Investigation of magnetized plasma created in snail targets at the PALS facility

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Magnetized plasma studies are necessary for many applications including laser-driven inertial fusion, modeling astrophysics relevant phenomena, as well as innovative industrial and medical applications. The presented research continues in previous PALS experiments, which principally confirmed the idea of forming the magnetized plasma in snail targets (ST) irradiated by moderate intensity laser beams [1]. The aim of the experiments is an enhanced understanding the processes of creating a magnetized plasma inside the ST target at different irradiation conditions related to the energy, polarization and the method of focusing the laser beam on the target, taking into account their construction. The subject of optimization studies were Cu targets with two diameters: Φ=1000 μm and Φ = 2000 μm, Fig. 1a. They were irradiated by 1ω radiation of the PALS iodine laser with an energy of about 500 J and linear or circular polarization

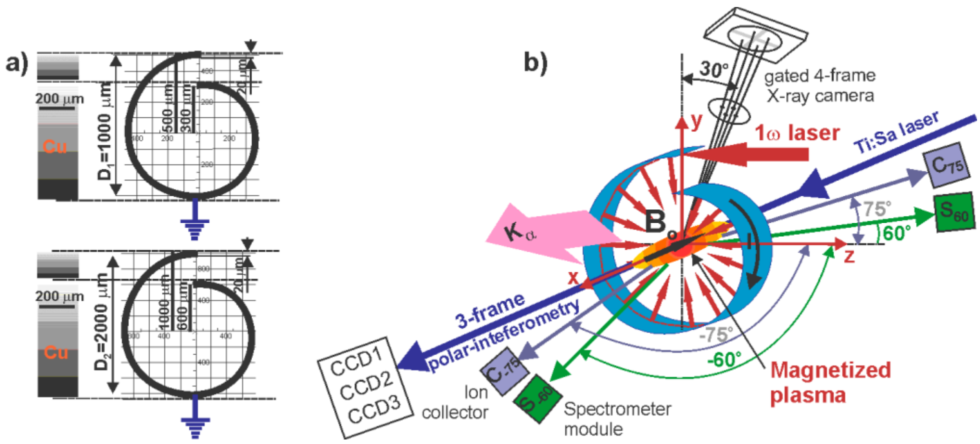

Fig. 1: *The construction of snail targets (a) and the method of their irradiation with a laser beam including the location of diagnostics in the experiment (b).*

The following diagnostics were used : (i) 3-frame complex interferometry allowing to measure time changes in the distribution of the magnetic field and electron density in the formed structure of the magnetized plasma, (ii) 2D imaging of the Cu Kα- line emission visualizing the process of hot electrons interaction along the target surface and obtaining information on the distribution of the energy deposited along the surface of the target, and (iii) a multi-channel magnetic electron spectrometer for measuring angular energy distribution and hot electron temperature. A 4-frame x-ray pinhole camera visualized the process of forming a magnetized plasma stream in the X-ray range with energy >1 keV. Figure 2 shows time sequences of complex interferograms illustrating the radial implosion of the plasma created from the inner surface of the ST in the case of targets with different diameters, irradiated by the 1ω iodine PALS laser beam (1.315 μm) with an energy of about 500 J.

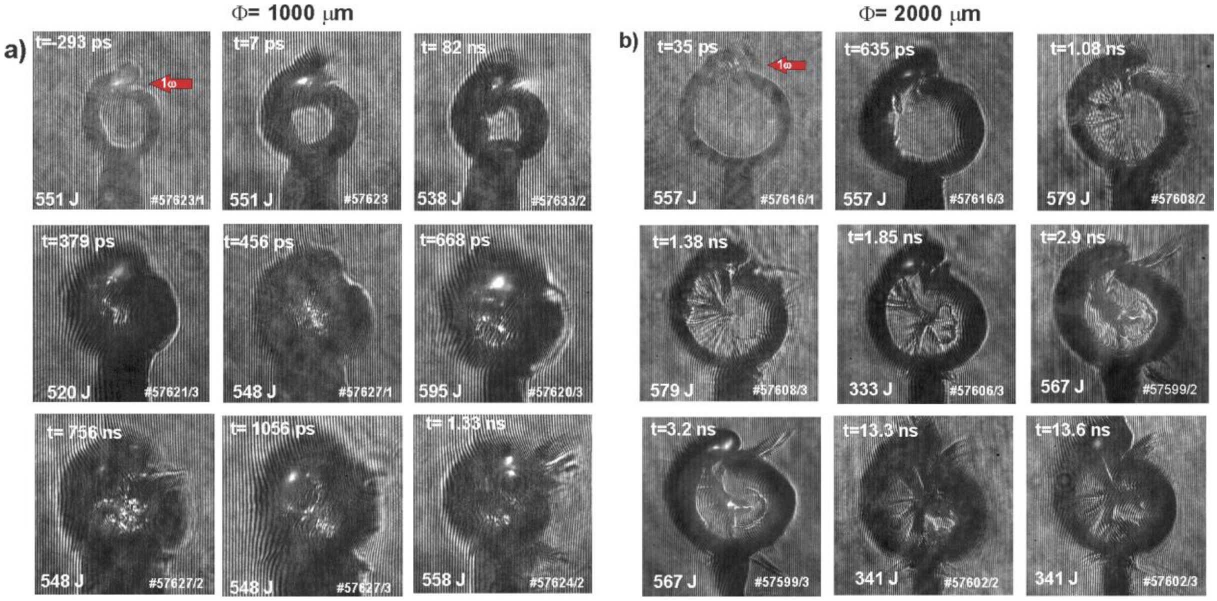

Fig. 2: *Complex interferograms illustrating the process of plasma formation inside snail targets of different diameters: a) Φ = 1000 μm, and b) Φ = 2000 μm.*

In the case of smaller diameter targets, Fig. 2a, the process of plasma implosion from the surface of the snail starts much earlier (about several hundred ps before the maximum laser intensity) compared to the larger diameter target. The formed dense plasma configuration in the center of the screw is visible after the end of the laser pulse. In the case of targets with a diameter of Φ = 2 μm, the process of creating the plasma on the surface of the target starts much later, at t> 1 ns. The characteristic stable configuration of the plasma with a current structure in the form of "jets" propagating to the center of the snail maintains in late times, even a dozen ns after the maximum of the laser pulse, Fig. 2b. A comparison of the plasma formation process in ST targets of different diameters depending on the polarization of the laser beam is shown in Fig. 3. Obviously, for both polarization the structure of the fringes on the interferograms seems to be very similar, which suggests there is no significant influence of the beam polarization on the plasma formation process.

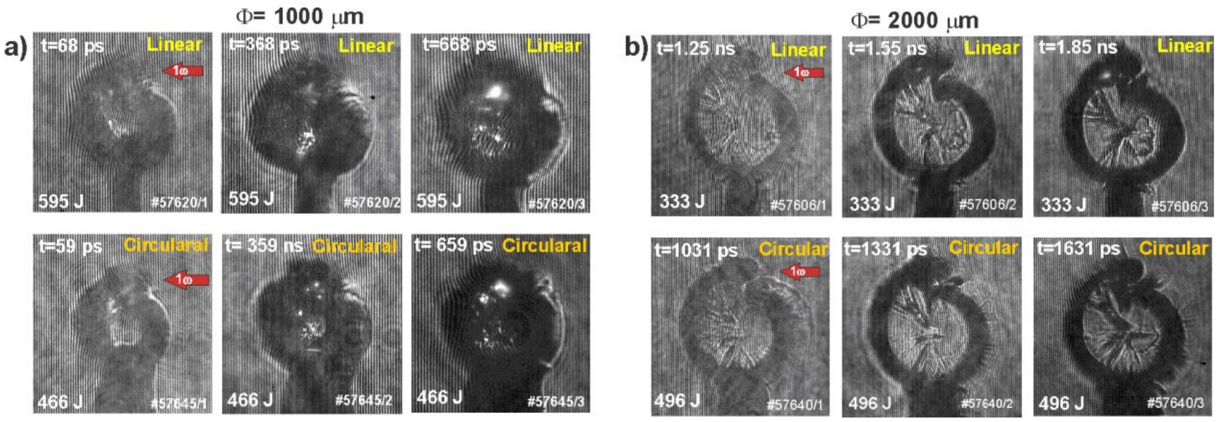

Fig. 3: *Comparison of the plasma stream formation process in ST targets with diameters: a) Φ = 1000 μm and b) Φ = 2000 μm irradiated by the 1ω PALS laser beam with linear and circular polarization.*

Quantitative differences in the plasma formation processes in the ST target depending on the beam polarization are seen in measurements of hot electron emission parameters using spectroscopic diagnostics and a 4-frame X-ray camera. In the case of ST targets with a diameter of 1000 μm, the differences resulting from the polarization are visible in measurements of Cu Kα emission, see

Fig. 4b. Irradiation of the target with a linearly polarized laser beam evidently increases the emission of photons emitted under the influence of hot electrons propagating along the surface of the target. The calculated energy of hot electrons deposited, both in the first "spot" (corresponding to the focusing of the laser beam on the target) and along the entire target surface, is clearly larger compared to the energy deposited when the target is irradiated by the circularly polarized beam.

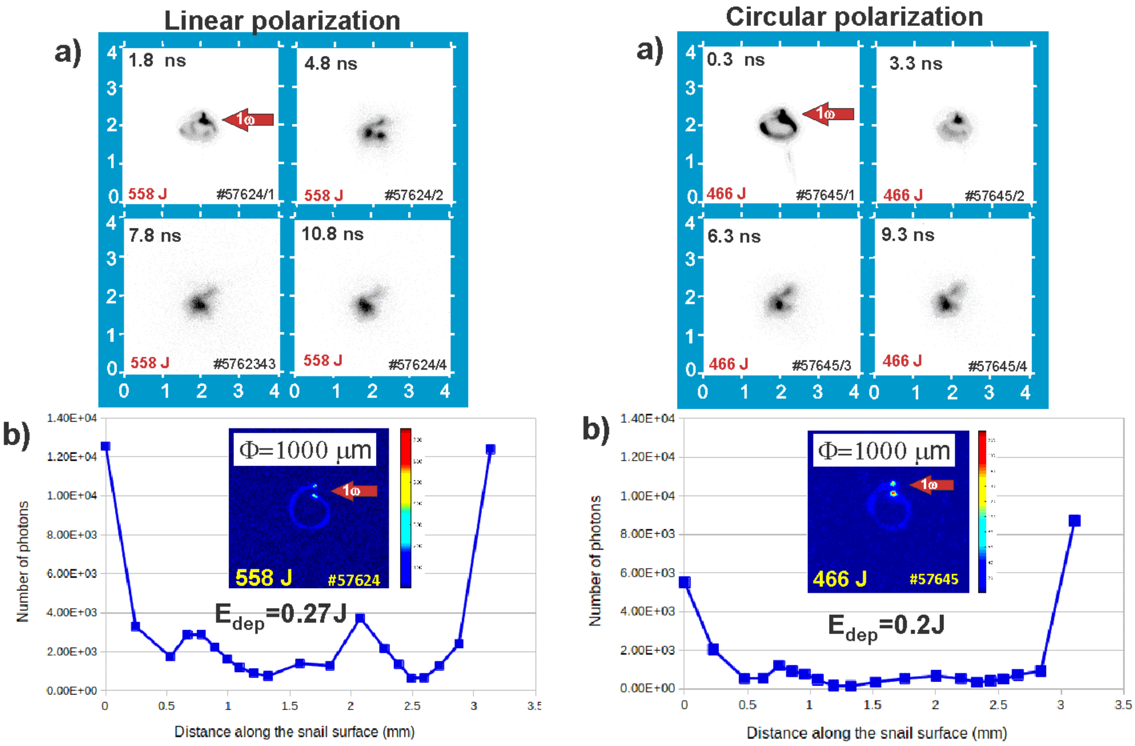

Fig. 4: Measurement results obtained using: a) a 4-frame X-ray camera and b) Cu Ka emission measurements illustrating the effect of a laser beam with linear and circular polarization on plasma formation and HE emission for targets with a diameter of 1000 μm.

In the case of targets with a larger diameter, the influence of the laser beam polarization on the Cu Kα emission, Fig. 5, reveals in absolute values of the energy deposited by hot electrons, which is clearly smaller compared to a target with a smaller diameter.

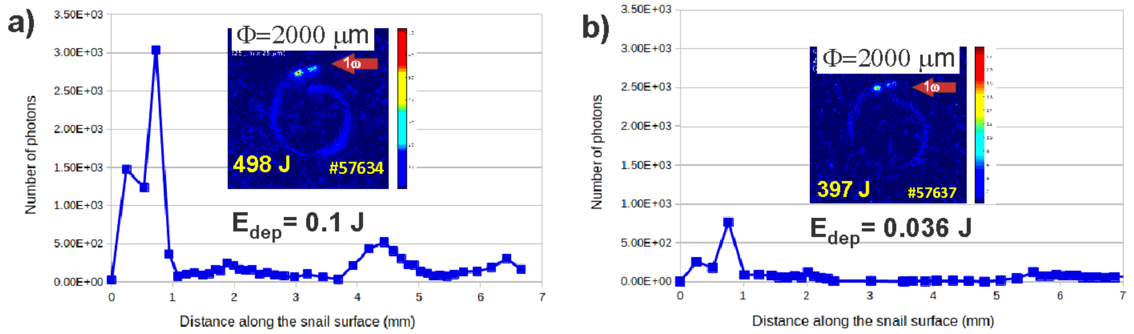

Fig.5: Results of Cu Kα- measurements illustrating the effect of the laser beam with linear (a) and circular (b) polarization on the energy deposited by HE along the surface of a target with a diameter of 2000 μm.

As for the visualization of the plasma formation process in the ST target, obtained with a 4-frame X-ray camera, Fig. 4a, the influence of the laser beam polarization on the plasma configuration does not seem to depend significantly on its polarization. In the case of a smaller diameter target, the final stage of the process is a dense plasma concentrated in the center of the target. The positive effect of the laser beam polarization on the hot electron emission from ST targets of different diameters is also seen in measurements of the electron energy spectra distribution by a multi-channel electron spectrometer. The results of their quantitative analysis providing information about the angular distribution of the number of emitted electrons, their energy and temperature for snail targets with different diameters ilrradiated by the 1ω laser beam of different polarization are presented in Fig. 6 and Fig. 7.

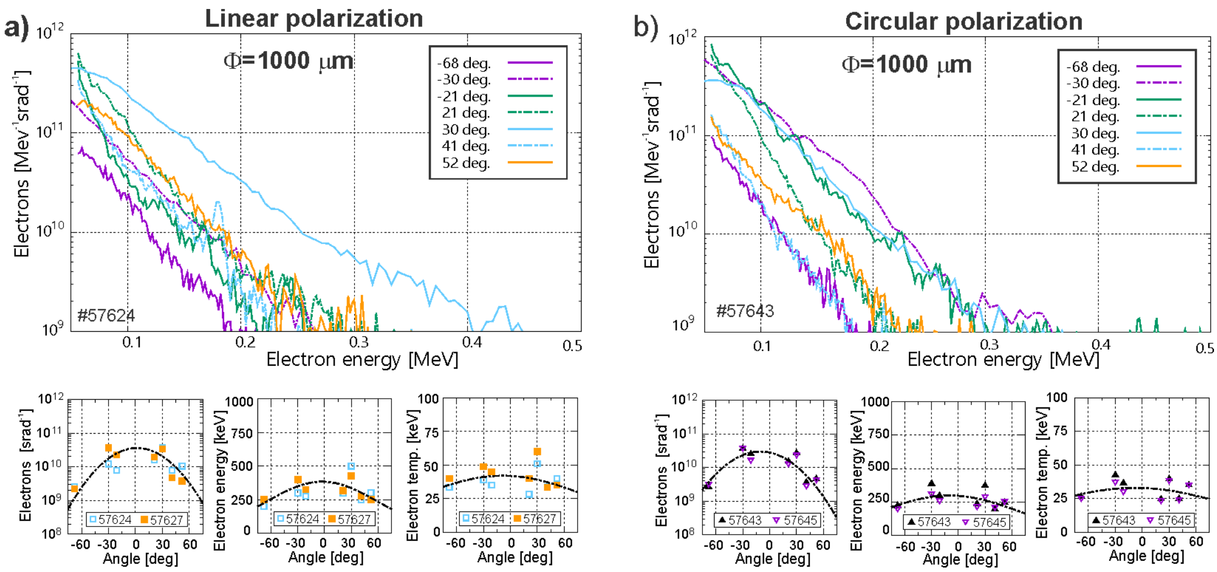

Fig.6: Comparison of the angular dependent electron energy spectra and emission parameters obtained when irradiating the targets with a diameter of 1000 μm by the 1ω iodine laser beam with an energy of about 500 J polarized: a) linearly and b) circularly.

The presented dependencies clearly demonstrate the influence of the laser beam polarization on the above-mentioned parameters of the electron emission from targets with different diameters. In the case of linear polarization, the electron energy and temperature values are definitely higher compared to circular polarization. A characteristic feature of these distributions is their flattened character which confirms that in comparison to the electron emission from flat targets, the emission of electrons from the plasma formed on the snail target is stronger in the direction perpendicular to the plane of the target. This flattened distribution character also proves that the formed configuration of the magnetized plasma actually has the symmetry similar to *the theta-pinch* system with the axial magnetic field perpendicular to the plane of the snail target.

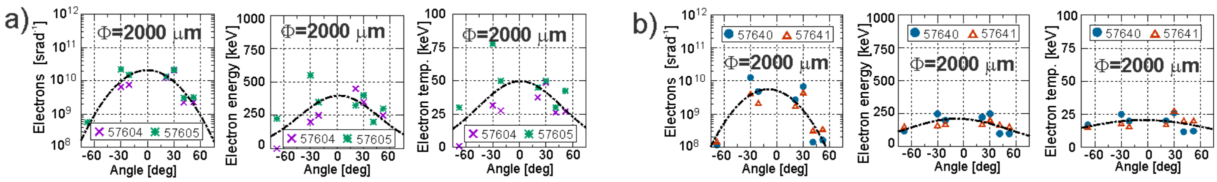

Fig. 7: *Comparison of electron emission parameters when irradiating the target with a diameter of 2000 μm by 1ω beam of an iodine laser with an energy of about 500 J polarized: a) linearly and b) circularly.*

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Reference:

[1] T. Pisarczyk et al, *Scientific Report*, **8**:17895, 2018.