

SELECTION OF RIB TARGETS USING ION IMPLANTATION*

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ABSTRACT

Experimental studies are under way at the Oak Ridge National Laboratory (ORNL) which are designed to measure the time evolution, ionization efficiencies, and release efficiencies of implanted elements diffused from refractory target materials which are candidates for forming radioactive ion beams (RIBs) at the Holifield Radioactive Ion Beam Facility (HRIBF). The diffusion coefficients are derived by comparing experimental data with numerical solutions to a one-dimensional form of Fick's second law for ion implanted distributions. In this report, we describe the experimental arrangement and provide time release data and diffusion coefficients for releasing ion implanted Cl from Zr_5Si_3 and ^{75}As , ^{79}Br , and ^{78}Se from Zr_5Ge_3 .

These experiments [4] are similar to those carried out at GSI [5] and are designed to measure the time evolution, release efficiencies, and diffusion coefficients of implanted species diffused from refractory target materials which are candidates for forming radioactive beams at the HRIBF. These experiments permit selection of the refractory target material most appropriate for swift release of the element of interest, as well as realistic estimates of the efficiency of the ion source for providing ion beams of the species prior to actual radioactive beam generation. For this purpose, we describe experimental equipment, procedures, and predicted release times for Cl implanted into Zr_5Si_3 and As, Br, and Se implanted into Zr_5Ge_3 . The diffusion coefficients derived from the experimental data are then used to model the release of radioactive ion beams from homogeneously distributed planar and spherical geometry targets which represent the actual distributions and target geometries which will be used for RIB generation at the HRIBF.

1 INTRODUCTION

Ion implantation offers a cost effective and powerful technique for predetermining the time-release behavior of stable complements of interesting radioactive species from target materials which are candidates for RIB generation in facilities such as the HRIBF now under construction at ORNL.¹ The method can also be used, as well, for determining diffusion coefficients for many element/target combinations which are fundamentally important toward the understanding of the kinetics and chemistry of the diffusion process.

Experiments are under way at the HRIBF which utilize HHIRF tandem accelerator beams to implant stable complements of interesting radioactive atoms into refractory targets mounted in the UNISOR [2] version of the FEBIAD ion source [3].

2 EXPERIMENTAL APPARATUS AND PROCEDURES

The 25-MV tandem accelerator, which will serve as the primary accelerator for RIBs at the HRIBF, is utilized to implant stable complements of interesting radioactive atoms into refractory targets maintained in the on-line FEBIAD ion source which is the standard source used at the UNISOR facility.

Before entering the target, the ion beam passes through a thin window of some heavy elemental material, such as tantalum, which slightly degrades the energy of the beam. The final energy after passing through the window is

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chosen so that the ions penetrate to a depth of 15 to 35 μm in a thin circular disk (~ 9 mm in diameter and ~ 1.5 mm in thickness) of the material of interest. The simulation program, TRIM [6], is used to numerically determine the position and distribution of the implanted species within the target material.

The target temperature, prior to ion implantation, is typically 1645°C; beam heating effects raise the target temperature in proportion to the beam power; this effect has been measured; typically a 10-Watt beam raises the temperature by an additional 50°C. The target, thus, resides at $\sim 1700^\circ\text{C}$ during the implantation. Particles diffuse out of the face of the entry side of the target, and effuse into the anode region of the ion source where they are bombarded with an electron beam accelerated from a hot cathode. A fraction of the particles are ionized, accelerated from the ion source, and mass analyzed. The intensity versus time spectra for each implanted species is monitored and recorded for both the "beam-on" and "beam-off" regions of the spectra. Typically, the intensity with beam-on-target increases until "saturation" is reached, at which point in time the beam is turned off. The time required to release 50% of the saturation value is defined as the release time for the particular species/target combination.

A simulation program called DIFFUSE [7] is used to solve Fick's second equation [8] and to determine diffusion coefficients D for Cl diffusing from Zr_5Si_3 and As, Br, and Se diffusing from Zr_5Ge_3 . The input parameters required by DIFFUSE include the particle distribution function as calculated by the use of TRIM, the depth of implantation, and the temperature T of the sample. Initial estimates of D are determined by fits to the data in the tail of the beam-off part of the intensity versus time release curve. D is then iteratively altered until an acceptable fit to the data is found.

3 RESULTS

The time-release information derived from ion implanted samples which have sharply Gaussian distributions is only of qualitative value for estimating release of radioactive species from actual RIB target materials which are more or less uniformly distributed within the sample. The release times from implanted targets are dependent on the sample temperature T , the initial distribution, as well as the depth of the implanted material. Therefore, information derived from such experiments cannot be directly used to predict release times of the complementary, short-lived, homogeneously distributed, radioactive species from the same target material. However, diffusion coefficients D can be derived by fitting solutions to Fick's second equation to experimental release data; the diffusion coefficients can then be used to predict release times of short-lived radioactive

complements of the implanted species from homogeneously distributed, planar- or spherical-geometry samples operated at the same temperature T which are the principal target geometries that will be used for actual RIB generation.

The experiments described in this paper were performed by implanting Cl^{18+} into Zr_5Si_3 and As^{13+} , Br^{13+} , and Se^{13+} ions into Zr_5Ge_3 targets maintained in the anode structure of the FEBIAD ion source. Figures 1 and 2 display the respective experimental time-release profiles, as well as comparisons with theory, for Cl implanted into and diffused from Zr_5Si_3 and Se implanted into and diffused from Zr_5Ge_3 samples. Diffusion coefficients, ranges of implantation, and release times for these projectile/target combinations are listed in Table I. From fits to these data, diffusion coefficients are derived which then can be used to predict the release times of short-lived radioactive species from homogeneously distributed spherical- or planar-geometry targets at the same temperatures. However, activation energies must be known in order to accurately predict the release times at other temperatures. Future plans call for the use of an ion source which has provisions for target temperature control.

6 CONCLUSIONS

The results of the present experiments clearly demonstrate that the ion implantation technique can be utilized as a practical and cost-effective means for evaluating candidate refractory targets for releasing specific elemental materials prior to their actual use in generating radioactive ion beams. Release time and efficiency information derived from such experiments can be used to realistically estimate beam intensities which could be generated in a particular ISOL ion source during RIB beam generation. Diffusion coefficients extracted from this data can also be used to optimize the target particle size and geometry in order to minimize the release time of the element of interest from the candidate target material. Diffusion coefficients are fundamentally important in many areas of solid-state physics, solid-state chemistry, and metallurgy. The method also offers a fast, simple, and cost-effective means for determining diffusion coefficients for element/solid target material combinations which are often time consuming, expensive and tedious to derive experimentally by other means. The method is only valid whenever the diffusion time τ_d is much longer than the effusion delay time τ_e and the transit time τ_t from the ion source to the detection system or τ_e and τ_c are known.

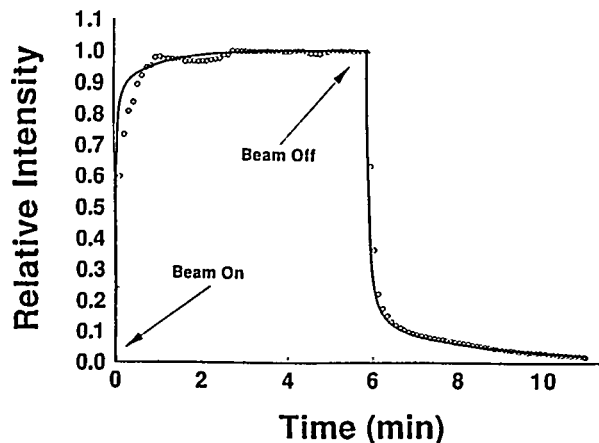


Fig. 1. Typical "beam-on-target" and "beam-off-target" time-dependence of $^{35}\text{Cl}^+$ ion beam intensity released from Zr_5Si_3 . The theoretical fits to the experimental data were determined by solution to Fick's second equation using the computer code DIFFUSE [7]; o experimental; — theoretical.

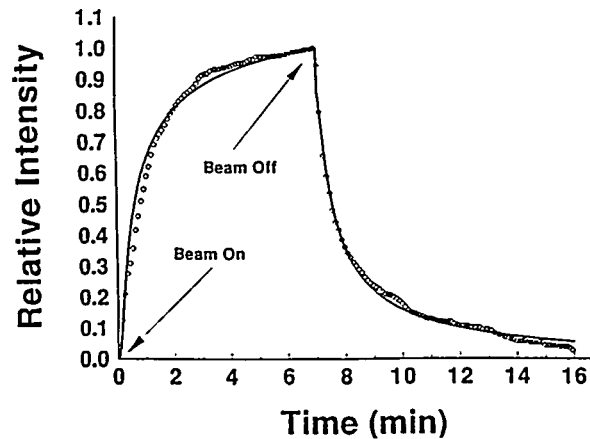


Fig. 2. Typical "beam-on-target" and "beam-off-target" time-dependence of $^{78}\text{Se}^+$ ion beam intensity released from Zr_5Ge_3 . The theoretical fits to the experimental data were determined by solving Fick's second equation by use of the computer code DIFFUSE [7]; o experimental; — theoretical.

Table I. Times τ and Diffusion Coefficients D for Selected Ion Implanted, Candidate RIB Species/Target Material Combinations

Species	Target Material	Implantation Depth (μm)	Target Temperature ($^{\circ}\text{C}$)	D (cm^2/s)	τ (s)
Cl	Zr_5Si_3	26	1695	1.2×10^{-5}	13
As	Zr_5Ge_3	18	1670	5.1×10^{-8}	39
Br	Zr_5Ge_3	16	1675	5.2×10^{-7}	7
Se	Zr_5Ge_3	18	1670	5.1×10^{-8}	40

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6. TRIM - the Transport of Ions in Matter, J. F. Ziegler, IBM Research, Yorktown Heights, New York 10598, USA.
7. DIFFUSE is a program that solves one- and three-dimensional forms of Fick's second equation. The code was written by G. D. Alton, J. Dellwo, and I. Y. Lee.
8. See, for example, *Diffusion in the Condensed State*, J. S. Kirkaldy and D. J. Young (The Institute of Metals, London, 1987), Ch. 1.

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