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Advanced sub-picosecond active optical diagnostics available at the PALS European Research Infrastructure

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Abstract. In this contribution the results of subpicosecond interferometric measurements of plasma density and the very first polarimetric measurements of spontaneously created magnetic fields in a laser-produced plasma conducted at the PALS Research Infrastructure are reported. For that purpose we are using a two-channel polaro-interferometer built at IPPLM Warsaw by T. Pisarczyk et al. A combination of iodine laser nanosecond pump and titanium-sapphire femtosecond laser probe is exploited for plasma diagnostics at the reported laser-target interaction experiments. A unique technique of synchronization of both the pulsed lasers used makes it possible to investigate the development of characteristic structures created in the plasma produced by a high-power laser with sub-picosecond temporal resolution, during the impact of a nanosecond laser pulse on the target. The aim of the experiment is to measure the electron density and magnetic field distributions of the ablative plasma created during the interaction of laser pulse with a fixed target, and to correlate the results with the data obtained by other diagnostic means.

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1. Introduction

The hot, dense, and intensely radiating tiny plasma objects produced by (sub-)nanosecond high-power lasers put extreme demands on the time and space resolution of the plasma diagnostics used, as well as on their resistance to strong electromagnetic and radiation noise. The standard passive radiation, spectroscopic and corpuscular diagnostic systems used at the PALS RI laser facility have been gradually supplemented by active optical diagnostics based on various models of multi-channel imaging laser interferometers, shadowgraphs and polarimeters developed for PALS by T. Pisarczyk et al. at IPPLM, Warsaw. Their latest versions [1,2] exploit for plasma probing a synchronized pulse of a high-power fs laser (Fig.1). The newest femtosecond polaro-interferometer described below makes it possible to visualize the distributions of plasma density and spontaneous magnetic fields with sub-ps precision.

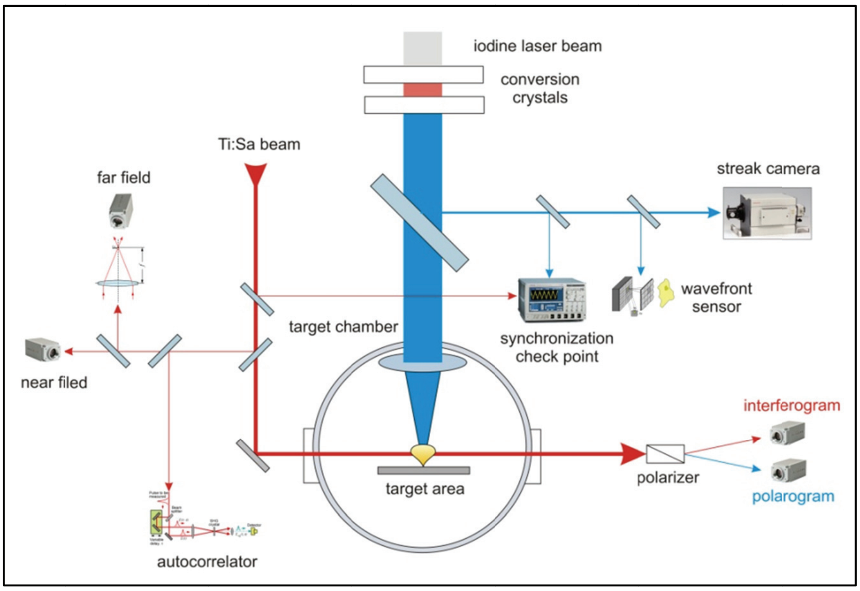

Fig. 1 General scheme of femtosecond optical diagnostics at the PALS RI

2. PALS Research Infrastructure

The PALS Research Infrastructure is a users facility offering its beam time to external researchers. The PALS key laser facility is a single-beam terawatt iodine laser system of MOPA configuration, unique in EU by its infrared wavelength of 1315 nm, belonging at the same time to only four European kJ-class lasers – Fig.2. The output infrared laser beam can be occasionally frequency up-converted by DKDP crystals into a visible (red or blue) light. The output energy of the 1st harmonic infrared laser pulse of a typical duration of 350 ps can be varied in the range 10 J - 1 kJ. The output TW laser beam of a diameter of 290 mm enters a vacuum interaction chamber, inside which it is focused into a focal spot of a diameter less than 0.1 mm. The laser beam generates hot plasma by interacting with solid state or gas targets mounted in the beam focal plane. The iodine laser is exploited for laser-plasma experiments at power density levels ranging from 10^{14} to $5x10^{16}$ W/cm^2 [3].

Fig. 2 View in the laser hall of the PALS iodine laser

The titanium-sapphire laser system at PALS consists of a laser oscillator of a central wavelength 810 nm, CPA regenerative amplifier Legend-F pumped by Q-switched Nd:YLF lasers, high-power multi-pass amplifier, and a pulse compressor. The repetition rate of its Micra oscillator is 76.24 MHz. The system is capable of delivering compressed output pulses of energy up to 1.2 J and duration less than 70 fs. A unique combination of synchronized long and short pulses generated by iodine and titanium-sapphire lasers [4-6] makes it possible to study the processes of interaction of intense radiation with targets with the required high (sub-picosecond) temporal resolution [7,8].

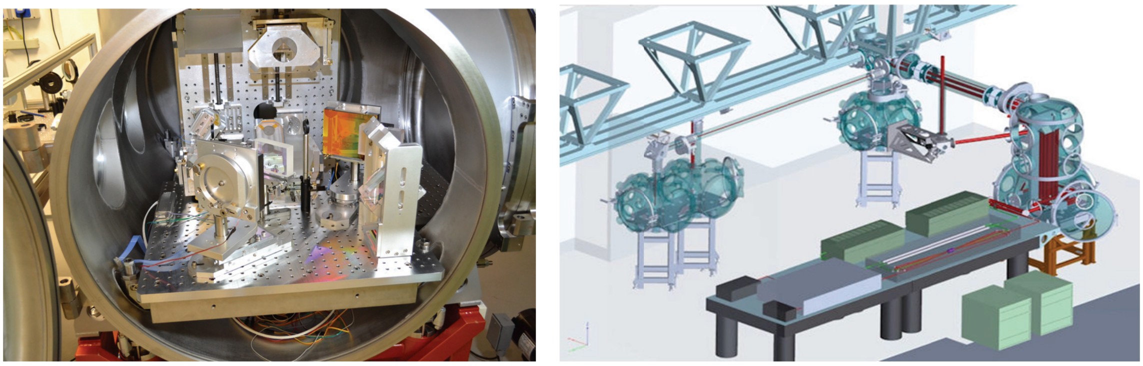

Fig. 3 Interior of the PALS Ti:Sapphire laser compressor (left) and a sketch of distribution of femtosecond beam lines

3. Experimental results

Two-channel polaro-interferometer consists of two independent channels which provide a possibility to measure the magnetic fields in two ways depending on the optical configuration of the polarimetric channel. In the first case, a polarogram and an interferogram are recorded in each channel and the magnetic field distribution in plasma on the basis of the Faraday rotation angle and the electron density distributions are calculated.

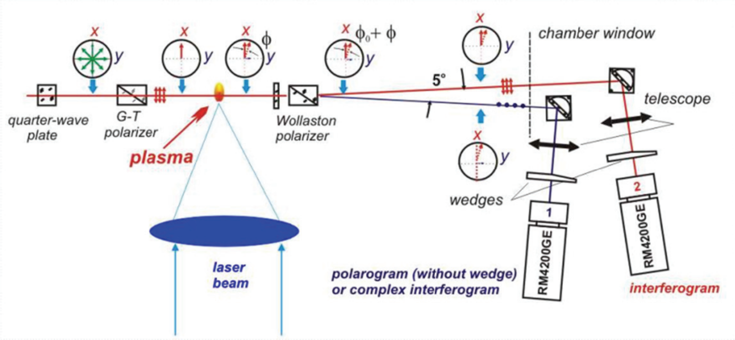

Fig. 4 Optical scheme two-channel polaro-interferometer.

In the alternate case, instead of the polarogram a complex interferogram is registered via initial rotation of the polarization plane with a wedge added in the polarimetric channel (see Fig. 4). Information about the magnetic field distribution can be obtained directly on the basis of the amplitude-phase analysis of the interferogram [11, 12]. The amplitude modulation is represented by changing the intensity of interferometric fringes, while the shift of interferometric fringes corresponds to the modulation of the phase.

In these experiments, planar targets made of materials with different atomic numbers (plastic and Cu) were illuminated by the main PALS 1ω laser beam with the energy of about 250 J focused to the minimal focal spot radius, R_L=50 μm.

A methodology presented in [9, 10] was used for polaro-interferometric measurements. To obtain the optimal registration conditions in the polarimentric channel, the initial rotation angle of the polarizer (**φ_0**) was determined using the following formula:

$$\varphi_0 \cong \arcsin\sqrt{\frac{1-\varepsilon(K-k)}{2+\varepsilon[2(K+k)+1]}} \tag{1}$$

Where: K is the coefficient of polarization of probing beam, k – polarization contrast, $\varepsilon = I_L/I_p$ (I_L – intensity of probing beam and I_p – intensity of plasma self-emission). The measurements were carried out for **φ_0 = 2°** according to the parameters $\varepsilon \cong 10^3$, $K \cong 0$, $k = 5\text{x}10^{-6}$.

The main goal is the understanding of amplitude and distributions of spontaneous magnetic field and electron density at different moments of the laser pulse interaction with targets made from materials with various atomic numbers Z (plastic, Cu).

Polarograms and the corresponding interferograms registered in each channel of the polaro-interferometer which illustrate the 1ω laser beam interaction with the plastic target, are shown on Fig. 5, while the complex interferograms and the interferograms associated with them are depicted in Fig. 6. The Faraday effect is clearly visible both on the polarograms and the complex interferograms and demonstrates a proper functioning of the polaro-interferometer. The Faraday effect is visible only in the bottom half of polarograms, which proves that the SPM has azimuthal symmetry.

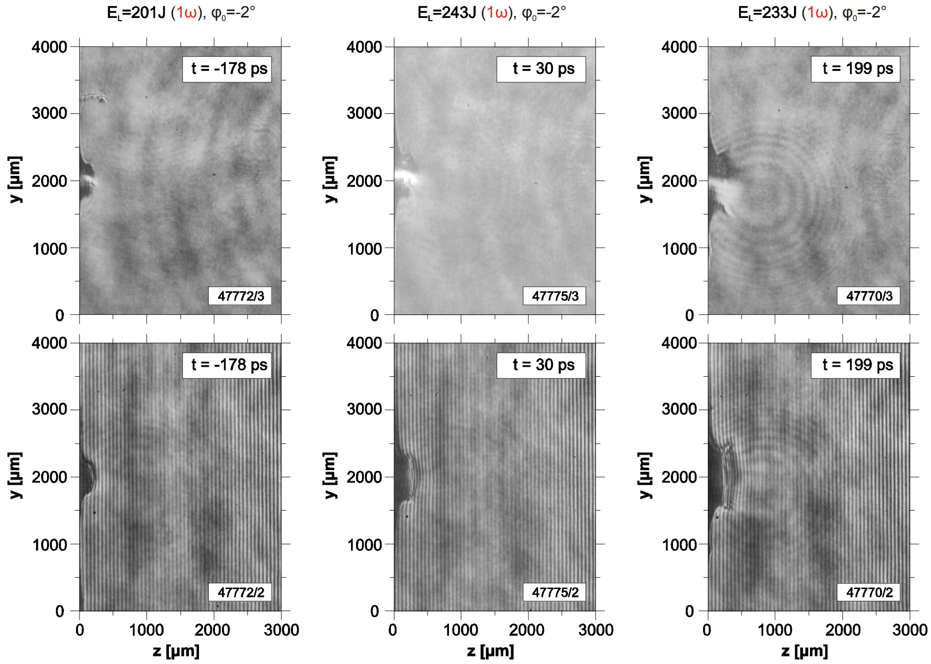

Fig. 5 Femtosecond polarograms (upper row) and interferograms of the plasma produced by the 1st harmonic iodine laser beam (1315 nm, 350 ps) on plastic targets.

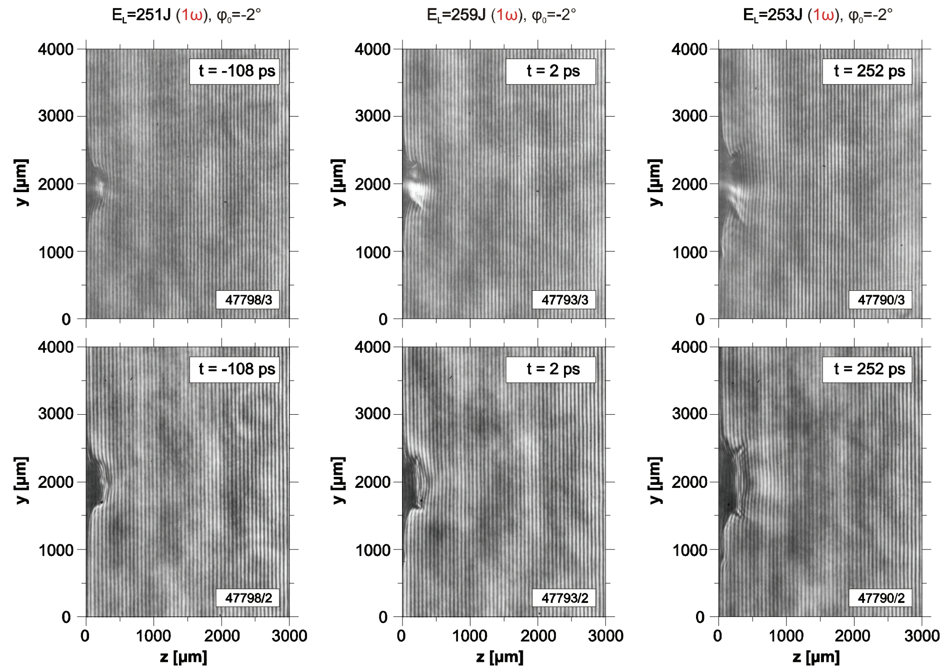

Fig. 6 Femtosecond complex interferograms (upper row) and standard interferograms of the plasma produced by the 1st harmonic iodine laser beam (1315 nm, 350 ps) on plastic targets

To obtain the distribution of the magnetic field, the methods of analysis described in papers [9, 10] have been applied. The equations describing the relationships of the Faraday rotation angle (φ) and the phases (***δ***) distributions with the plasma parameters are applied, namely:

$$\varphi(y) = 5.24 \cdot 10^{-17} \cdot \lambda^2 \int_y^R \frac{B_\varphi(r) n_e(r) y dr}{\sqrt{r^2 - y^2}} \quad \text{and} \quad \delta(y) = 8.92 \cdot 10^{-14} \cdot \lambda \int_y^R \frac{n_e(r) r dr}{\sqrt{r^2 - y^2}} \qquad (2)$$

where $B_\varphi(r)$ is the azimuthal magnetic field distribution, $n_e(r)$ is the electron density distribution, λ is the wavelength of a probe beam.

An examples of magnetic field and plasma density distributions obtained by analyzing the polarograms and interferograms are shown on Fig.7.

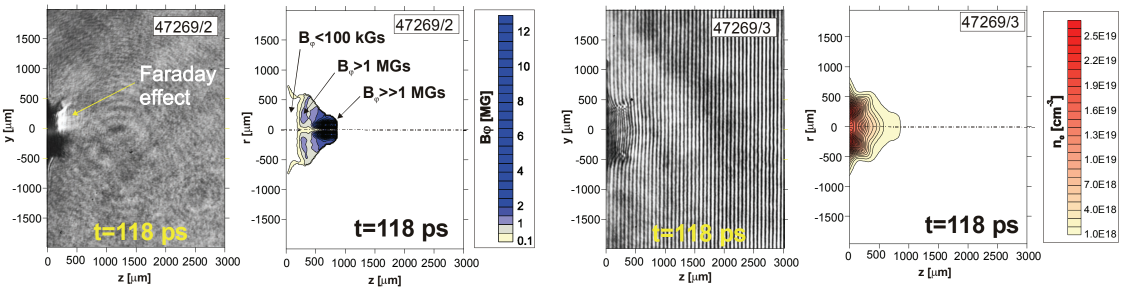

Fig. 7 Example of the calculated magnetic field and electron density distributions (shot 47269, 350 J, 1315 nm, $\Delta t = 118$ ps)

The future analysis of obtained results will be focused on understanding of an influence of the ablative plasma expansion character on the SMF structure, namely: (i) the spherical expansion of the fast component in case of the light target materials and (ii) the planar (axial) expansion which is enforced by a heavy plasma [13].

Processing of a large amount of collected data is under way, further results will be presented in more details by T. Pisarczyk et al. and Chodukowski et al. at the 42nd European Physical Society Conference on Plasma Physics in Lisbon in June 2015.

4. Conclusions

An original laser polarometer/interferometer has been designed at IPPLM Warsaw and applied for measurements of the distribution of electron plasma density and spontaneous magnetic fields in laser-produced plasmas at the PALS RI in Prague. By exploiting a synchronized Ti:Sapphire laser the apparatus makes it possible to probe the plasma produced by a nanosecond iodine laser with a sub-picosecond resolution. Application of two different methods for determining of the magnetic field distributions highly increases reliability of the obtained results.

Acknowledgement

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