

Degradation of Lithium fluoride thin targets on Carbon Backing Irradiated with 68 MeV ^{17}O Beams at EMMA Facility of TRIUMF



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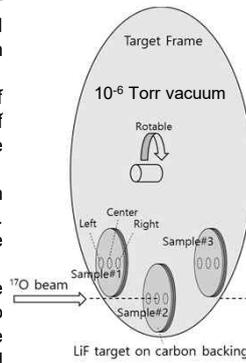
1. Introduction

- An experiment was conducted to investigate the possible influence of a reaction on the astrophysical s process. To study the states dominating the $^{17}\text{O}(\alpha,\gamma)^{21}\text{Ne}$ reaction rate indirectly, $^{7}\text{Li}(^{17}\text{O},t)^{21}\text{Ne}^*(\gamma)^{21}\text{Ne}$ reaction was measured. ^{17}O beam accelerated to 68 MeV at ISAC-II was impinged on a thin lithium fluoride (LiF) target on carbon backing for populating states in ^{21}Ne through the $^{7}\text{Li}(^{17}\text{O},t)^{21}\text{Ne}$ reaction.
- In the experiment, failures caused by lattice damage caused by radiation in all the targets occurred during the beam running time. A study was conducted to analyze the cause of target destruction of the target so that the next same experiment could be conducted again efficiently with the prediction of target lifetime.

2. Methods & Results

Experimental setting

- Continuous $^{17}\text{O}^{4+}$ beam with 1 mm beam diameter (FWHM: 0.8 mm) accelerated to 68 MeV at ISAC-II was continuously impinged perpendicularly on a thin LiF target on carbon backing.
- LiF films with a thickness of 100 $\mu\text{g}/\text{cm}^2$ and density of 2.635 g/cm^3 were deposited on carbon backing films of thickness 30 $\mu\text{g}/\text{cm}^2$ and density 2.25 g/cm^3 . The three target samples (#1, #2 and #3) were used.
- The area to which the beam is irradiated for each target was divided into three: left, center and right. Targets were mounted onto target frames which were fixed to the rotatable target wheel in a target chamber.
- A Faraday cup inside the target chamber can be maneuvered into the beam path periodically to measure the absolute beam current. During the experiments, the currents were measured as around from 1.0 to 6.6 nA corresponding to 1.6×10^9 to 1.0×10^{10} ions/s.



Target lifetime investigation

- Yntema and Nickel have made a significant contribution to the development of the model for destruction of the thin target in heavy ion beam. The durability of solid target when bombarded with heavy ions is mainly determined by sputtering, thermal evaporation and lattice damage caused by radiation [1].

Thermal evaporation and target lifetime

- The lifetime (t_E) of thin targets as determined by evaporation can be expressed by

$$t_E \approx \frac{N_0 d}{3 \cdot 2V(T)} \quad (1) [1]$$

N_0 , d are the atomic density and target thickness, respectively. $V(T)$ is the time rate of evaporated target atoms per surface area as a function of the target temperature T [2].

- For the calculation of temperature, the energies deposition per volume unit per incident ion on graphite and LiF film as a function of target depth and radial distance are calculated by Monte Carlo code of FLUKA (Fig. 1. (a)). With the data from the energy deposition as a function of the radial distance, the temperature of both is explored as a function of target depth and radial distance by steady state thermal analysis using ANSYS assuming the beam intensity is 1.0×10^{10} ions/s (Fig. 1. (b)).

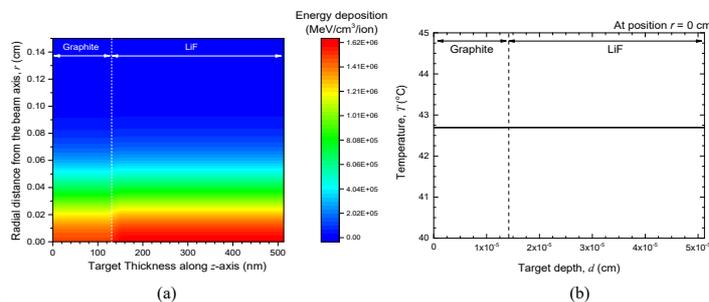


Fig. 1. (a) 2D map of the deposited energy per volume unit per incident ion. In the z-axis direction graphite film is in the range of 0 ~ 133 nm and LiF film is in the range of 133 ~ 512 nm. (b) Temperature as a function of target depth for graphite and LiF film at center of beam path $r = 0$. The horizontal line: $T(d, r = 0) = 42.7^\circ\text{C}$.

3. Conclusion

- The lifetime of thin LiF film as determined by lattice damage was calculated for the first time using the equation (1) Nickel et al. suggested, and there was good agreement between the calculated and the experimental lifetime.

4. Reference

- [1] Yntema, J. L., and F. Nickel. "Targets for heavy ion beams." Experimental Methods in Heavy Ion Physics. Springer, Berlin, Heidelberg, 1978. 206-235. Sigmund, Peter.
- [2] Gikal, B. N., et al. Calculation of lifetime of charge-exchanging carbon targets in intense heavy ion beams. No. JINR-R-9-2005-110. Flerov Laboratory of Nuclear Reactions, 2005.
- [3] Toulemonde, M., et al. "Electronic sputtering of metals and insulators by swift heavy ions." Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 212 (2003): 346-357.
- [4] Liu, J., et al. "Tracks of swift heavy ions in graphite studied by scanning tunneling microscopy." Physical Review B 64.18 (2001): 184115.
- [5] Refke, A., V. Philipps, and E. Vietzke. "Chemical erosion behavior of graphite due to energetic oxygen impact." Journal of nuclear materials 250.1 (1997): 13-2

- The calculated maximum temperature is 42.7°C at the center of beam path. Thermal sublimation(evaporation) rates $V(T)$ of LiF and graphite are calculated as 0.0 using Hertz-Knudsen equation:

$$\Phi = \frac{N_A p_v}{\sqrt{2\pi M R T}} \quad (\text{molecules cm}^{-2}\text{s}^{-1}). \quad (2)$$

N_A , M , R and p_v are the Avogadro's number, the molecular weight, gas constant and vapor pressure.

- Thermal evaporation does not affect the target lifetime under the given experimental conditions.

Sputtering and target lifetime

Electronic stopping powers in C and LiF film calculated by TRIM are 1.10 keV/nm and 1.14 keV/nm, respectively, but they cannot exceed the thresholds for electronic sputtering of LiF [3] and C [4]. Also, nuclear sputtering yields in both C and LiF films are negligible as they are less than 0.0 using TRIM. It was found that the chemical sputtering yield of carbon during oxygen ion impingement on carbon is close to 1 independent on temperature and incident ion energy [5]. Nuclear, electronic and chemical sputtering yield are all small enough that lifetime t_s of target determined by sputtering does not need to be considered.

Radiation damage and target lifetime

- The energy loss of energetic heavy ions caused by elastic atomic collisions with target atoms, which is named as nuclear stopping power $(\frac{dE}{dx})_n$, can lead to atomic displacements in solid state targets. The lifetime (t_D) of thin targets as determined by lattice damage and stress was suggested by Nickel et al. (1969) [1] to be

$$t_D \approx \frac{N_0}{2N_D} \quad (3)$$

N_D is the time rate of atomic displacements per unit volume caused by heavy ions.

- For the estimation of the lifetime of the target as determined by lattice damage, N_D (displacements/cm³/s) for each material could be derived from Monte Carlo Calculation of TRIM using full cascade model and FLUKA . 1.4 eV and 21 eV of displacement energies for LiF and graphite were taken in the calculation, respectively.

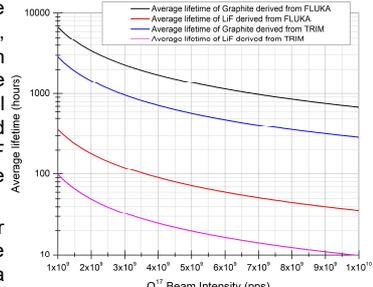


Fig. 2. Average lifetime of carbon and LiF in beam diameter spot as a function of ^{17}O beam intensity

- The average lifetime in beam diameter spot determined derived from the equation (1) can be expressed as a function of beam intensity as shown below in Fig. 2.
- Areas exposed to different fluences at the target are degraded and perforated in around beam diameter spot size. Using equation (3), lifetime of the target was calculated with N_D obtained from TRIM. Calculated lifetime of the target is compared to the experimental lifetime which is the period of being used before disposal as shown in table I. Calculated lifetime of the target with LiF deposited on carbon is determined as the calculated lifetime of only LiF film, not carbon film due to long lifetime. the LiF films seem to be degraded due to lattice damage, and the moment LiF film may be perforated or torn, the carbon film which has been intact may be also torn together.

Table I: Comparison of calculated lifetime and time to rejection in the experiment

	Sample#1 center	Sample#1 right	Sample#1 left	Sample#2 center	Sample#2 right	Sample#3 center
Fluence (ions/cm ²)	4.59E+16	4.82E+16	3.73E+16	4.34E+16	2.90E+16	1.19E+16
DPA (Displacement/atom)	6.23E-01	6.54E-01	5.06E-01	5.89E-01	3.93E-01	1.61E-01
Average intensity (ion/s)	4.39E+09	4.72E+09	6.07E+09	5.35E+09	3.18E+09	5.39E+09
Experimental lifetime (hour)	22.8	22.3	13.4	17.7	19.9	4.8
Calculated lifetime (hour)	20.3	18.9	14.7	16.6	28.0	16.5