Sustainability and stability of lanthanide targets for high fluence beam facilities

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Introduction

With the advent of complex experiments intended at addressing problems associated with rare and exotic nuclear isotopes, there is a constant demand for a holistic development on all fronts ranging from theoretical framework to front end electronics used. Detector setups have improved leaps and bounds with the active use of advanced gamma ray detectors like segmented high purity germanium (HPGe) [1], instead of the conventional HPGe [2]. Besides the hardware stage, there have also been multiple critical improvements in the way data is acquired and processed for complete information regarding a particle interaction within a detector volume. As an active example, pulse shape analysis (PSA) [3] associated with segmented HPGe has drastically boosted gamma array efficiencies all the way up from ~10% to 30-40% [1]. Besides gamma ray detection, improvements have occurred in the realm of particle detectors as well with new position sensitive detectors now available [4] that can be very useful in tracking charged particles.

Certainly, all this development at the down-stream end of an experiment must be preceded by complementary improvements at the first stages, vis-à-vis, the beam and target. Ion acceleration in terms of providing stable, high current beams for almost all isotopes in the periodic table has been available for quite some time in India [5]–[7]. Furthermore, there are options to use very high current isotopic beams [8]. Currently used beam currents of around a few particle-nano amperes (pnA) would shoot up by an order of ~100 in case of high current facilities. This boost in beam energy would also require adjustments to be made to the target materials- so as to ensure they remain stable under high ion-fluence for long durations and also offer reusability. In rare-earth metal thin films, the probability of oxide formation is high which makes its physical structure prone to damage even during prolonged use with low beam currents. Furthermore, thick targets used in nuclear structure studies have a poor heat dissipation in low pressure conditions, which makes the targets more susceptible to breakage.

Experiment Details

A ^{164}Er target (Fig 1) of ~1 mg/cm^2 thickness has been fabricated by the cold rolling technique and used to conduct an isomer study at IUAC [9]. The experimental conditions where the target has been bombarded by 185 MeV pulses of ^{28}Si beam from LINAC for over 250 hours with a beam current of ~6 nA, are similar to conditions anticipated for a high beam current facility. Bombardment of packets of high energy heavy ions results in sudden rises in the sample temperature, mimicking the situation for a target facing high beam current. These temperature spikes can permanently alter the nature- physical as well as chemical- of the sample leading to damage and/or unexpected experimental results.

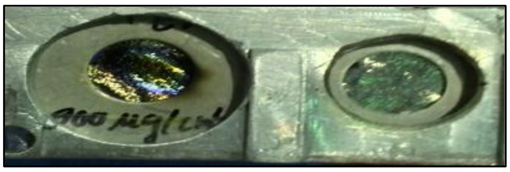

Fig 1: *^{164}Er samples on target ladder. (Left): after experiment; (right): before experiment.*

Test Results

In order to understand changes that the target sample might have undergone after the experiment, the irradiated and non-irradiated samples have been taken through X-Ray

Diffraction (XRD) tests; this helps understand structural phase changes and also the onset of crystallinity. As can be observed from Fig 2, irradiation has not induced structural changes. This is a significant observation regarding the stability of the target material.

The morphological changes were monitored using Scanning Electron Microscope (SEM) while Energy Dispersive X-ray Spectroscopy (EDS) measurements (Fig 3) were conducted to detect elemental compositional changes. A slight enhancement of the oxygen peak intensity was observed.

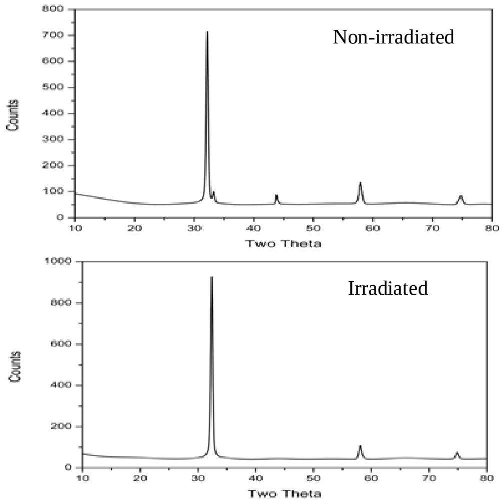

FIG 2: *Comparison of X-ray diffraction spectra for samples before (above) and after (below) irradiation.*

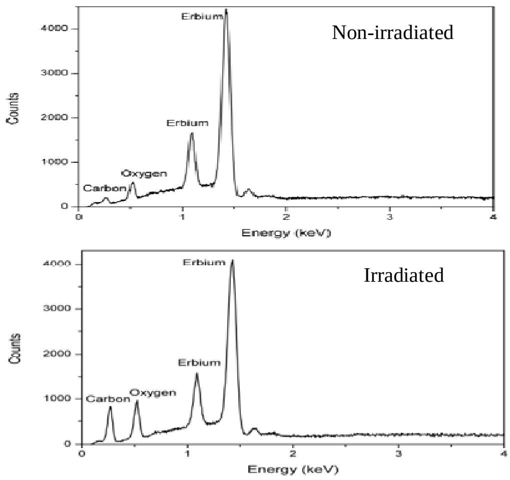

FIG 3: *Comparison of EDS spectra for samples before (above) and after (below) irradiation.*

Subsequently, Raman spectroscopy was used to check the likely conversion of erbium to its oxides as seen by the increased oxygen content in EDS. However, the formation of oxides was ruled out.

Summary

As per the results currently available, it can be estimated that the prepared ^{164}Er samples are very stable under beam conditions. Cold rolling lends physical robustness to these targets and these lanthanide thin films can thus be safely used for experiments that involve bombarding target materials with intense beam currents to the tune of a few hundred pnA. The target's sustainability against high energy beam pulses offers the scope of reusability for these extremely rare and expensive lanthanide samples that can assist in exploring rare nuclei near the drip line. Further studies regarding observation of other changes in the samples' physical, chemical, magnetic or electrical nature are being undertaken and the results will be shared with the community during the conference.

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