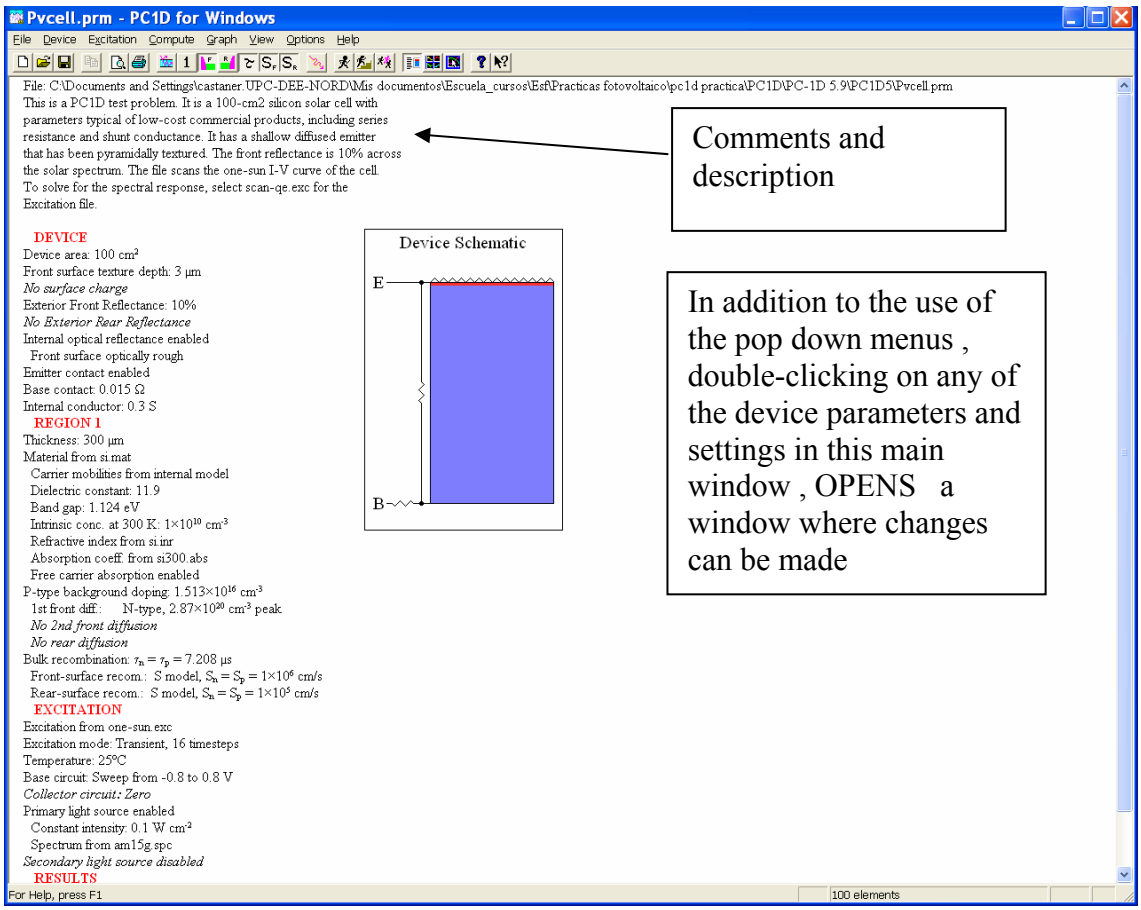
SIMULACION DE LAS CARACTERISITICAS DE LAS CELULAS SOLARES MEDIANTE PC1D.

The simulation of the solar cell characteristics consists on the numerical computation of the solution of the semiconductor equations for a given geometry of the device and for a given light spectrum: two current equations, two continuity equations and Poisson's equations are simultaneously solved by using a discretization scheme, both spatial and temporal.

Main menu

The main window, after the file **Pvcell.prm** has been opened is shown in Figure 1



After an area where comments can be made (double-click allows also for changes or editing), a DEVICE , REGION, EXCITATION and RESULTS areas can be found.

DEVICE area includes information on area (front surface) kind of surface texturing if any, charge build-up in the surface, reflectance for the two exterior surfaces and data about the internal optical reflectance. At this point also information about the location

of the electrical contacts can be defined. Finally data on the internal leakage in form of resistance or diodes can be added

REGION information includes the data relevant for any of the different device layers, thac can be up to three different and adjacent ‘ regions’. Each region can be made of different material, having its own bandgap, mobility, dielectric constant and recombination parameters. Each region is also specified by its thickness.
Each region also allows to specify the doping profile, including a background doping and two diffusions, one from the front and the second from the back surfaces of eac region. Recombination at the front and back surfaces can also be specified

EXCITATION information includes excitation Mode that can be equilibrium, steady state or transient, temperature of the device and information on the external sources that can be used to bias the device. This includes nominal values of voltage sources and internal resistance values. Those sources can also be made to sweep from one initial voltage to another, in order to be able to plot I-V characterisitics

Detailed descriptions of the menus follow

Menu Device

Select, Insert and Remove region

A region is a part of the device made of a certain material that is adjacent to the other regions. A region can be described by the material properties , thickness, background doping and two diffusions one at the front and one at the rear of that region
This menu allows :

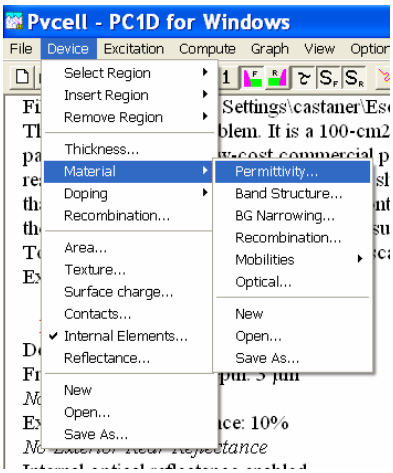
1) to create (***Insert***) as many regions as required by the device geometry (limited to 3)
2) to ***select*** among the regions already created to further define its thickness, doping profile etc
3) To delete (***Remove***) regions from the ones created

Thickness

Introduce the value of the region thickness

Material

This menu allows selecting the values of a number of material parameters. The most important materials have their parameters defined in a file that can be loaded by the command ***Open.*** Files for Silicon, Gallium Arsenide (GaAs), Aluminum gallium arsenide (AlGaAs), Indium Phosphide (InP) and Germanium are included . Parameters for other materials can be individually input by opening the menu windows corresponding to permittivity, Band structure, Band gap narrowing, recombination, mobilities and optical properties

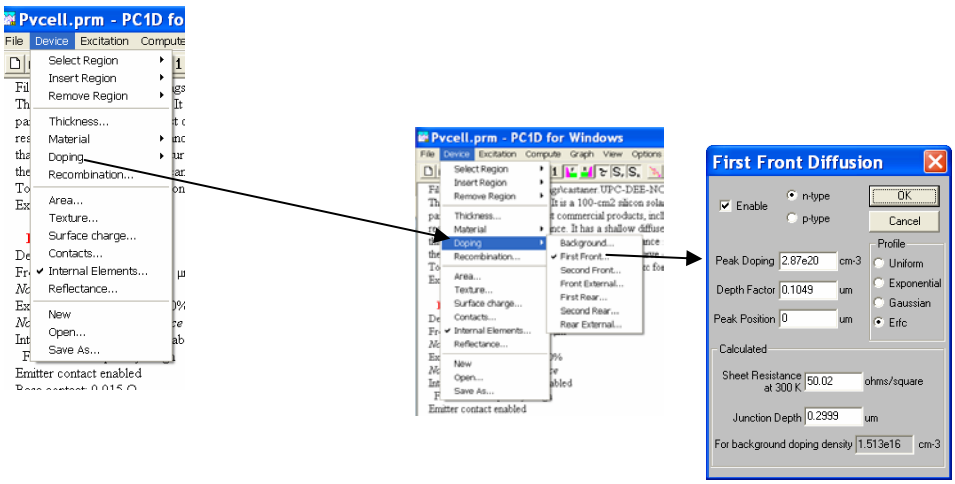


Doping

Once selected a region, a number of parameters to set the doping profile can be adjusted.

First the background doping concentration is defined and then

It can be defined a front first diffusion, where doping type, peak doping concentration and profile type (uniform, exponential, gaussian or complementary error function) can be introduced. From these data the program computes two important parameters: the junction depth and sheet resistance. The Depth factor allows to adjust the value of the junction depth. When a gaussian profile is selected, the value of the position of the peak concentration can also be selected



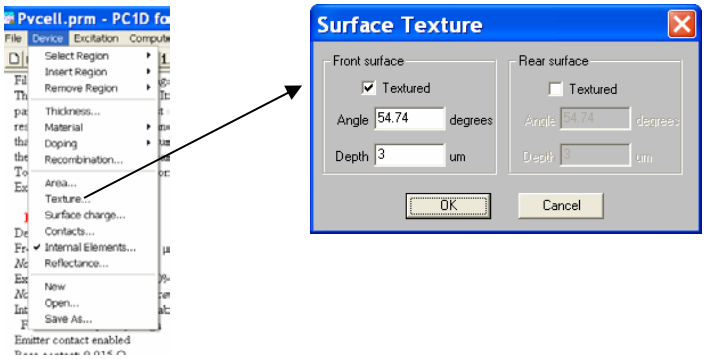
Similar procedure can be followed to set the parameters of a second front diffusion if this is required by the device.
In solar cells the back of the base layer has also a back diffusion in order to create what is called the back surface field. This diffusion is of the same doping type than the background semiconductor

Recombination
The main recombination parameters can be set in the corresponding window, fort he bulk semiconductor and fort he front and back surfaces. Those values are normally included in the parameter file fort he material selected but can be individually adjusted. This includes the electron and hole lifetimes and the values of the net LLI(low level of injection) recombination lifetime and the diffusion length.

Front and rear surfaces recombination velocities can also be entered in this window.

After setting the value of the front surface area, some properties of the surface can be set

Texture
The surface of a solar cell has to be build in such a way that the surface reflection is reduced to a minmum. _This can be achieved by texturing the surface creatind piramids which depth and angle can be set

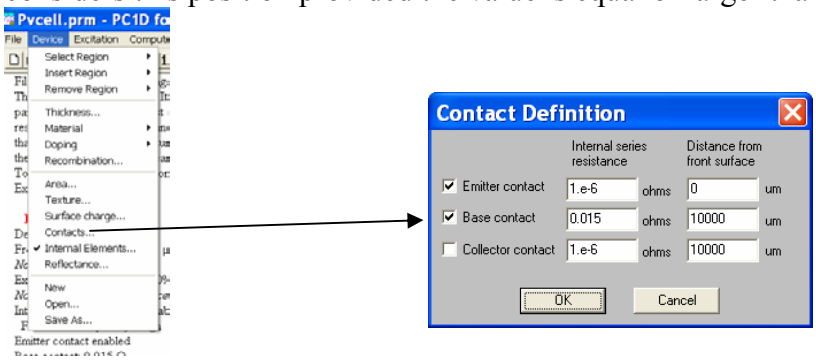


Surface charge

In case a surface charge has to be modelled to take into account accumulation or depletion of the surface, this menu should be used

Contacts

For a solar cell the contacts of the emitter and base should be activated and the spatial position of the contacts writen in the corresponding window. The origin of coordinates is taken at the front surface, that is the emitter surface x=0 and the emitter contact is taken at this position. The base contact is placed at the back surface. The program considers this position provided the value is equal or larger than the device thickness



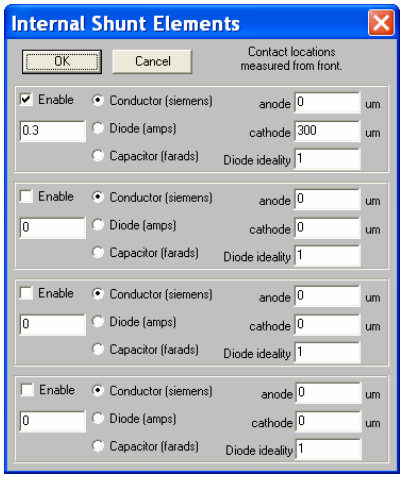
Internal elements

The internal elements are leakage elements that allow a more realistic simulation. These can be

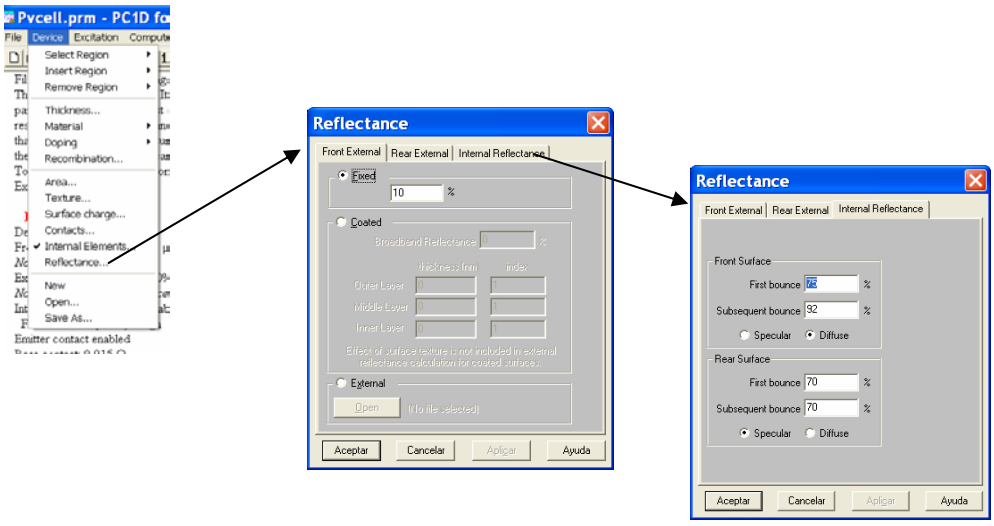
- Conductor (1/resistor)
- diode
- capacitor

Those elements appear in the equivalent circuit as parallel elements and hence draw current from the load. In each of these elements the positions of the contact have to be declared and the value given.

- for the resistor the value is the conductance
- for a diode the saturation current and the ideality factor have to be provided
- and for the capacitor , the value of the capacitance



Reflectance

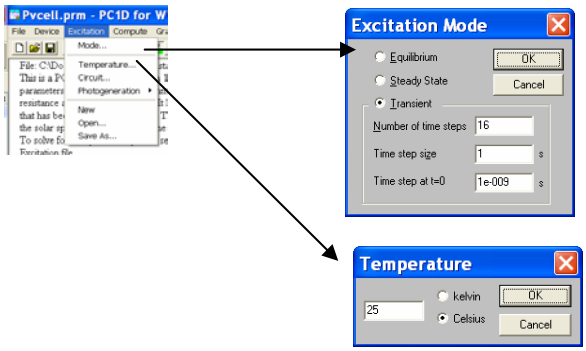


The external reflectance of the front and rear surfaces can be specified either as a fixed percentage or as a combination of thin coatings up to three layers. The thickness and the refractive index have to be provided in that case, or a file loaded using the external option.
Additionally the photons may be internally reflected at the front and back surfaces and the parameters can also be specified, as the percentange of reflection in the first and subsequent bounces

Menu Excitation

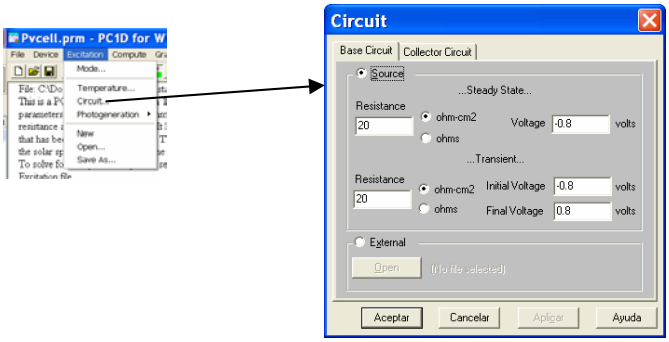
The menu EXCITATION allows to select the

MODE that can be ***equilibrium,*** that means that the thermal equilibrium is considered, so this means that there is not an electrical or optical excitation to the device. It can be ***Steady-state*** which means that electrical or optical excitations can be applied which are independent of time, and finally a ***Transient*** excitation can be considered in such a way that an electrical (voltage) excitation or an optical excitation that are depending on the time are applied. Transient mode is used to compute the I-V characteristics of a solar cell in such a way that a sweeping voltage source is applied and the value goes from from a minimum value to a maximum value. In case of a transient simulation the number of steps and the step size can be selected.



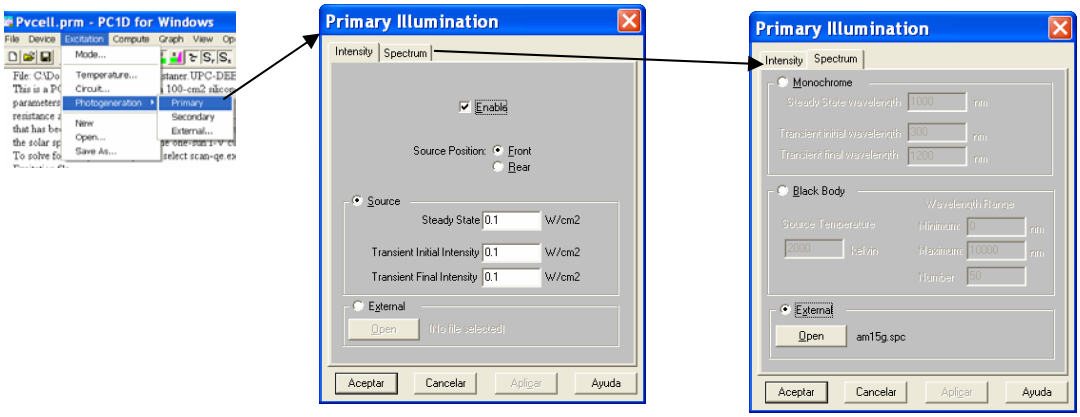
Circuit submenu

This subcircuit is used to select the circuit configuration that provides bias to the device The emitter is set to GROUND potential by the simulator and in the case of a solar cell the base can be biased by a circuit having a voltage source and a series resistor. The value of the resitance can be set in this window and also the value of the voltage source. If the analysis is Steady-state a single value of the voltage source has to be given, whereas a maximum and a minimum value have to be given in case of transient analysis. The parameters of the circuit can also be given using an external file



Photogeneration

A Primary, Secondary or external photogeneration source can be used. Normally one would use a ***Primary*** source and the position (front or rear) intensity and spectrum can be selected. In case of I_V curves computation the external file containing te sun's spectrum has to be selected (file am1.5g) . In case that a quantum efficiency computation is desired , then a monochrome spectrum is suitable and a transient simulation from an initial to a final wavelength has to be chosen.

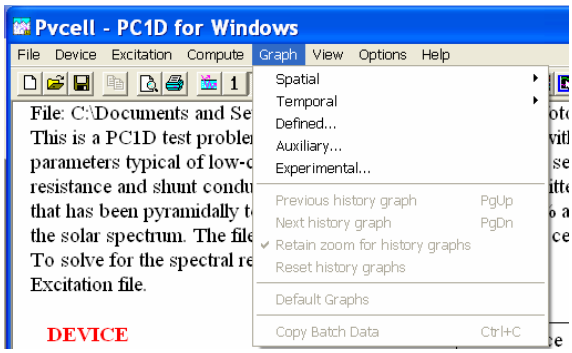


Menu Graph

This menu allows to plot the simulation results. The most common plots are the ***Spatial*** and the ***Temporal***.

Spatial graphs have in the x-axis the valu of the spatial position inside the device (x) and the magnitudes that can be plotted are several parameters of the solar cell that depend on the internal position such as the doping concentration, the electric field etc. This allows to have a deep insight to the physics of the solar cell.

Temporal graphs have in the x-axis a different variable, which is the applied base voltage in case of I-V plots or the light wavelength in case of quantum efficiency plots

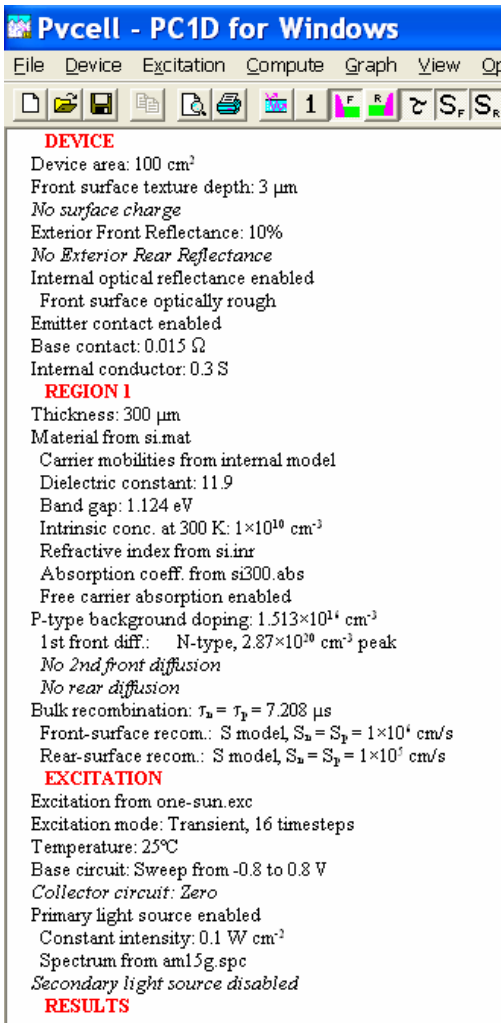


Excercise 1

The main objective of this exercise is to compute the main solar cell parameters under standard illumination:

I-V Characteristics (Open circuit voltage, Short circuit current, Fill Factor), Efficiency and Quantum efficiency.

Step 1: open the file Pvcell.prm
NOTE that pressing F1 the help menu is activated



Step 2: Analize the file (to answer yo may require to go into de PC1D programme and open the menus)

2.1 Draw an sketch of the doping profile from the top to the bottom surface.
What is the value of the emitter thickness?
What is the value of the BSF layer?
2.2 Draw a sketch of a zoom the surface of the cell

2.3 Draw an schematic of the circuit that is implemented in the file and give the value of the main parameters of the components
2.4 What kind of simulation are we doing?
What is the range of applied voltages?
How many points include the simulation?

Step 3. Run the simulation
3.1Write the values listed under the RESULTS heading and give the meaning
3.2 Open the ***graph*** menu and select ***Base I-V/Power option***
Using the zoom estimate the value of theshort circuit current, the open circuit voltage and the maximum power. Compare with the values obtained in the point 3.1
Step 4. Introduce a Back diffusion
4.1 Enable the option first rear diffusion
4.2 Choose the p type, a Gaussian profile, a peak doping of 1.e20cm^{-3} and a junction depth of 3 μm.
4.3 Run a new simulation
4.4 Open the ***graph*** menu and select ***Base I-V/Power option***
using the zoom estimate the value of the short circuit current, the open circuit voltage and the maximum power. Compare with the values obtained in the point 3.2.
4.5 Evaluate the Solar cell new efficiency.

Excercise 2

The objective of this second exercise is the calculation of the Solar Cell Quantum Efficiency.
To compute the Quantum Efficiency using PC1D we need to make some changes in the simulation file used in exercise 1.

Step 1: open again the file Pvcell.prm used in excercise 1

Step 2: Make all necessary changes in the file

2.1 Open the **Excitation** menu and select the **Circuit** option
Introduce 0 V for voltages and 0.002 Ωcm^2 the source resistance at steady state and transient.
2.2 Open the **Excitation** menu and select the **Photogeneration >>> Primary** option
Choose a monochrome spectrum and select 300 nm for steady state wavelength
2.3 Run the simulation
2.4 Open the ***graph*** menu and select **temporal >>> Quantum Efficiency**
Give the values of the Internal and External Quantum Efficiency at λ= 600 nm.