TARGET MATERIALS FOR A LOW ENERGY PEPPER-POT EMITTANCE DEVICE

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Abstract

The ion cancer therapy facility HIT in Heidelberg [1] is producing ions (H, He, C and O) from two ECR sources at an energy of 8 keV/u with different beam currents from about 80 µA up to 2 mA. Typical sizes for the beam in the LEBT range from are 5 – 30 mm. Matching the always slightly changing output from the ECR sources to the first accelerating structure, an RFQ, demands a periodical monitoring of the beam emittance. For that, a special pepper-pot measurement device is under design, whose most important parts are a damage-resistant pepper-pot mask and a vacuum-suitable scintillator material. The material lifetime, the list of feasible materials, the modelling of the target damage will be discussed.

PEPPER-POT SCINTILLATOR SCREEN DESIGN

As part of the ongoing development at HIT, and to provide necessary information for beam dynamics, high quality emittance and beam profile measurements are needed. A pepper-pot device is under investigation to provide a 4-D emittance measurement.

Location

The Pepper-Pot Scintillator Screen system should fit within the existing beam line components (vacuum boxes already used with beam diagnostics equipment like Faraday cups, profile grids and slits). The N1DK1 vacuum boxes will be equipped with a fast iris shutter, a pepper-pot mask and a scintillator screen. The N1DK2 vacuum boxes will contain a 45 degrees tilted mirror inside and a CCD camera outside. (Figure 1)

The Pepper-Pot Principle

The pepper-pot mask, which is perpendicular to the beam and contains a regular array of identical holes, splits the beam into beamlets. The beamlets drift toward the scintillator screen where they are imaged. The determination and the arrangements of the optical component must be designed in such a way that it meets its basic function requirements:

- The production of an image of a suitable size,
- The system should fit into the available space.

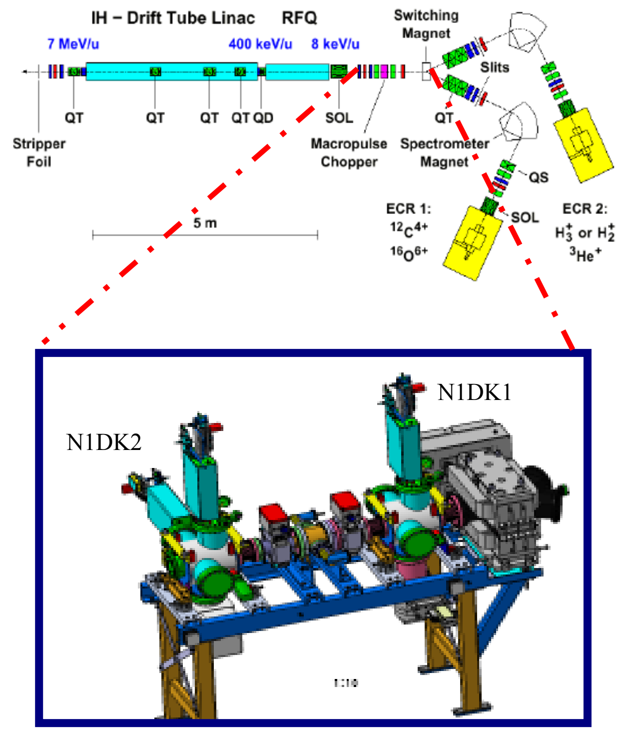

Figure 1: The Low Energy Beam Transport at HIT and the position of the Pepper-Pot Scintillator Screen device within the LEBT.

Some considerations [2] in the choice of the aperture parameters have to be followed so that:

- The beamlets images on the scintillator screen are larger than the mask aperture d,
- The pepper-pot mask thickness, Ls, should be small enough to prevent any smearing effects due to multiple slit scattering
- The separation spacing, w, should be much larger than the mask aperture d to prevent the beamlets from overlapping at the screen.

Different optical systems have been designed along the previous set of rules [2] depending on the minimum beamlet width. From the arguments given above, a set of the pepper-pot parameters (Table1) with a 0.2 mm hole diameter, 1.5 mm separation, and 0.1 mm maximum depth was calculated.

Due to a beam size of 10–20mm on the mask and at 8 keV / u energy, the drift length from the mask to the measurement screen is approximately between 65 and 150 mm.

Table 1: Pepper-pot parameters

Parameters	value
RMS beam size σ	10-20 mm
Pepper-pot Hole Diameter d	0.2 mm
Pepper-pot Hole Spacing w	1.5 - 2 mm
Pepper-pot mask thickness Ls	< 0.1 mm
Drift Length Ld	65-150 mm
Minimum Beamlet width	0.2 -0.24 mm
Resolution Pepper Pot	3.2 - 1.6 mrad

Scintillator Screen

The pepper pot mask and the measurement screen will be aligned perpendicularly to the beam because of their small separation distance. The beam images will be thus produced by a transparent scintillator such as crystals (ruby, YAG : Ce / Pr) or glass materials (quartz …) and will be captured by a suitable CCD camera.

BEAM TARGET INTERACTION

When an ion impinges on a solid, it loses kinetic energy through interactions with atoms. This transfer of energy from the ion to the target atoms results in ion reflection and backscattering, atomic sputtering and deposition, solid damage and heating. The impinging ions come finally to rest in the solid through a set of nearby adjacent inelastic and elastic collisions of atoms, called a collision cascade.

However, ions implanted into a solid can modify the physical properties of the solid due to both chemical and structural change in the target. Heating of the target by an ion beam leads to a fast thermodynamic response of the target. Consequently, during and after the irradiation, the distribution of the target density is changing. The energy loss dynamic of the ion beam within the material should be also investigated.

At the target, the beam maybe focused to a small spot where the deposition process dominates and also the thermal forces. For that, an estimation of the deposited beam energy is compared to the energy needed to melt the physical volume of the target [3]. Since the penetration depth is much smaller than the physical dimension of the target, a better estimation will be to calculate the energy required to melt the range volume. Obviously this estimation can only be coherent if no heat transfer around the range volume takes place during the beam pulse. This is not the case. In order to fully understand the thermal aspects of intense pulsed beam on materials, the time dependence heat transfer has to be taken into account. The timescale for heat to spread through the thickness of the material should be simulated. Similarly, the space evolution of the heated material should be replicated.

DAMAGE OF THE TARGET

The damage of the target consists of three principles. One consists in the change of the molecular structure which is unrecoverable. The molecular bond breaking is followed by atom displacement, creation of vacancies, and also sputtering, surface roughness, surface segregation. The other one is the preservation of the molecule integrity. The hit atom doesn't have enough energy to leave the site and then it will vibrate releasing this given energy as phonons. The phonons energy is deposited into the material lattice which can increase the present damage. Finally, the mixing of these two phenomena takes over and provides distortions to the target: mixing of layers and also atomic mixing [4]. A direct consequence of these damages could be a diminution in the light output, and in the durability of the material.

Consequently, changes in the properties are related to the structure damage of the target. Clearly, a simulation of the energy loss through the material would provide important information about the change in the properties of matter within the target.

Atomic mixing (figure 2), also called the slowing down process of intense ion beams into matter is the most important process. It consists of three main effects:

- Cascade Mixing (1),
- Recoil Implantation (2),
- And Diffusion (3).

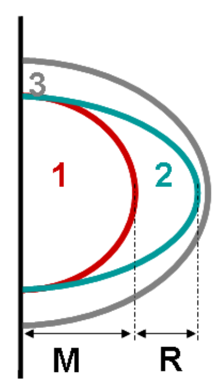

Figure 2: Atomic mixing [3].

The cascade mixing zone (1), the recoil implantation zone (2) and the diffusion factor (3) have to be distinguished and correlated to the structure damage of

the target and to the physical output parameters (heat, light output, durability).
A model should be used to quantify the influence of these mixing effects.

SIMULATIONS

TRIM [5], the Transport of Ions in Matter code, is based on the Binary collision approximation. It means that each incident ion finds the same unmodified substance. Any effects as ion deposition or surface erosion are neglected. TRIM doesn't treat any recoil phonon coupling in a solid.

Under irradiation with different ions, the ratio of electronic to nuclear stopping powers varies for both the primary ion and the secondary recoils produced.

Helium impinging into SiO_2 with a density equal 2.32 g/cm3 is represented in figure 3-a. Each time an ion has a collision with a target atom, there is one vacancy created (red dots). The target atom then recoils and all its collision that causes vacancies are plotted with green (for silicon atoms) and blue dots (for oxygen atoms). When the recoil atom stops it is plotted with green or blue dark dots. A single ion may produce half hundred vacancies (red), whereas a single recoil atom gets few vacancy plotted (green and blue). Consequently, the ion energy has been transferred to the target through principally inelastic scattering (i.e. electronic energy loss). The recoil cascade is slightly visible.

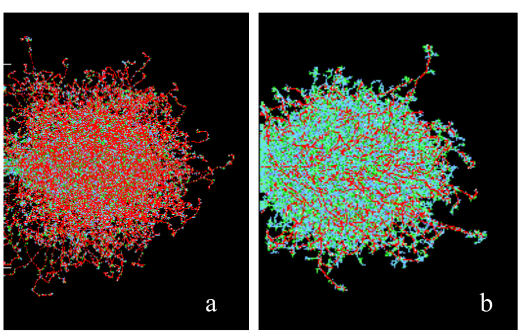

Figure 3: TRIM simulation of Helium (a) and Carbon (b) ion impinging into SiO_2 at 8 keV/u with the total number of ions equal to 1000. The longitudinal range and straggle (in parentheses) of Helium and Carbon are 866 Å (133 Å) and 282 Å (133 Å).

As you can see on the preceding picture (figure 3-b) the Carbon ion track shows red dots, representing vacancies for which the target atoms (Si and O) are knocked away from their lattice. However, Carbon ion beam–target interaction shows mostly some blue (Oxygen atoms) and green dots (Silicon atoms). There is enough energy for the target atom to recoil and cause other vacancies until it does not have enough energy, so that the target atom will vibrate back to its original position site releasing its energy as phonons. By vibrating back to their original position, the recoil atoms (blue/green) track follows the same initially created (red dots) and thus, they superpose. This picture can be misleading by assuming that the nuclear energy dissipation (15%) dominates the electronic energy dissipation (27%).

Since atomic mixing and recoil implantation distort the depth profile simultaneously, a model for which all interactions experienced by an atom should be used. Monte Carlo Codes coupled with thermal processes or Molecular Dynamic approximation [6] take into considerations the distortions caused by mixing effects such as the slowing down process within a material. Even if TRIM is a B.C approximation, this program should be used for the input of parameters needed for the M.C or M.D code.

CONCLUSION

Of concern is the temperature at the surface giving rise to stresses that could result in erosion, atomic mixing in the collision cascade. A model is needed in this area to better understand the beam target interaction and its effects on the target, and to find solutions such as the choice of the target.

The optical layout of the ion beam through the Pepper-Pot Scintillator Screen system should be finalised using one of this code: SIMION, the ion and electron optics simulation software or PARMILIA, the Phase And Radial Motion in Ion LInear Accelerators software.

Further developments this year will include a beam test of possible transparent materials. Short and long time effects should be studied.

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