

Hard X-ray and fast electron generation from dielectric nanostructured targets

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Abstract

We report on the generation of hard X-ray quanta with energies up to 800 keV from nanostructured ZnO surfaces irradiated by non-relativistic laser pulses in single-shot mode. We demonstrate more than one order of magnitude enhancement in efficiency of X-ray generation in the range of photon energies above 100 keV and provide evidence of a dramatic increase in flux of fast electrons for nanostructured targets in comparison with polished surfaces.

It was recently argued [1] that nanowire arrays of micron length scales allow an effective increase in the penetration depth of the laser energy leading to so called volumetric plasma heating. As a result of this very efficient absorption of the laser energy, electron densities of one-two orders of magnitude above the critical one with multi-keV temperatures can be reached. In this contribution we investigate the potential of such nanostructured targets to generate hard X-ray photons being irradiated by moderate energy ultrashort laser pulses.

Experiments were conducted at a 1 kHz, 804 nm wavelength femtosecond laser system delivering 55 fs pulses with up to 3.5 mJ energy. The beam was focused by an off-axis parabolic mirror into a 5 μm FWHM spot on the surface of a solid target providing the peak intensity on the target of about 10^{17} W/cm². Experiments were performed with two morphologically different types of samples produced by vapour transport. The first type, the “grass” sample, is a disordered array of single crystalline nanowires with diameters of 70-100 nm, average spacing of about 200 nm and lengths of several microns, arranged vertically on a sputtered <100 μm thick ZnO:Al layer deposited on a 500 μm silicon wafer (Fig.1a). The second type, the “spaghetti” sample, represents a pile of nanowires with the parameters close to the grass-sample, but chaotically arranged along the surface (Fig.1b). We specially emphasize the fact that the wires are transparent for the laser radiation, therefore volume ionization and explosion by high intensity fields can be achieved.

To reveal influence of surface structuring on the efficiency of hard X-ray generation, a polished 300 μm thick crystalline ZnO plate was used as a reference target. Interaction of the laser beam with the targets happened in a vacuum chamber pumped down to 10^{-4} mbar. However, spectral diagnostic of the emission was conducted in air after the emission was passing through a 50 μm thick kapton window. After every shot, the samples were moved by a 2D translation stage to ensure single-shot exposure.

Spectra of the generated X-ray emission were measured with two bent crystal spectrometers based on toroidal SiO₂ 10-1 and cylindrical LiF 220 crystals, using cooled back-illuminated X-ray CCD cameras as detectors. Another X-ray CCD camera was directly detecting photons with energies up to 25 keV under a collection angle $\approx 15^\circ$ relative to the sample surface. To detect higher energy quanta, two Timepix detectors capable measuring photon energies up to 1 MeV were used.

The X-ray spectra of emission detected by the Timepix detectors are presented in Fig.1. While the yield of X-ray emission at Zn K α and K β lines is essentially independent on surface morphology (not shown here), an increase in the efficiency of generation of high-energetic quanta (> 50 keV) is observed for nanostructured targets (Fig.1c,d). The measured hard X-ray spectrum reaches the border of the detector sensitivity and a flux enhancement of more than one order of magnitude in the region above 100 keV is registered. The efficiency depends on laser polarization (Fig.1c,d), suggesting that the Brunel mechanism of electron heating might be involved [2]. Also, it was verified that the CCD detector in the high-resolution spectrometer near the output window additionally detects the flux of fast electrons, which is more than two orders of magnitude higher for nanostructured targets than for polished ones.

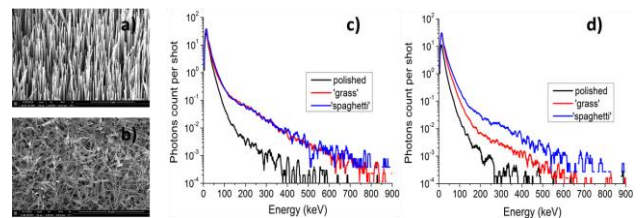


Fig. 1. Scanning electron microscopy (SEM) images of the a) “grass” and b) “spaghetti” sample; c) Timepix hard X-ray spectra from the polished sample (black line), “grass” sample (red) and “spaghetti” sample (blue) for p-polarized laser beam; d) the same for s-polarized laser beam.

References

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- [2] F. Brunel, Phys. Rev. Lett. 59, 52 (1987).