Improvement of the Target Durability for the Heavy Element Production

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Introduction

The search for new elements with low production cross sections makes it necessary to enhance the beam intensity on the target in order to keep the required beam time at a reasonable length. For element 112 for example the cross section for the synthesis was ~ 1 pb. This corresponds to one event per week on average [1]. A higher beam current, however, leads to severe problems concerning the targets. To synthesize heavy elements at the SHIP set-up lead and bismuth targets are used [2]. At present the maximum beam intensity is limited by the low melting temperatures of lead with 600 K and bismuth with 544 K, respectively. In this range the cooling via radiation is small. Since the target wheel rotates in vacuum there is also no heat conduction via surrounding gas. The third mechanism for temperature reduction is heat conduction along the target itself. But since the target layers are very thin and the amorphous carbon layers are poor thermal conductors, this process is not very effective. Therefore, technical improvements had to be developed in order to protect the targets from melting.

Implemented Improvements:

Several improvements to reduce the stress on the targets are already implemented [3]. After an increase of the active target area by nearly 60%, the Gaussian-like intensity profile of the heavy-ion beam was refined to illuminate the area as complete as possible. To optimise the intensity distribution, two octupole magnets will be installed in the beam line, allowing for a rectangular beam intensity profile across the size of the beam spot.

The background of scattered particles at the detector position has higher energies on the left hand side than on the right. A reduction of this background with a homogeneous degrader is not very effective since one has to take care not to absorb the reaction products. We therefore developed aluminium degraders with a wedge-shaped thickness profile. Depending on the projectile-target combination, degraders with a slope of up to 3 µm over 100 mm length are used. This results in a reasonable compromise between background reduction and slowing down of the evaporation residues, since too low kinetic energies of the latter lead to too low implantation depths and thus to losses of escaping alphas.

To further enhance the durability of the targets at high currents, we investigated different possibilities in parallel that could possibly be combined later on, as there are chemical compound targets, target cooling, and target monitoring [4].

Chemical Compound Targets

The first idea concerning the improvements for the target material itself was to find some chemical compound of lead and bismuth, which is suitable and has a higher melting temperature compared to that of the pure element. We decided to concentrate in the beginning on lead compounds since this is the target material that is needed more often. There exist significantly more binary phases for lead than for bismuth; with the help of the known phase diagrams and suitable vapour pressures several compounds are ruled out.

The compound in question should be non-toxic, the melting temperature being considerably higher than 700 K in order to profit from radiation cooling. On the other hand the evaporation temperature should not be too high because then the target material would have to be evaporated with an electron gun which involves a much higher material consumption than thermal evaporation. For highly enriched material that could be very cost-intensive.

Up to now we have already synthesized and evaporated two lead compounds, namely ^{208}PbS and $Tm^{208}Pb_3$. Leadsulfide has a melting temperature of about 1400 K but at approximately 1220 K it already has a vapour pressure of 10^{-3} bar. The evaporated targets look very homogeneous. They have a black colour which should be advantageous concerning the radiation cooling. The targets do not show any signs of aging, oxidization or other visible alterations, and they are mechanically stable. A disadvantage could be that the compound is non-metallic and therefore electrostatic charging could become a problem. With a scanning electron microscope one can see that the surface consists of very small needles and looks furry.

$Tm^{208}Pb_3$ is a metallic compound. Since there is no known binary phase diagram, we estimated the melting temperature from two neighbouring phase diagrams of rare earth elements with lead, namely $DyPb_3$ that has a melting temperature of T_M ~ 1170 K and $YbPb_3$, T_M ~ 1010 K. Presumably the melting temperature of the thulium compound should be somewhere in-between. We chose thulium despite these unknown quantities since thulium is the most insensitive one of the rare earth elements that usually are oxidized easily. The material as evaporated looks a bit brittle but in principle homogeneous and mattly metallic. But this material shows an obvious aging after one or two weeks. There is a sort of whisker growth of metallic lead on the surface. Besides, the surface begins to look inhomogeneous and starts to oxidize after some time.

Targets were produced from both compounds but they could not be tested with the heavy-ion beam so far.

Target Cooling

Another possibility to avoid the melting of the targets is an active cooling with a He-jet. A He-jet will be blown at the beam spot on the target thus transporting heat load away from the target surface. Additionally the He-jet will result in a low pressure He-atmosphere in the target chamber thus allowing for a cooling of the whole target wheel through convection and conduction. In order to avoid vacuum windows, the whole target chamber of SHIP will have to be reconstructed a differential pumping system has to be installed. To optimise the measures and distances for this new target chamber design, test experiments are inevitable.

Target Monitoring

Another item, we are working on, is a new target monitoring system. On the one side we use an infrared camera to observe the thermal distribution across the target during irradiation. It is also helpful for the controlling of the experiments concerning new target materials and target cooling. On the other side we work on the implementation of an online thickness measurement of the targets by scanning them with an electron beam and analysing the energy loss behind the target with a position sensitive detector. This will be done in a position of the wheel opposite to the irradiation spot.

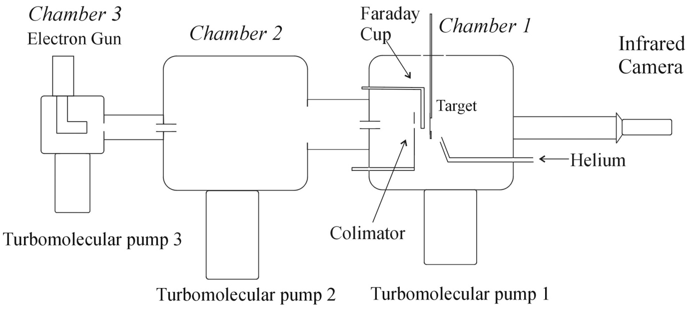

Figure 1: Test bench for high-current production target at SHIP. The target in Chamber 1 is heated by an electron beam. The electron beam can be measured by a movable Faraday cup. The target can be cooled with a He-jet guided through a Laval nozzle. The temperature distribution is measured via an infrared camera.

Test Bench for a high-current Production Target

Since beam time is rare, valuable and the most expensive part of heavy-ion experiments we had to create the possibility to test offline all the improvements described above. We therefore constructed a set-up where all the components developed can be built in to test and optimise the dimensions and the overall performance.

The test bench basically consists of three vacuum chambers arranged in a line, as is shown in Figure 1. Each chamber is connected with a high vacuum pumping system with turbomolecular pumps. The heavy-ion beam is simulated by an electron beam. The electron beam gun is mounted in chamber 3 and the electron beam is guided and focused by electromagnetic lenses on the target, which is placed in chamber 1. Behind chamber 1 an infrared camera is flanged to a long tube so that the target can be observed from the rear side. The temperature distribution of the beam spot on the target as well as melting of the target material can be recorded. By holding the power of the electron beam constant the durability of up to five different target materials mounted on one ladder can be compared directly with each other. Also depicted in Figure 1 is the first stage of the target cooling with a He-jet which is transported directly to the electron beam spot on the target via a Laval nozzle.

Recently the fixed target ladder was replaced by a target wheel that can be driven in the same way as in the SHIP set-up. In Figure 2 two infrared snapshots of a target mounted on a target wheel in the test bench are shown. In both cases the target wheel was rotating with 375 rpm. In the upper picture the wheel was rotating in vacuum and an energy of 1.3 W was deposited in the target with the electron beam. In the lower picture the chamber was filled with a low pressure atmosphere of 0.6 mbar He. To reach the same maximum temperature of 150°C as in vacuum an energy deposition of 2.7 W is needed. The energy increase of 1.4 W is a measure for the cooling efficiency of the additional atmosphere. In the same way the cooling efficiency of the He-jet or He-jets, blowing from both sides onto the target, will be tested and optimised. It is also noteworthy that minimum temperature of 85°C in vacuum (upper picture) is reduced to 35°C in He-atmosphere (lower picture).

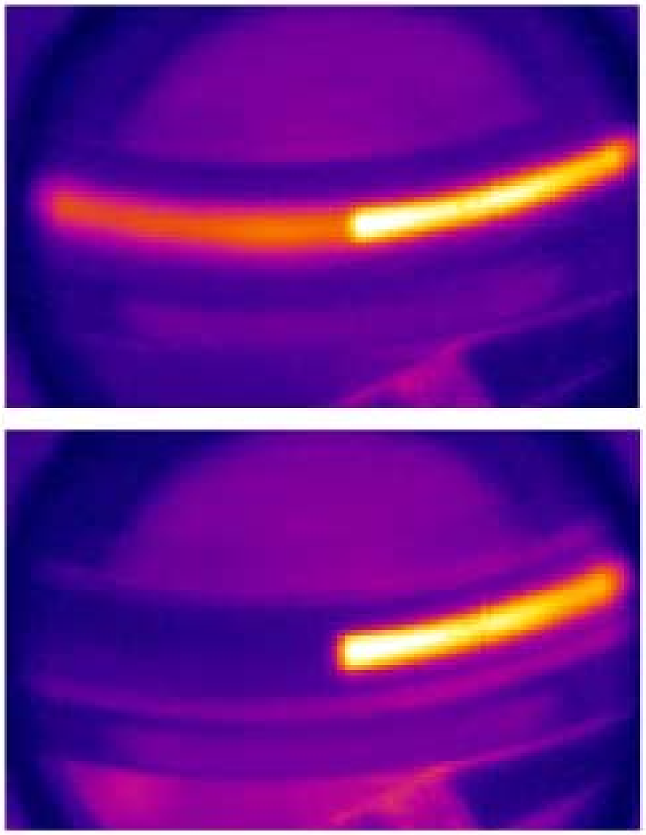

Figure 2: Infrared snapshot of 208Pb-targets mounted on a wheel rotating counter clockwise with 375 rpm. *Upper*: In vacuum, deposited energy 1.3 W; *Lower*: In 0.6 mbar He-atmosphere, deposited energy 2.7 W.

The test bench is also applied for the development and testing of the differential pumping system. Further on the online thickness monitor will be implemented in the test bench with a second smaller electron gun mounted in front of chamber 1.

We also try to reproduce the measured data by temperature calculations. These calculations are performed as function of the velocity of the target wheel, the backing material and backing thickness, the gas flow and the geometry of the target cooling.

References:

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