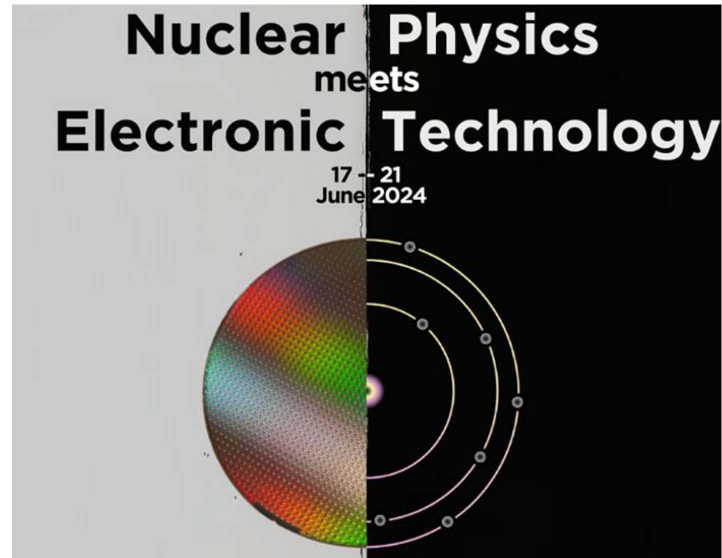
AS Be ST

A 7-Beryllium electron capture STudy for nuclear and solid state physics



Simulation of Ion implantation processes using the SRIM software

mariaconcetta.canino@cnr.it

Marica Canino CNR-IMM

NPMET School - SRIM software Hands-on

SRIM Main Menu

Calculation
40

Logo ?

?

Stopping / Range Tables ?

TRIM Calculation ?

Experimental Stopping Powers

J. F. Ziegler
U.S.N.A.
Annapolis, MD

M. D. Ziegler
U.C.L.A.
Los Angeles, CA

J. P. Biersack
Hahn-Meitner Inst.
Berlin, Germany

SRIM Version
SRIM-2008.04

SRIM Tutorials

Legal Notice

Quit

Contributions by E. Dabich, H. Paul, D. J. Marwick, G. A. Cuomo, W. A. Porter

(c) 1984,1989,1998, 2003, 2008 by J. F. Ziegler, M.D. Ziegler, J. P. Biersack (SRIM.com)

Outline

- SRIM introduction
- Theory
- How to setup an ion implantation simulation
- SRIM Output
- Ion implanted profile construction: dose and concentration

Exercise 1: Al ion implantation in 4H-SiC to form a 300 nm deep junction

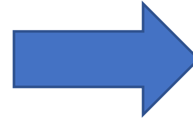
Exercise 2: Implantation through a mask.

Exercise 3: implantation and damage.

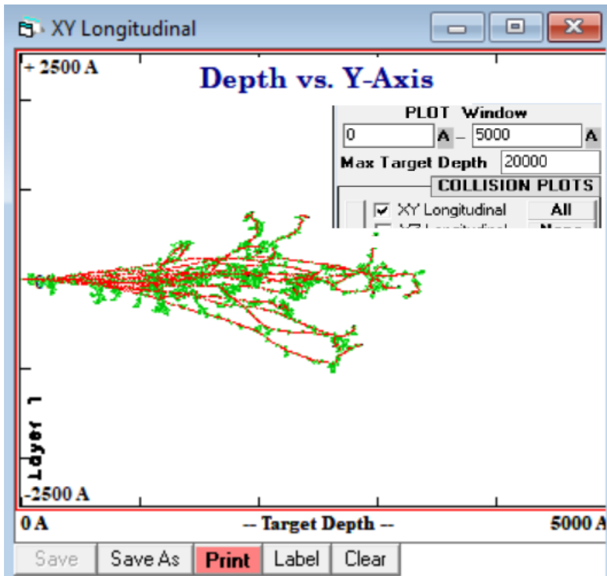
Exercise 4: Implantation through a stopping layer.

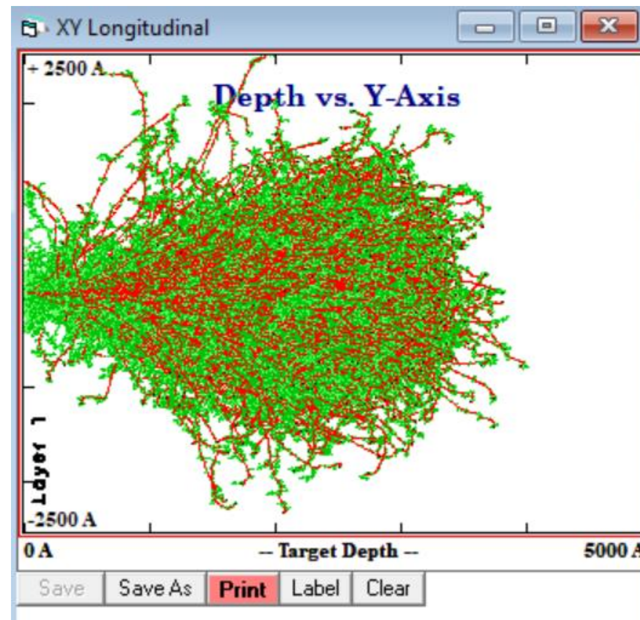
The SRIM software

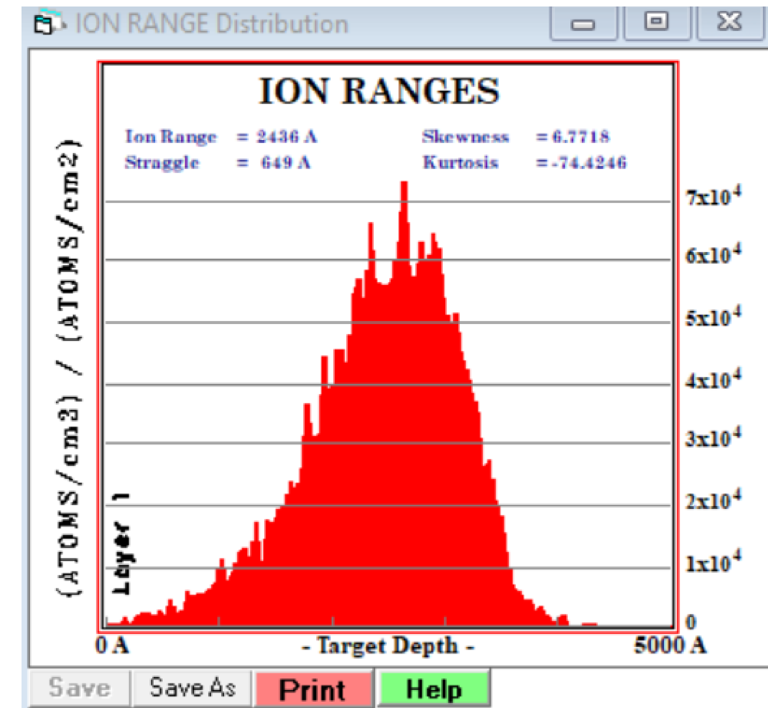
TRIM= Transport of ions in matter
Monte Carlo computer program that calculates the interactions of energetic ions with **amorphous** targets



SRIM: stopping and range of ions in matter
quantitative evaluation of how ions lose energy into matter and the final **distribution** of these ions after they stop within the target



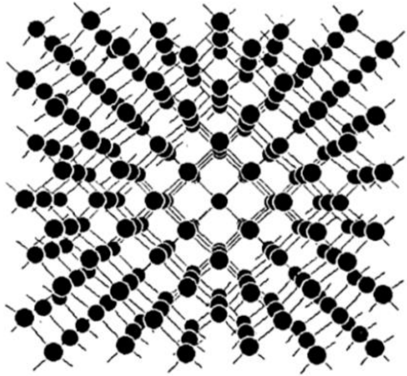




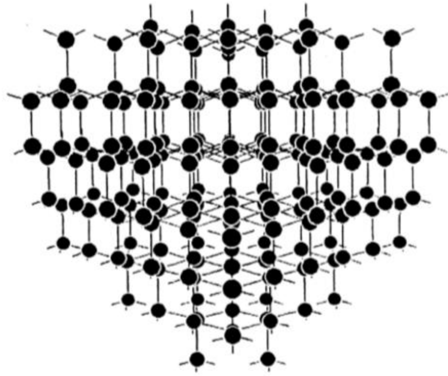
SRIM Approximation: amorphous material

AS BeST

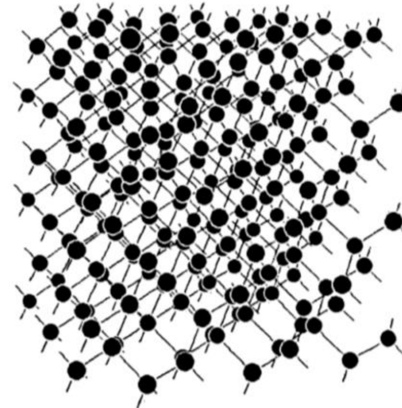
Channeling effect in crystalline solids



(A) Axial channeling

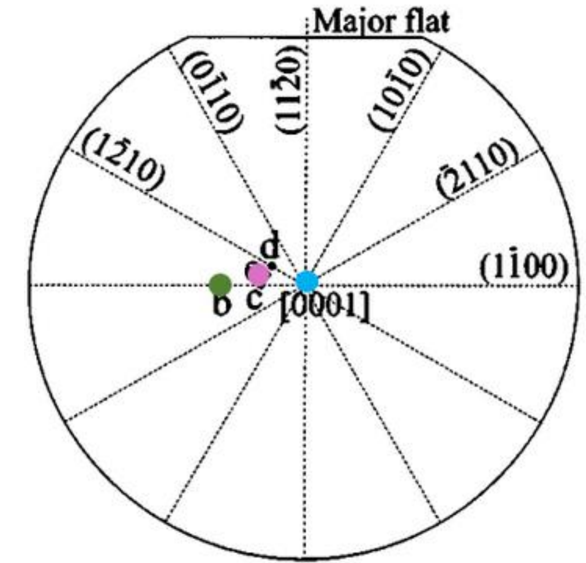


(B) Planar channeling

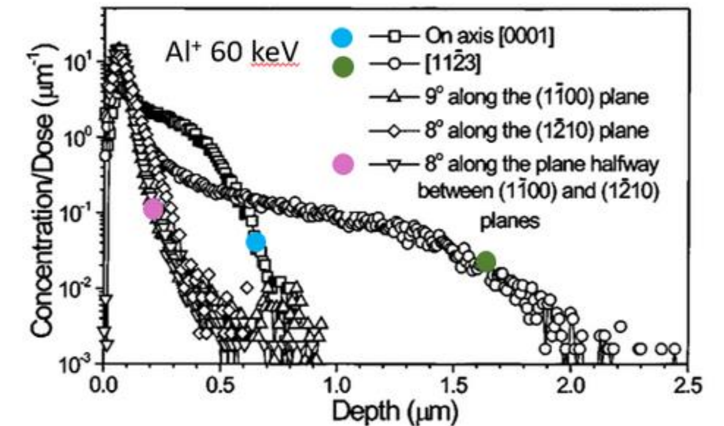


(C) No channeling (Random arrangement)

<0001> on-axis 4H-SiC



SIMS profiles



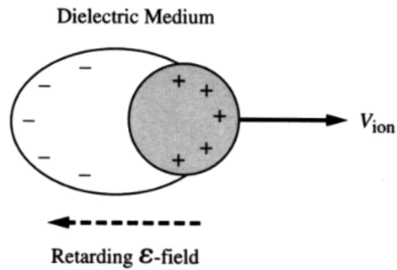
More pronounced implant tail consequent to channeling

Channeling reduction by target tilting

Stopping power

Stopping power= energy loss per unit length of the ion path

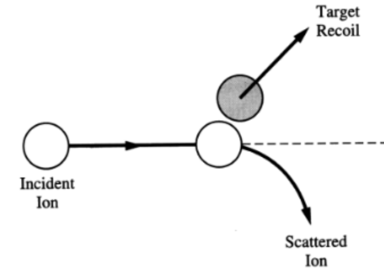
Electronic stopping: losses to target electrons



Electronic: Electric field "drag" created by positive ion moving in a flood of electrons

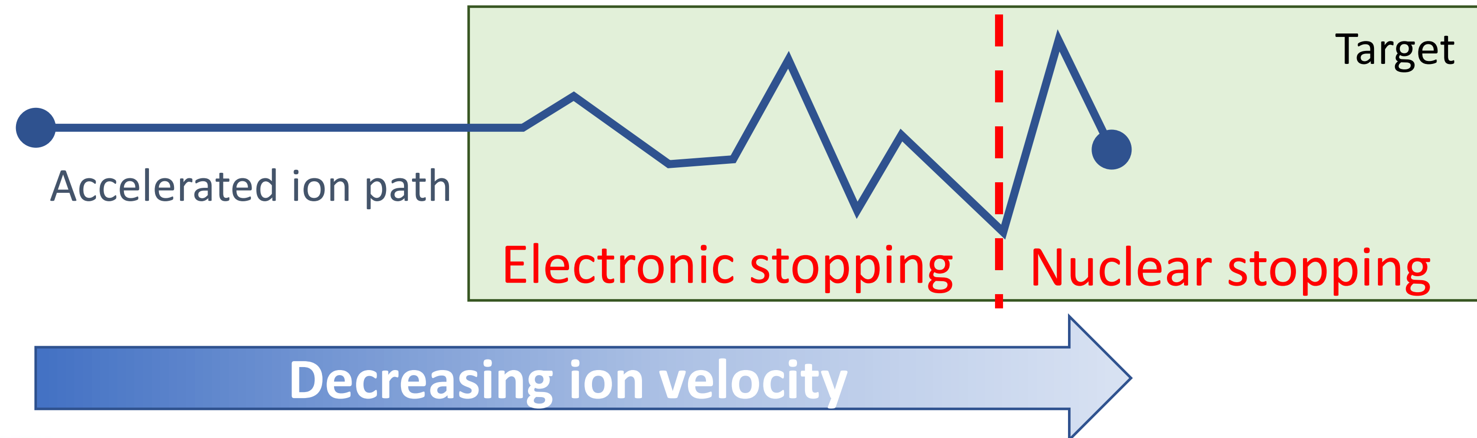
Electron excitation and **heat**

Nuclear stopping: losses to the nuclei

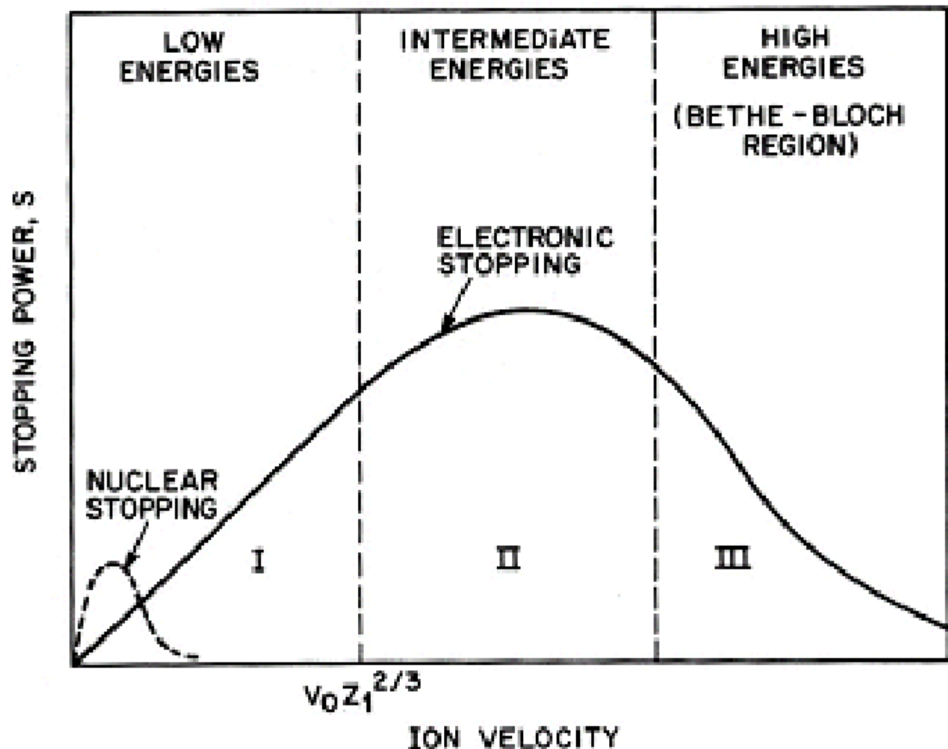


Nuclear: Impact with cores of atoms causes damage.

Displacement and **lattice damage**



Stopping powers in SRIM



A. Cruz, Radiat. Eff., 88 (1986), p. 159

Ion = Aluminum (13)
Target = All Solids

Norm Tgt = Cu(29)
STOP 2003
STOP 1998---
Plotted are Tgt.Names

Data Sym	Citation Number	Total Points	Pts <1	Pts ≥1	Old Ref
*C	1986-Lenn2	1	1	0	1705
*C	1986-Lenn2	1	1	0	1705
Al	1981-Mumi	1	1	0	1499
*C	1965-Ormr	10	11	0	203
*C	1966-Fast	9	9	0	247
*C	1979-Ward	2	2	0	1165
*C	1991-Abde2	6	2	4	1906
*C	1996-Hari	6	5	1	1831
*C	2001-Zhan	5	5	0	2351
Al	1979-Ward	2	2	0	1165
Al	1981-Mumi	1	1	0	1499
Al	1991-Abde2	6	2	4	1906
Al	1997-Joki2	7	7	0	2240
Ti	1976-Fors	12	5	7	821
Fe	1976-Fors	12	5	7	821
Ni	1976-Fors	12	5	7	821
Ni	1979-Ward	2	2	0	1165
Cu	1976-Fors	12	5	7	821
Cu	1991-Abde2	14	5	9	1906
Ag	1976-Fors	12	5	7	821
Ag	1979-Ward	2	2	0	1165
Ag	1991-Abde2	13	5	8	1906
Ta	1991-Abde2	17	7	10	1906
Au	1962-Tepl	1	1	0	362
Au	1976-Fors	12	5	7	821
Au	1979-Ward	2	2	0	1165
Au	1991-Abde2	14	7	7	1906

Data Sets=27 (195pts)
Mean Error= 4.5 o/o

Aluminum Stopping (eV-cm^2/10^{15})

Ion = Aluminum (13)
Target = All Solids
STOP-2003

Data Sets=27 (195pts)
Mean Error= 4.5 o/o

Stopping Experiment/Theory

Ion Energy (keV/amu)

Marica Canino CNR-IMM

SRIM Main Menu

Calculation
40

Logo ?

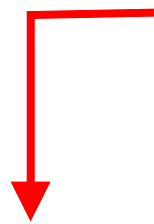
?

Previous slide

?

TRIM
Calculation

?



Next slide

J. F. Ziegler
U.S.N.A.
Annapolis, MD

M. D. Ziegler
U.C.L.A.
Los Angeles, CA

J. P. Biersack
Hahn-Meitner Inst.
Berlin, Germany

SRIM Version
SRIM-2008.04

SRIM Tutorials

Legal Notice

Quit

Contributions by E. Dabich, H. Paul, D. J. Marwick, G. A. Cuomo, W. A. Porter

(c) 1984,1989,1998, 2003, 2008 by J. F. Ziegler, M.D. Ziegler, J. P. Biersack (SRIM.com)

Stopping range calculation

Setup page

Ion Stopping & Range Tables

Ion Stopping and Range Tables

	Symbol	Name	Atomic Number	Mass (amu)	Ion Energy Range (keV) Lowest	Highest
Ion	Al	Aluminum	13	26.982	10	10000

Target — Target Description: Aluminum in C-Si — Density (g/cm3): 3.1600 — Gas Tgt.

Add Element | Compound Dictionary | Restore Last Target

Delete Element	Symbol	Name	Atomic Number	Weight (amu)	Stoich	Atom %
X	C	Carbon	6	12.011	1	50.00
X	Si	Silicon	14	28.086	1	50.00

Stopping Power Units: MeV / (mg/cm2)

Compound Correction: 1

Calculate Table | Clear All | Main Menu | Quit | Problem Solving

Result file

SR Calculation: SRIM Outputs\Aluminum in C-Si

Disk File Name = SRIM Outputs\Aluminum in C-Si

Ion = Aluminum [13] , Mass = 26.982 amu

Target Density = 3.1600E+00 g/cm3 = 9.4917E+22 atoms/cm3
======= Target Composition ========

Atom Name	Atom Numb	Atomic Percent	Mass Percent
C	6	050.00	029.95
Si	14	050.00	070.05

====================================

Bragg Correction = 0.00%
Stopping Units = MeV / (mg/cm2)
See bottom of Table for other Stopping units

Ion Energy	dE/dx Elec.	dE/dx Nuclear	Projected Range	Longitudinal Straggling	Lateral Straggling
10.00 keV	3.739E-01	1.821E+00	128 A	57 A	41
11.00 keV	3.921E-01	1.822E+00	138 A	61 A	44
12.00 keV	4.095E-01	1.820E+00	149 A	65 A	47
13.00 keV	4.263E-01	1.817E+00	159 A	69 A	50
14.00 keV	4.424E-01	1.812E+00	170 A	73 A	53
15.00 keV	4.579E-01	1.806E+00	180 A	77 A	56
16.00 keV	4.729E-01	1.799E+00	191 A	81 A	59
17.00 keV	4.875E-01	1.791E+00	202 A	85 A	61

Print | Close

Compound dictionary

Common Compounds

Categorized | Alphabetic

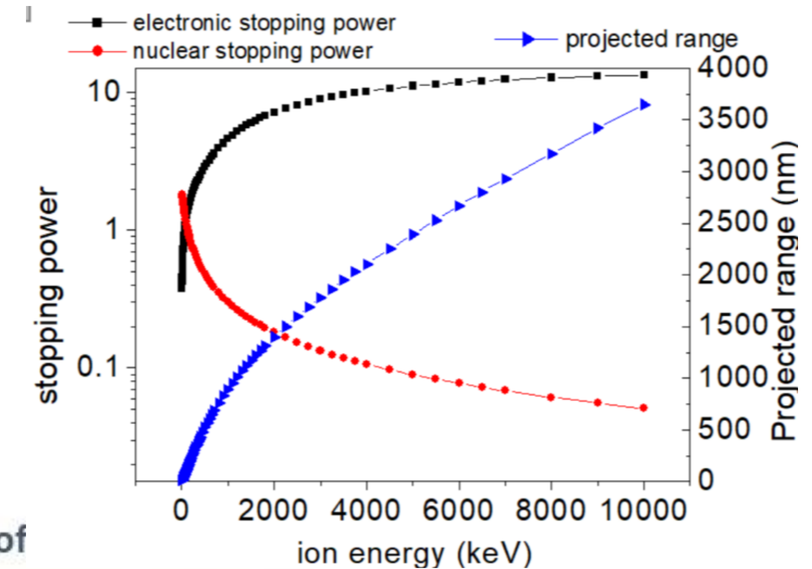
Common Name | Density (g/cm3) | Atomic Stoichiome

- NUCLEAR PHYSICS MATERIALS
- COMMON IMPLANTATION COMPOUNDS
- COMMON TARGET MATERIALS
- PLASTICS / POLYMERS
- METAL ALLOYS
- ICRU DESIGNATED COMPOUNDS, with Helmut Paul's additions
- BIOLOGICAL MATERIALS (Human)
- BIOLOGICAL MATERIALS (Misc.)
- LIQUIDS / GASES

indicates availability of special bond correction *
% = Mass % shown instead of Atomic %

Add to Target

Output plot

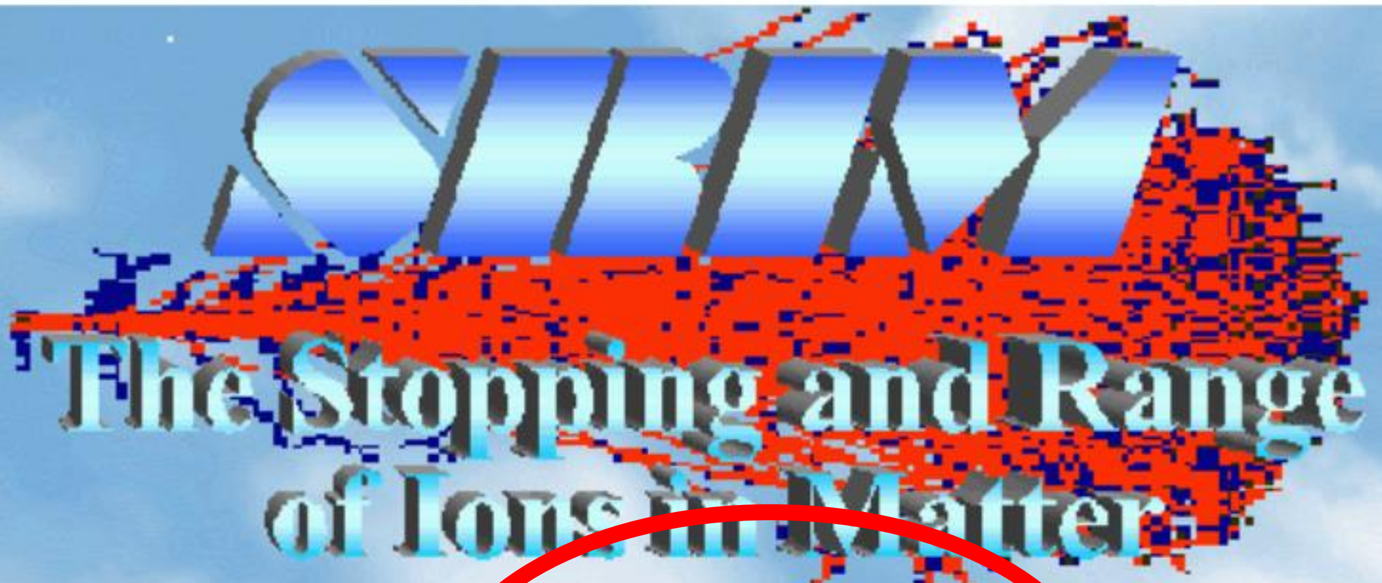


Useful for a first determination of the implantation energy range needed to achieve a desired dopant profile

SRIM Main Menu

Calculation

40



Logo ?

?

Stopping / Range Tables

?

TRIM Calculation

?

Experimental Stopping Powers

J. F. Ziegler
U.S.N.A.
Annapolis, MD

M. D. Ziegler
U.C.L.A.
Los Angeles, CA

J. P. Biersack
Hahn-Meitner Inst.
Berlin, Germany

SRIM Version

SRIM-2008.04

SRIM Tutorials

Legal Notice

Quit

Contributions by E. Dabich, H. Paul, D. J. Marwick, G. A. Cuomo, W. A. Porter

(c) 1984,1989,1998, 2003, 2008 by J. F. Ziegler, M.D. Ziegler, J. P. Biersack (SRIM.com)

TRIM Setup Window

Read Me

TRIM (Setup Window)

TRIM Demo ?

Restore Last TRIM Data ?

Type of TRIM Calculation

DAMAGE: Ion Distribution and Quick Calculation of Damage ?

Basic Plots: Ion Distribution with Recoils projected on Y-Plane ?

? ION DATA

	Symbol	Name of Element	Atomic Number	Mass (amu)	Energy (keV)	Angle of Incidence
PT	H	Hydrogen	1	1.008	10	0

? TARGET DATA

Input Elements to Layer 1

Layers: Add New Layer ?

Add New Element to Layer | Compound Dictionary ?

	Layer Name	Width		Density (g/cm3)	Compound Corr	Gas
X	Layer 1	10000	Ang	0	1	

		Symbol	Name	Atomic Number	Weight (amu)	Atom Stoich or %	Damage (eV) Disp	Latt	Surf
X	PT			0		1	100	20	3	2

How to setup a TRIM calculation

- Ion: type, isotope, energy
- Target: number of layers; composition, density, thickness
- Simulation: type, plotting window depth, output

Special Parameters

Name of Calculation: H (10) into Layer 1

Stopping Power Version: SRIM-2008 ?

? AutoSave at Ion # 10000

? Total Number of Ions 99999

? Random Number Seed

Plotting Window Depths ?

Min 0 Å

Max 10000 Å

? Output Disk Files

? Ion Ranges

? Backscattered Ions ?

? Transmitted Ions/Recoils

? Sputtered Atoms ?

? Collision Details

? 0 Special "EXYZ File" Increment (eV)

Resume saved TRIM calc.

Use TRIM-96 (DOS)

Save Input & Run TRIM

Clear All

Calculate Quick Range Table

Main Menu

Problem Solving

Quit

SBeST

SRIM-2008.04

File Help, FAQ and Scientific Explanations

Help | Animate | Continue | Change TRIM | 100% ION ENERGY 0% | Now: 432 of 99999 Ions

ION

Ion Type	Al	26.982 amu
Ion Energy	200	keV
Ion Angle	0	degrees
Completed	431	of 99999

SHOW LIVE DATA HELP

TARGET DATA

? Al (200) into No. 590 Silicon Carbide (1 layers, 2 atoms)

	Layer Name	Width (A)	Density	C (12.011)	Si (28.086)	Solid/Gas	Sto
1	No. 590 Silicon Carbide	10000	3.160	0.50000	0.50000	Solid	
	Lattice Binding Energy			3	2		
	Surface Binding Energy			7.41	4.7		

Calculation Parameters

Backscattered Ions	0
Transmitted Ions	0
Vacancies/Ion	1512.5

ION STATS	Range	Straggle
Longitudinal	2252 A	640 A
Lateral Proj.	469 A	585 A
Radial	732 A	383 A

Type of Damage Calculation

? Quick: Kinchin-Pease

Stopping Power Version

? SRIM-2008

% ENERGY LOSS	Ions	Recoils
Ionization	47.84	17.25
Vacancies	0.16	1.71
Phonons	0.61	32.42

SPUTTERING YIELD

	Atoms/Ion	eV/Atom
TOTAL		
C	0.000000	0.00
Si	0.000000	0.00

? Save every 10000 ions

Random Number Counter 474480

HELP

Plots

PLOT Window

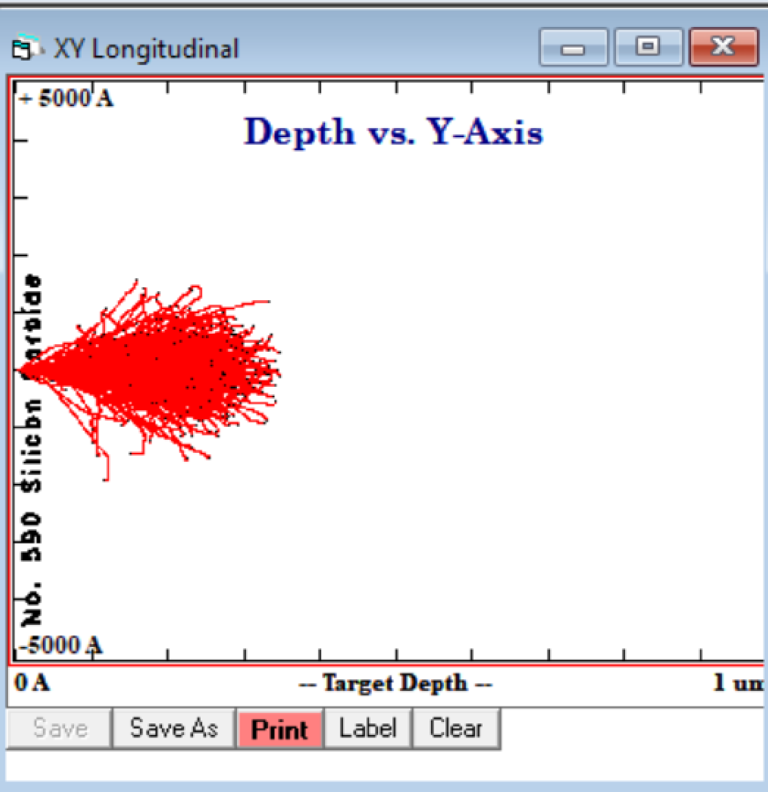
0 A – 10000 A

Max Target Depth 10000

COLLISION PLOTS

- [x] XY Longitudinal — All
- [ ] XZ Longitudinal — None
- [ ] XY Ions Only — Tile
- [ ] YZ Lateral — Clear

Background color White/Black



DISTRIBUTIONS

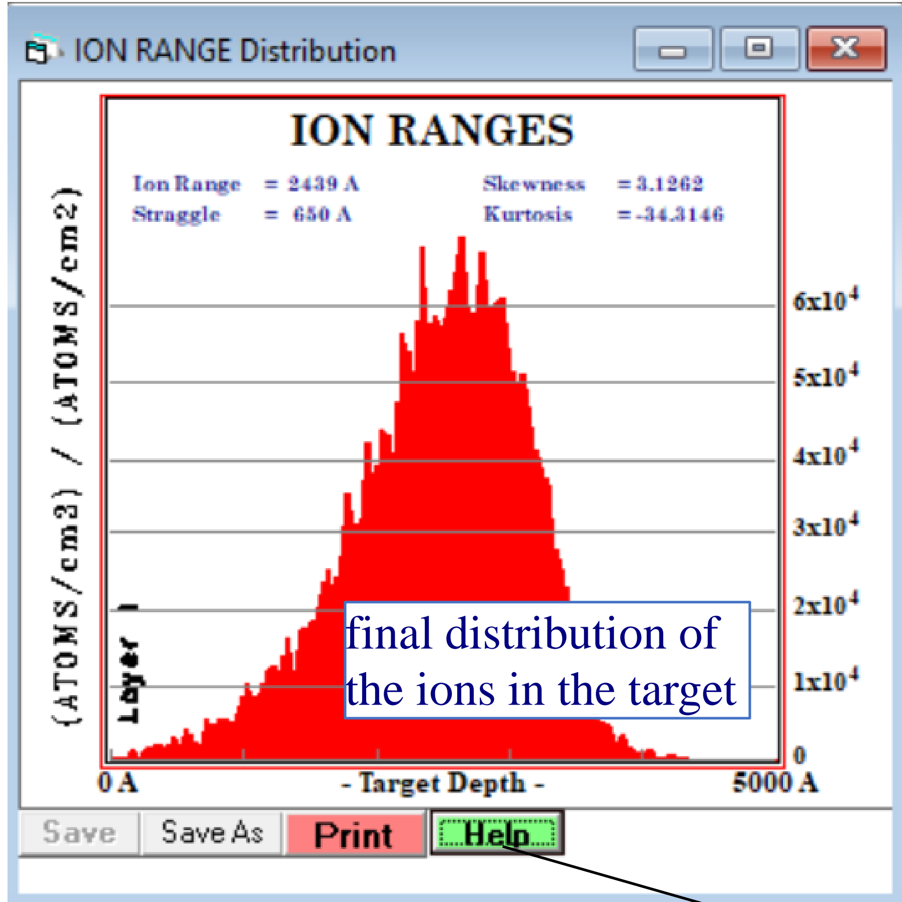
File Plot

- ? Ion Distribution
- ? Ion/Recoil Distribution
- ? Lateral Range
- ? Ionization
- ? Phonons
- ? Energy to Recoils
- ? Damage Events
- ? Integral / Differential Sputtered Ions
- ? Ion Ranges (3D data)
- ? Backscattered Ions
- ? Transmitted Ions
- ? Collision Details

HELP

SRIM output ion distribution

AS Be ST

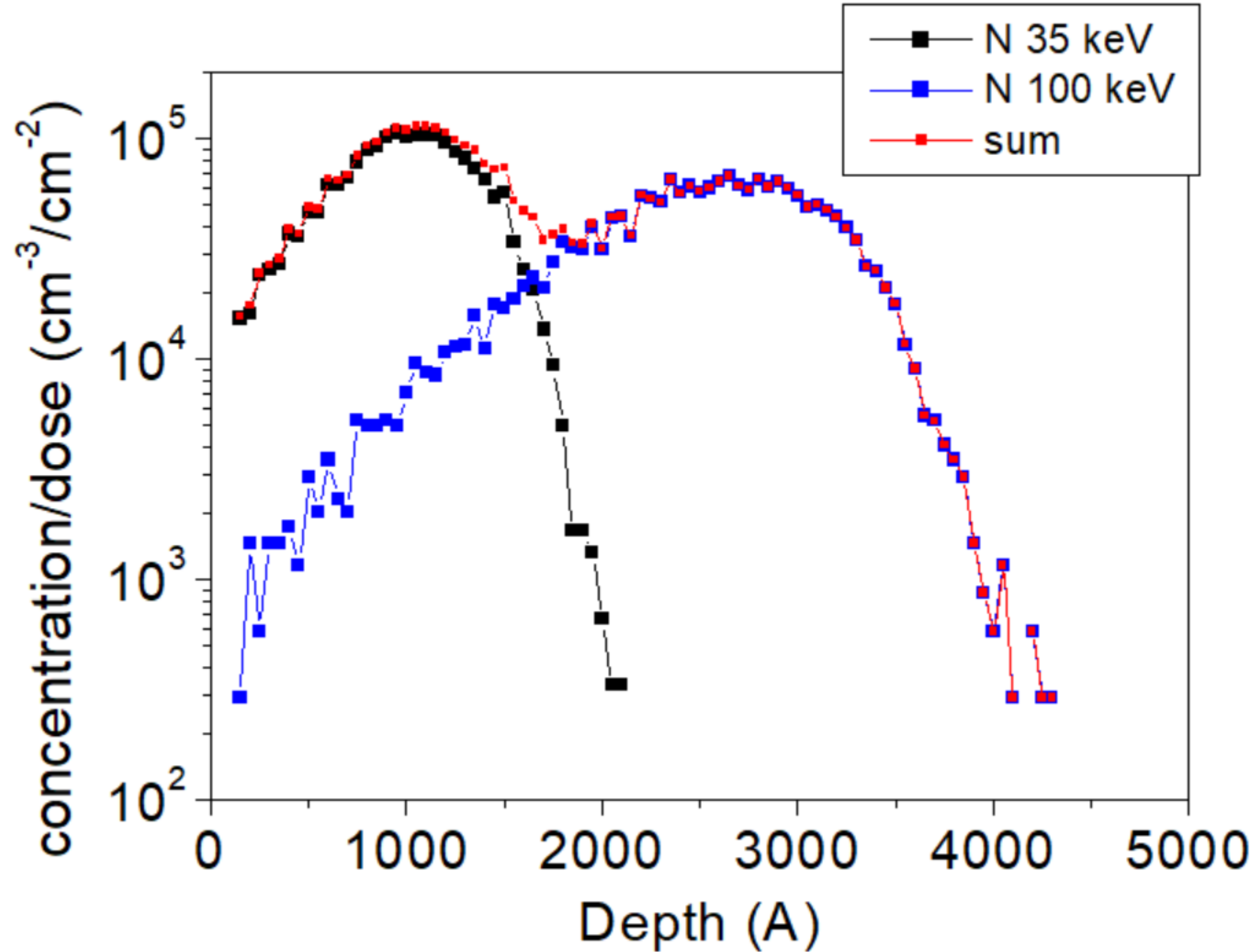


The Ordinate is set so that by multiplying by an ion-beam dose, normally in units of "Atoms/cm2", the plot reads directly as a concentration in units of ***atoms/cm3***.

Dose = Fluence = areal density of injected ions [cm^{-2}]
Concentration = number of ions per unit volume in the target [cm^{-3}]

Ref. SRIM help button

Multiple ion implantation



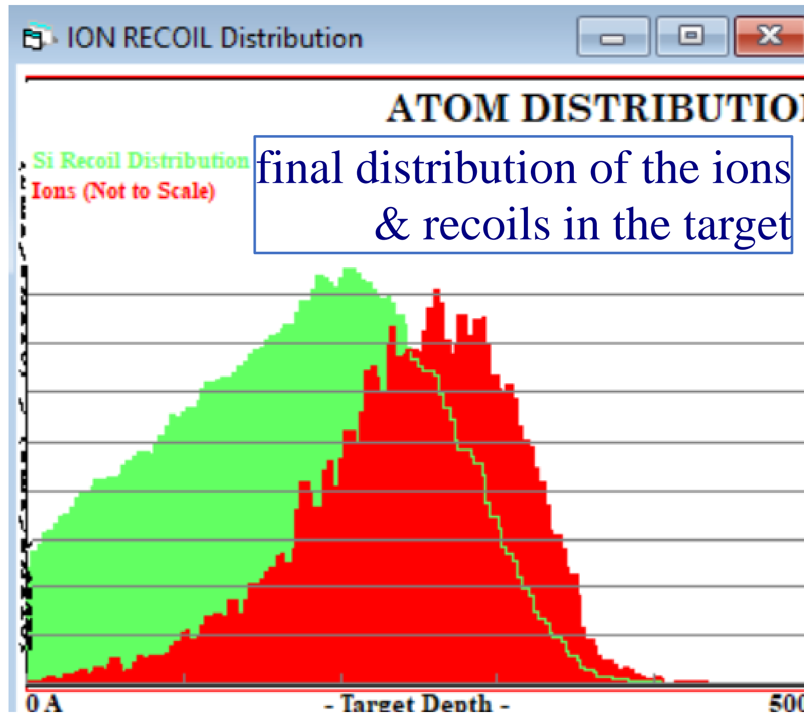
For ion implantation at multiple energies the profile is the sum of the single implant profiles.

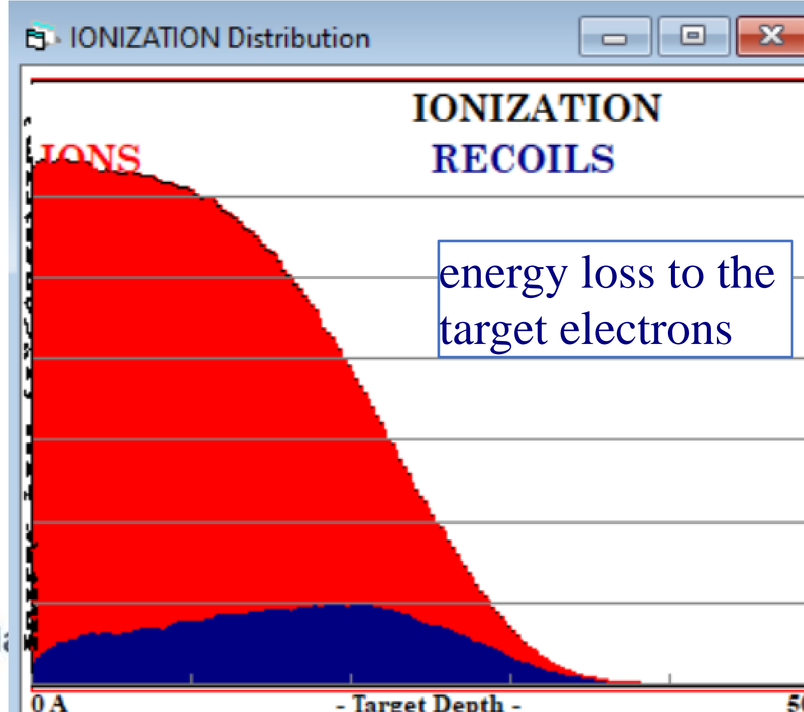
AS Be ST

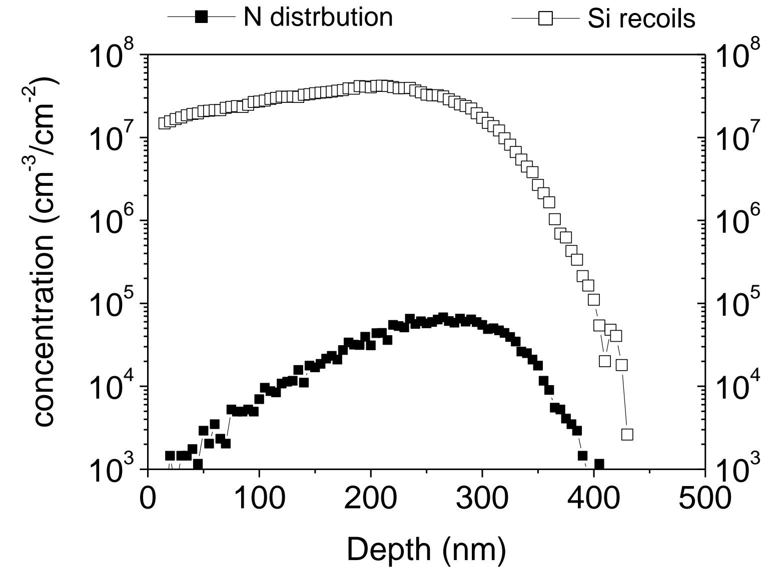
SRIM output files

DISTRIBUTIONS

?	File	Plot	
?		☑	Ion Distribution
?	☐	☑	Ion/Recoil Distribution
?	☐	☐	Lateral Range
?	☐	☑	Ionization
?	☐	☐	Phonons
?	☐	☐	Energy to Recoils
?	☐	☐	Damage Events
?	☐	☐ ☐	Integral / Differential — Sputtered Ions
?	☐		Ion Ranges (3D data)
?	☐		Backscattered Ions
?	☐		Transmitted Ions
?	☐		Collision Details



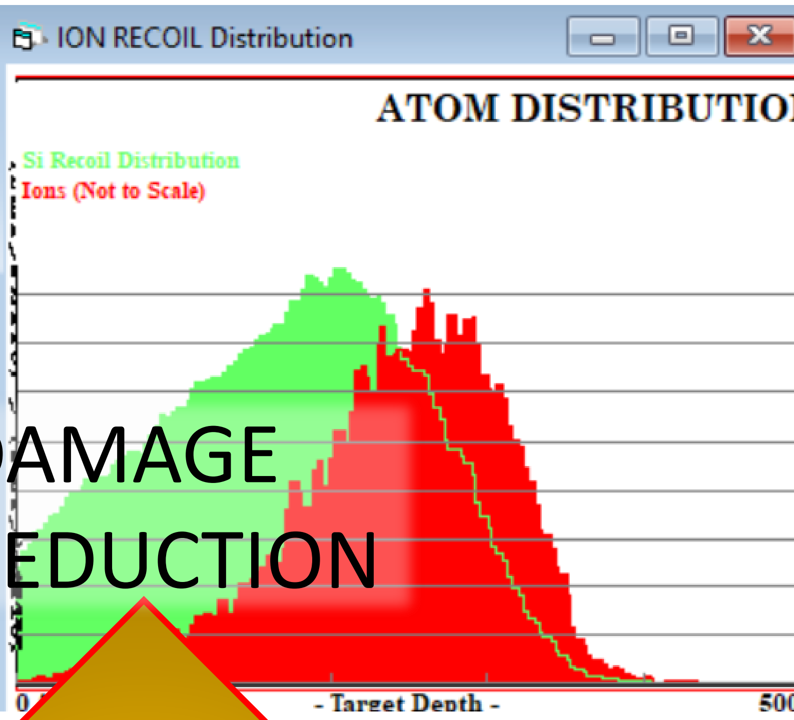




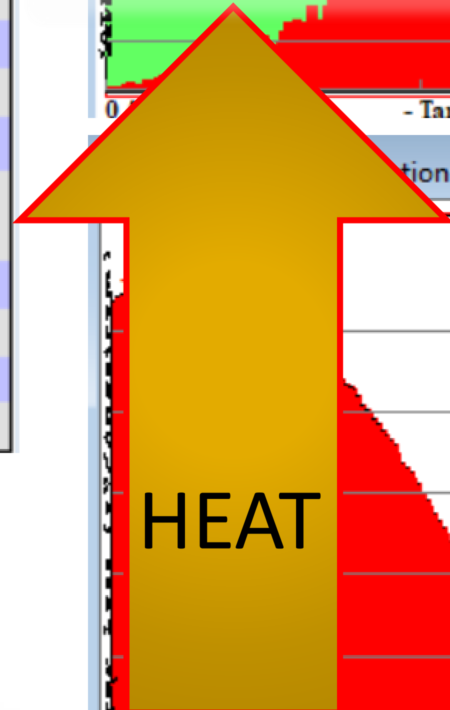
The atom distribution plot generated by SRIM is scaled to the recoil distribution. Above is the in-scale plot (log scale).

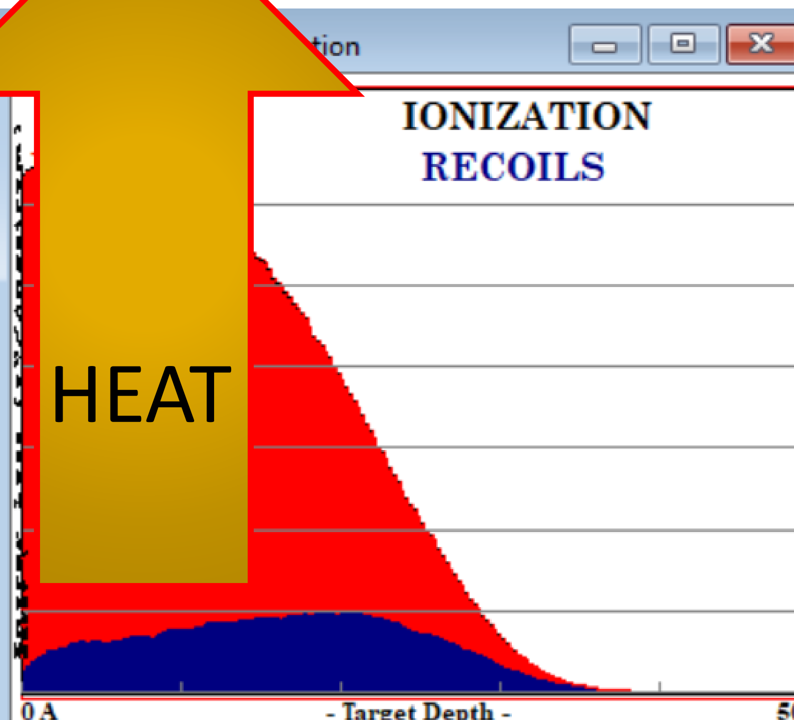
The data relating to "Ions" is the direct energy transferred from the ion to the target electrons. The data relating to the "Recoils" is energy transferred from recoiling target atoms to the target electrons.

Dynamic annealing



DAMAGE
REDUCTION





The heat generated through energy loss to electrons can result in the annealing of the lattice damage during ion implantation. This process is referred to as dynamic annealing. Dynamic annealing can be promoted also by hot ion implantation.

Damage at the ion end of range.

Excercise 1

AS Be ST

Calculate the ion implantation energy and dose required to generate the following dopant profile in 4H-SiC (density =3.21g/cm^3)
Phosphorus, 2×10^{20} cm^{-3} concentration and 250 nm depth.

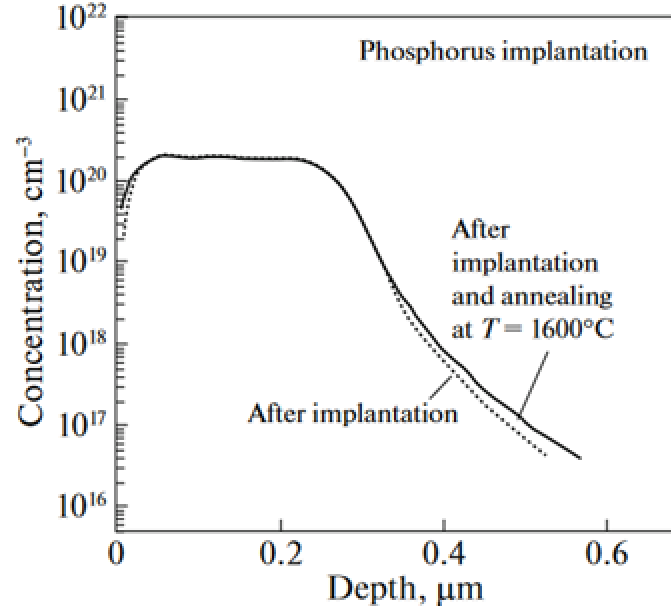
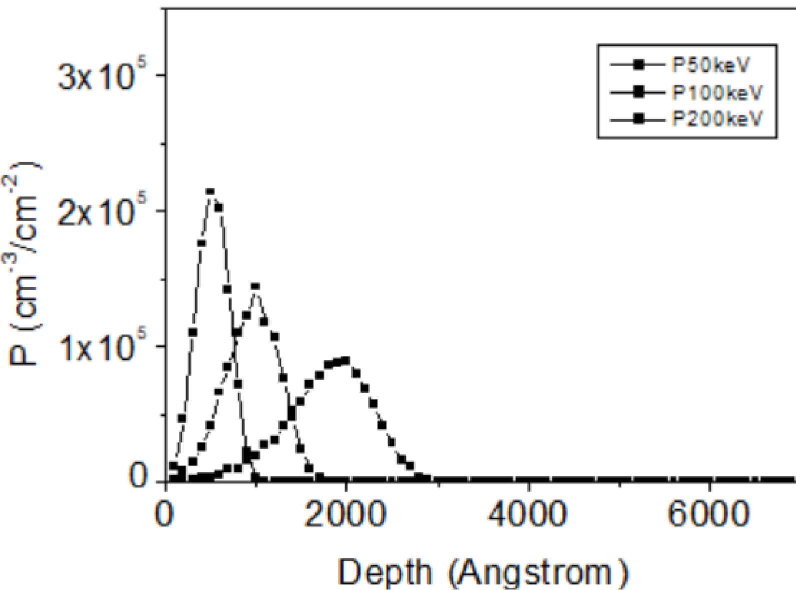


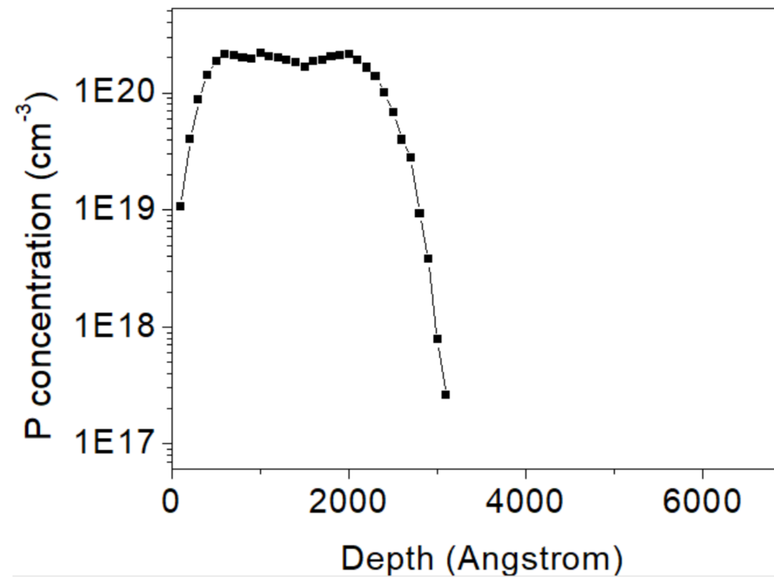
Fig. 9. Depth profiles of phosphorus atoms implanted in 4H-SiC: as-implanted and after annealing in Ar at a temperature of 1600°C for 30 min [3].

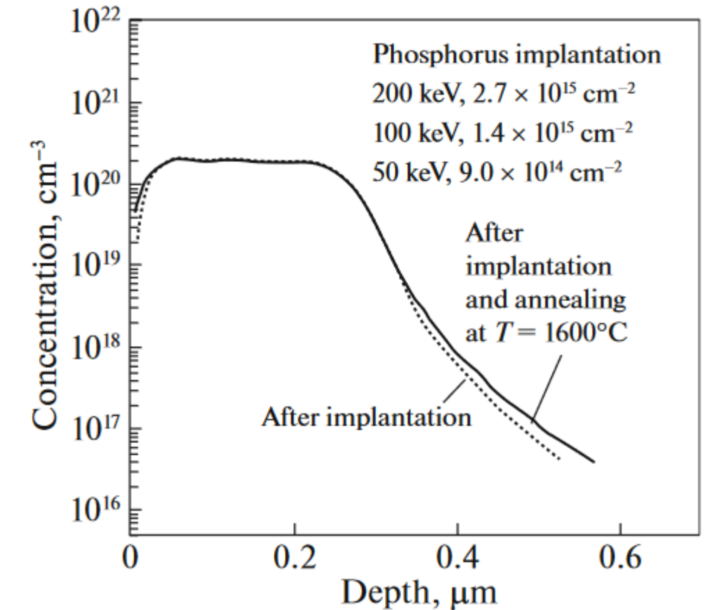
A.V. Afanasev *et al.*, Semiconductors, 56 (2022) p. 472
DOI: 10.1134/S1063782622130024

Solution to excercise 1

Calculate the ion implantation energy and dose required to generate the following dopant profile in 4H-SiC (density =3.21g/cm^3)
Phosphorus, 2×10^{20} cm^{-3} concentration and 250 nm depth.







Sum of the profiles multiplied by singles doses.

Can you notice any discrepancy btween SRIM simulation and SIMS profile? Can you comment?

Excercise 2

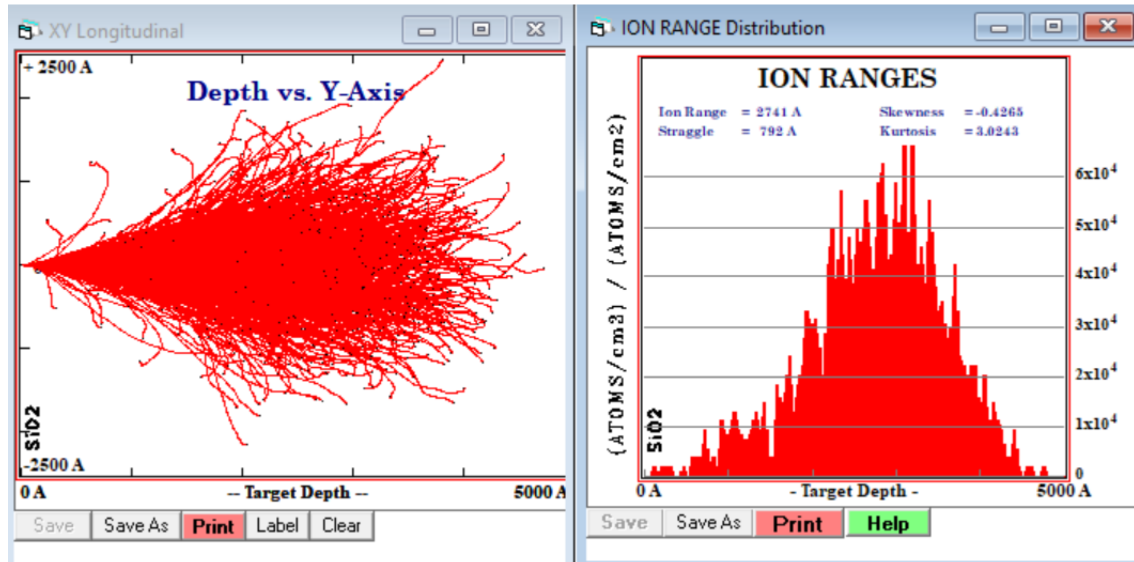
Determine the minimum thickness required for a SiO_2 layer deposited on top of the SiC wafer to be used as ion implantation mask.

Solution to excercise 2

Determine the minimum thickness required for a SiO_2 layer deposited on top of the SiC wafer to be used as ion implantation mask.

$$t > R_p + \Delta R_p =$$
$$(269.6+69.7)\ nm = 339.3\ nm$$

Is the above value safe?




```
==================================================================
        Calculation using SRIM-2006
        SRIM version ---> SRIM-2008.04
        Calc. date   ---> giugno 14, 2024
==================================================================

Disk File Name = SRIM Outputs\Phosphorus in  O-Si

Ion = Phosphorus [15] , Mass = 30.974 amu

Target Density =  2.3200E+00 g/cm3 = 6.9759E+22 atoms/cm3
======= Target  Composition ========
   Atom   Atom   Atomic    Mass
   Name   Numb   Percent   Percent
   ----   ----   -------   -------
     O      8    066.67    053.26
    Si     14    033.33    046.74
====================================
Bragg Correction = 0.00%
Stopping Units =  MeV / (mg/cm2)
See bottom of Table for other Stopping units
```

Ion Energy	dE/dx Elec.	dE/dx Nuclear	Projected Range	Longitudinal Straggling	Lateral Straggling
10.00 keV	3.445E-01	2.230E+00	157 A	66 A	49 A
11.00 keV	3.613E-01	2.239E+00	169 A	71 A	52 A
12.00 keV	3.774E-01	2.245E+00	182 A	76 A	55 A
13.00 keV	3.928E-01	2.248E+00	194 A	80 A	59 A
14.00 keV	4.076E-01	2.248E+00	207 A	85 A	62 A
15.00 keV	4.219E-01	2.247E+00	219 A	89 A	65 A
130.00 keV	1.364E+00	1.399E+00	1744 A	506 A	389 A
140.00 keV	1.416E+00	1.355E+00	1879 A	535 A	415 A
150.00 keV	1.466E+00	1.314E+00	2015 A	564 A	441 A
160.00 keV	1.512E+00	1.276E+00	2151 A	592 A	467 A
170.00 keV	1.555E+00	1.240E+00	2287 A	619 A	493 A
180.00 keV	1.597E+00	1.207E+00	2423 A	646 A	518 A
200.00 keV	1.676E+00	1.146E+00	2696 A	697 A	567 A
225.00 keV	1.768E+00	1.079E+00	3036 A	758 A	627 A
250.00 keV	1.856E+00	1.021E+00	3374 A	816 A	686 A

Excercise 3

Calculate the ion implanted profile and the damage profile generated by 50 keV He and 1000 keV Si ion implantation in Si.

Solution to exercise 3

Calculate the ion implanted profile and the damage profile generated by 50 keV He and 1000 keV Si ion implantation in Si.

As-ii: amorphization at R_p (Si)

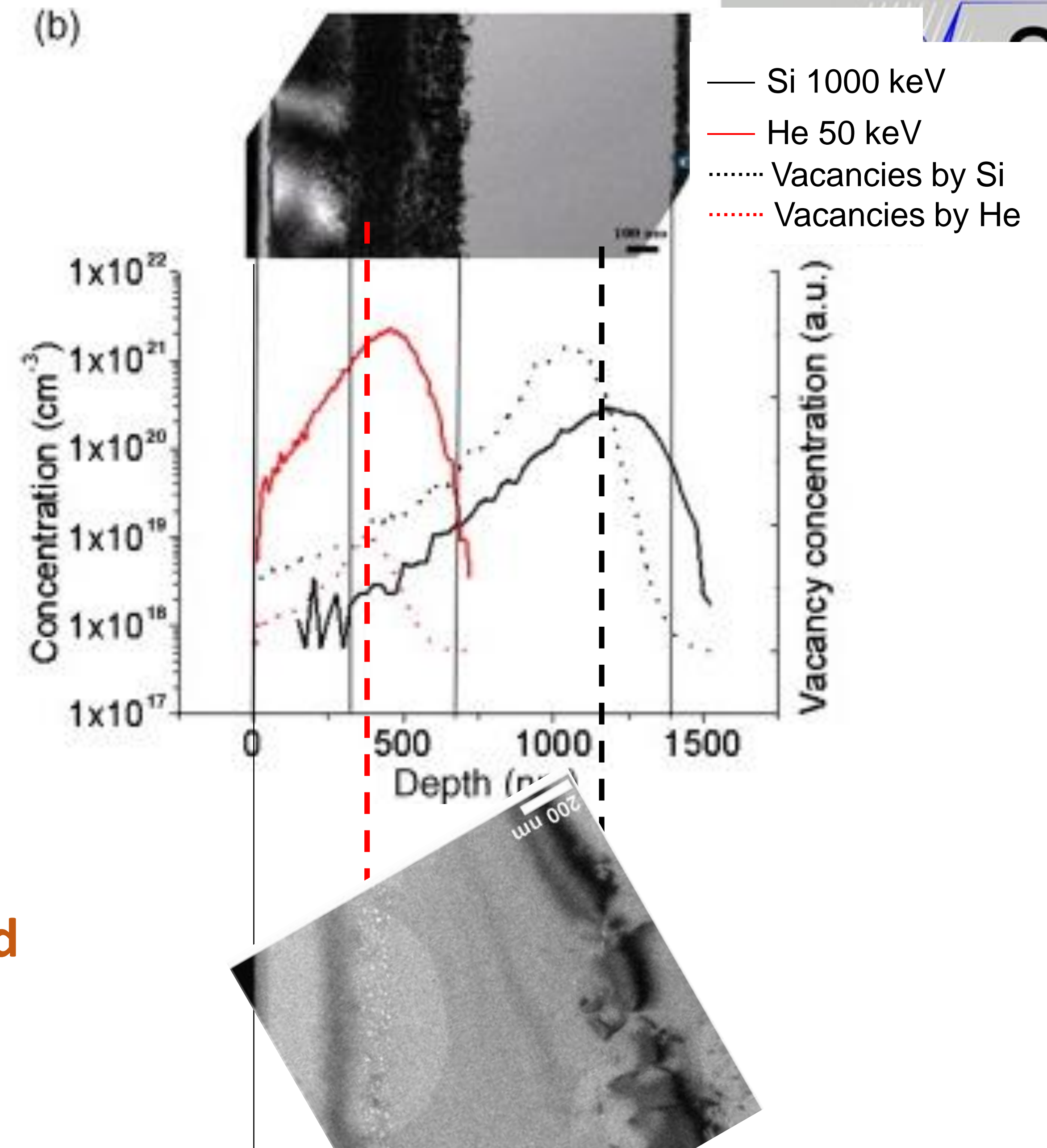
After annealing:

- Damage at the Si End Of Range
- He-filled bubbles at the vacancy peak of He ii.

as-ii
BF TEM

SRIM

Annealed
BF TEM



M. Canino *et al.*, Defect engineering via ion implantation to control B diffusion in Si. Mat. Sci Eng B, 159–160 (2009) pp. 338-341. https://doi.org/10.1016/j.mseb.2008.10.033.

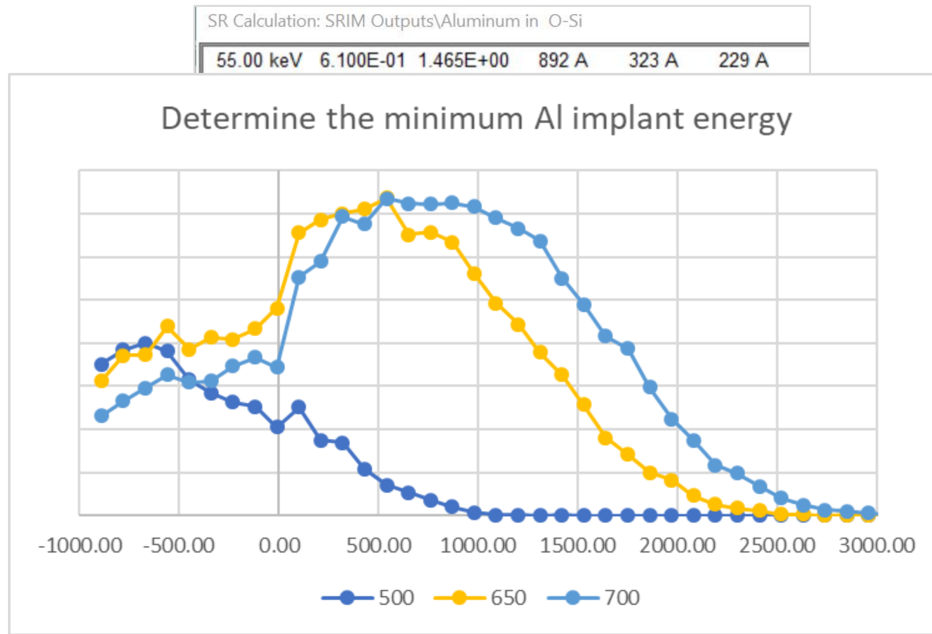
Excercise 4

Calculate the ion implantation parameters (energies and doses) necessary to generate a 300 nm deep implanted box profile in 4H-SiC, with Al concentration equal to 5×10^{19} cm^{-3}. The SiC layer is covered by a 1080 nm thick Al layer.

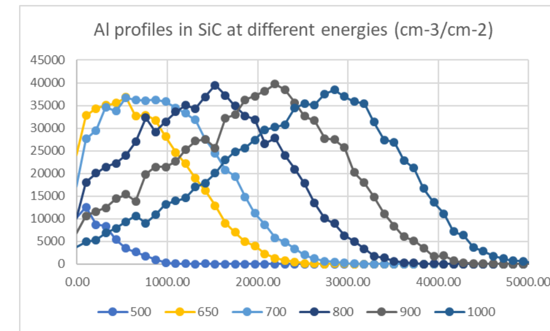
Solution to excercise 4

AS BeST

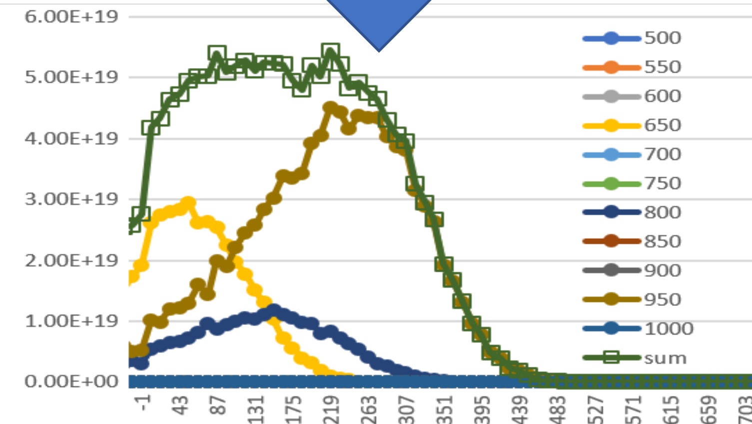
Calculate the ion implantation parameters (energies and doses) necessary to generate a 300 nm deep implanted box profile in 4H-SiC, with Al concentration equal to 5×10^{19} cm^{-3}. The SiC layer is covered by a 1080 nm thick Al layer.



Minimum Al implantation energy



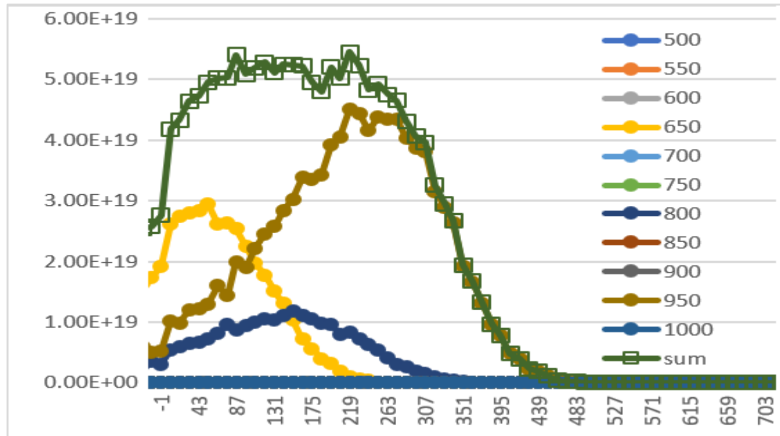
Choose three energy values and calculate the doses



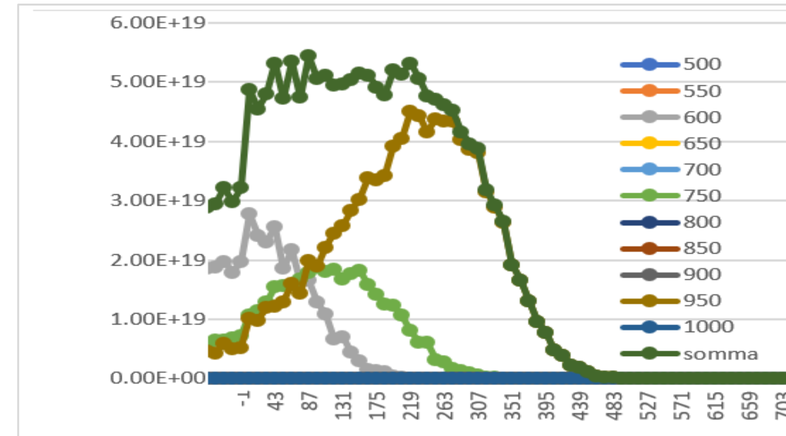
Solution to excercise 4

Calculate the ion implantation parameters (energies and doses) necessary to generate a 300 nm deep implanted box profile in 4H-SiC, with Al concentration equal to 5×10^{19} cm^{-3}. The SiC layer is covered by a 1080 nm thick Al layer.

Dose dependence on the energy choice

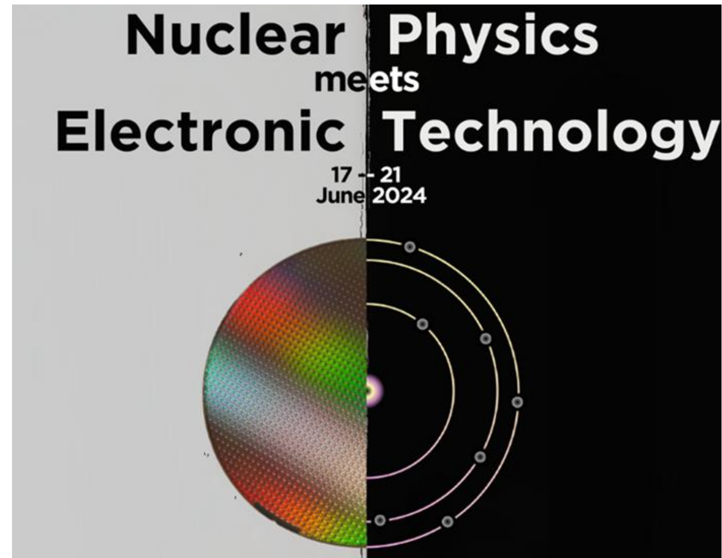


650	700	750	800	850	900	950	1000	sum
8.00E+14	0.00E+00	0.00E+00	3.00E+14	0.00E+00	0.00E+00	1.20E+15	0.00E+00	2.30E+15



600	650	700	750	800	850	900	950	1000	somma
8.00E+14		0.00E+00	5.00E+14		0.00E+00	0.00E+00	1.20E+15	0.00E+00	2.50E+15

AS BeST



Thank you!

mariaconcetta.canino@cnr.it

Material at: https://drive.google.com/drive/folders/1YT4cwKaSgspdnMJyEtXdv8s3lQpa6E5J?usp=sharing
Short link: https://shorturl.at/yhfRX