

A Low Energy Radioactive Ion Implanter for Materials Studies

S. K. Shrestha^a, D.J. Smith^a, H. Timmers^a, A.P. Byrne^b, D.H. Chaplin^a, W.D. Hutchison^a, J.X. Wei^a

^aSchool of Physics, University of New South Wales at the Australian Defence Force Academy, Canberra, ACT 2600, Australia

^bDepartment of Nuclear Physics, Research School of Physical Sciences and Engineering, Australian National University, Canberra, ACT 0200, Australia

Introduction

Nuclear techniques of analysis such as Perturbed Angular Correlation (PAC) spectroscopy and Nuclear Magnetic Resonance of Oriented Nuclei (NMN) are well established for the study of structural and magnetic properties of crystalline materials. In both techniques a radioactive isotope is introduced into the material as a probe. Radioactive decays of the probing nuclei may be detected to extract information about local electric and magnetic fields and study, for example, structural properties of the host material or annealing processes. While diffusion is a common method to introduce radioactivity to host materials, with ion implantation the number of introduced nuclei can be controlled explicitly and is not affected by physical properties of the host material as is the case for diffusion. The use of negative-ion implantation has the added advantage that negative ions can be produced abundantly for most elements.

Recoil implantation of energetic radioactive ions is routinely used in Canberra, however, structural damage to crystals is often severe. The direct implantation of radioactivity at low energies would minimize such damage and improve the efficacy of NMN and PAC studies. A low energy ion implanter to facilitate such work is currently under development in the radiation laboratories (of the University of New South Wales) at the Australian Defence Force Academy.

The Implanter

SNICS Negative Ion Source

Implantation Energies: 50 - 150 keV

Mass Separation: Single-Focusing Dipole Magnet

Beam Transport: Quadrupole – Dipole – Quadrupole Magnets, Einzel Lens

Vacuum: $< 10^{-7}$ mbar

Four Position Target Ladder



- Cs⁺ ions are produced by a tantalum ionizer immersed in cesium vapour.
- The Cs⁺ ions strike material inside a cold copper cathode.
- Sputtered material partially forms negative ions.
- The negative ions are accelerated by passing through a potential difference of up to 150 kV.
- Ions are mass-selected using a single-focussing dipole magnet and implanted.

Mass Resolution

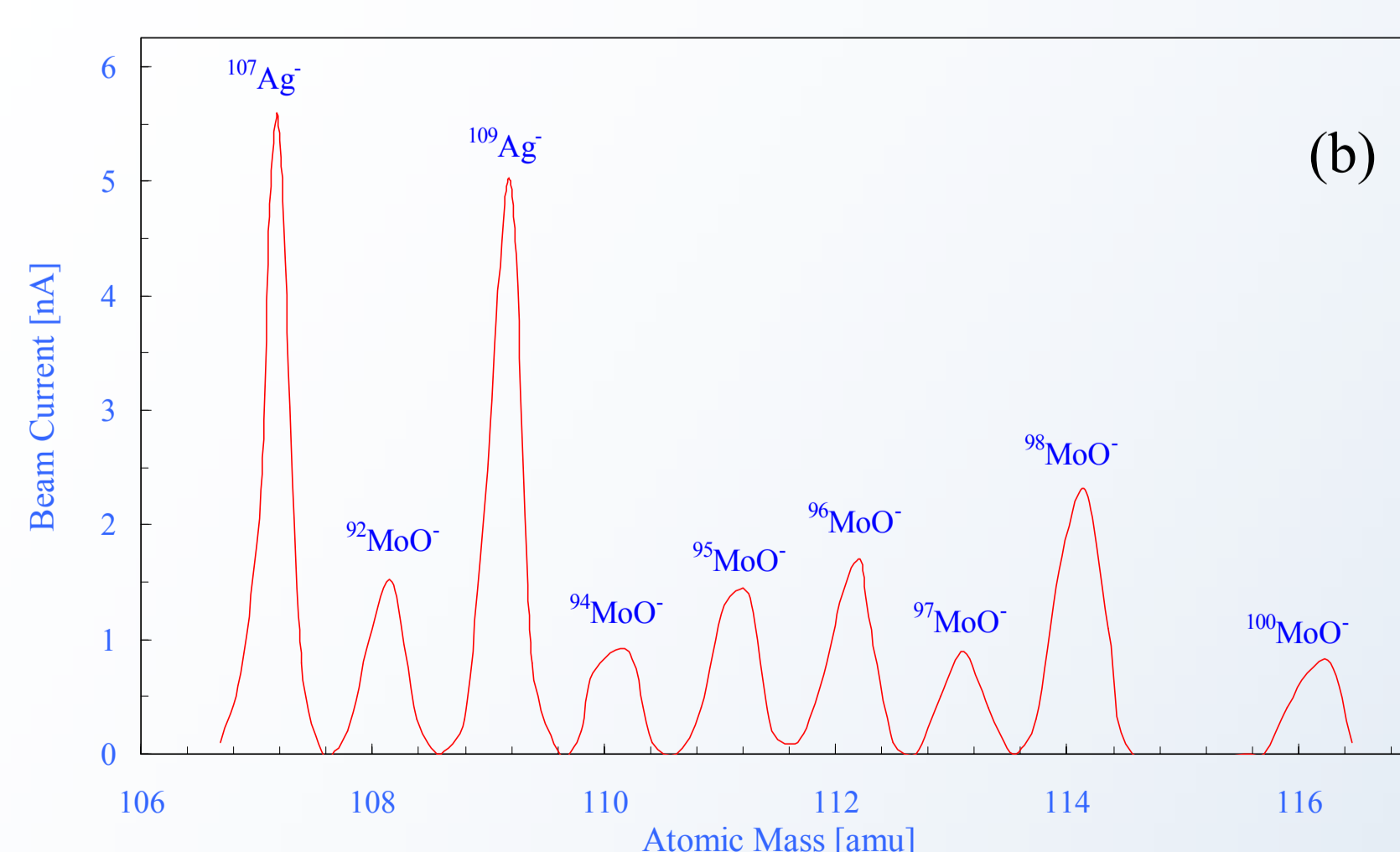
The mass resolution has been studied for several different ion source cathodes, including Al₂O₃, MoO, and In₂O₃.



Partial mass spectra for a MoO cathode.

(a) Peaks corresponding to different Mo isotopes can be clearly identified and are well separated.

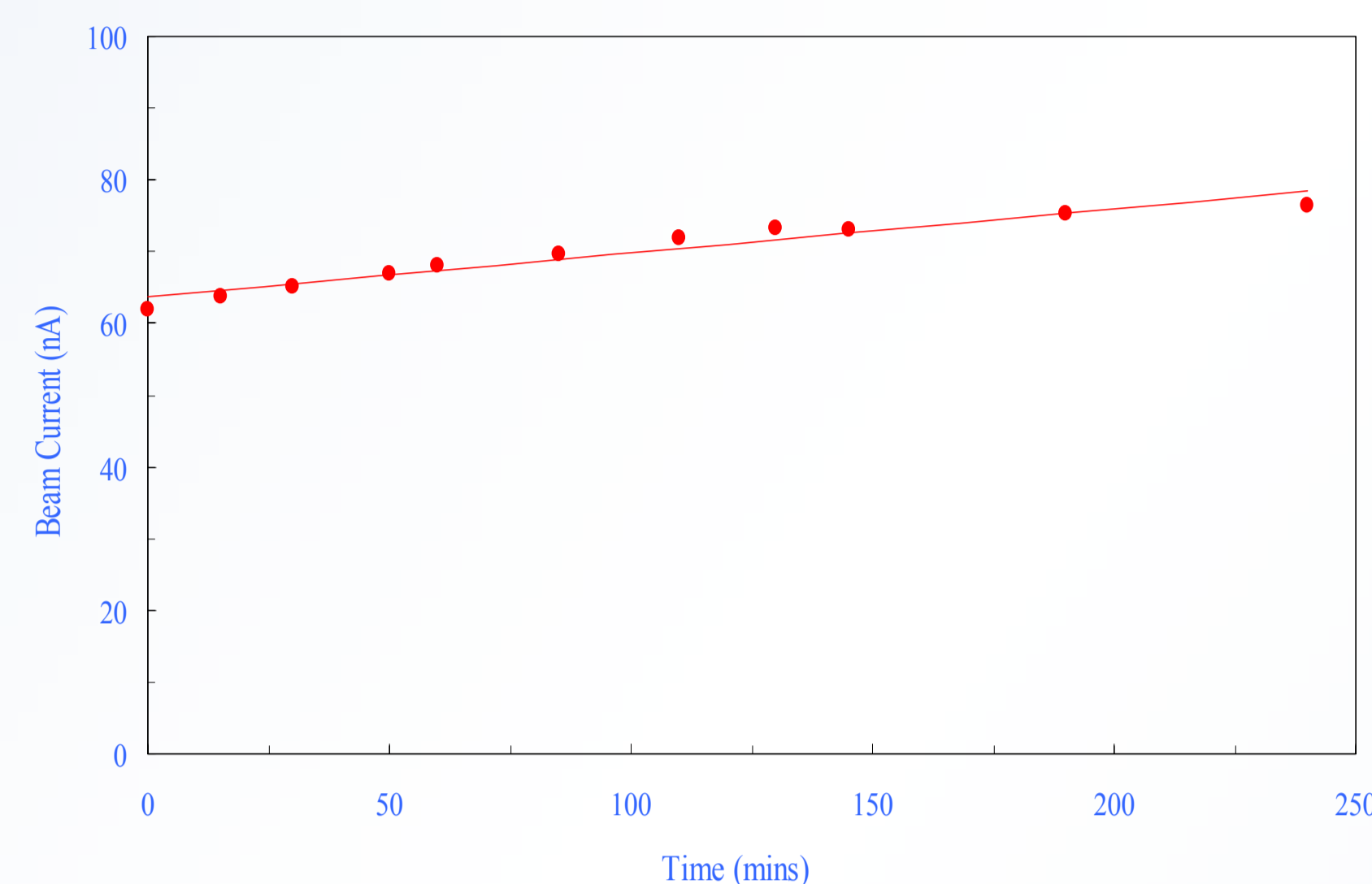
(b) The oxides of these isotopes and two peaks corresponding to residual Ag in the source are also well resolved.



- All stable Mo isotopes, two stable Ag isotopes from residual silver in the source, and molybdenum oxide ions are fully separated.
- Mass spectra are similar to those measured by Middleton [1].
- Over the interesting mass region of $1 < A < 130$ the ion species are resolved to better than 1 amu.
- This spans the mass number of radioactive ¹¹¹In, which is a standard PAC probe, but also a successful NMN probe.

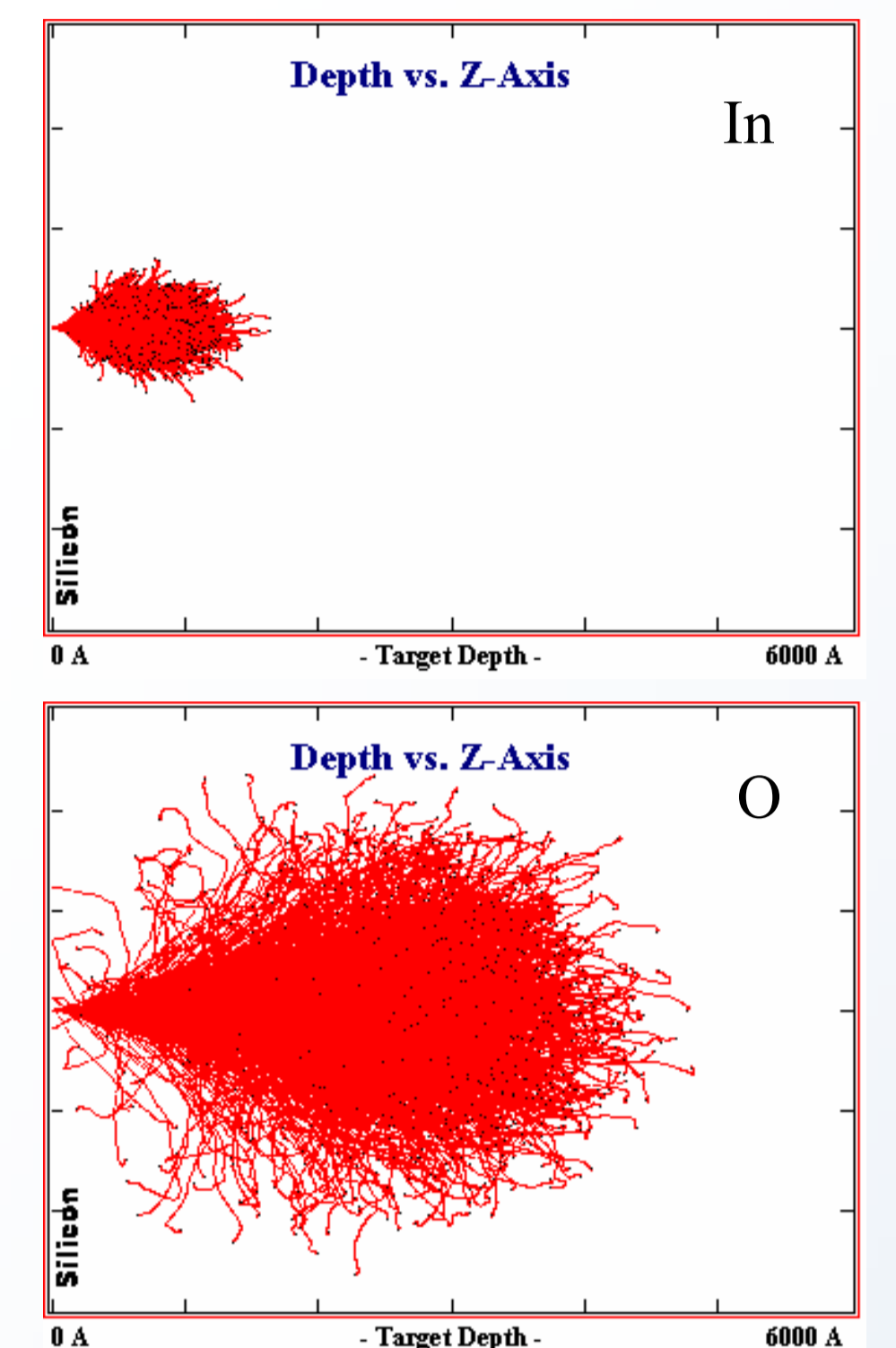
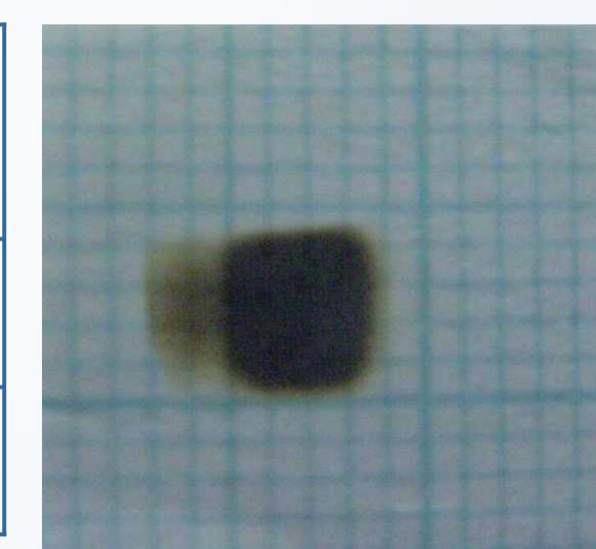
Implantation of Stable Nuclei

- 105 keV and 125 keV ¹¹⁵InO⁻ ions have been implanted into a silicon wafer.
- The oxide of the stable isotope was chosen, since the abundant production of elemental In ions has not yet been developed for this source.



Current of InO ions as a function of implantation time for a typical implantation. Averaging is possible as the current increases linearly during the implantation.

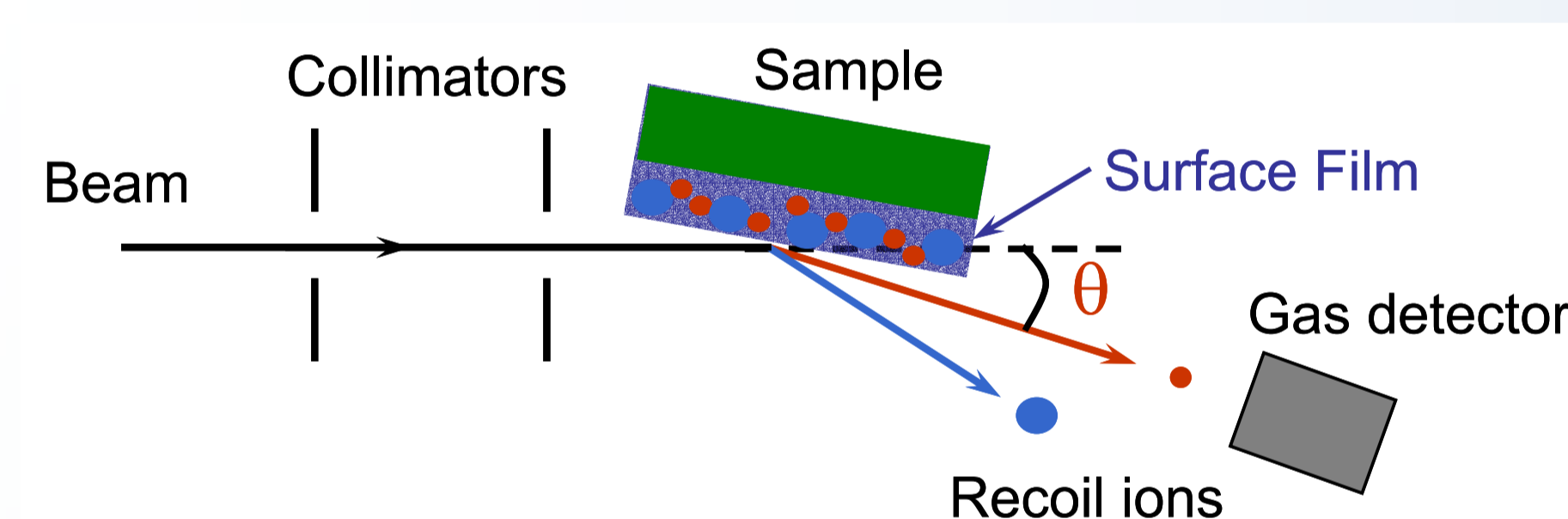
	Energy (keV)	Current (nA)	Time (min.)
Implantation I	125	89.3	105
Implantation II	105	71	240



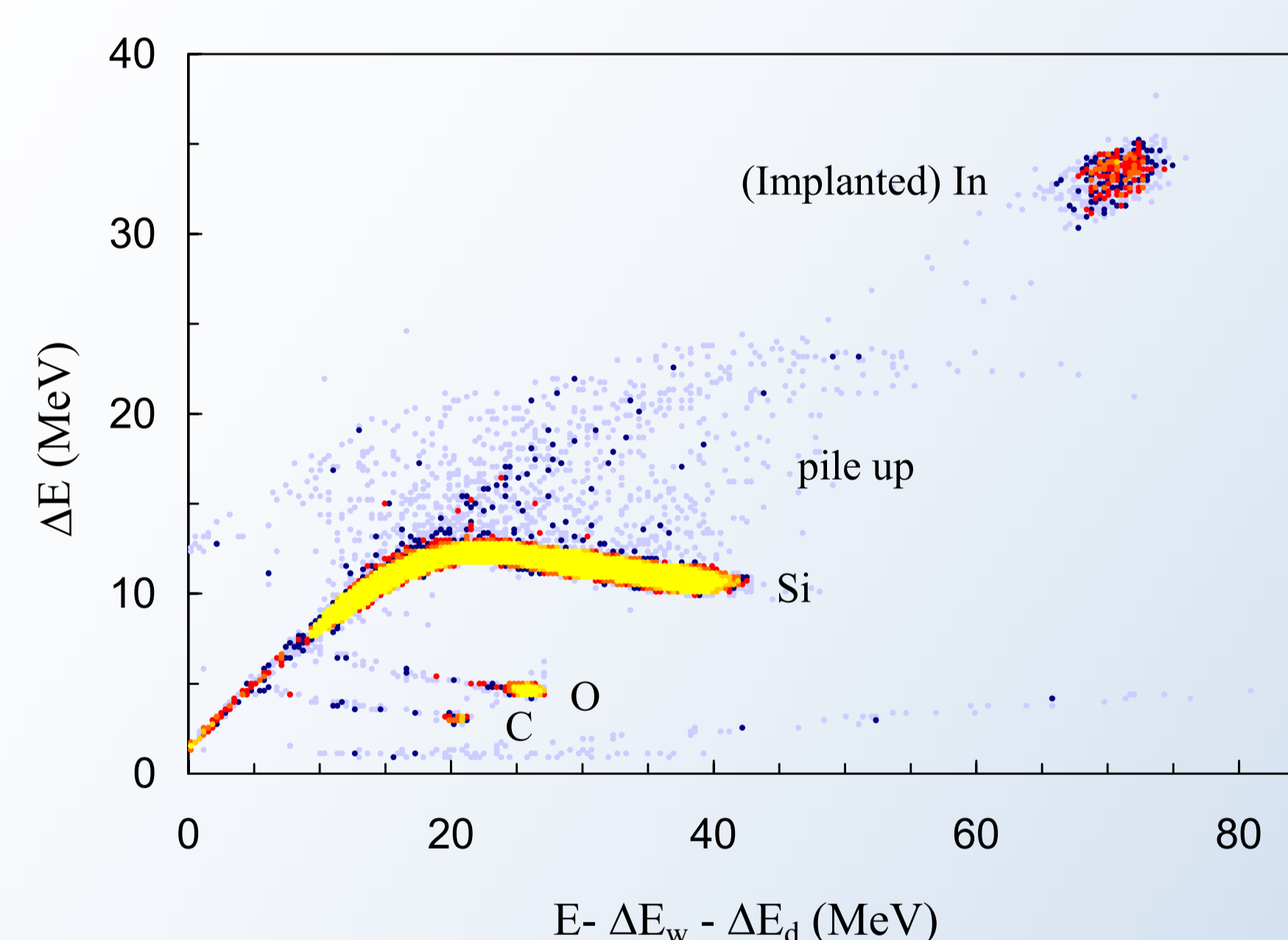
- SRIM simulations suggest a good separation inside the host of implanted In and O atoms.
- Implantation of InO⁻ may thus be an effective alternative to the implantation of elemental In.

The beam spot size for the implantations was chosen to facilitate subsequent analysis of the implanted area.

Elastic Recoil Detection



- Projectile ions strike the sample.
- Constituent nuclei recoil and are ejected.
- Recoil ions are detected by a gas ionization detector.



ERD analysis of an InO implanted silicon wafer. The energy loss signals ΔE for all detected recoil ions are plotted as a function of the reduced ion energy E . The spectrum shows in addition to implanted In and O, Si from the host, and traces of C from surface contamination.

- ERD analysis with a projectile beam of 200 MeV ¹⁹⁷Au [2].
- The measured fluences $2.1 \pm 0.3 \times 10^{16}$ at/cm² (105 keV implantation) and $5.7 \pm 0.7 \times 10^{16}$ at/cm² (125 keV implantation) agree with those measured during the implantation.

Summary and Outlook

- The low energy radioactive ion implanter at the Australian Defence Force Academy has been commissioned for the implantation of stable isotopes.
- A mass resolution of better than 1 amu has been achieved for ion masses in the range of $A = 1-130$. This includes the mass region around radioactive ¹¹¹In, which is a standard PAC probe, but also a successful NMN probe.
- Implantations of indium oxide ions into silicon have successfully been performed and verified with ERD analysis.
- Results suggest that the implantation of ¹¹¹In and other radioactive isotopes is feasible.
- It is planned to produce suitable ion source cathode material for the implantation of ¹¹¹In with the fusion reaction ¹²C + ¹⁰³Rh and the carbon beam being delivered by the 14UD Pelletron Accelerator in Canberra.

References:

[1] R. Middleton, A Negative Ion Cookbook, University of Pennsylvania, Philadelphia, USA.

[2] H. Timmers, T.D.M. Weijers, R.G. Elliman, Nucl. Instr. Meth. B 190 (2002) 393, and references therein.