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Need and Fabrication of Self-Supporting Thin Targets in Medium Mass Region

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ABSTRACT

Self supporting very thin feasible targets of iron, vanadium, chromium of thickness 700 μg/cm^2, 600 μg/cm^2, 800 μg/cm^2 respectively, have been fabricated by using different techniques - thermal evaporation and rolling method at Tata Institute of Fundamental Research, Mumbai. Freshly prepared self-supporting target in the mass region A ~50-60 fulfill one of the strong need of neutron induced cross-section measurement by direct particle counting method and by surrogate method, which play a significant role in fusion reactor technology. Neutron induced reaction having high requirement in fusion reactor application have been studied with maximum energy of the outgoing particle and energy loss within the target by using TALYS-1.9 and SRIM code respectively. TALYS-1.9 and SRIM-2008 calculations optimize the thickness of the target in order to reduce the energy loss and self absorption of outgoing particle in the sample materials.

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Introduction

In nuclear physics and nuclear chemistry, a target can be defined as an object or system subjected to bombardment by particles such as electrons, protons, etc. or to radiation. The projectiles could originate from spontaneously decaying radioisotopes or can be delivered by an apparatus producing charged projectiles such as elementary particles or heavy ions. Self-supporting thin target of various elements are always required for the experiments. The target preparation is crucial step for getting thin and uniform self supporting foils which are used in the experiment of nuclear reactions with ion beam and charged particles [1]. The neutron induced reaction nuclear database is not available for various radio nuclides produced in fusion environment during its operation, due to the non-availability of target . An alternate method is used to measure the cross-section, double differential cross-section, which is known as surrogate technique. Self supporting targets are required for such type of crucial measurement.

Requirement of self-supporting targets for reactor technology

Medium mass region A~50-60 is of great concern mainly for the shielding blanket, vacuum vessel and divertor component of the upcoming fusion reactor. Stainless Steel (SS) which is a suitable candidate structural materials for all the above critical components contain mainly the elements in the mass region A~50-60 [2]. The main composition of elements present in International Thermonuclear Experimental Reactor (ITER) grade Stainless Steel SS316L(N)-IG are Fe(64.74%), Ni(12.25%), Cr(17.50%), Mo(2.50%), Mn(1.80%), C(0.022%), N(0.07%) P(0.025%), S(0.0075%), Si(0.5%), Nb(0.01%), Ta(0.01%), Ti(0.15%), Cu(0.30%), Co(0.05%), B(0.001%), Al(0.05%), V(0.004%), Zr(0.002%), Sn(0.002%), W(0.001%), Pb(0.0008%), Bi(0.0008%), O(0.002%), K(0.0005%) [3]. During the fusion reactor operation, a large number of nuclear reactions will take place which includes all the neutron induced reactions as well as charged particle induced reactions. For all the types of reactions, which will take place inside the reactor, cross section is one of the fundamental database required for more detail understanding of the interaction of particles with materials. There are many method of experimental cross-section measurement. Direct particle counting and surrogate reaction method requires, self supporting thin target for cross-section measurement [4]. In the present work our main concern is to show the need of self-supporting thin target and to optimize the method of preparation of self supporting very thin target in medium mass region (A~50-60), which can be used for cross-section measurement by direct charged particle counting method and surrogate method.

Theoretical calculations used for fabrication of self supporting thin target in mass region A~50-60

As discussed above SS is one of the most important material going to be use in thousand of tons in the development of fusion reactor. Apart from the reaction cross-section whose daughter is unstable (having half-life of the order of h, min, days) there are many reaction having stable or long-lived daughter as shown in the Table-1. These are the most challenging reaction having no/discrepant experimental data in EXFOR data library [5]. There is a great demand of the neutron induced reaction

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Table-1: List of some challenging neutron induced reaction required for fusion reactor,with their maximum energy of the ejectile and energy loss within the target by using TALYS-1.9 and SRIM-2008 code

S.No.	Reaction	Target($t_{1/2}$)/daughter($t_{1/2}$)	Max. energy of outgoing particle (MeV)(Calculated from nuclear modular code TALYS-1.9)	Present status of experimental cross-section data	Thickness optimized from the SRIM code
1.	$^{56}Fe(n,\alpha)^{53}Cr$	Target and daughter both are stable	9 MeV	Less exp. data, due to limitation of activation technique	153 μg/cm^2
2.	$^{58}Ni(n,\alpha)^{55}Fe$	stable/2.73y	8.23 MeV	Less exp. data , due to long-lived daughter	129 μg/cm^2
3.	$^{59}Ni(n,p)^{59}Co$	7.6×10^4 y/stable	4 MeV	Direct experiment is not possible, First time measured by indirect technique i.e. Surrogate reaction $^6Li+^{56}Fe$ [11]	130 μg/cm^2
4.	$^{55}Fe(n,p)^{55}Mn$	2.73 y/stable	4.5 MeV	Direct experiment is not possible, First time measured by indirect technique i.e. Surrogate reaction $^6Li+^{56}Fe$,$^6Li+^{52}Cr$ [7]	121 μg /cm^2

cross section for all type of targets i.e. either target is stable or unstable and daughter is stable or unstable. Reaction $^{56}Fe(n,\alpha)^{53}Cr$ have very less experimental data as its daughter isotope is stable, so the main crucial part of the experiment for cross section measurement is to make the self supporting very thin target, so that α-particle losses its minimum energy within the target. The energy of outgoing alpha particle calculated with nuclear reaction modular code TALYS-1.9 [6] is different for various reactions. For a minimum energy loss (50 keV) of alpha particle the optimized thickness of iron is 153 μg/cm^2 for $^{56}Fe(n,\alpha)^{53}Cr$. Reaction $^{58}Ni(n,\alpha)^{55}Fe$ has long-lived residual nucleus ^{55}Fe, having half life 2.73 year. Outgoing alpha particle energy and optimized thickness is shown in Table-1, for different nuclear reactions having discrepant or less experimental data. Apart from these reaction $^{55}Fe(n,p)$, $^{59}Ni(n,p)$ in which the target itself is not stable and due to lack of availability of the target material, the reaction cross section measurement is not possible.

Experimental

The experimental cross section measurement play an important role in fusion reactor technology. First time Pandey et. al. [7] recently measured the cross section of $^{55}Fe(n,p)$, $^{59}Ni(n,xp)$ reactions by surrogate ratio method, required for fusion reactor applications. For these reactions $^{55}Fe(n,p)$ and $^{59}Ni(n,xp)$, self supporting chromium and iron targets are prepared of 800 μg/cm^2 and 700 μg/cm^2 respectively.

The target required are ^{52}Cr, ^{56}Fe, ^{51}V. All these self supporting targets has been prepared at target lab, Tata Institute of Fundamental Research by using rolling, thermal evaporation technique. This technique has been earlier applied for the measurement of the neutron induced fission and capture cross sections [8, 9]. First time charged particle emission cross section (n,xp) has been measured by surrogate method . The main base on which surrogate technique works is Bohr's compound nucleus theory. According to Bohr's theory – The mode of formation of compound nucleus is independent of its mode of decay. Therefore, for those reactions where target is unstable, surrogate technique is used to determine their cross section. For performing these experiment, self supporting target is required. The self supporting target is the heart of such type of experiment. So, the different techniques which are used at TIFR, Mumbai for preparation of these targets is given here briefly.

Results and Discussion

The main job is to prepare the fresh self-supporting target of very low thickness. The preparation of target material is a challenging task. Different methods are used for the preparation of target. The target preparation is an important step for getting thin and uniform self-supporting foils to be used in the experiment of nuclear reactions with ion beam and charged particles. Chromium is a transition metal which is brittle, grey and hard [10]. Chromium is very brittle target and therefore cannot be rolled. Several attempts were made for rolling chromium by giving it heat treatment and then rolling but it failed. Thermal Vacuum evaporation is the best option for chromium target preparation. Setup was cleaned totally with alcohol to avoid contamination in deposition process. Around 20 mg chromium was used, chromium chunks were powdered and used. Tantalum boat was used for the deposition. In addition to boat assembly, the tantalum cone installed was installed on the top of boat for focused deposition on desired foil area and minimize the loss of material. This tantalum cone was fabricated in Target lab. Copper foils of thickness 12 mg/cm^2, 15 mg/cm^2 and 20 mg/cm^2 were used. Copper foils were used as substrate and kept at a height of 2.2 cm from boat. After reaching the desired vacuum (5.56 × 10^{-5} mbar), voltage was applied between the copper electrodes. Voltage applied was (26 - 28 V) from Variac. As the evaporation started, it continued for 4 min and 53 sec, to reach the thickness of ~ 800 μg/cm^2 (approximately), on the desired foil area. After the deposition was completed, copper foils were treated in 10% concentrated HNO_3 solution, to get self supporting target of chromium having thickness ~ 800 μg/cm^2 (approximately) .

Iron can be made self-supporting in the thickness of 700 $\mu g/cm^2$ and greater. Iron reacts with water, so care should be taken to preserve it. Iron self supporting target can also be made by rolling method. Iron sheet was heated in tungsten boat for half an hour at 400 °C. After heat treatment iron became soft from earlier and was easily rolled till 700 μg/cm^2.

Vanadium was vacuum sealed in quartz glass ampoule and annealed at 500-550 °C. Annealing process was done multiple times. Rolling was done easily after this process. We are successful to get vanadium target of thickness 600 μg/cm^2.

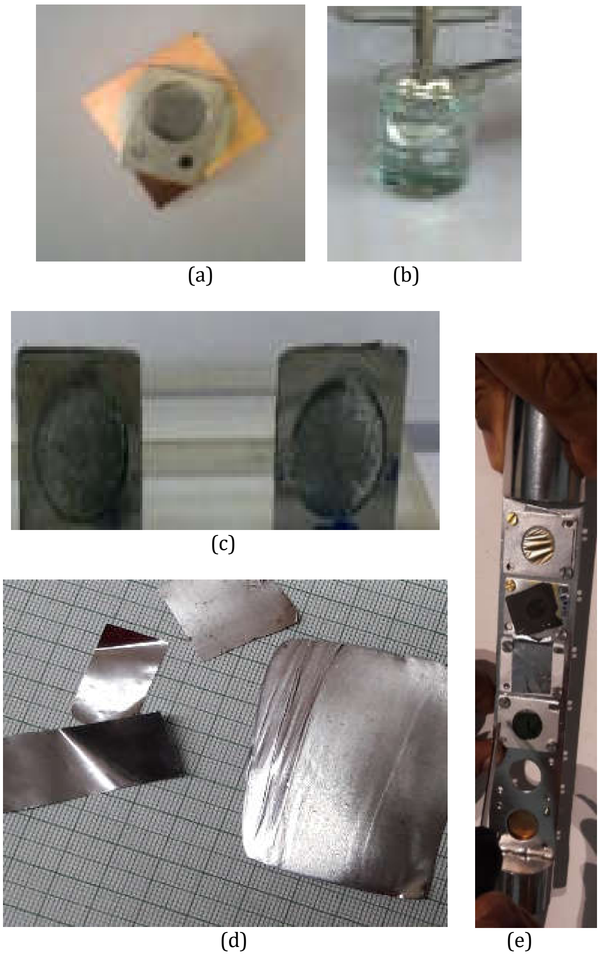

Figure 1: (a) Cr deposited copper foil sandwiched in between two stainless steel target frame (b) immersed in diluted HNO_3 (c) self-supporting thin film of chromium (d) iron and vanadium target (e) various targets placed in target ladder

Figure 1 shows the various self supporting thin foils prepared in target laboratory at TIFR, Mumbai. Often elements in this mass region are brittle and therefore very complex or difficult to make self supporting target of very low thickness. The sample should be thin enough in order to reduce the energy loss and self absorption of p, α particle in the sample material. Since these materials all combine with water, it is necessary to store such targets in desiccators when not in use. Melting point of the boat (crucible) should be more than the target material. Order of vacuum is around 10^{-6}-10^{-5} mbar during thermal evaporation technique. Self-supporting target preparation in mass region 50-60 is a difficult task. The thickness of the self-supporting target prepared for the experiment is in between $600 - 800\,\mu g/cm^2$. Here, Table-2 shows the various optimized parameter for preparation of different self supporting thin film.

Table 2: Various optimized parameters for preparation of different self supporting thin films

Target Element	Temperature	Time Duration	Vacuum	Thickness of foil
Chromium	450 °C	4 min and 53 sec	10^{-6} - 10^{-5} mbar	800 μg/cm^2
Iron	400 °C	6 min and 50 sec	No vacuum	700 μg/cm^2
Vanadium	500-550 °C	7 min and 40 sec	No vacuum	600 μg/cm^2

Conclusions

Successfully prepared self supporting very thin feasible targets of iron, vanadium, chromium of thickness 700 μg/cm^2, 600 μg/cm^2, 800 μg/cm^2 respectively, by using different techniques. Due to very brittle nature of these targets, the self supporting thin film preparation of less than one micron is a challenging task. In the present work we have optimized the process parameters to obtain a stable (durable) self-supporting thin film of the required thickness by using thermal vacuum evaporation and rolling techniques. Natural Iron, Vanadium, Chromium targets are required as a self supporting foils (target) for nuclear research experiment. For the cross-section study, self supporting target is the backbone of the experiment of direct particle counting and surrogate technique. It is very important to have knowledge of optimized process parameters by which we can prepare the fresh targets at the time of Nuclear Physics experiment.

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References

1. World Anna Stolarz, Target preparation for research with charged projectiles, J Radioanal Nucl Chem, 2014, 299, 913–931.
2. R.A. Forrest, Data requirement for neutron activation Part I: Cross sections, Fusion Engineering and Design, 2006, 81, 2143- 2156.
3. P. V. Subhash et. al., Activation and Radioactive Waste Analysis for Survey X-Ray Crystal Spectrometer of ITER, FUSION Science And Technology, 2017, 71, 215-224.
4. J.E. Escher et al., Compound-nuclear reaction cross sections from surrogate measurements, 2012, ReV. Mod. Phys, 84, 353-397.
5. Exfor data library, https://www-nds.iaea.org/exfor/exfor.htm.
6. A.J. Koning, S. Hilaire and S. Goriely, TALYS-1.9, A Nuclear Reaction Program, User Manual, NRG, Petten, Netherlands, (2015).
7. B. Pandey et al., Measurement of ^{55}Fe(n,p) cross sections by the surrogate-reaction method for fusion technology applications, Phys. Rev.C, 2016, 93, 021602 .
8. B. Pandey et. al., Chromium target preparation for the measurement of nuclear data for fusion technology, Journal of Materials Science & Surface Engineering, 2014, 1 (3), 78-80.

9. B. K. Nayak et. al., Determination of the ^{233}Pa(n,f) reaction cross-section from 11.5 to 16.5 MeV neutron energy by the hybrid surrogate ratio approach, Phys.Rev. C, 2008, 78, 061602.
10. Retrieved from : http://en.wikipedia.org/wiki/chromium.
11. J. Pandey et al., Determination of ^{59}Ni(n,xp) reaction cross sections using surrogate reactions, Physical Review C, 2019, 99, 014611.