A Low Energy Radioactive Ion Implanter for Materials Studies

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A negative ion source, variable energy (0 -150 kV) radioactive ion implanter is being developed to study the electric and magnetic properties of exotic solid state materials via ultra sensitive, hyperfine interaction spectroscopies such as PAC and NMRON. Recent commissioning tests have shown the facility to efficiently produce, mass-select and transport negative ion beams of various stable isotopes. Over the interesting mass range A = 1-130 the mass resolution is better than 1 amu. In preparation towards controlled implantation of the versatile ^{111}In radioactive probe, stable $^{115}InO^-$ molecular ions have been successfully implanted into crystalline silicon. The implantation and the accuracy of the fluence determination are verified with ERD.

1. Introduction

Nuclear condensed matter spectroscopies such as Perturbed Angular Correlation (PAC) and Nuclear Magnetic Resonance on Oriented Nuclei (NMRON) are well established for the study of structural, electrical and magnetic properties of relatively simple crystalline materials. In both spectroscopies a radioactive impurity isotope is introduced into the material as a probe, sensitive to the local electronic fields through characteristic precessional frequencies. The directional distribution of emitted radiation detected following decay may then provide information about these fields and subsequently structural and annealing properties of the host material. While thermal diffusion, melting and *in situ* particle irradiation are common methods to introduce radioactivity to (restricted) host materials, with ion implantation the number of introduced nuclei can be controlled explicitly, regardless of host limitations such as low temperature phase transformations, loss of single crystal phase integrity and, in the case of NMRON on metals, minimal radio frequency skin depth problems due to shallow implants. The use of negative-ion implantation has the added advantage of versatility; negative ions can be produced abundantly for many elements [1].

Recoil implantation of energetic radioactive ions is routinely used at the Australian National University (ANU), 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 NMRON and PAC studies. A low energy ion implanter to facilitate such work is currently under development in the radiation laboratories of the School of Physics at the Australian Defence Force Academy.

2. Description of the Facility

A photograph of the low energy radioactive ion implanter is shown in Fig.1. In the ion source Cs^+ ions are produced by a tantalum ionizer immersed in Cs vapour [2]. The Cs^+ ions strike material inside a cold copper cathode. Sputtered material partially forms negative ions by accepting electrons from neutral cesium atoms. The negative ions are then accelerated by passing through a potential difference of up to 150 kV. Following acceleration the ion beam is mass-selected using a single-focussing dipole magnet. Beam transport and 2D focussing are achieved with two sets of quadrupole magnet singlets, straddling the separator magnet

(Fig. 1). Mass-selected ions are focussed onto the sample with an electrostatic Einzel lens.

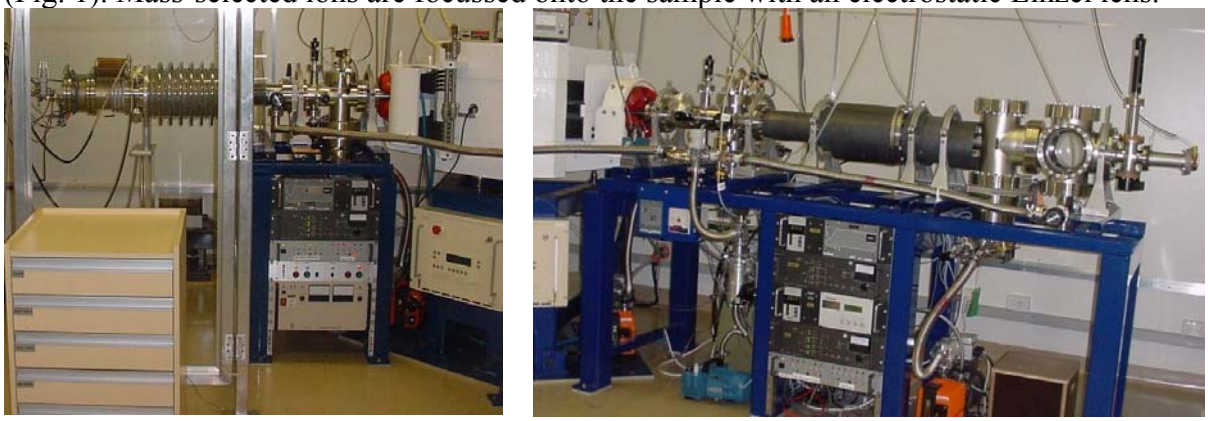

Fig 1: The low energy 150 keV radioactive negative-ion implanter.

3. Mass Resolution

The mass resolution achievable with the facility has been studied for several different ion source cathodes, including Al_2O_3, MoO, and In_2O_3. Mass spectra obtained for the MoO cathode are shown in Fig.2. It is evident that all stable isotopes of Mo are separated. The spectra are similar to those measured by Middleton [3]. The two stable silver isotopes from residual silver in the source and MoO ions can also be identified. The different ion species are resolved to better than 1 amu. The mass region studied spans the mass number of radioactive ^{111}In, which is a standard PAC probe, but also a successful NMRON probe.

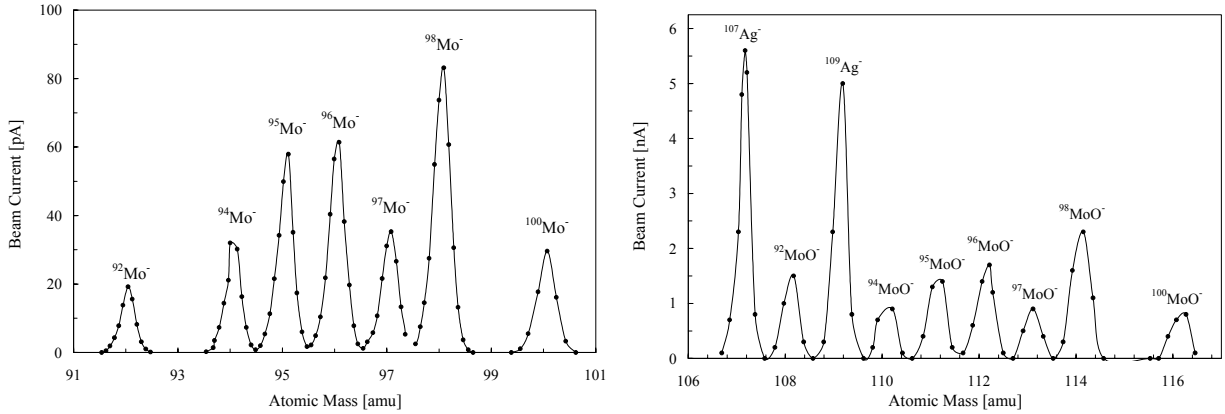

Fig.2: Partial mass spectra for MoO cathode. (a) Peaks corressponding to different Mo isotopes can be clearly identified and are well separated. (b) The oxides of these isotopes and two peaks corresponding to residual Ag in the source are also well resolved

4. Verification of ion implantation with ERD analysis

In order to verify that implantations of In ions can be performed with the facility, stable $^{115}InO^-$ ions have been implanted into a silicon wafer at test energies of 105 keV and 125 keV. The oxide was chosen since the abundant production of elemental In ions has not yet been developed for this source. Simulations of the implantation have been performed using the program package SRIM 2003 [4]. These suggest that the implanted In and O atoms are well separated inside the host, so that the co-implanted oxygen should not affect PAC measurements on the material.

For the 105 keV implantation, the current of $^{115}InO^-$ increased linearly from 62 nA to 76 nA over the duration of the implantation, which was 4 hours. The 125 keV implantation

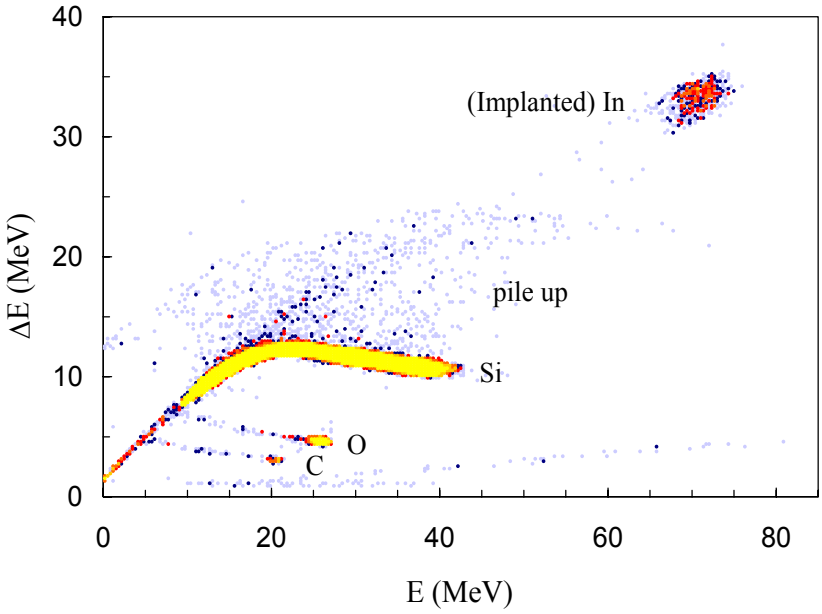

Fig.3: A two-dimensional spectrum from the ERD analysis of silicon wafers implanted with InO^-. The labels indicate groups of events associated with a specific element. In the colour scale yellow represents the highest number of counts, whereas light-blue corresponds to the lowest number of counts.

was broadly similar.

The implanted samples were analyzed with Elastic Recoil Detection (ERD). Details of the ERD technique are given elsewhere [5]. Here, a projectile beam of 200 MeV ^{197}Au ions was used. The recoil ions were detected at a scattering angle of 45º using a gas ionization detector with a detection solid angle of 3.5 msr. The measured energy loss signals ΔE of the recoil ions as a function of the detected ion energy E, for one of the implanted samples, are displayed in Fig. 3. In this 2D spectrum, groups of events associated with a particular element can be distinguished. Analysis of the spectrum shows that in addition to In, O and Si (from the host), traces of C are also present in the silicon wafer and as surface contamination. Most of the oxygen is from the implantation and some presumably also from surface contamination. Quantitative analysis of the ERD data shows that the indium was implanted with fluences of 2.1 ± 0.3 x 10^{16} atoms/cm^2 and 5.7 ± 0.7 x 10^{16} atoms/cm^2 in the 105 keV and 125 keV implantations, respectively. These values agree with the fluences deduced from the beam current measurements during implantation.

5. Conclusions

The production, transport and implantation of different ion beams of stable isotopes have been demonstrated for the new radioactive ion implanter at the School of Physics. Mass resolution better than 1 amu has been achieved for A = 1-130. Implantations of stable indium oxide ions into silicon have successfully been performed and verified with ERD analysis. The results suggest that the implantation of ^{111}In and other radioactive isotopes is feasible with this facility. As the next development step it is planned to produce suitable ion source cathode material for the implantation of ^{111}In by using the fusion reaction ^{12}C + ^{103}Rh with the carbon beam being delivered by the 14UD Pelletron Accelerator at the ANU in Canberra.

Acknowledgements

The authors are grateful for the technical support they have received from the workshops at the School of Physics, and from David Weisser and Tony Watt of the ANU.

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