# SCINTILLATION SCREEN RESPONSE TO HEAVY ION IMPACT


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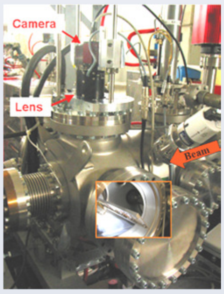
## Abstract

For quantitative transverse ion beam profile measurement, imaging properties of scintillation screens have been investigated for the working conditions of the GSI linear accelerator. In previous studies, in the ion energy range between 4.8 and 11.4 MeV/u the imaging properties of the screens were compared with profiles obtained using standard techniques like SEM grids and scraper. Detailed investigations with e.g. Calcium and Argon ion beams on various radiation-hard materials show that the measured beam profiles can differ from those measured with standard methods and depend on several beam and material parameters.

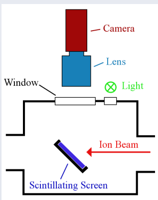
For the practical usage of scintillators, it is necessary to have predictions for the response of the scintillator to a given ion beam. An existing model for the light yield of scintillators for single particle irradiation has been extended to include the effect of overlapping excitation tracks.

To validate the model, dedicated measurements with homogeneous Carbon and Titanium ion beams at 11.4 MeV/u have been carried out. To understand the mechanisms, the beam flux has been varied between 5E6 and 2.6E8 particles/(ms*cm2) and the pulse length between 5 and 0.5 ms. The results of the measurement are presented and discussed. The measured light yield can be compared to the model calculations.


## Experimental setup for investigation of imaging qualities




A stepping motor driven target ladder holds 6 screens of ∅ 30mm ⇒ Observation without longer interrupts to ensure the same beam properties for all materials. Setup allows to store the number of particles that generated the beamspot




- **Camera:** AVT Stingray F033B (VGA monochrom), FireWire interface
- **Lens**: Linos MeVis 25mm, Stepping motor iris, 10 pixel/mm spatial resolution, sensitive to **400 – 700 nm**
- **DAQ:** Rack PC with FPGA card
- **GUI:** C++, individual image and particle storage

## Investigated materials

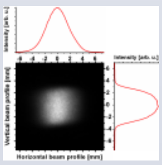
| Type | Material | Supplier |
|---|---|---|
| **Ceramic** | $ZrO_2$ :Y (Z700), $ZrO_2$:Y+20% $Al_2O_3$ (Z700 20 A), $ZrO_2$:Mg (Z507), AlN, $Al_2O_3$ and $Al_2O_3$:Cr | BCE special ceramics |
| **Quartz glass** | Pure: Herasil 102, | Heraeus quartz glass |


## Data analysis

- Quantitative analysis were performed with the projections.
- The shape of the peak can change due to several processes in the material.
- The shape of the projections are characterized by:
  - center μ (1st moment)
  - standard deviation σ (2nd moment)
  - skewness γ (3rd moment)
  - kurtosis κ (4th moment, peakedness)
  - For a σ=2mm beam spot an increase of ≈10% in sigma corresponds to 0.2mm, which is too small to be detected by a SEM-Grid.

Example of horizontal projection

Example of original image

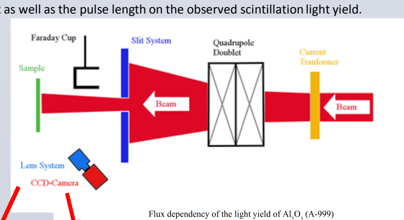



## Experimental setup for investigation for beam flux dependency

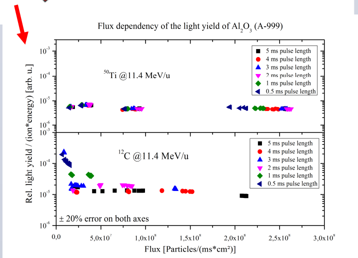
To validate the developed model for $Al_2O_3$, a new experimental setup has been completed in the materials research branch at GSI. The idea is to investigate the influence of the beam flux as well as the pulse length on the observed scintillation light yield.

- To achieve a homogenous beam spot on the sample, only a small part of the ion beam is used.
- The max. difference of the beam intensity on the beam spot of 1cm² is 20%.

- First measurements has been carried out and the data look very promising.
- The experiment has been carried out with two ion species: $^{50}$Ti and $^{12}$C @ 11.4MeV/u → about 15% c
- Beam spot size is 1cm²
- 1E9 -1E7 ions per pulse
- Pulse length: 5 to 0.5 ms
- Light yield measured in the region between 400 and 700 nm.
- With this data it should be possible to validate the model



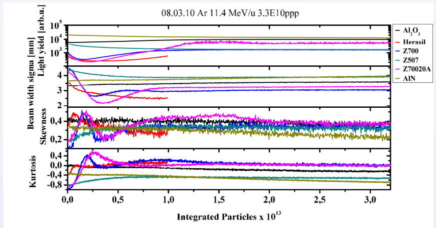

Example of 1cm² beam spot on $Al_2O_3$ sample




Measurement

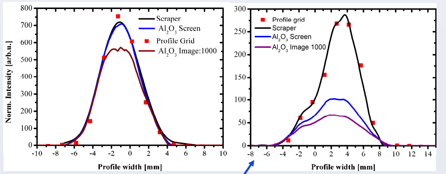
## High current investigations

- Measured in the region between 400 – 700 nm.
- Typical ion currents for the beam delivery to the GSI synchrotron are in the order of several mA.
- An example for a high current measurement is shown, where the screens are irradiated by $Ar^{10+}$ of I =260 μA within 200 μs delivery time.
- As expected, the light yield of the various materials differs of several orders of magnitude.
- Different values for the profile width and higher moments causes problem for accurate measurement. (Steady state temperature on the backside of $Al_2O_3$ is 200°C)
- Non-radiative decays compete with luminescence ⇒ temperature and fluence dependence.




$Ar^{10+}$ @ 11.4 MeV/u, ~3.3*$10^{10}$ ppp, 260 μA, 200 μs, 1.7 Hz, 1000 pulses, $P_{peak}$= 12 kW, $P_{aver}$= 4.1 W

## Comparison of beam profile with reference methods



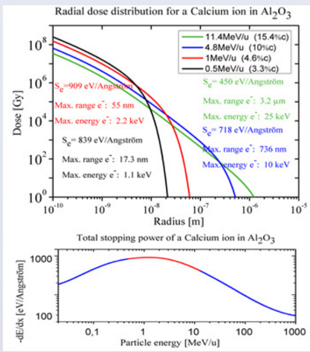

$^{48}Ca^{10+}$ @ 4.8 MeV/u, ~4.3*$10^{10}$ ppp, 13.5 μA, 5 ms, 1 Hz, $P_{peak}$= 317 W, $P_{aver}$= 1.59 W

$^{48}Ca^{10+}$ @ 11.4 MeV/u, ~1.87*$10^{10}$ ppp, 26 μA, 1.2 ms, 1 Hz, $P_{peak}$= 1,37 kW, $P_{aver}$= 1.63 W

**Saturation effect @ 11.4 MeV/u is not due to material degradation**

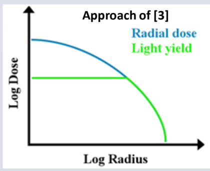
- The scraper scan method gives a beam profile with much higher spatial resolution then the profile grid.
- For 4.8 MeV/u the methods are in good agreement for the first macro pulse. After 1000 pulses a deformation of the profile is detected, which can be attributed to both material degradation (e.g. generation of traps) and spectral effects.
- In the 11.4 MeV/u case even the profile of the first macro puls does not reflect the ion beam. This saturation behaviors can be described by the model, with an overlap of ion tracks in space and time.
- An influence of the emission spectra could be excluded by dedicated measurements [1].

## A quantitative model for $Al_2O_3$



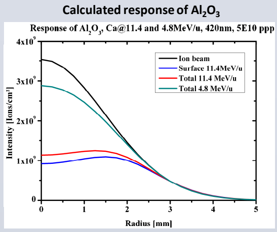

**The radial dose distribution around the path of an ion**

- The distribution is governed by the the ion species, its velocity and target material [4].
- The faster the ion, the further its stopping power is deposited away from the ions track.
- The aria under the curve is normalized to the given stopping power.
- Even though the stopping for 4.8 and 0.5 MeV/u is similar, the radial dose distribution is very different.
- Between 11.4 and 0.5 MeV/u is a factor of 2 in stopping power, but one order of magnitude in the maximum dose.
- Thus, the radial dose distribution depends more on the ion velocity then on the stopping power.

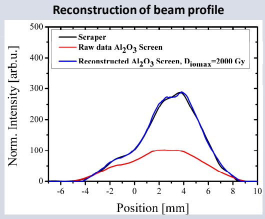



- The observed behavior of $Al_2O_3$ can be described by an overlap of the ion excitation tracks in space and time which leads to reduction of the light yield in the overlapping regions.
- The model is based on;
  - The radial dose distribution around the ions path.
  - The estimations concerning the behavior in the overlapping regions.
  - A maximal energy dose which can be converted into e-h pairs[3].
- The developed model has only one fitting parameter; the maximum dose, which causes the maximum excitation inside the material.
- The Lambert-Beer absorption is included in the calculations.
- The model is able to reconstruct saturated images.

**Calculated response of $Al_2O_3$**




**Reconstruction of beam profile**




Validation

## Summary and Outlook

- $Al_2O_3$ shows the best results of the investigated materials and is able to measure properly up to a certain beam flux and accumulated fluence.
- The observed behavior of $Al_2O_3$ can be understood in terms of saturation effects and material degradation.
- The developed model is able to describe the saturation effects which are caused by an overlap of ion excitation tacks.
- The model has to be verified by the experimental results of last beam time.
- The UV emission of $Al_2O_3$ can also be considered as possible solution for imaging problems [1]

## References


[1] E. Guetlich et al., "Scintillation screen studies for high dose ion beam applications, " IEEE Transactions on Nuclear Science, Vol. 59, No. 5, pp. 2354 – 2359, October 2012.

[2] P. Forck, "Lecture Notes on Beam Instrumentation and Diagnostics",GSI Darmstadt (2011), http://www-bd.gsi.de/index.php?cmd=publications .

[3] K. Michaelian et al., "Model of ion-induced luminescence based on energy deposition by secondary electrons," in *Physical Review B*, 1994.

[4] R. Katz et al., "The calculation of radial dose from heavy ions; predictions of biological action cross sections" Nucl. Instr. and Meth. in Phys. B, 107 (1996), 287-291