EE669: Simulation Exercise

Doping in Silicon using Ion Implantation

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Credits: First version of this exercise, Soumyadip Chatterjee
Credits: J. F. Siegler, M. D. Ziegler, J. P. Biersack, http://www.srim.org/

Introduction

Ion implantation is an important doping process in the current semiconductor manufacturing industry. In this exercise we will use SRIM software package to explore the basics of the ion implantation. SRIM can be run only on MS Windows machines.

Installing the package:-

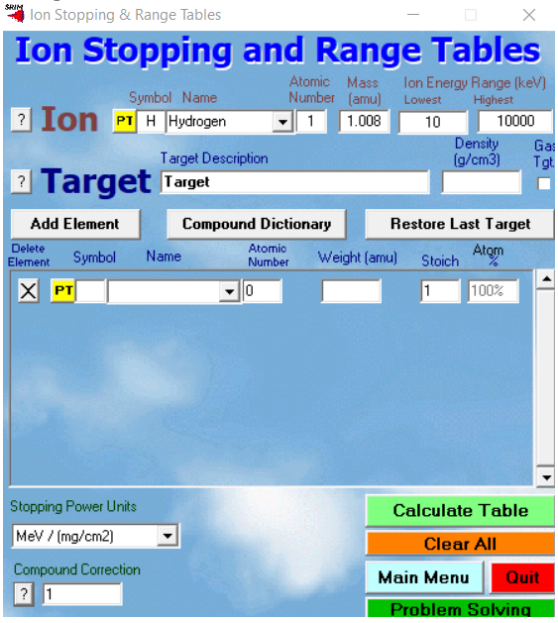
You can download the tool from the following link:-
http://www.srim.org/SRIM/SRIMLEGL.htm
You are advised to download SRIM 2008, as it is known to install without any problems on most MS Window installations in use today. A file named SRIM-2008.e would be downloaded to your computer. Copy this file to an appropriately named newly created folder where you will install the software. Change the extension of the file to .exe and double click on this file to extract the files needed for installation. You will find a SetUp file in the folder. Double click to install SRIM. You are ready to go.

The adventurous can download the SRIM-2013 versions and try to install.

You will find SRIM.exe file in the folder. Launch the program by double clicking on this file. You should see the following GUI.

How to use this simulation tool?

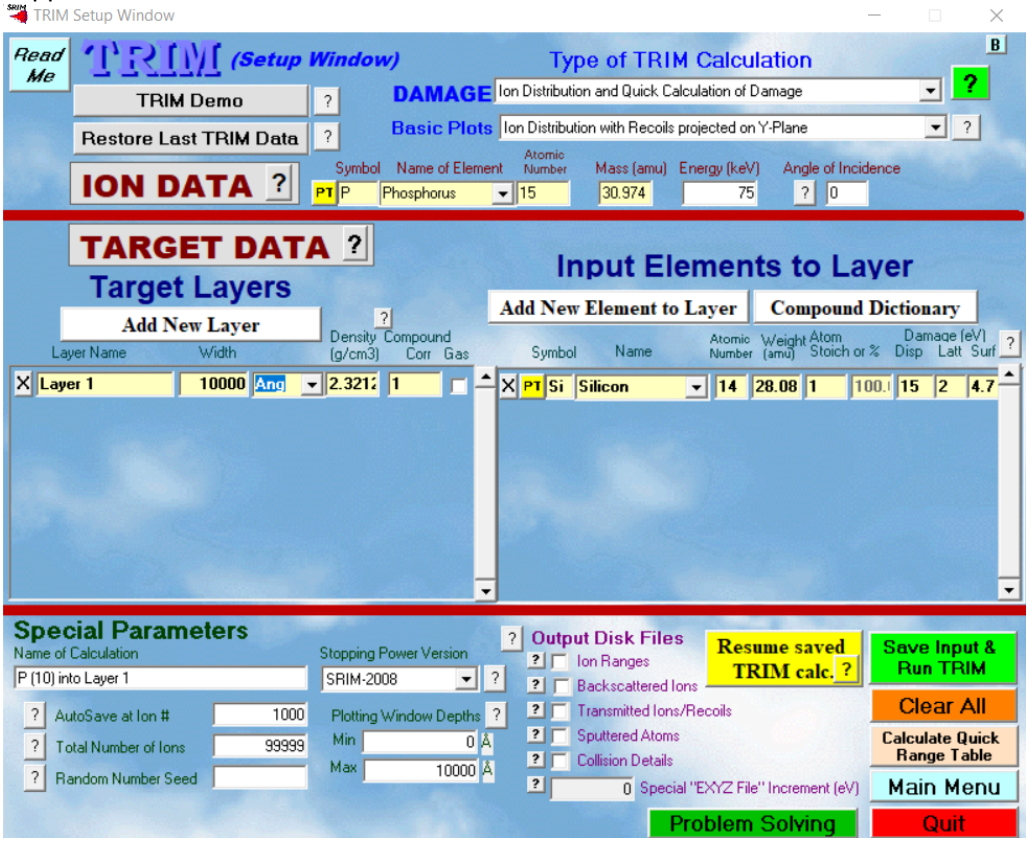
- You can first go through the SRIM tutorials to learn about the tool in details.
- Now, let's start the simulations. Click on Stopping/Range Tables. This will help you to quickly calculate the projected range and the straggle for a range of ion energies for an ion of your choice, in a target material of choice. The following window will appear on clicking "Stopping/Range Tables".



- Here you can select the dopant ion, the ion energy range and the target material.

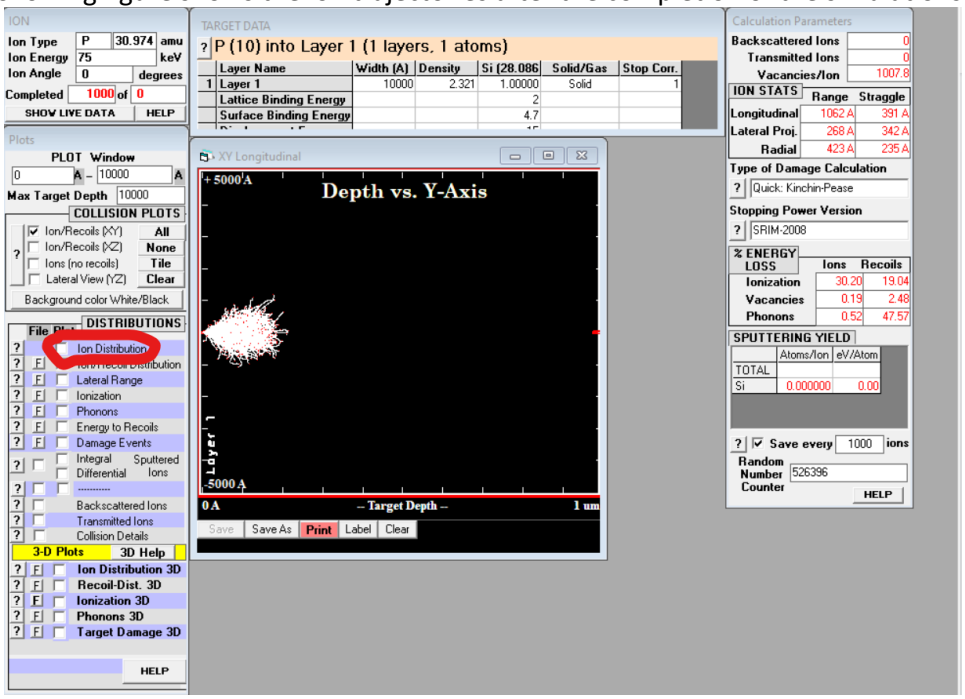
- PT stands for periodic table.
- To calculate the range of Boron implantation into Silicon, do the following:
  - Click on PT next to “Ions”. Choose Boron from the periodic table. Insert the ion energy range of interest.
  - You can choose an element or compound as target. To choose Silicon for target, click on PT below “Add Element”.
  - Click on “Calculate Table”.
- The data obtained from the calculations can be used as initial design of the detailed simulation experiments using TRIM.

- Detailed simulations of ion implantation to obtain various distributions, you need to execute TRIM simulations.
- For that, go back to main menu and select “TRIM Calculation”. The following window will appear.

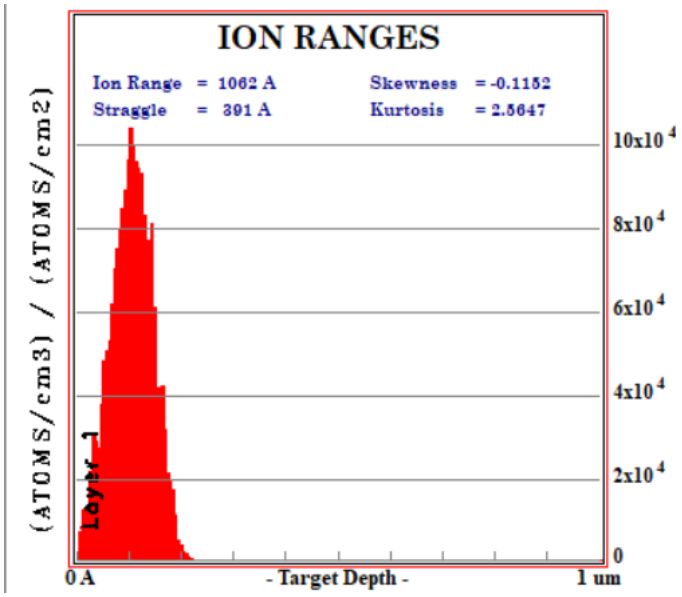


- In the example shown above, Phosphorous implantation to Silicon at an acceleration energy of 75 keV is simulated.
  - The thickness of silicon (shown as “Width”), in the example shown is 10000 Å or 1000 nm. Please note that the depth resolution of the simulated output depends on the thickness. So if the range is 50 nm and the target thickness is specified as 1000 nm, you would get only a few useful data points in the depth profile. It is recommended that the thickness of the material is ~ Range + 6 * straggle. Both range and straggle obtained from the range calculations described previously.
  - You may change the “Total Number of Ions” under “Special Parameters” section. Please note that the number of ions should be sufficiently large to produce a smooth profile. However larger the number of ions, longer is the computation. You may try 9999 ions to start with.
- The layer can be also be a compound. TRIM includes a library of compounds.

- You can add multiple layers, each layer can be an element or compound. If you have 3 layers, the layer 1 would be at the top, layer 2 would be below it and so on.
- Click 'Save Input & Run TRIM' option to start the simulation. The simulation will take some time to run. While the simulation is running, you can see ion trajectories for each of the ion implanted. By checking different boxes under "DISTRIBUTIONS" you can see the live evolution of various distributions including ion and damage distributions. The following figure shows the ion trajectories after the completion of the simulations.



- Now, check the ion distribution textbox circled in the distribution section. The following graph will appear.



- We can see that the y-axis represents the ratio of target doping density to implant dose. You can save the ion distribution in a text file for further processing by clicking on the "F" box in front of "Ion/Recoil Distribution". The profile can be used for various purposes, for example as input to Sentaurus.
- To convert the "Ion distribution" to dopant concentration: please click on help in the "ION RANGES" plot, and follow the method mentioned in the resulting pop up window.

Exercise:

1. In this exercise, we would try to develop an intuitive understanding of the dependence of the skew of the profile on the ion mass. The steps in the simulation:
    a. Determine the range for Boron implantation to Silicon for an ion energy of 40 keV using "Stopping/Range Tables" simulation.
    b. Determine the energy for Indium implant that would result in the same range as was obtained for Boron in the above case.
    c. Setup TRIM simulations for 99999 ions for Boron. Save the ion distribution.
    d. Do the same for Indium.
    e. Convert the resultant distributions to concentration profiles as described in the previous section, for a dose of 10^{13} cm^{-2}.
    f. Plot the concentration profiles for both Boron and Indium in one graph.
    g. Comment on the results.
2. Design of the thickness of poly-Si for gate application. Assume that a deep source/drain implant of Boron is carried out at 3 keV and dose of 3 x 10^{15} cm^{-2}. In a self-aligned poly-Si gate process for MOSFET fabrication, such an implant would be carried out after the poly-Si gate is formed. Assuming that the surface of the channel region has a n-type dopant concentration of 10^{17} cm^{-3}, what is the minimum thickness of poly-Si that would ensure no appreciable change in the threshold voltage of the MOSFET?