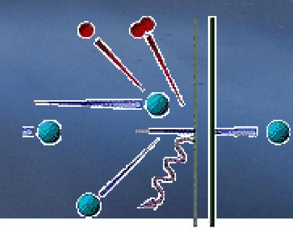
SA-JINR INTERNATIONAL STUDENT PRACTICE

Positron Annihilation Spectroscopy in Material Structure Studies

Mashamba Dakalo Rollet, Storm Johnson, Siwisa Lindelwa

Supervisor: Dr. Krzystof Siemek

(Dzhelepov Laboratory of Nuclear Problems)



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Outline

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- Results from TRIM simulations
- Defects of supermalloy irradiated with 10^{14} Xe ions
- Defects of supermalloy irradiated with 5×10^{12} Xe ions
- Results from measurements using the variable energy positron beam
- Defect concentration
- Conclusions

Section 1 (Siwisa Lindelwa, University of Johannesburg)

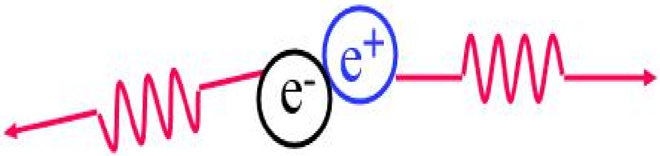
Aim

Study of Xe ions implanted defects in supermalloy using positron annihilation spectroscopy

Positron annihilation spectroscopy (PAS)

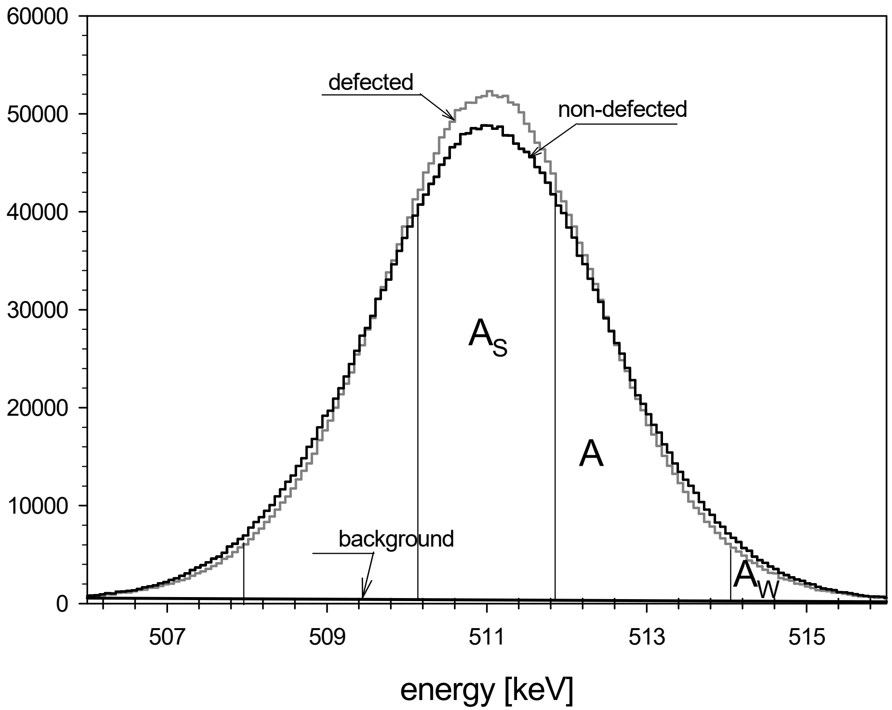
- DOPPLER BROADENING SPECTROSCOPY (DBS)
  - MEASURES THE BROADENING OF THE ANNIHILATION LINE
- POSITRON ANNIHILATION LIFETIME SPECTROSCOPY (PALS)
  - MEASURES THE ELAPSED TIME BETWEEN IMPLANTATION OF POSITRON AND PRODUCTION OF ANNIHILATION RADIATION
- ANGULAR CORRELATION MEASUREMENT

DBS technique



γ-ray (511keV ± ΔE)

Doppler effect causes energy change. The finite momentum of positron-electron pair causes annihilation energy of 511keV to be Doppler shifted by an amount of ΔE.



$$S = \frac{A_S}{A}$$

S-parameter indicates the presence of vacancy defect. It increases with the increase in defect concentration.

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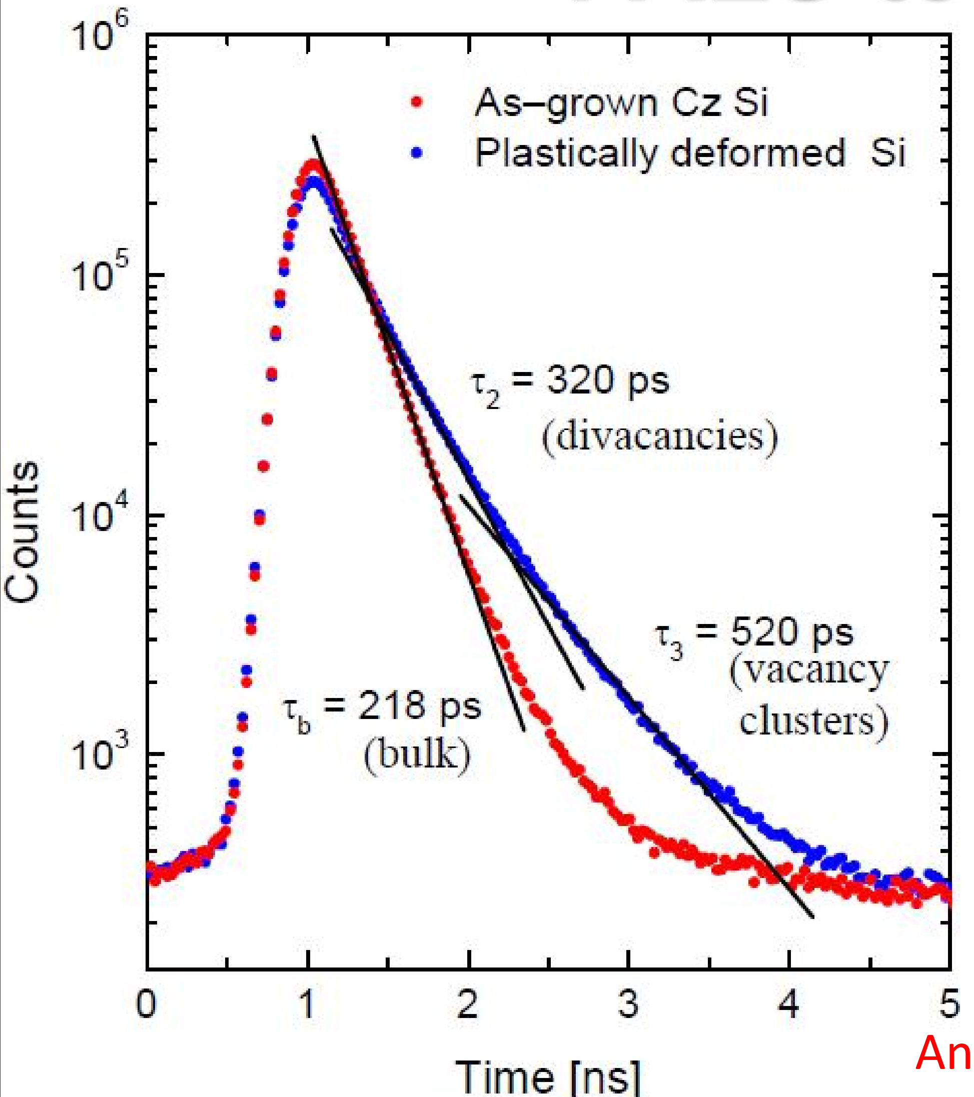
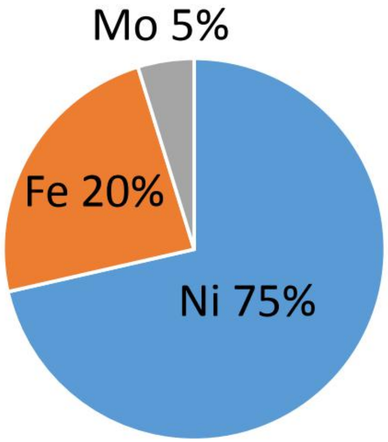
PALS technique



- Once positrons are implanted in a material they thermalize and annihilate through interaction with electrons.
- This annihilation releases gamma rays that can be detected by suitable detector.
- The rate of annihilation is faster in free defect position and slower in position where voids are available due to lower density of electrons

An example of a positron lifetime spectrum

Supermalloy properties and uses



Chemical composition

Supermalloy

Applications

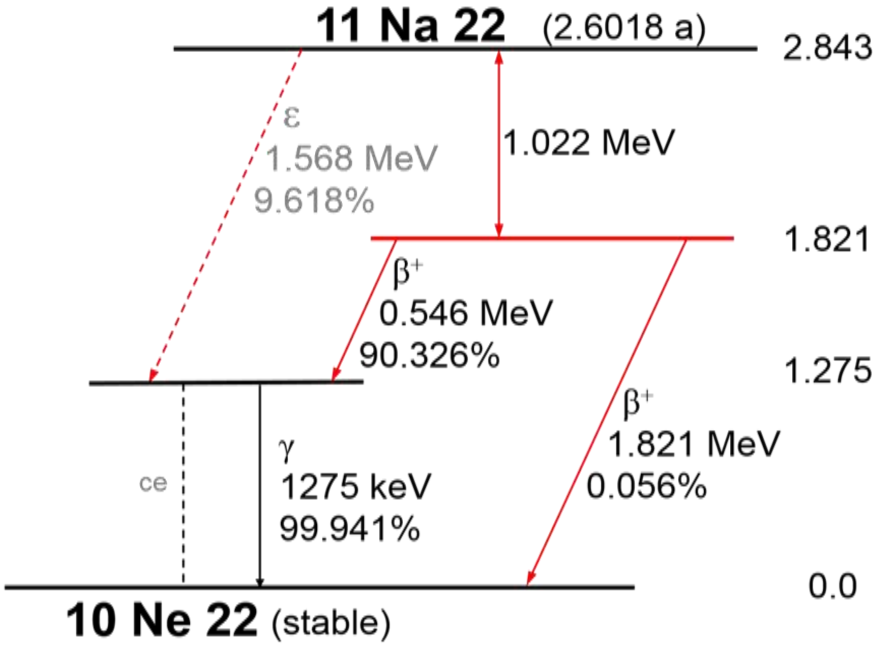
- Magnetic Amplifiers
- Pulse Transformers

Properties

- High permeability
- Low coercivity

Section 2 (Mashamba Dakalo Rollet, Tshwane University of Technology)

Na-22 decay scheme



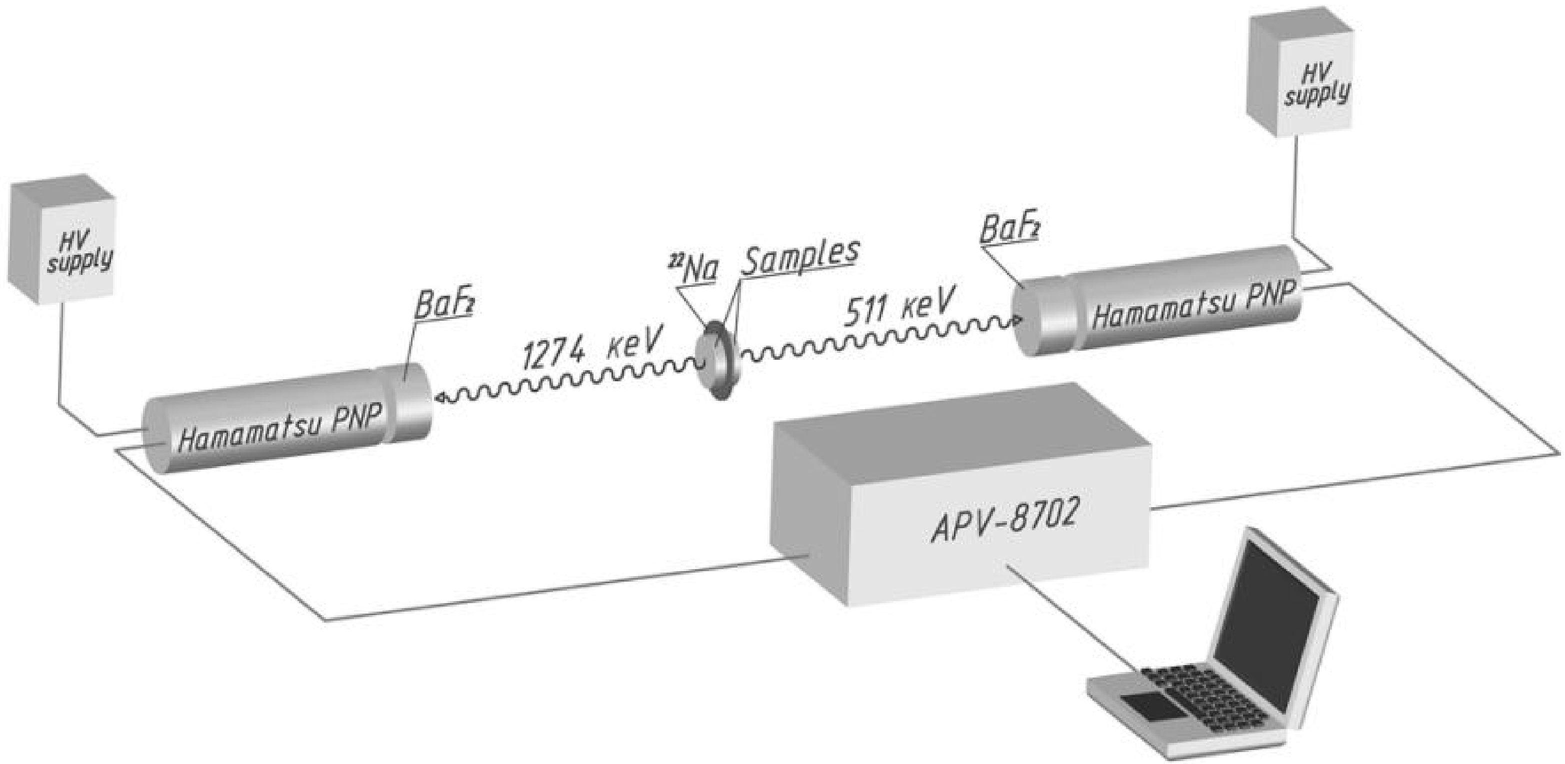
$$^{22}_{11}\mathrm{Na} \rightarrow \, ^{22}_{10}\mathrm{Ne}^* + \, ^{0}_{1}\mathrm{e} + \, ^{0}_{0}\nu_e$$

$$^{22}_{10}\mathrm{Ne}^* \rightarrow \, ^{22}_{10}\mathrm{Ne} + \gamma$$

$$^{0}_{1}\mathrm{e} + \, ^{0}_{-1}\mathrm{e} \rightarrow \gamma + \gamma$$

- Na-22 is a radioactive isotope which decays and emit positrons (β^+ decay)
- The positron emission is followed by gamma emission
- The photon is the start signal of the experiment
- When a positron annihilates with an electron, two back-to-back gamma rays are produced

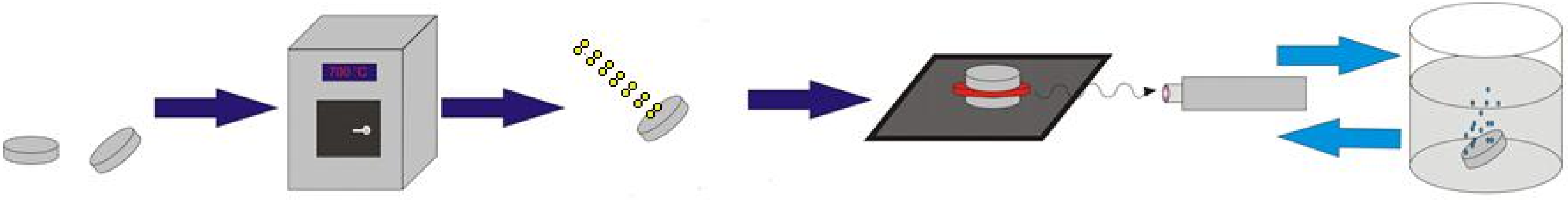
Experimental setup for PALS



Positron lifetime spectroscopy apparatus

Methodology

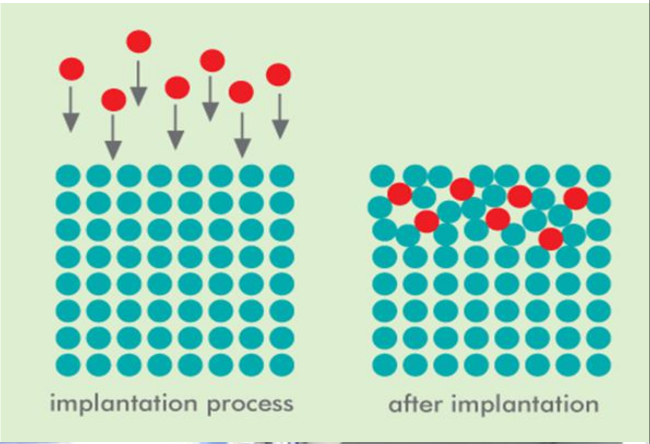
1. Supermalloy samples were annealed to remove all defects
2. Supermalloy samples were irradiated with Xe ions
3. Na-22 positron source was sandwiched between two supermalloy samples, and the positron lifetime for samples was measured
4. Etching was performed after each measurement using HNO_3 and HCl



1. 2. 3. 4.

Methodology

- Ion implantation was performed at IC-100 cyclotron at Flerov Laboratory of Nuclear Reactions at JINR
- Samples irradiated with Xe^{26+} heavy ions at energy 167 MeV using doses of 10^{14} and 5×10^{12}

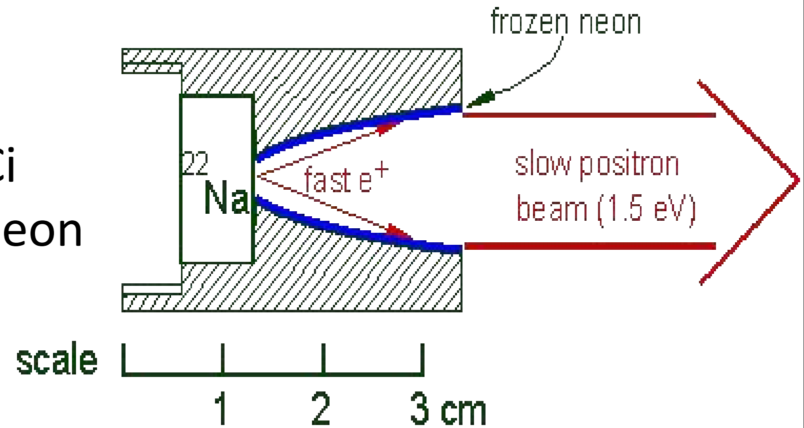


Positron beam

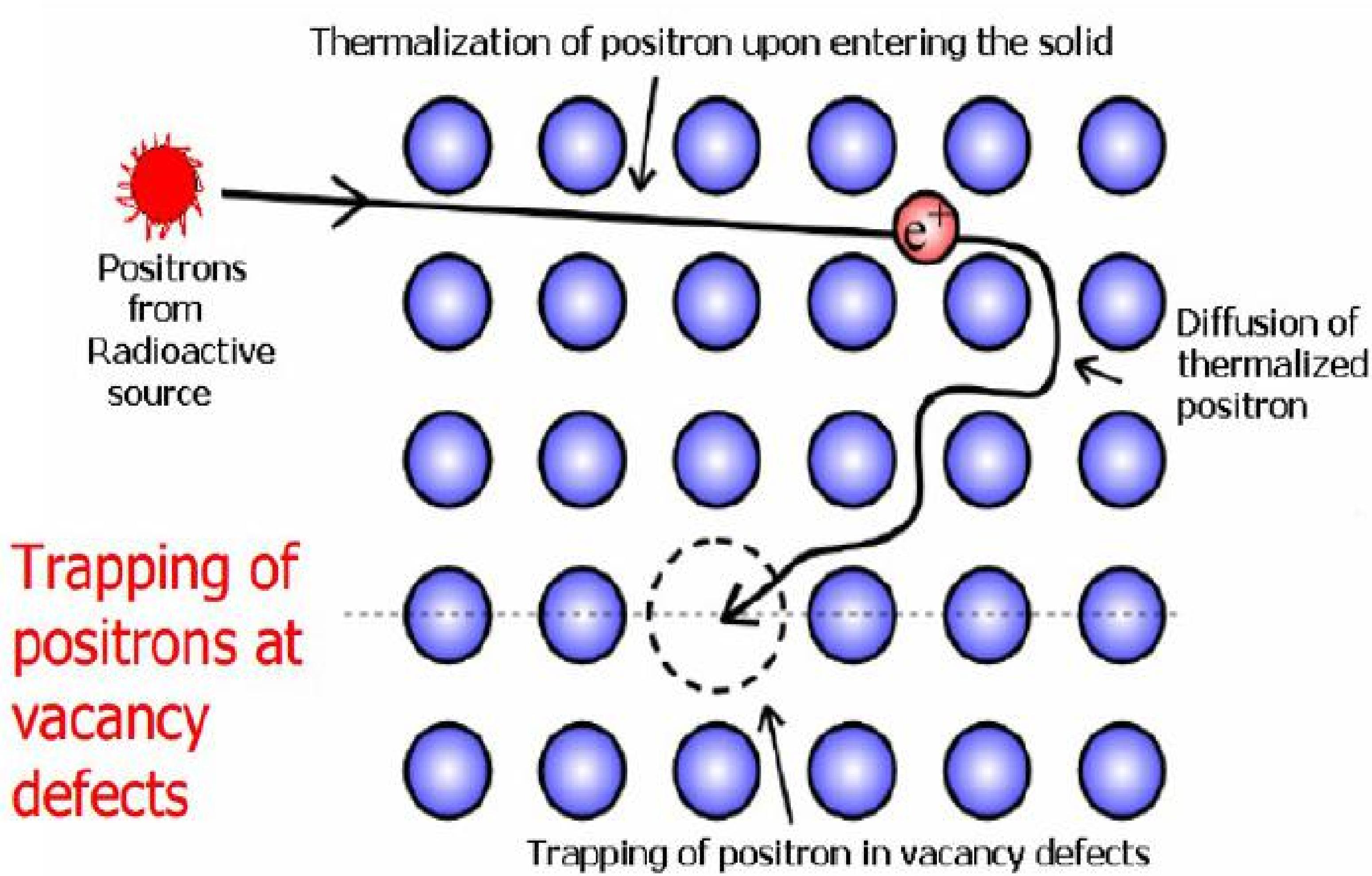
Na-22 source supplied by iThemba LABS

Variable energy positron beam located in Dzhelepov Laboratory of Nuclear Problems at JINR

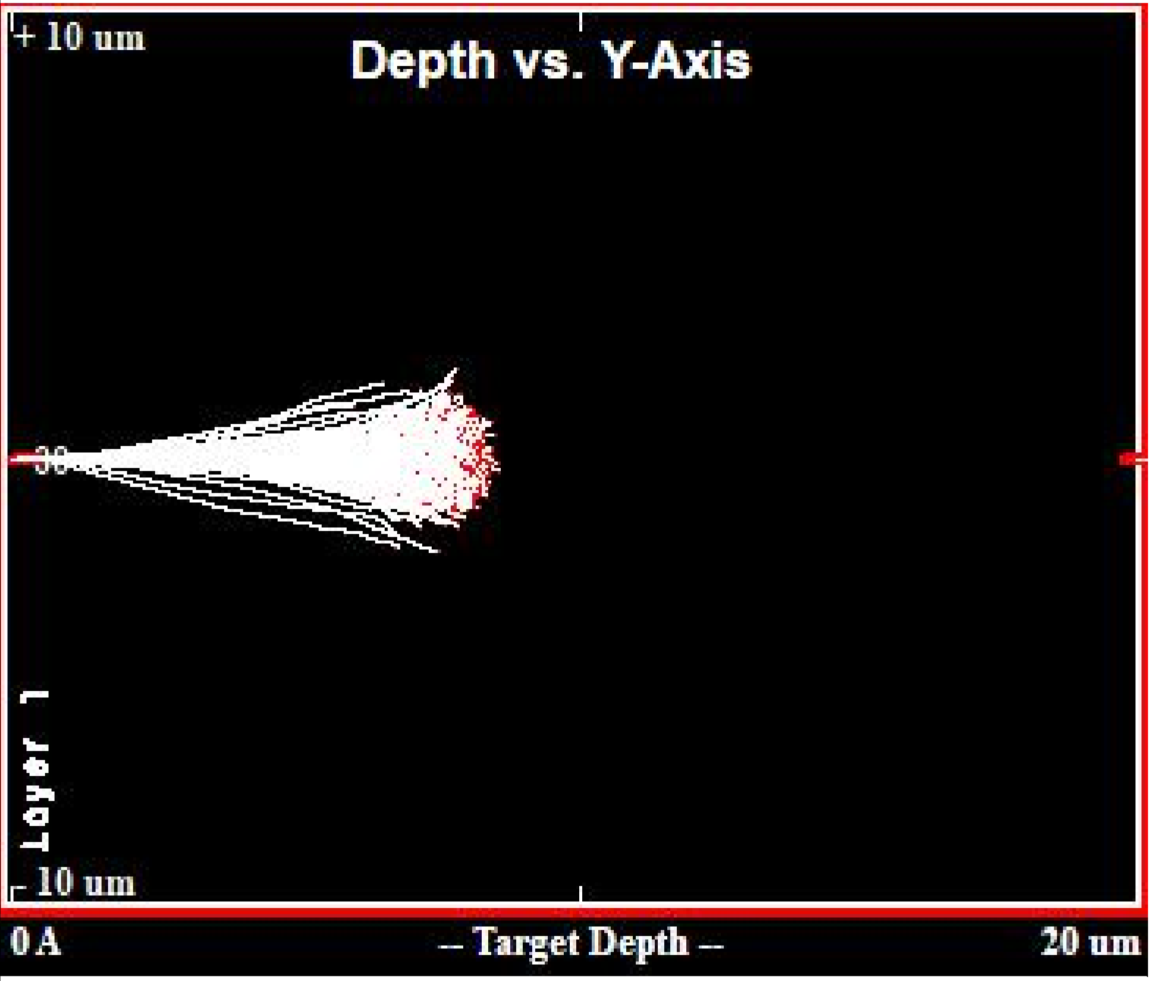
- The positron source has a high activity of 50 mCi
- Positrons emitted are moderated using frozen neon
- The slow positrons can be accelereted using an electric field



Thermalization of positrons



Monte Carlo simulations using SRIM/TRIM

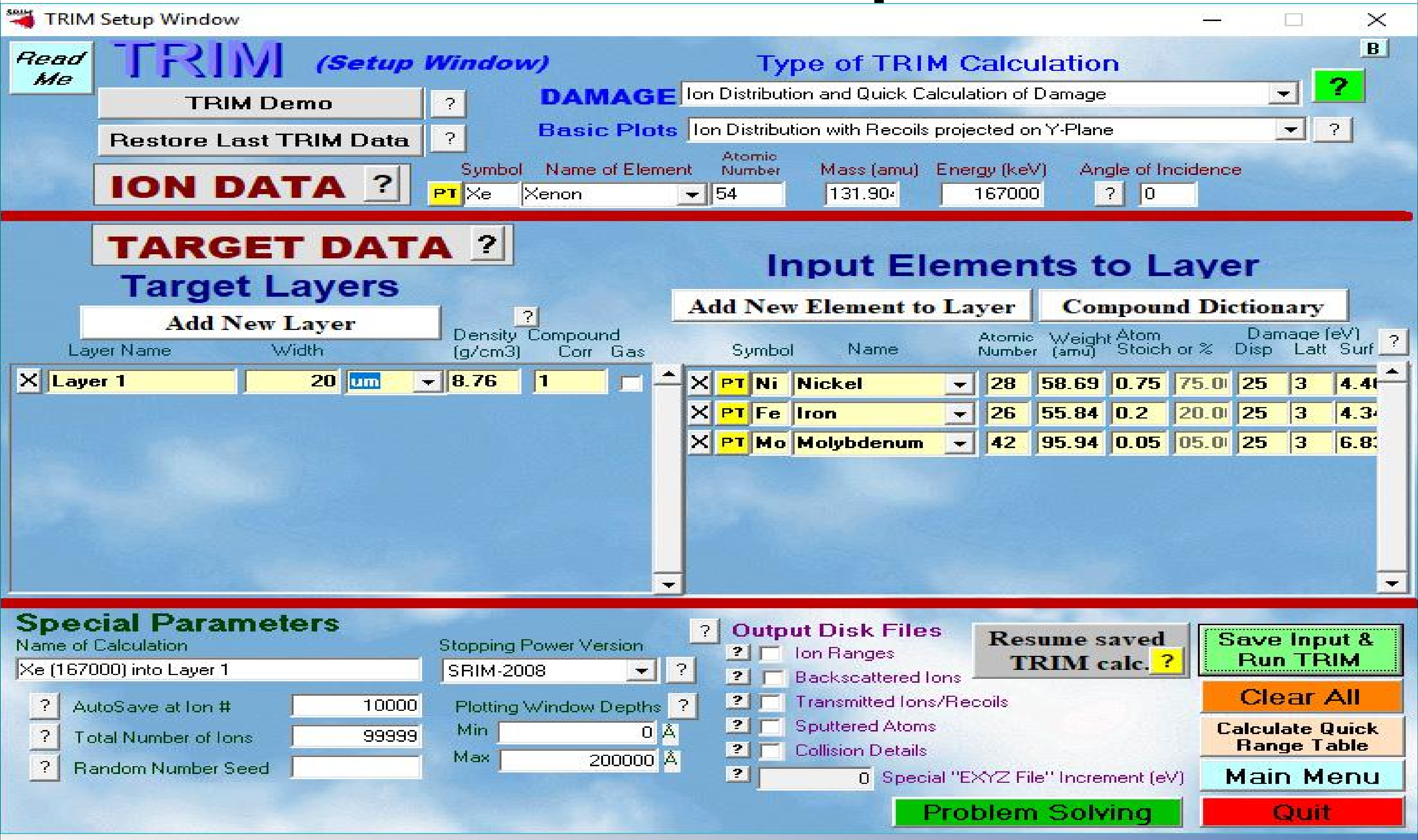


TRIM calculations for supermalloy implanted with 167 MeV Xe ions

What is SRIM?

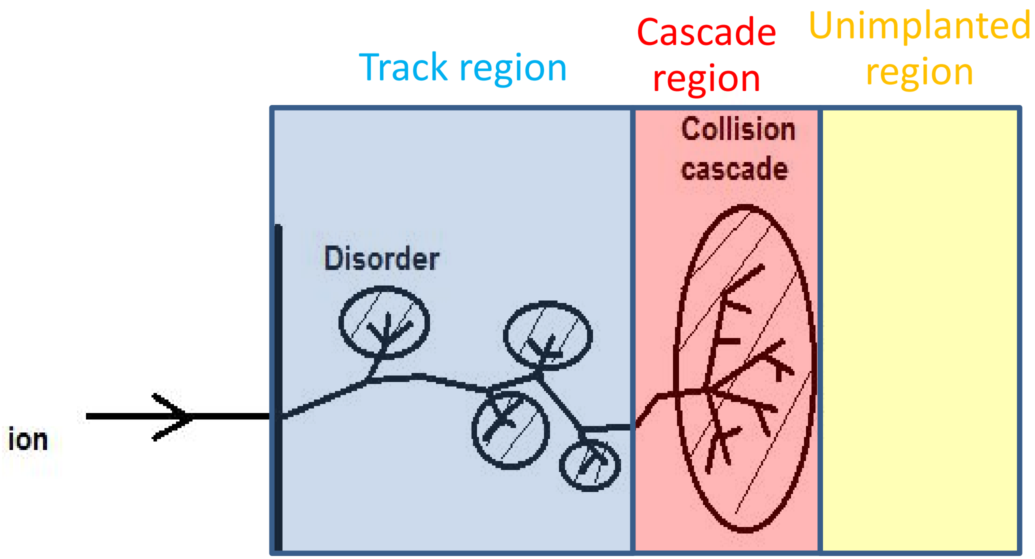
- Stopping and Range of Ions in Matter (**SRIM**)
- A group of computer programs which calculate interaction of ions with matter
- The core of SRIM is a program Transport of Ions in Matter (**TRIM**)

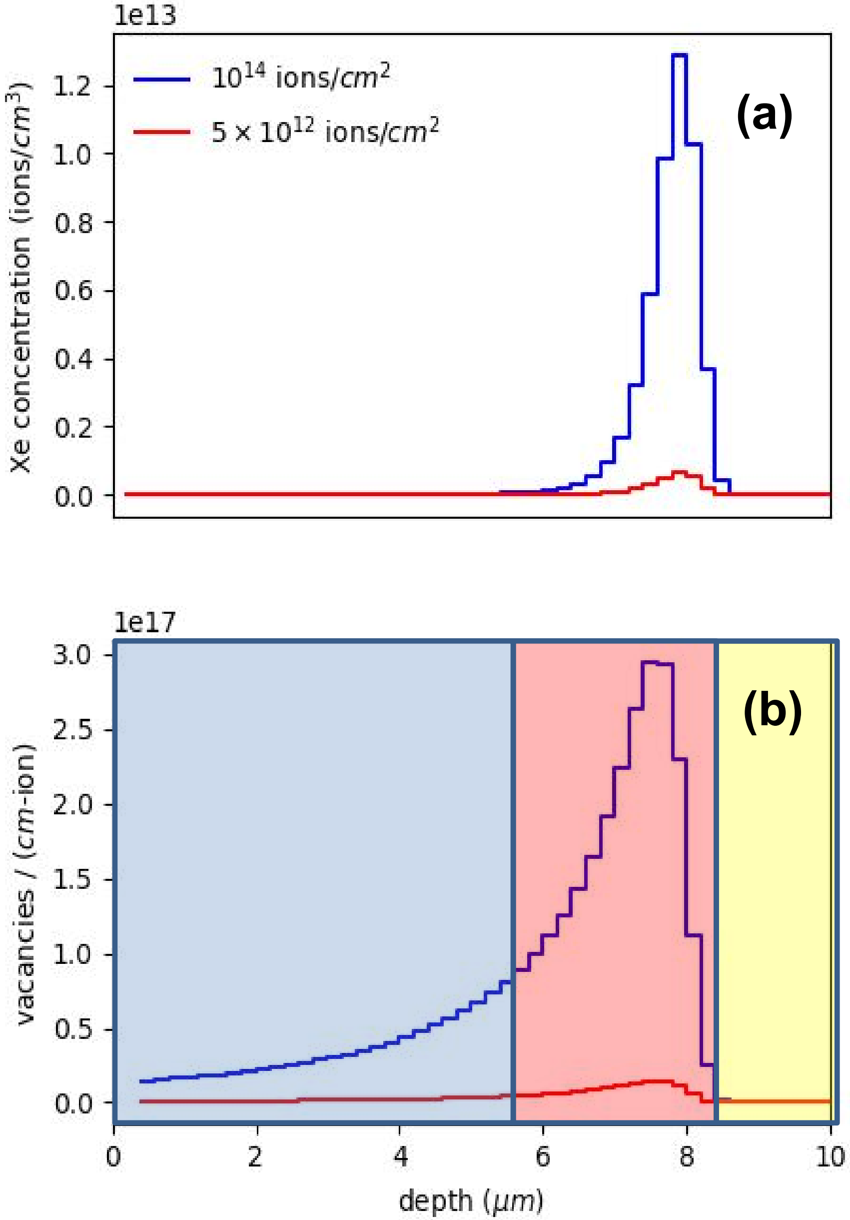
How does TRIM operate?



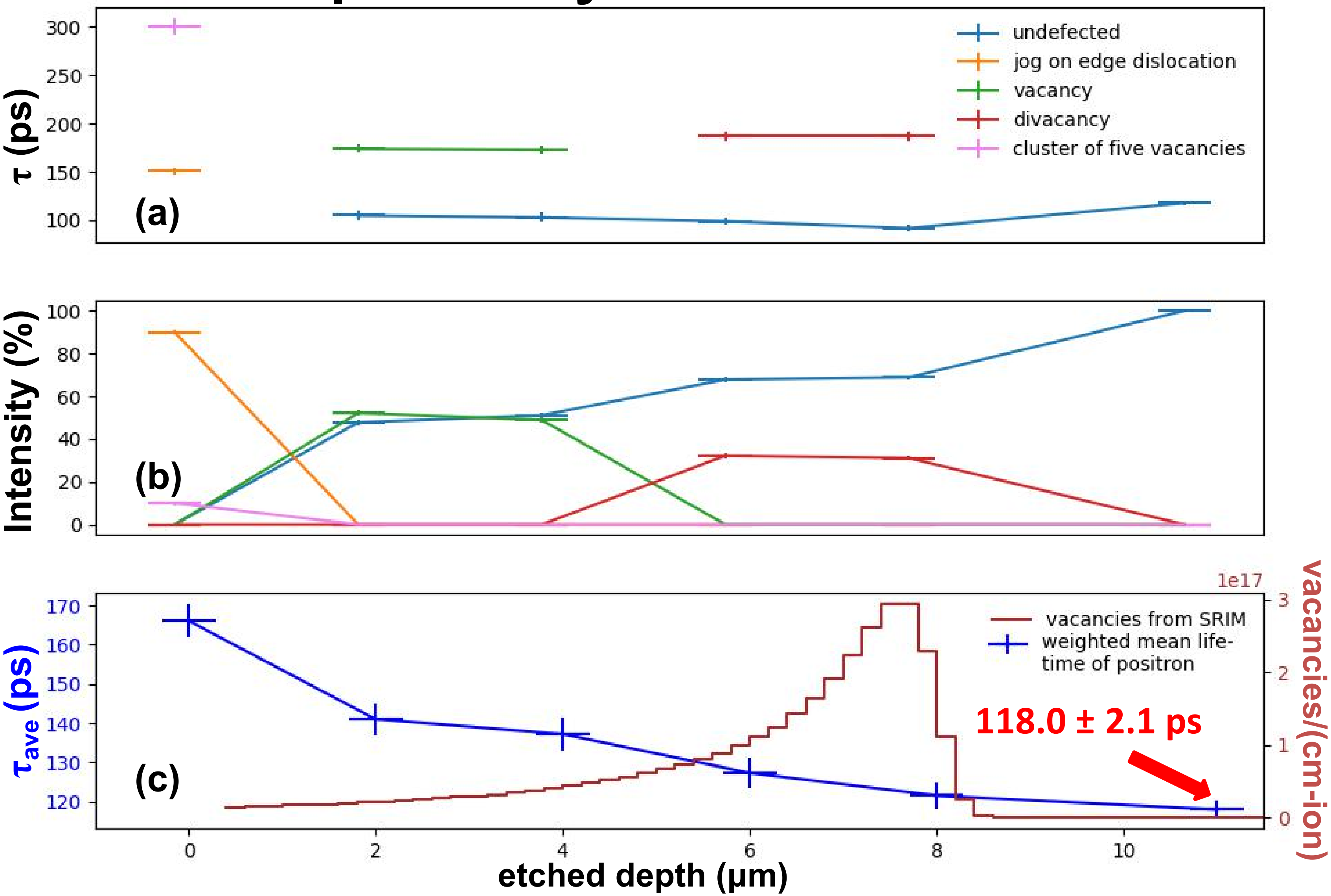
Section 3 (Storm Johnson, University of Cape Town)

Results from TRIM simulations

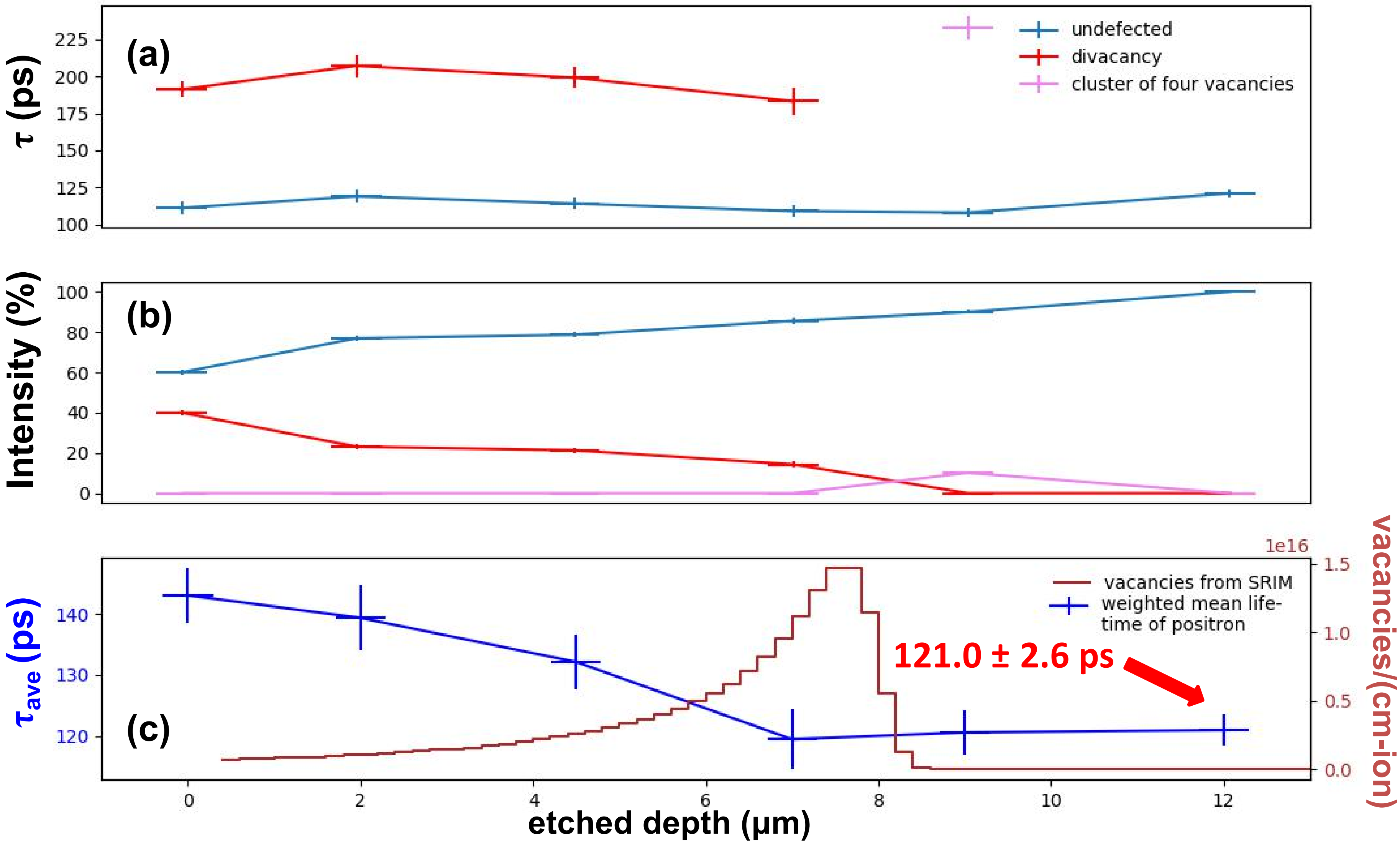




Defects of supermalloy irradiated with 10^{14} Xe ions



Defects of supermalloy irradiated with 5×10^{12} Xe ions



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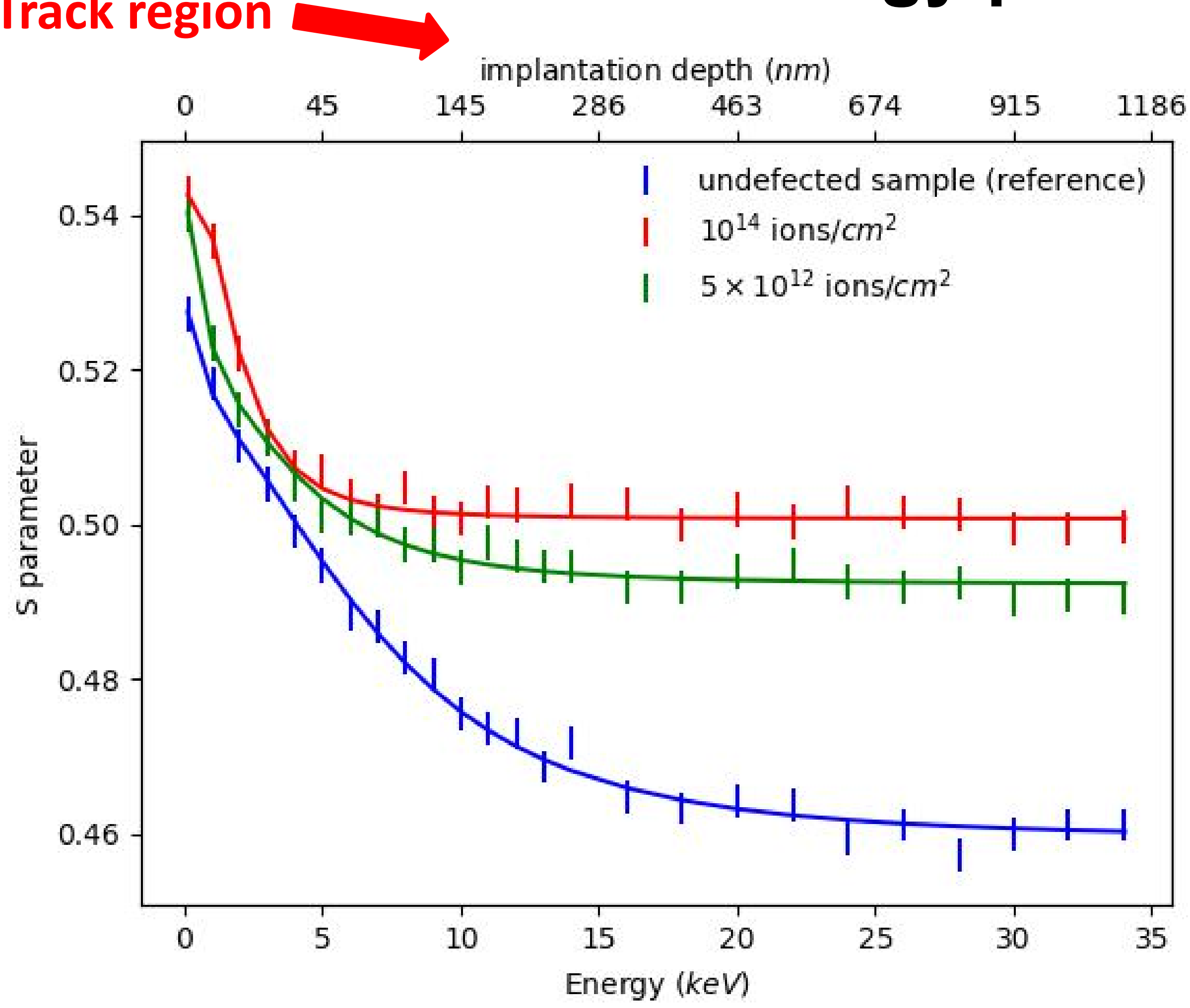
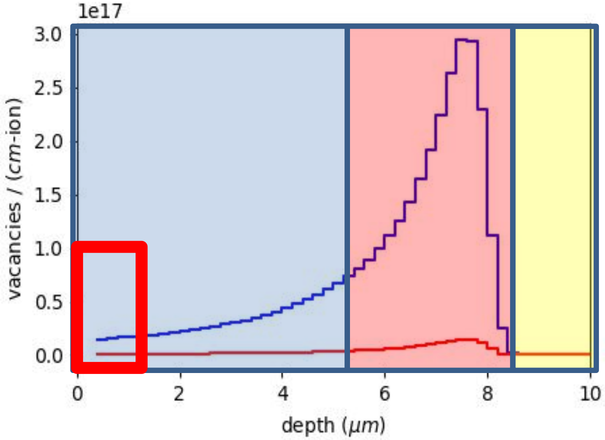
Results from measurements using the variable energy positron beam

Track region





Mean implantation depth

$$\bar{x} = \frac{AE^n}{\rho}$$

, where for supermalloy :

$A = 2.66\,\mu g.cm^{-2}keV^{-n}$

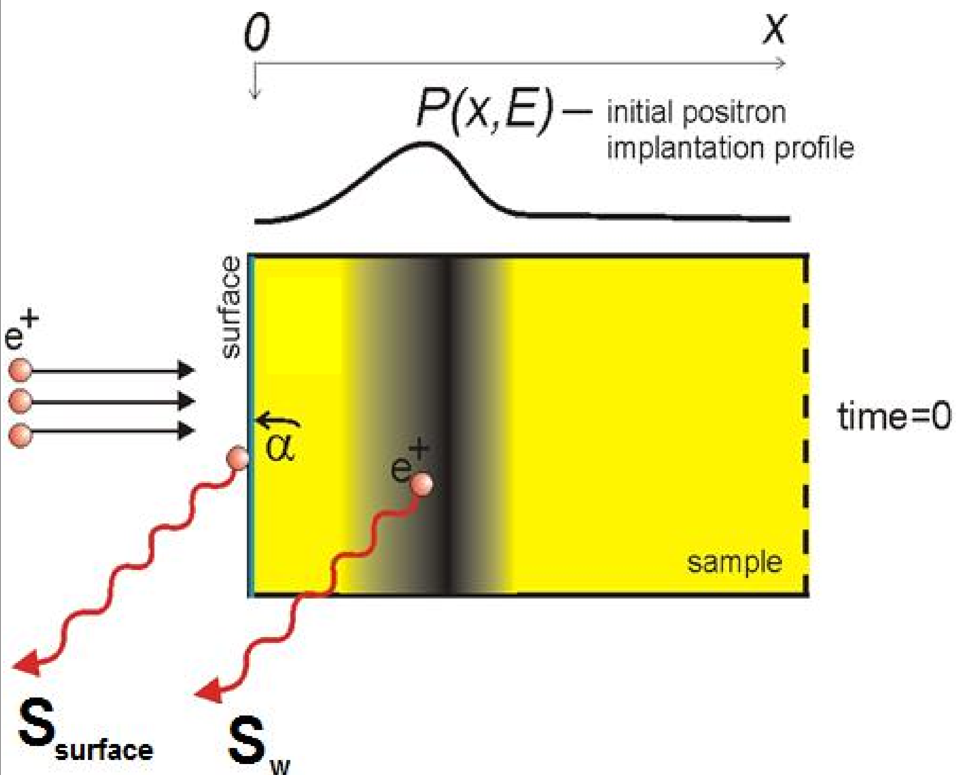
$n = 1.68$

$\rho = 8.76\,g.cm^{-3}$.

Results from measurements using the variable energy positron beam

Diffusion equation

$$S(E) = \mathrm{S}_w + (\mathrm{S}_{surface} - \mathrm{S}_w)\frac{\alpha}{\alpha + L_+\lambda_{bulk}}\int_0^\infty P(x,E)\exp(-x/L_+)dx$$



Makhovian implantation profile

$$P(x,E) = \frac{mx^{m-1}}{x_0^m}\exp\left[-\left(\frac{x}{x_0}\right)^m\right]$$

, where for supermalloy :

$$\langle m \rangle = 1.76$$

$$x_0 = BE^n$$

$$B = 3.67 \text{ nm.keV}^{-n}$$

Results from measurements using the variable energy positron beam

Diffusion equation

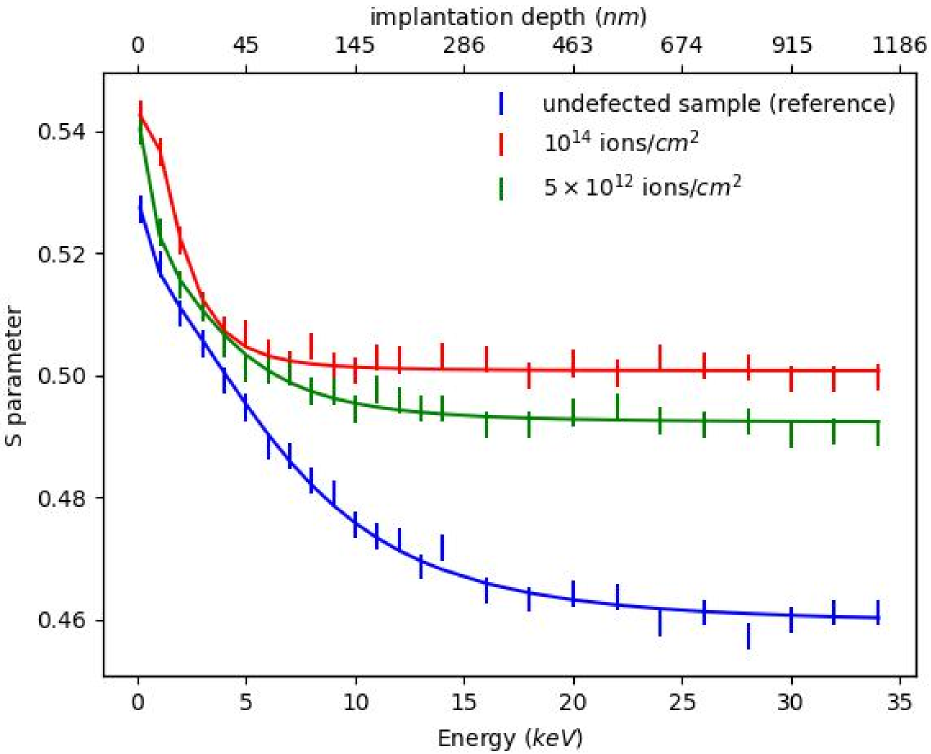
$$S(E) = S_w + (S_{surface} - S_w)\frac{\alpha}{\alpha + L_+\lambda_{bulk}}\int_0^{\infty} P(x,E)\exp(-x/L_+)dx$$

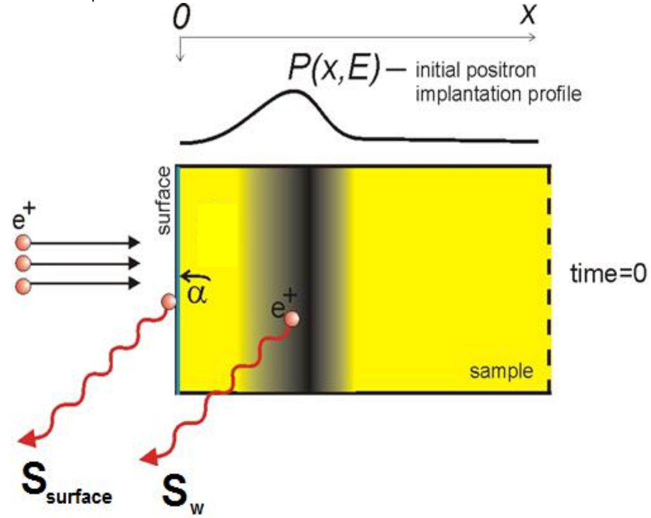
, where:

$S_{surface}$ - S value for surface

S_w - S value for defected area

L_+ - positron diffusion length





Defect concentration

$$C_v = \frac{1}{\mu\tau_{bulk}}\left(\left(\frac{L_{bulk}}{L_+}\right)^2 - 1\right)$$

, where:

L_+ and L_{bulk} are parameters obtained from the fit,

trapping coefficient μ and,

undefected positron lifetime τ_{bulk}

Calculating $\Rightarrow$

C_v for 10^{14} ions/cm^2 $= 1755 \pm 736$ ppm

C_v for 5×10^{12} ions/cm^2 $= 90 \pm 38$ ppm

Conclusions

- Irradiating samples with ions can produce a variety of defects in the samples
- This process can be modelled through Monte Carlo simulations using SRIM
- Types of defects in sample can be determined from positron lifetimes
- Variable energy positron beam technique can be used to study the defects in the track region
- Concentration of defects can be calculated from fit parameters of diffusion equation

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