# Investigation of spontaneous magnetic fields, electron and ion emission in laser-produced plasma experiments at PALS

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For understanding a relation between a spontaneous magnetic fields (SMF) and electron and ion emission, a comprehensive investigation of the ablative plasma produced at planar massive and double-layer Cu targets (massive Cu coated by different thickness layers of plastic) was carried out. The driver pulse was the 1-st harmonics of the PALS iodine laser providing intensity up to $10^{16}$ W/cm$^2$. A three-frame femtosecond complex interferometry [1] setup was used to investigate space-time distribution of SMF and plasma density. The parameters of electron distribution were analyzed by the 2D imaging of Kα line emission from Cu and the multi-channel magnetic electron spectrometer. Additionally, the return target current associated with hot electrons escaping the plasma was monitored with a current probe and the angular distribution of ion emission was measured using a grid system of ion collectors. Two-dimensional numerical simulations with the ATLANT-HE code and an analytical model including fast electron generation and transport have been used for interpretation of experimental data.

Optical scheme of 3-frame polaro-interferometer illustrating the space-time separation of frames and a typical 3-frame sequence of complex interferograms obtained by means of this system are shown in Fig. 1. To realize optimal conditions for complex interferometry, the interferograms were recorded at the initial angle of polarizer $\varphi_o$=-$2^0$ (anti-clockwise) in each channel according to the methodology described in paper [2]. For this initial angle of polarizer, Faraday effect in the upper half of the complex interferogram is clearly observed (see Fig. 1).

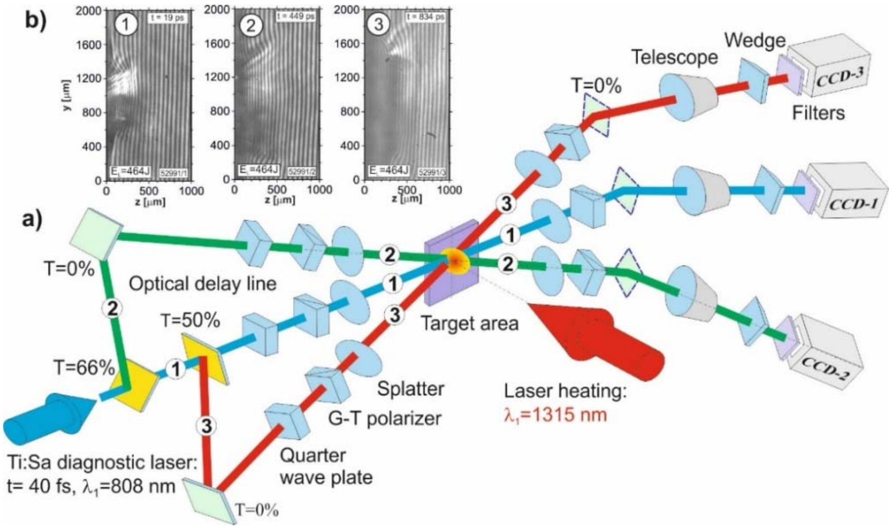



Fig. 1 Optical scheme of the 3-frame complex interferometer (a) and a typical sequence of obtained interferograms (b).

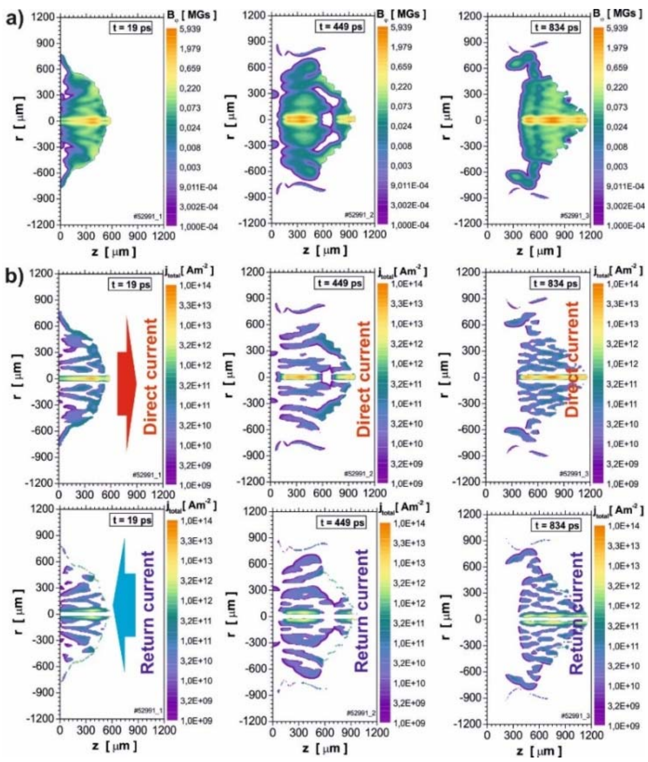



Fig. 2 Space-time SMF distribution (a) and corresponding current density distribution (b) obtained from the sequence of interferograms depicted in Fig. 1a.

To obtain information about the space-time SMF distribution, the amplitude-phase methodology described in paper [1] has been used. In Fig. 2, the SMF distribution in the ablative plasma for different expansion times (a) along with the corresponding current density distribution (b) based on the sequence of interferograms from Fig. 1b are presented. The obtained current density distribution clearly confirms the results of previous measurements carried out using the classical polaro-interferometry [3]. The main current in the ablation plasma is formed by electrons moving from the target (the so-called direct current) within a narrow cylinder near the axis of the plasma stream, with a diameter comparable to the laser beam. Such a distribution of electrons in the ablation plasma agrees well with the electron energy spectra recorded at different angles to the target normal using a multi-channel magnetic spectrometer. Most electrons with energies in the range of 58 - 400 keV are emitted in the axial direction, the maximum electron population being close to 60 keV.

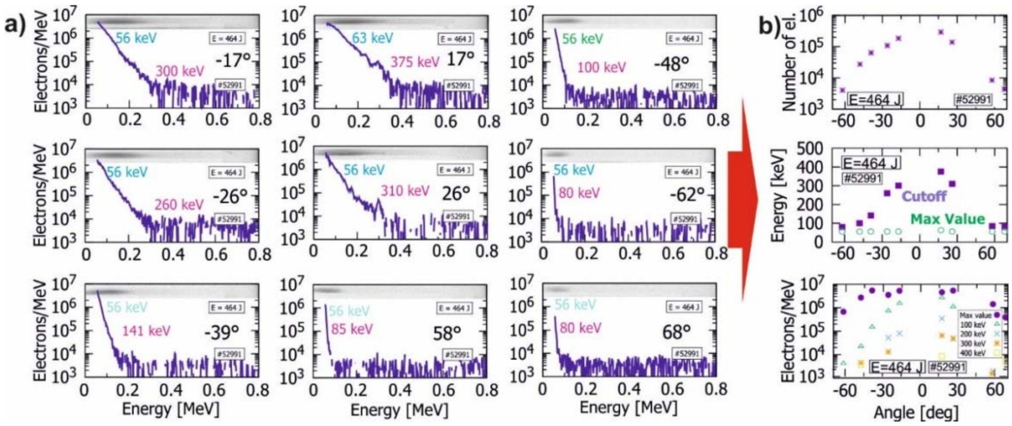
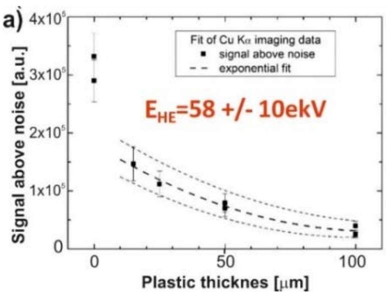



Fig. 3 Angular distributions of electron energy spectra (a) obtained via comparison of emission parameters at different emission angles (b).

Measurements of electron distribution performed by means of 2D imaging of Cu Kα-line emission identify the generation of fast electrons with energy of about 60 keV and conversion efficiency of up to 3%, Fig. 4. thickness plastic layers




b)

| Shot# | $E_L$ [J] | Signal | HE dose [J] | Conv. [%] |
|---|---|---|---|---|
| 52985 | 481 | 331676 | 5,54 | 1.15 |
| 52986 | 479 | 289899 | 4.84 | 1.01 |
| 52989 | 458 | 799292 | 13.3 | 2.90 |
| 52990 | 516 | 587401 | 9.81 | 1.90 |
| 52991 | 464 | 243956 | 4.07 | 0.88 |
| 52992 | 452 | 216132 | 3.61 | 0.80 |

Fig. 4 Exponential fit of experimental data as a function of the plastic layer thickness (a) and the fast electron conversion for different shots (b).

To obtain information about the fast electron energy, the space and time integrated intensity of Cu Kα emission measured at Cu targets coated with different was fitted by the function

I(x)=Aexp(-x/L), where A is the fitting constant, x the plastic thickness, and L the attenuation coefficient. The L value dependence on the HE energy was derived from the Monte Carlo simulation performed with the Penelope code [4], the calculated values were approximated by means of the 2nd degree polynomial.

The distribution of the return current suggests that its maximum (about 6 kA) is associated with the emission of high energy electrons leaving the ablation plasma in the initial expansion phase.

The results of complex interferometric studies and the emission of electrons are in line with results of 2D numerical modelling using the ATLANT-HE code [5, 6].They propose the resonant mechanism of the laser energy absorption in the considered case of the . This phenomenon is of a paramount importance for understanding generation of fast electrons and energy transport inside the target, e.g. to the shock wave. The characteristic average values of electron temperatures $T_e$=2-3 keV and the spatial scale of L~ 100 μm are accompanied with generation of fast electrons having the maximum energy of E~ 100 keV.

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