Investigation of high power laser -induced spallation phenomena in target and collimator materials for next generation accelerators*

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The design of new high power accelerator facilities at FAIR, HiLumi LHC and FCC needs advanced solutions for beam intercepting devices such as production targets, collimators, beam windows, absorbers and dumps. The interaction of high energy, high intensity particle beams with solids induces shock waves, phase and density changes, nano-structuring and spallation. In order to understand the failure mode and to predict component lifetimes, a concerted effort on studying the behavior of traditional and novel material in conditions similar to the operating environment is going on in large collaborations projects such as EuCARD2. Both radiation hardness for high flux beam exposure and dynamic mechanical response during beam impact are investigated for traditional materials like graphite, and for novel composite materials purposely developed for high energy particle beams applications.

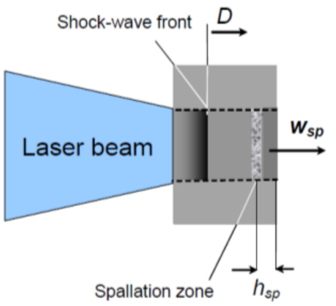

Figure 1: Sketch of the laser – induces spallation experiment on thick targets (D is the shock-wave front velocity and w_{sp} and h_{sp} are, respectively, the velocity and thickness of spallation plate) [1].

Within the experiment P089, investigations of spallation phenomena in different graphite grades, copper-diamond and molybdenum-graphite composites were conducted at the Z6 experimental area, using shock waves induced by the PHELIX laser at GSI. A pulsed laser beam with a wavelength of 530 nm, 1.4 ns pulse duration and energies of 120 J was focused to a spot size of 1.3 mm on the target. Typical beam intensities were about 0.6 ´ 10^{13} W cm–2. For inferring the spall strength s* and strain rate $\dot{\varepsilon}$ we measured the depth of spallation groove h after laser beam impact on the target. The s* and $\dot{\varepsilon}$ values were calculated using a numerical code based on hydrodynamics equations [2]. It was assumed that the ablation pressure pulse on the front target surface has the same shape as the laser pulse. The spallation strength was considered to be the minimum pressure modulus in the spallation plane [1]. Figure 2 shows optical microscope images of ablation crater on the laser facing side of a thick isotropic graphite target and of the rear spallation crater on the same target.

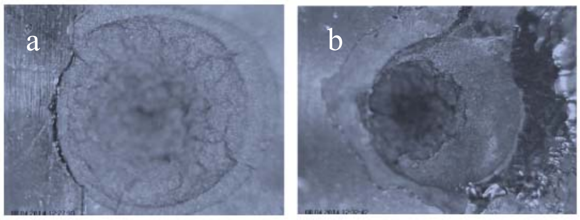

Figure 2: Optical micrographs of (a): ablation spot on the front side and (b): spallation crater on the rear face of a thick graphite target exposed to laser beam.

Raman spectroscopy has been used for first investigations of microstructural transformations induced by the laser shock wave in the sample. As shown in figure 3, the material in the spallation crater shows a higher degree of graphitization than the initial structure, indicating that the material temperature reached values above 2000 ºC. Future detailed Raman spectroscopy mappings of the craters will be performed for investigating the possible formation of high pressure carbon phases like rhombohedral graphite and diamond. Spallation strength values between 1 and 2 GPa were found for isotropic graphite experiencing strain rates between 10^6 and 10^7 s^{-1}.

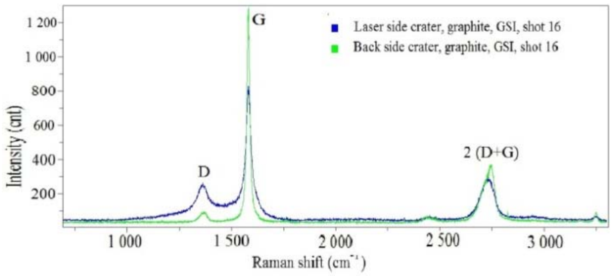

Figure 3: Raman spectra of graphite target after laser beam impact in the ablation crater (blue) and spallation crater (green).

[1] S.A. Abrosimov et al., Quantum Electronics 44 (6) (2014) 530 – 534.
[2] D. Batani, V.I. Vovchenko, G.I. Kanel, et al. Dokl. Ross. Akad. Nauk, 389 (3), 328 (2003).

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