Project of Thin Targets for the NUMEN Experiment

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Abstract. The goal of the NUMEN collaboration is the measurement of the cross sections of Double Charge Exchange reactions for several couple of ion projectile-target, in order to provide helpful data to study the nuclear matrix elements of the neutrino-less double β-decay. The need of big statistics and high precision in the measurements require the use of high intensity beams and very thin targets. This creates some problems to the design of the target frame and to the dissipation of the heat generated by the beam. The present paper reports a possible solution for the cooling system and the production technique of a tin target, together with the results of the preliminary tests of heat dissipation.

1. Introduction

The NUMEN project [1][2][3] aims to get information on the nuclear matrix elements of neutrino-less double beta decay from experimental measurements of heavy-ion induced Double Charge Exchange reactions (DCE). A statistically significant collection of DCE data will be obtained taking advantage of the high ion beam current (up to 50 µA), which will be available in the next future at INFN-LNS (Catania, Italy) [4], and of the MAGNEX spectrometer [5][6], which allows to measure high resolution energy spectra and absolute cross sections at very forward angles even for very rare processes [7][8][9]. This requires that the targets be thin and uniform, to keep a good energy resolution. On the other hand, the large beam current together with the small thickness require that the generated heat inside the target be efficiently dissipated to avoid target damages.

The experiment will investigate the following target nuclei: ¹¹⁶Sn, ¹¹⁶Cd, ⁷⁶Ge, ⁷⁶Se and ¹³⁰Te using ¹⁸O and ²⁰Ne beams. Their thickness will vary from 250 nm to 500 nm. Preliminary calculations addressed the solution of the heat dissipation problem toward the deposition of the thin target on a highly conductive substrate, as explained in Section 2. The design of the tin target has been completed and some prototypes have been realized with different deposition techniques, as illustrated in Section 3. The results of a preliminary test of the heat dissipation in the deposited tin using a LASER beam as heater are reported in Section 4. The conclusions are drawn in Section 5, together with the plan of the future work.

2. The Target Cooling System

An ion beam produces, by ionization, a rate of heat inside a target, which is usually dissipated through the surrounding cold frame. In the case of NUMEN, the beam intensities are so high that this dissipation technique is not sufficient to take away the total power. Simple calculations show that the thermal stationary state of a self-sustained target surrounded by a cold frame reaches temperatures widely exceeding the melting point in the central region under the beam spot [10]. A more complex system, made by a deposition of the target material on a thin layer of pyrolytic graphite, ensures a large heat...
transfer from the central region to the surrounding cold frame, thanks to the high thermal conductivity of the graphite. A sketch of the system is shown in Figure 1.

The solution of the heat equation gives the time evolution of the temperature profile along the radius and has been calculated using a MatLab code for several target materials, beam currents and intensities. The result of these calculations is that, after few milliseconds, the temperature is nearly uniform along the beam axis (z-axis), in both target and graphite, while the spatial distribution of the temperatures reaches a stationary state after few seconds. Moreover, the temperature of the target looks only slightly warmer than the substrate at the same radius, showing that the heat flows preferably from the target to the substrate. Finally, the maximum temperature is always along the beam axis, as expected. Therefore, it is sufficient to maintain the temperature along the z-axis below the melting point in order to avoid the target damage. Figure 2 shows these results for a 116Sn target, 500 nm thick, illuminated by a 50 μA beam current of 18O⁸⁺ ions at 15 MeV/u and cooling temperature T_{cold} = 100 K.

3. Tin Deposition on Graphite Substrate

The first prototype of the target-substrate system has been obtained by using Electron Beam Deposition of Sn on graphite. Since in the above calculations the target film was supposed uniform and perfectly adherent to the graphite, several attempts (substrate at various temperatures, annealing after deposition) were made to obtain a high-quality film of tin on pyrolytic graphite.

Figure 2: a) the distribution of the temperature after 5 s is shown as a function of the radius and of the depth; b) the maximum temperature (at r = 0, z = 0) is reported as a function of the time.
Each result was examined by Field Emission Scanning Electron Microscope technique (FESEM), to check the homogeneity of the deposited samples.

![FESEM images](image1.png)  ![FESEM images](image2.png)

*Figure 3: FESEM images: a) top view of a 500 nm thick Sn sample, deposited at room temperature; b) top view of a 500 nm thick Sn sample, deposited at 175°.*

In Figure 3a the image of a deposition at room temperature shows an unsatisfactory result, because the black areas indicate that quite large empty spaces separate the grains. After several trials with different substrate temperatures, with and without annealing, the best deposition was obtained at 175°, without annealing. In Figure 3b, the surface appears much more compact and uniform. In order to check the adhesion of the tin on the graphite, some FESEM images were taken on the side of the deposition: even if they looked better, nevertheless the effects of the deposition on the border could mask the true situation. Therefore, the adhesion was tested in the experiment described in the next Section.

4. Preliminary Test of Heat Transfer Inside the Target

A preliminary test of the heat dissipation inside the Sn-graphite system has been performed using a LASER as heat source. The LASER spot had a radius of ≈1 mm and penetrated only for a few nm in the Sn. Therefore, the heat source was not uniform along the beam axis, while it is in the case of the heat generated by the ion beam. The setup of the experiment consisted of a metal frame in contact with the Sn-graphite system, maintaining the blue region of the graphite at room temperature. An IR LASER (808 nm wavelength) irradiated the center of the system on the side of the tin, with power ranging from 1.5 to 12 W. A thermal camera, looking at the Sn target, monitored the temperature of the tin every 3 ms, while a pyrometer, located beyond the target, monitored the temperature of the graphite in the center of the disk. The stationary temperature along the beam axis was calculated for this configuration using the same Matlab code of Section 2.

The results of the measurements are the following: a) the temperatures measured by the thermal camera and pyrometer reach the stationary state within 1 s, in agreement with the calculations, b) the stationary temperature is the same (within the instrumental errors) on the tin and graphite surfaces. These results show that the calculation technique is correct and that the heat, generated in tin, quickly transfers to the graphite along the beam axis. This suggests that the contact between the tin and graphite surfaces is uniform, as supposed in the calculations.
Figure 4 shows the trend of the measured (blue) and calculated (orange) stationary temperature as a function of the LASER power. Both look linear, but the slope of the data is lower. It is easy matter to demonstrate that the stationary temperature is proportional to the power entering in the system, therefore the disagreement is probably due to the reflection of the LASER light on tin, which decreases the true entering power with respect to the nominal one. It must be remarked that the temperatures reached in this experiment are much lower than in the future NUMEN measurements, therefore more severe tests are needed, with suitable ion beams.

5. Conclusions

A method for cooling thin targets under an intense ion beam has been studied. Such method involves the usage of a large pyrolytic graphite substrate. The target material is deposited on such substrate by means of the Electron Beam Deposition in order to enhance the heat dissipation. To stay within the smoothness requirements of the Sn target, several depositions were carried out with different process parameters, eventually obtaining satisfactory results. Concerning the heat dissipation, the effectiveness of the solution has been studied with a MatLab code and tested with a laser beam, giving encouraging results. More severe tests with ion beams of energy and intensity close to the future NUMEN beams are planned in the next future.

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