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Design and test of an innovative static thin target for intense ion beams

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Summary. — In the present work an innovative design for thin target suited for high intensity beam is proposed, which consists in the deposition of the target material on a substrate of pyrolytic graphite, whose in-plane thermal conductivity allows a quick dissipation into a heat sink. Such a target cooling system has been designed for the NUMEN experiment (hosted at LNS-INFN, Catania), which will use targets of particular isotopes under highly intense ion beams. The time evolution and the spatial distribution of the temperature have been numerically calculated. Results of these calculations show that the target/graphite system can tolerate ion beams with intensities of about 50 eμA and energy of 15 MeV/u. A significant non-uniformity in the target thickness would limit the energy resolution of the reaction products. A technique, based on the α-particle transmission, is used for measuring the thickness and uniformity of the target. Preliminary results from tests with this technique applied to the graphite substrate are shown.

1. – Introduction

Modern Nuclear Physics experiments often investigate rare reactions, some of which require precise spectroscopy measurements and high statistics. An example of this kind of experiments is the NUMEN project, hosted at the LNS-INFN ion beam facility in Catania, whose aim is to measure the cross section of Double Charge Exchange (DCE) reactions. These measurements will help to evaluate the Nuclear Matrix Element of neutrinoless double-β decay ($0\nu\beta\beta$) [1], since the two processes share the same initial and final states of the involved nuclei. In the firsts phases of the project, NUMEN will study the following target candidates: ^{130}Te, ^{76}Ge, ^{116}Sn, ^{76}Se and ^{116}Cd with two types of reactions: (^{20}Ne, ^{20}O) and (^{18}O, ^{18}Ne). In advanced phases of the experiment, also other isotopes (^{160}Gd, ^{100}Mo, etc) will be used as well. In section 2, the target cooling system is described and the heat transfer through the target and substrate is presented.

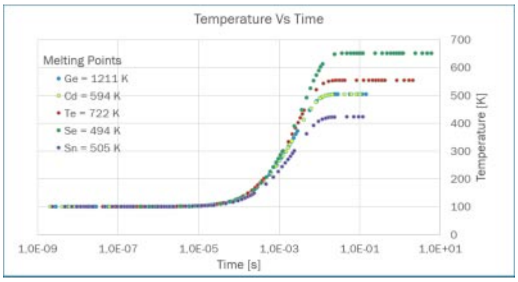

Fig. 1. – Time evolution of the temperature at the centre of the targets deposited on a HOPG substrate, assuming a beam of $^{18}\mathrm{O}^{8+}$ or $^{20}\mathrm{Ne}^{10+}$ at 50 eμA and 15 MeV/u. The numerical error on the temperature is smaller than the size of the symbols.

In section 3, the contributions to energy resolution of the measured reaction products are discussed. In section 4, the α-particle transmission technique for the characterisation of the targets is described.

2. – Target cooling system

The proposed solution to make the target more heat-durable consists in depositing the target material on a 10 μm thick substrate of Highly Oriented Pyrolytic Graphite (HOPG), which features a very high in-plane thermal conductivity of about 2000 W/(m·K). The heat deposited by the beam is efficiently dissipated in the heat sink through the substrate [2]. The substrate, which is larger than the target, is pinched between two copper crowns which are maintained at low temperature by a cryocooler. The target layer is a few hundred nm thick, with a diameter of 1 cm. It is deposited by electron beam evaporation. Several prototypes have been produced and characterized with a Field Emission Scanning Electron Microscope (FESEM) [3]. A code was written to numerically evaluate the temperature evolution of the target-substrate system, from a few nanoseconds after the irradiation up to the steady state. The code solves the heat equation for a system of two materials, supposing a gaussian heat source (simulating the ion beam) and a cold boundary at fixed temperature. Calculations were performed for Ge, Cd, Te, Se and Sn targets, showing that the steady state is reached in a few tens of ms. Figure 1 presents the time evolution of the temperature at the center of the target layer. It shows that all of the targets can withstand the power deposited by an ion beam of $^{18}\mathrm{O}^{8+}$ or $^{20}\mathrm{Ne}^{10+}$ with an energy of 15 MeV/u and an intensity of 50 eμA (25-30 W of deposited power), but the Se target which can tolerate a maximum current of about 35 eμA.

3. – Contributions to the energy resolution

The kinematics of the DCE reactions will be reconstructed from the energy and scattering angle of the projectile reaction products measured by the MAGNEX large acceptance spectrometer [4]. The energy resolution should be sufficient to distinguish most of the different states populated in the residual nuclei, typically of the order of 500 keV.

There are several contributions to the energy resolution: the beam energy definition by the LNS Superconducting Cyclotron (0.1 % FWHM) [5], the straggling in the target and in the substrate, the dispersion due to the random depth of the reaction point in

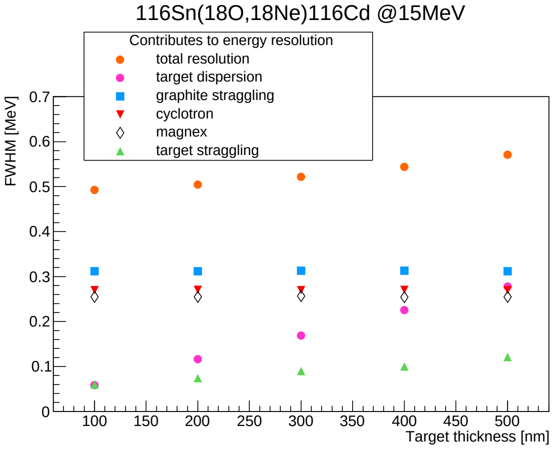

Fig. 2. – FWHM of the different error sources to the energy resolution of the measured reaction products, including the graphite substrate, as a function of the target thickness. The thicknesses of the target and substrate were assumed to be uniform.

the target, the deterioration in energy resolution due to MAGNEX (0.1 % FWHM) [4]. The contributions from the target and substrate increase with their thickness and non-uniformity. This is the reason why the target thickness cannot be increased arbitrarily. As an example, we consider the ^{116}Sn(^{18}O, ^{18}Ne)^{116}Cd reaction at 15 MeV/u. The FWHM of the abovementioned error sources is reported in figure 2, together with their sum in quadrature, as a function of the thickness of the Sn target. Both the target and the graphite substrate have been assumed to be uniform. It can be observed that for a target thickness below $\approx$ 400 nm, the total energy resolution remains within the desired range. Assuming a target thickness distribution with an average of 400 nm and a FWHM of 160 nm (40%), the total resolution increases of $\approx$ 70 keV with respect to the uniform case. Similar results were found for the remaining targets, whose thickness limit has been evaluated in a similar way.

4. – Characterisation

Several samples of Sn and Te targets have been produced by Electron Beam Deposition; a thorough study on the deposition parameters (i.e. substrate temperature, buffer layer,...) was carried out in order to achieve satisfactory results. Tens of Sn and Te samples, deposited with different deposition parameters, were analyzed using a FESEM microscope, which however does not provide reliable information about the thickness and uniformity. An α-particle spectroscopy apparatus was then setup to gain such knowledge. The first set of measurements has been dedicated to the evaluation of the effective thickness of the graphite substrate. An additional difficulty is given by the presence of a layer of durable acrylic adhesive on the graphite back. Several methods for removing it have been explored (plasma etching, chemical etching, ultrasound bath, annealing). A preliminary result is reported in figure 3. Two different alpha-energy peaks measured on a sample, namely G11, before and after 3 hours annealing at 380 °C, are shown. The maxima of the peaks have been obtained by gaussian fit and correspond to an adhesive layer decrease from $\approx$8 μm to $\approx$1.5 μm.

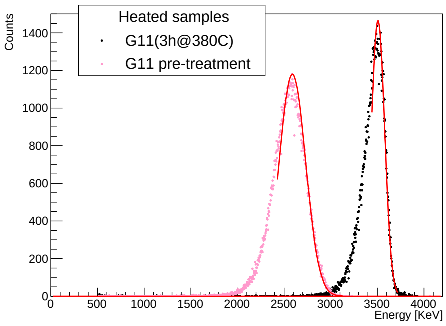

Fig. 3. – Alpha spectrum of the graphite sample G11, analyzed before (pink) and after the heat treatment (black). The continuous lines are Gaussian fits.

5. – Conclusions

A new solution has been proposed to increase the heat dissipation in thin targets. The cooling system is based on a 10 μm thick pyrolytic graphite, whose high in-plane thermal conductivity allows to quickly transfer the heat from the target to the heat sink. Numerical evaluations show that, taking into account the heat deposited by a 50 $e\mu$A ion beam at 15 MeV/u, the maximum reached temperatures at the targets center are lower than the isotopes melting point. The only exception is represented by the Se target, for which the maximum beam current is evaluated to be around 35 $e\mu$A.

In order to distinguish the different energy levels of DCE reaction products, an energy resolution of 500 keV is needed. In order to properly evaluate the targets thicknesses, error sources deriving from the apparatuses and the target/graphite system had been accounted for. For a Sn target, a reasonable thickness was found to be around 400 nm. Finally, a setup based on α-particle transmission has been used in order to measure the targets thicknesses and non-uniformities. The first set of measurements has been performed to test the degree of the removal of an acrylic adhesive layer, with positive results.

REFERENCES

[1] Cappuzzello F. *et al.*, *Eur. Phys. J. A*, **54** (2018) 72, https://doi.org/10.1140/epja/i2018-12509-3 , and references therein.

[2] Iazzi F. *et al.*, *Materials and Contact Characterisation VIII*, **116** (2017) . doi:10.2495/MC170071.

[3] Capirossi V. *et al.*, *Nucl. Instr. and Meth. in Phys. Res. A*, (2018) , in press. https://doi.org/10.1016/j.nima.2018.08.081.

[4] Cappuzzello F. *et al.*, *Eur. Phys. J. A*, **52** (2016) 167. https://doi.org/10.1140/epja/i2016-16167-1.

[5] Cappuzzello F. *et al.*, *Nucl. Instr. and Meth. in Phys. Res. A*, **763** (2014) 314. https://doi.org/10.1016/j.nima.2014.06.058.