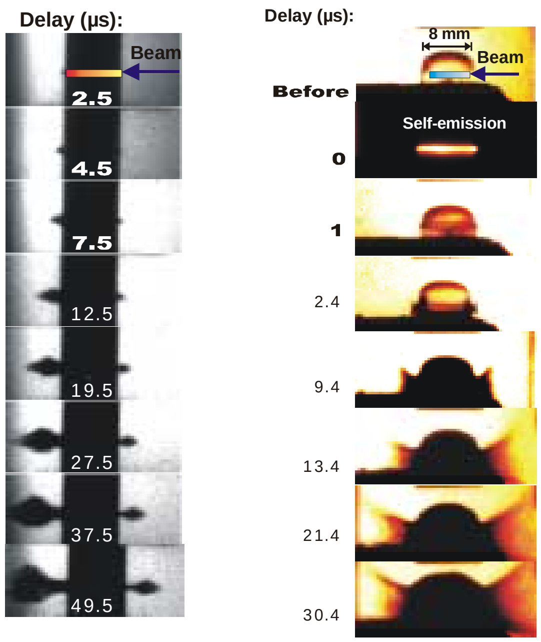
Shadowgraphy measurements on the heavy ion beam interaction with solid targets

E. Dewald[1], C. Constantin[2], S. Udrea[2], D. Varentsov[2], D.H.H. Hoffmann[2,1], J. Jacoby[1], U. Neuner[2], A. Tauschwitz[2], J. Wieser[1], N.A. Tahir[2], A Kozyreva[2], U. Geißler[2], M. Roth[1], P. Spiller[1] and R. Bock[1]
[1]GSI Darmstadt, [2]TU-Darmstadt

At the HHT experimental area, strongly coupled plasmas are created by the interaction of the SIS heavy ion beams with solid targets. To obtain a high energy deposition in the target, the ion beam is focused by the plasma lens [1] to diameters smaller than 1 mm in the focus. The generated plasmas have densities close to the solid state density, volumes of several mm^3 and temperatures up to 1 eV. The characterization of the matter under such extreme temperatures and pressures is of relevance for equation of state (EOS) studies, in astrophysics for understanding the formation of heavy elements in supernovae, for designs of future heavy ion driven Inertial Fusion Experiments (IFE) and others.

A wide range of optical diagnostics, such as shadowgraphy, time resolved spectroscopy in visible and VUV ranges, and schlieren techniques were recently developed to study the target behavior at the interaction with the ion beam.

Up to now, metallic and cryogenic gas crystal targets [2] were used for the ion beam heating experiments, characterized by backlighting shadowgraphy and time resolved spectroscopy. For these experiments the backlighter was a high energy (250 J) Xe flashlamp and the target dynamics was detected with a fast multiframing camera, capable to acquire simultaneously eight frames with an exposure time above 10 ns.



a *b*

Figure 1: Superrange target dynamics in beam-target interaction experiments for 1 µs beam duration (50-200 ns exposure):
(a) 6 mm thick Pb plate, Kr beam, 300 MeV/u, N=10^{10} ions,
(b) 8 mm Ne crystal, U beam, 200 MeV/u, N=10^9 ions

Figure 1 shows typical hydrodynamics of targets larger than the ion beam range, for metallic plates and cryogenic gas crystals. Due to the non-uniform energy deposition, for the Pb plate (Fig. 1a) the matter expansion in the Bragg peak region is clearly more pronounced than in the direction opposite to the beam as it can be seen also in Figure 2. Moreover, due to a strong radial temperature decrease from the axis, the heated expanding matter has a droplet shape. For EOS studies the experiments are simulated by the BIG2 two-dimensional hydrodynamic code. According to the simulation, a maximum temperature of 0.3 eV is reached in the plate by ion beam heating. The matter expansion velocity is used to benchmark the simulation.

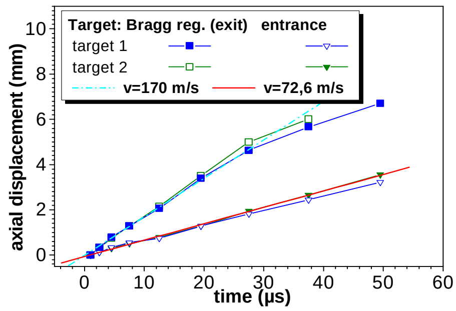


Figure 2: Axial matter expansion for the Pb plate (Fig. 1a)

Quite a different behavior was observed for the cryogenic gas targets, i.e. for most of the crystals there is a symmetric matter expansion even for targets thicker than the ion beam range (Fig.1b). This is mainly explained by the drilling effect of the beam which shifts the range during the beam pulse beyond the target thickness. This can be experimentally observed from the target self-emission and 1 µs after the beam (Fig 1b). For a specific energy deposition of 6.8 kJ/g, a maximum temperature of 0.48 eV is reached in the Bragg peak region according to the BIG 2 simulation. Furthermore, the Bragg peak in the crystals is less pronounced than in the metal plates which results in a more uniform energy deposition. A high expansion velocity (470 m/s) was observed in the first 5 µs, after which it decreases in 10 µs to a constant velocity of 140 m/s. For cryogenic crystals this behavior was already predicted in [3].

Another interesting feature is that the radial shockwave generated by the heated matter destroyes the crystal structure and consequently its transparence as it can be observed in Fig. 1b for the pictures taken 1, 2.4 and 9 µs after the beam.

Several experiments were performed using different ion beams, cryogenic crystals (H, D, Ne, Ar, Kr, Xe) and metallic plates.

The shadowgraphy measurements give an insight into the beam-target interaction and into the generated plasmas. Furthermore, the matter dynamics can be used to benchmark the simulation code as well as the used EOS data.

Acnowledgement: This work was supported by BMBF.

References

[1] M.Stetter et al., Fus. Eng. Des. 32-33(1996) 503
[2] U.N.Funk et al., Nucl. Inst. And Meth.A 415 (1998) 68
[3] M. Dornik, Ph.D. Thesis, TU Darmstadt, 1997