : Substrate and Gate Current Extraction
1.14 mos1ex14.in : PMOS : Breakdown Voltage Extraction
1.15 mos1ex15.in : NMOS : Gate Length Scaling

Figure 2.3 MOS Application Example List

Deckbuild: Examples ∇) Index ∇ Sub-section v) Load example) Section 1 MOS1 : MOS Application Examples 1.1 mos1ex01.in : NMOS : Id/Vgs and Threshold Voltage Extraction Requires: SSUPREM4/SPISCES Basic MOS ATHENA to ATLAS interface example simulating an Id/Vgs curve and extracting threshold voltage and other SPICE parameters. No advanced features are used in this example so as to demonstrate simple functionality. This example demonstrates: process simulation of a MOS transistor in ATHENA process parameter extraction (eg. oxide thicknesses) autointerface between ATHENA and ATLAS simple Id/Vgs curve generation with Vds=0.1V · parameter extraction for Vt, linear gain (beta) and mobility rolloff (theta) The process simulation in SSUPREM4 follows a standard LDD MOS process. The process steps are simplified and default models are used to give a fast runtime. The polysilicon gate is formed by a simple geometrical etch. Before this point the simulation is essentially one dimensional and hence is run in ATHENA's 1D mode. After the poly etch, the structure converts to 2D. The grid used in this example is defined quite tightly. However the statement **init ... spac.mult=3** relaxes the mesh in X and Y directions by a factor of three. A more typical mesh for MOS simulation can be obtained by setting **spac.mult=1** Using DeckBuild's auto-interface the process simulation structure will be passed

Using DeckBuild's auto-interface the process simulation structure will be passed into ATLAS automatically. This auto-interface therefore allows global optimization from process simulation to device simulation to spice model

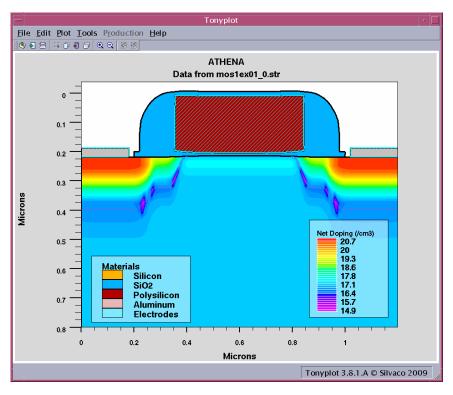
Figure 2.4 Example Description Window

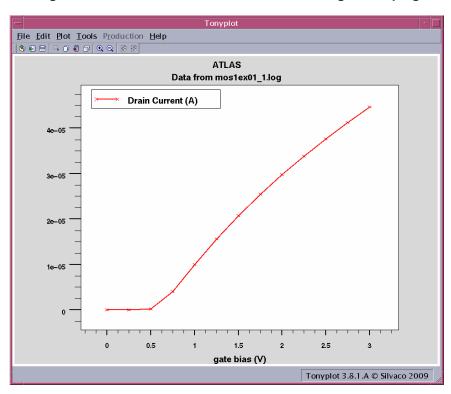
To view an explanation of any particular example simply double click the example in which you are interested. Double click the first example, entitled "NMOS : Id/Vgs and Threshold Voltage Extraction" to view an explanation of that example. The resulting display window is shown in Figure 2.4. Scroll down the window to read the full description. In order to load this particular example into the DeckBuild runtime environment click the "Load Example" button at the top right of the "DeckBuild: Examples" window. The main DeckBuild window should now appear as in Figure 2.5.

💳 Deckbuild V3.38.2.R – mos1ex01.in, dir; /home/derekk/manu 🕐 🗔
go athena
line x loc=0.0 spac=0.1 line x loc=0.2 spac=0.006 line x loc=0.4 spac=0.006 line x loc=0.6 spac=0.01
line y loc=0.0 spac=0.002 line y loc=0.2 spac=0.005 line y loc=0.5 spac=0.05 line y loc=0.8 spac=0.15
init orientation=100 c.phos=1e14 space.mul=2
P-well formation including masking off of the nwell diffus time=30 temp=1000 dryo2 press=1.00 hcl=3
etch oxide thick=0.02
P-well Implant implant boron dose=8e12 energy=100 pears
diffus temp=950 time=100 weto2 hcl=3
Well drive in starts here diffus time=50 temp=1000 t.rate=4.000 dryo2 press=0.10 hcl=3 diffus time=220 temp=1200 nitro press=1 diffus time=90 temp=1200 t.rate=-4.444 nitro press=1
(next) (line) (stop ⊽) (cont) (run) (quit) Line: 1
paste init pause clear restart kill Stop: None
OPTOLITH : Enabled ATHENA multicore : Enabled
It is now Mon Feb 2 09:58:17 2009
Executing on host: sanmateo
Loading model file 'athenamod' done.
ATHENA started ATHENA

Figure 2.5 Example Input File Now Loaded Into DeckBuild

Running the example is simply a matter of clicking the "run" button. On completion, two plots will appear on the screen. The first is a color contour plot of the process simulated structure displaying "Net Doping" and the second is a simple threshold voltage, Vg versus Id plot. These plots are shown in Figures 2.6 and 2.7 respectively. It should be noted that it is not necessary to actually run the simulations in order to view the results, since these structure files and line graphs are loaded into the current working directory as soon as the "Load Example" button is selected.





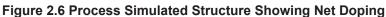


Figure 2.7 Device Simulated Line Graph Showing Vg Versus Id

Section 2.3: Viewing the Results

SILVACO's visualization tool called "TonyPlot" is a feature-packed plotting program. We will only touch on some of its more basic capabilities in this tutorial. When a structure file or line graph is saved in SILVACO's TCAD package, almost every quantity required to create the structure file or line graph, will be automatically included into the file and will be available for plotting.

For example, in the structure file plot, if you wish to plot other calculated quantities such as "Donor Concentration," click the following sequence:

Plot... Display... Define... Contours...

then pull down and scroll the "Quantity:" box to obtain a list of plottable quantities. If you followed the sequence, two additional GUI displays should appear as in Figure 2.8. Select any new quantity and click "Apply."

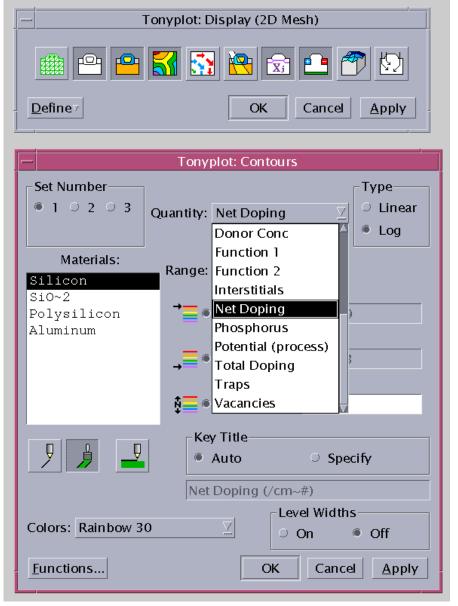


Figure 2.8 The GUIs Related to Selecting Plottable Quantities

It will often be necessary to view a "cutline" slice through a plot. To do this, close other plotter related windows by clicking "OK," then return to the main plot and select the following sequence:

Tools... Cutline...

For now we will use the default "vertical cutline" box, but the horizontal or diagonal cutline box could also be selected in the "cutline" GUI. Return to the main plot, click and hold down the left mouse button where you want to start the cutline. Drag the mouse vertically and let go of the left mouse button where you wish to finish the cutline. When you let go of the left mouse button, the cutline plot will automatically appear showing a cutline of the currently displayed quantity. Click "OK" on the cutline box if you are now done with making cutlines.

To overlay other quantities on the new cutline graph, left click the line graph to make it the current active plot (a white border around the plot indicates which plot is currently active). Now click:

Plot... Display ...

and select other quantities to overlay on the line graph. For example, if you add Arsenic, Boron and Phosphorus to the line graph, it should now appear as in Figure 2.9. A similar sequence on the Vg versus Id curve will also allow other electrical quantities to be overlayed on that line graph.

On a final note, you can plot a file by typing "tonyplot <filename>" into a terminal or console window or you can plot structures directly in DeckBuild by highlighting a structure file name and clicking the following sequence:

Tools... Plot... Plot Structure

To plot a structure file created during a simulation automatically, simply add the lines:

structure outfile=<filename> tonyplot <filename>

into your input file and the simulator will save the structure file created up until that point in the input file. It will then plot it automatically once the simulator reaches that point. You can save and plot as many structure files as you wish at any point during the simulation.

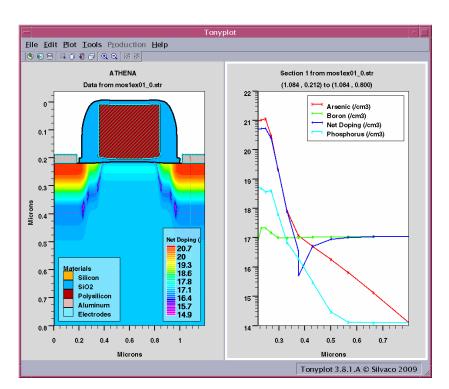


Figure 2.9 Cutline Graphs

Section 2.4: Automated Input File Creation and Editing

By now you should have a pretty reasonable idea how to load, run and view the results of TCAD examples. We will now demonstrate just how simple it is to create your own process simulation input files or to modify existing ones.

The input files are all simple ASCII text format so you can create an input file with any ASCII editor. However, DeckBuild includes a feature that creates process simulation input files automatically via a simple GUI.

For simplicity, rather than take the user through the repetition of creating a process simulation input file from scratch, we will demonstrate how to add lines of code to our existing input file. The same technique can be used to create an entire input file by simply repeating this procedure for each process step.

Once the simulation space and initial substrate have been defined using the "line" and "init" statements (see the first few lines of the loaded example), a process simulation simply consists of numerous consecutive diffusions, implants, etches and deposits. Every one of these steps can be written automatically using DeckBuild.

Return to our example input file. Suppose we wanted to add a second, low energy 10keV "P-Well Implant" after the first one. Left click in the top DeckBuild window, one line after the first P-well Implant. Now click the following sequence of buttons:

Commands... Process... Implant

The "DeckBuild: ATHENA Implant" window should appear. Creating the additional implant line is now just a matter of filling in the boxes, using the sliders or filling in the values followed by depressing the return key. For a 10keV boron implant, with a dose of 1e11/cm2 at an angle 7 degrees to the perpendicular and a rotation of 27 degrees to the major flat, the implant GUI should appear as shown in Figure 2.10. Once you are done inputting the information, click "Write" and the new line will appear in the input file.

All deposits, etches, implants, diffusions, electrodes, mesh creation, wafer initialization and structure file saves, etc., can be created in exactly the same way. Since the input files are simple ASCII text, editing parameters in the intuitive syntax input files is simply a matter of using the usual copy, paste and delete functionality included in DeckBuild.

	Deckbui	Id: ATHEN	A Implant	
Impurity:	Boron	Phosphorus	Arsenic	Bf2
	Antimony	Silicon	Zinc	Selenium
	Beryllium	Magnesium	Aluminum	Gallium
	Carbon	Indium		
Dose (ions/cm2):	<u>1.0</u> 1.0 []=		– 9.9 Exp: 🗵	11
Energy (KeV):	<u>10</u> 0 •]=		5 00	
Model:	Dual Pearson	Gauss Ful	l Lateral Moi	nte Carlo
Tilt (degrees):	7 0 =]=		90	
Rotation (degrees):	<u>27</u> 0 -]-		360	
Continual rotation:				
Material type:	Crystaline	Amorphous		
Damage:	Point defects	<311> Cl	usters Disl	ocation loops
Comment:				
		WRITE)		

Figure 2.10 The Completed Implant GUI

Chapter 3: Navigating the Manual and Self Training the Easy Way

At first sight, the size of the manuals may seem a little daunting, but this section will show the new user just how simple it is to find the specific information required by using the examples to navigate the manual.

Using the input file we loaded in Section 2.2 as an example, let us say we wanted to understand what the "SRH" parameter does in the device simulation section of the input file, which appears on the line beginning with "models."

In both the process and device simulator, the first word on any line is known as the "statement." In this example, since the first word on the line is "models" we now know that we need more information on the "models statement" if we are to find out what the parameter "SRH" means.

All SILVACO products include manuals in pdf format. We are looking for information in the device simulator, so we need to invoke the ATLAS manual. The manuals can be accessed via the "sman" facility which can be invoked by typing "sman" in a console or terminal window. Figure 3.1 shows what the manual should look like.

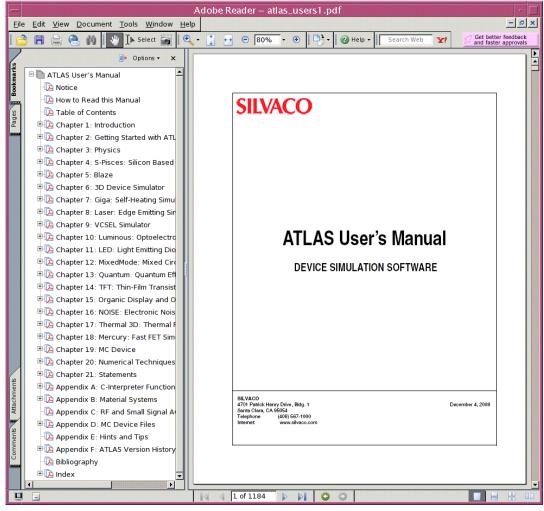


Figure 3.1 The ATLAS Manual PDF Interface

One of the most powerful features of the manual is the "Statements" chapter. This chapter contains an alphabetical listing of all the statements in the device simulator. Since we are looking for information on the "models" statement, click on the expansion "+" symbol next to the Statements chapter in the Index located on the left side of the page. Scroll down the alphabetical listings until you reach the "Models" statement. Click the expansion "+" sign next to the Models statement to see its contents.

At this point, we now have a choice. If you have already guessed that "SRH" is an acronym for "Schottky Read Hall" recombination, then click the section titled "Recombination Models Flags." If you had no idea what the parameter "SRH" was, click the "MODELS" heading to start at the beginning of this section. At the beginning of this section is another alphabetical listing of all parameters associated with the models statement. Scroll down until you reach "SRH" and the table will inform you: what type of parameter it is, any default value applied to it and what the units of the parameter are. Once you know what kind of parameter it is, scroll down the rest of the section until you find it in the description section below. You could also use the "Edit... Find..." feature to search for "SRH" in the description section. Whichever method used, you should now be located at the section where a brief description of the SRH parameter is given, as shown in Figure 3.2.

		10000000 10000	be Reader – atlas_u	sers 1.pdf
ile <u>E</u> dit <u>V</u> iew		lelp		
🚰 🖪 🚔 🤇	👌 🙌 🚺 🚺 🚺 Select 📷	•	100% - 🟵	Bearch Web Y Organize your digital photos
·	📑 Options 🗸 🗙			
1 1 21	.21: LASER			MODELS
B- 🔁 21	.22: LED			WODELS
± 🔁 21	.23: LOAD			
E 🔁 21	.24: LOG	co	NSRH.LAW	Enables the concentration dependent Shockley-Read-Hall recombination model using the alternate parameter set given in
1 21	.25: LX.MESH, LY.MESH			Table 3-58.
E 🔁 21	.26: MATERIAL	HN	SAUG	Enables Auger recombination model that has co-efficients depending on Lattice temperature and carrier concentration
	.27: MEASURE			(see Equations 3-334 and 3-336).
	.28: MESH	KL	AAUG	Enables Klaassen's model for concentration dependent auger
	.29: METHOD			coefficients (see Chapter 3: "Physics", Equations 3-323, 3-324, and 3-325).
	.30: MOBILITY	ка	JGCN, KAUGCP, KAUGDN and	Specify parameters of Klaassen's Auger recombination model
	.31: MODELS		JGDP	(see Chapter 3: "Physics", Equations 3-171 and 3-172).
	Syntax Description	KL	ASRH	Enables Klaassen's model for concentration dependent lifetimes
	Mobility Model Flags			for Shockley Read Hall recombination (Chapter 3: "Physics", Equations 3-294 and 3-295).
	Recombination Model Flags	KS	RHCN, KSRHCP, KSRHGN,	Specify parameters of Klaassen's SRH recombination model
	Direct Tunneling Flags	KS	RHGP, KSRHTN and KSRHTP	(see Chapter 3: "Physics", Equations 3-294 and 3-295).
	Generation Model Flags	- NI	FERMI	Includes the effects of Fermi statistice into the calculation of the intrinsic concentration in expressions for SRH recombination.
	Carrier Statistics Model Flags	OP		
	Quantum Carrier Statistics Mo	OP	rr	Selects the optical recombination model (see Chapter 3: "Phys- ics", Equation 3-321). When this parameter is specified, the COPT
- 🔁 i	Energy Balance Simulation Fla			parameter of the MATERIAL statement should be specified.
- 🔁 i	Lattice Heating Simulation Flac	PI	C.AUG	Enables the carrier and doping concentration dependent Auger rate coefficient model given by Equations 3-334 and 3-335.
- 🔁 i	Defect Generation Model 🚽 🗕	S	DISSOC	Enables the singlet dissociation model described in Section
	Magnetic Field Model			15.3.3: "Exciton Dissociation".
	Model Macros	SC	ISRH	Enables Scharfetter concentration dependent lifetime model.
	General Parameters	SR	I	Specifies Shockley-Read-Hall recombination using fixed lifetimes
	Model Dependent Parameters			(see Chapter 3: "Physics", Equation 3-290).
	Quantum Model Parameters Exciton Model Flags	SR	H.EXPTEMP	Enables the alternative model for the Lattice Temperature dependence of the recombination lifetimes.
	Model Selection Example	TR	AP.AUGER	Enables the dependence of recombination lifetime on carrier den- sity as given by Equations 3-306 and 3-307.
-02	Confirming Model Selection		AP.COULOMBIC	Specifies that the Poole-Frenkel barrier lowering for columbic
E 🔁 21	.32: MQW	I IR	AF . COVIONDIC	wells will be used for traps.
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	.33: ODEFECTS		1.00.11.00.1-	
			3.50 x 11.00 in 911 of 1184	

Figure 3.2 Locating the Description of the "SRH" Parameter

This information may be sufficient for the user to know what the parameter is and its default values. If however, you now wish to understand the physics and formulas in which this parameter is used, the description for 'SRH" in the Statements Chapter, cross references the reader to the Physics Chapter 3, Equation 3-290 to find out more information. If you cross references to Equation 3-290, we find a full description or the SRH model, as shown in Figure 3.3.

Physics

Shockley-Read-Hall (SRH) Recombination

Phonon transitions occur in the presence of a trap (or defect) within the forbidden gap of the semiconductor. This is essentially a two step process, the theory of which was first derived by Shockley and Read [188] and then by Hall [77]. The Shockley-Read-Hall recombination is modeled as follows:

$$R_{SRH} = \frac{pn - n_{ie}^2}{TAUP0\left[n + n_{ie}exp\left(\frac{ETRAP}{kT_L}\right)\right] + TAUN0\left[p + n_{ie}exp\left(\frac{ETRAP}{kT_L}\right)\right]}$$
3-290

where ETRAP is the difference between the trap energy level and the intrinsic Fermi level, T_L is the lattice temperature in degrees Kelvin and TAUN0 and TAUP0 are the electron and hole lifetimes. This model is activated by using the SRH parameter of the MODELS statement. The electron and hole lifetime parameters, TAUN0 and TAUP0, are user-definable in the MATERIAL statement. The default values for carrier lifetimes are shown in Table 3-56. Materials other than silicon will have different defaults. A full description of these parameters are given in Appendix B: "Material Systems".

Table 3-56. User-Specifiable Parameters for Equation 3-290

Statement

Default

Statement	Parameter	Default	Units
MATERIAL	ETRAP	0	eV
MATERIAL	TAUNO	1×10 ⁻⁷	s
MATERIAL	TAUPO	1×10 ⁻⁷	s

Note: This model only presumes one trap level which, by default, is ETRAP=0 and it corresponds to the most efficient recombination centre. If the TRAP statement is used to define specific trap physics then separate SRH statistics are implemented as described earlier in "Trap Implementation into Recombination Models" section on page 3-16.

Figure 3.3 The Full Description of the SRH Model Cross Referenced

With a few clicks of the mouse, we have found what a parameter is, together with a full physical description of how this parameter works in the simulator and what other user definable parameters are in the equation that are under the users control. Now you understand how the manuals work in conjunction with the examples.

The SILVACO website offers a wealth of technical information in our library section currently located at:

http://www.silvaco.com/tech_lib/index.html

Here information is sorted into four categories, namely:

- 1/ Simulation Standard (a SILVACO publication)
- 2/ Presentation Materials
- 3/ Books published referencing SILVACO Software
- 4/ Published Papers (Peer Reviewed Technical Publications)

SILVACO's Simulation Standard is a quarterly TCAD publication that includes detailed application notes and results of simulations covering a wide range of technologies. There is also a Hints and Tips section that answers some frequently asked questions. All Simulation Standard publications, dating back for many years, are available on the SILVACO web site. Use the search facility to find an article on the subject you are interested in.

The documents under the heading "Presentation Materials" contain several types of presentations. There are PowerPoint presentations showing application examples and explanations of syntax etc. There are also academic course materials showing how to incorporate SILVACO TCAD software into coursework. Other sections list patents aided by SILVACO software plus a listing of text books referencing SILVACO software.

The final two sections in the Technical Library section list text books and published papers under numerous technology headings that have all used SILVACO software in their creation.

If this all seems like information over-load, SILVACO has once again made searching for information as simple as possible by including a search box that quickly and efficiently takes the user to the information required.

In conclusion we hope we have demonstrated just how simple it is to use SILVACO software and to find the information you need to teach yourself how to succeed in your TCAD simulations.