INTRODUCTION

TRIM (the Transport of Ions in Matter) is the most comprehensive computer simulation of ions travelling through matter. It is a Monte-Carlo calculation which follows the ion into the target, making detailed calculations of the energy transferred to every target atom collision. TRIM will accept complex targets made of compound materials with up to eight layers, each of different materials. It will calculate both the final 3D distribution of the ions and also all kinetic phenomena associated with the ion's energy loss: target damage, sputtering, ionization, and phonon production. All target atom cascades in the target are followed in detail. The programs are made so they can be interrupted at any time, and then resumed later. Plots of the calculation may be displayed, saved, and printed when needed (it takes 5 seconds to begin viewing a saved calculation).

There are 6 parts to the practical: The first two are relatively easy and are essentially there to help the student guide his way into the program, whereas the remaining 4 parts are slightly more taxing. Parts 3-6 are relevant to 4 different scientific disciplines; that of nuclear microscopy (characterization of buried electronic devices), ion implantation (semiconductors), secondary ion mass spectrometry (surface science), and radiation therapy (cancer treatment).

The student should write a final report, which should contain a brief introduction, 6 sections (each with conclusions, comments, discussion, room for improvements etc), in a concise yet informative manner. There is no set format. It is however good policy to put all the diagrams you are asked to print in an appendix section, and refer to them from the main text.

Before starting the student should read through and understand the physics contained in the supplied notes: Chapter 4 from the Stopping and Range of Ions In Solids, by Ziegler, Biersak and Littmark.
GETTING STARTED

The program can be run by clicking the icon \texttt{SRIM2003} on the desktop followed by the “TRIM Calculation” button. Start by entering the Demo (Demonstration) area, and try out the below 4 steps before venturing to more sophisticated parts. The program is comprehensive and it is therefore inevitable that you will make mistakes as you go.

Step by step

1. \textbf{Choose Type of TRIM Calculation:} TRIM allows the user to omit certain aspects of collision kinetics in order to increase the speed of the calculation. “Full Damage Cascades” includes all normal kinetics of the ion penetrating the target. The “Quick” calculation ignores target atom cascades and limits the calculation to the ion trajectories. The “Sputtering” calculation includes special plots related to target atom sputtering.

2. \textbf{Ion Data:} Enter either the ion atomic number, select the ion name from a list of elements, or enter the chemical abbreviation for the ion. Selecting the button marked “PT” brings up a convenient periodic table of all elements. The other ion boxes will automatically be updated when you enter information into any of these three boxes.

3. \textbf{Target Data:} The left box display a list of target layers. One layer is always highlighted. The elements in this layer are described in the right box. By clicking on any target layer, it is highlighted and its elements are displayed in the right box. The \textit{layer name} is used by TRIM in graphs and output files. It is recommended that you specify something meaningful, e.g. \textit{SiO2} or \textit{Silicon}. The \textit{layer width} can be specified in a unit selected from the drop-down list. \textit{Layer density} is calculated to be a weighted average of the elements in the layer when the \textit{Auto} box is checked. Check the \textit{gas} box to indicate that the layer is a gas instead of a solid (default).

4. \textbf{Save input & Run TRIM:} Any plot can be displayed by activating its check-box. It will show the calculation up to that point. If you keep the plot open, it will be automatically updated after each ion. This window lists the statistical averages for the calculation to date. When any plot is printed, all of the data of this window is also included on the printed form.
PROJECTS

1) Particle beam weapons.
   A linear accelerator capable of accelerating a proton beam to 1 GeV has been constructed for warfare purposes. [Hint: Use the DEMO option for this part]
   
a) What is the range in air of a 1 GeV proton beam?
   
b) What is the radius of the particle beam at the end of range (i.e. radial straggling), assuming that a narrow parallel beam emerges from the accelerator?
   
c) What would you consider to be a minimum safe distance from the end of the proton range (i.e. you need to be outside the range straggling)?
   
d) Would you be safer at the end of range or closer to the source of the beam?
   
e) Plot the relevant graphs.

2) Proton ranges. [Hint: Use the DEMO option for this part]
   a) What is the range of 10 MeV protons in beryllium?
   
b) What is the longitudinal straggling (i.e. range straggling)?
   
c) What is the radial straggling at the end of range?
   
d) Plot the relevant diagrams.
   
   [Note the plot covers the end of range region only; find out in the next sections how to do this manually]

3) Nuclear microscopy: IBIC.
   In nuclear microscopy, one of the new techniques we are developing is that of Ion Beam Induced Charge. In this technique a focused high energy proton beam is fired into an electronic material, device, or IC, and the electron/ion pairs produced by individual protons are collected. The collected ion/electron pairs give information of the active regions of the specimen, including the number of trapping centers in the material. Because the protons penetrate relatively deeply into the sample we can study regions inside the material, and can provide unique information on buried structures.
The limitation of the IBIC technique is that we need to extract the information before we damage the material. Assuming we are using a 2 MeV proton beam, and investigating silicon, calculate the followings:

a) What is the depth limit at which the 2 MeV proton beam will provide IBIC information (i.e. what is the range of 2 MeV protons in Si)?

b) What is the range straggling?

c) What is the radial straggling at the end of range?

d) Use the Trim options available and investigate the depth at which the maximum damage occurs (i.e. vacancies produced by recoiling silicon atoms), and why?

e) Plot the relevant diagrams.

4) **Implantation: Doping of silicon with boron.**

When an element such as boron (3 valance electrons) is introduced into a silicon lattice site it creates a missing electron and therefore a missing covalent bond. A nearby covalently bound electron can migrate to the boron atom leaving behind a positively charged hole. This is the basis of p-type silicon. P-type silicon can be made by implanting high energy boron ions into the silicon.

a) What is the depth distribution of 200 keV boron ions in silicon? Comment on how this distribution compares with that of 200 keV protons in silicon.

b) What is the damage incurred during the implantation process? Comment on how the damage compares with that of 200 keV protons in silicon.

c) Plot relevant diagrams.

5) **Sputtering: Focused ion beam machining, and secondary ion mass spectrometry.**

Focused ion beams are now being used for ion beam machining, since the interaction between the incident ion and the sample surface can result in sample atoms being sputtered from the surface. Ion beam sputtering is also used in surface analysis and characterization using a technique called SIMS (Secondary Ion Mass Spectrometry), where the sputtered ions and molecular fragments are mass analyzed. Consider the SIMS analysis
of gallium arsenide (GaAs) using an argon (Ar) beam:

a) What is the energy of the Ar beam which gives the greatest sputter yield? [Consider the beam energies 1, 3, 10, 30, 100, 300, 1000 keV].

b) How does the optimum sputter yield compare with the sputter yield for protons of the same energy?

c) How does the optimum sputter yield compare with the sputter yield for gold atoms of the same energy?

d) Plot relevant diagrams.

6) **Ion beam radiation treatment.**

Some cancers (tumours) can be cured by ionizing radiation. The mechanism for radiation therapy is that ionizing radiation can damage the local cellular chemistry of the tumour such that the cancer cells die. The problem is that for tumours rooted inside the body, in order to treat the tumour by radiation, the tissue surrounding the tumour is also affected.

One promising (although expensive) technique is to use high energy protons as the ionizing radiation. Consider a patient that has been diagnosed to have a small brain tumour. The tumour, which is 2 mm in diameter, has a further 3 mm of brain tissue between it and the skull, which is 4 mm thick. Covering the skull is 1 mm of skin.

a) What is the proton energy required to deposit the maximum amount of energy (i.e. the maximum number of recoil atoms produced) at the position of the centre of the tumour? What is the ratio of the radiation dose at the centre of the tumour compared with the tissue that the proton beam has traversed in targeting the tumour (assume negligible beam broadening)?

b) Plot the relevant diagrams.

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