Experimental and theoretical investigation of femtosecond laser plasma

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We present a new experimental-theoretical method, which allows one to determine on the femtosecond time scale the parameters of plasma generated during and after an action of subpicosecond laser pulses on solid targets [1].

The experimental part of the proposed method consists of the femtosecond optical interferometry, which makes one possible to determine not only the module, but also the phase of the complex index of reflection of the weak probe laser pulse from the plasma generated on the surface of a solid target irradiated by the powerful pump laser pulse, $\sim 10^{13} \div 10^{14}$ W cm^{-2}, at different delays between the pump and probe pulses, $\sim 10^2 \div 10^3$ fs.

The source of irradiation is a Cr:forsterite laser system generating femtosecond pulses at a wavelength of $\lambda_1 = 1240$ nm [2]. The full width at half maximum of the pulses is measured using an autocorrelator of the noncollinear second harmonic and is equal to $\tau_L \simeq 110$ fs in present experiment for the sech^2 envelope shape.

The measurements use a Michelson interferometer with the transfer of an image of the surface of the sample under investigation to the plane of the CCD matrix. Aluminum films with thickness of ~ 1 μm deposited on a glass substrate are used in the experiments.

The target is heated by a p polarized laser pulse at the main laser wavelength λ_1 for the angle of incidence 45°. The spatial distribution of the pumping irradiation intensity on the target corresponds to the Gaussian with a focus beam diameter of ~ 70 μm at a level of e^{-2}. The probe pulse (s polarized, the second harmonic $\lambda_2 = 620$ nm) with varying time delay is incident perpendicularly to the sample surface.

A probe beam (object) reflected from the sample interferes with the reference beam and forms an interference ring fringe in the CCD matrix plane [1]. A frame detected by the CCD matrix is a spatial intensity distribution $I(x,y) = |E_{\rm obj}|^2 + |E_{\rm ref}|^2 + 2{\rm Re}\{E_{\rm obj}E^*_{\rm ref}\}$, as a result of the interference of the object $E_{\rm obj}(x,y) = \widetilde{r}(x,y)A_1(x,y)\exp[i\varphi_1(x,y)]$ and reference $E_{\rm ref}(x,y) = A_2(x,y)\exp[i\varphi_2(x,y)]$ waves, where A_i and φ_i, $i = 1$, 2, are the amplitudes and phases of the interfering waves, respectively. In this case, the object wave carries information on the complex reflection coefficient of the sample, which can be represented as $\widetilde{r}(x,y) = r(x,y)\exp[i\Psi(x,y)]$, where r and Ψ are the absolute value and phase of the complex reflection coefficient, respectively.

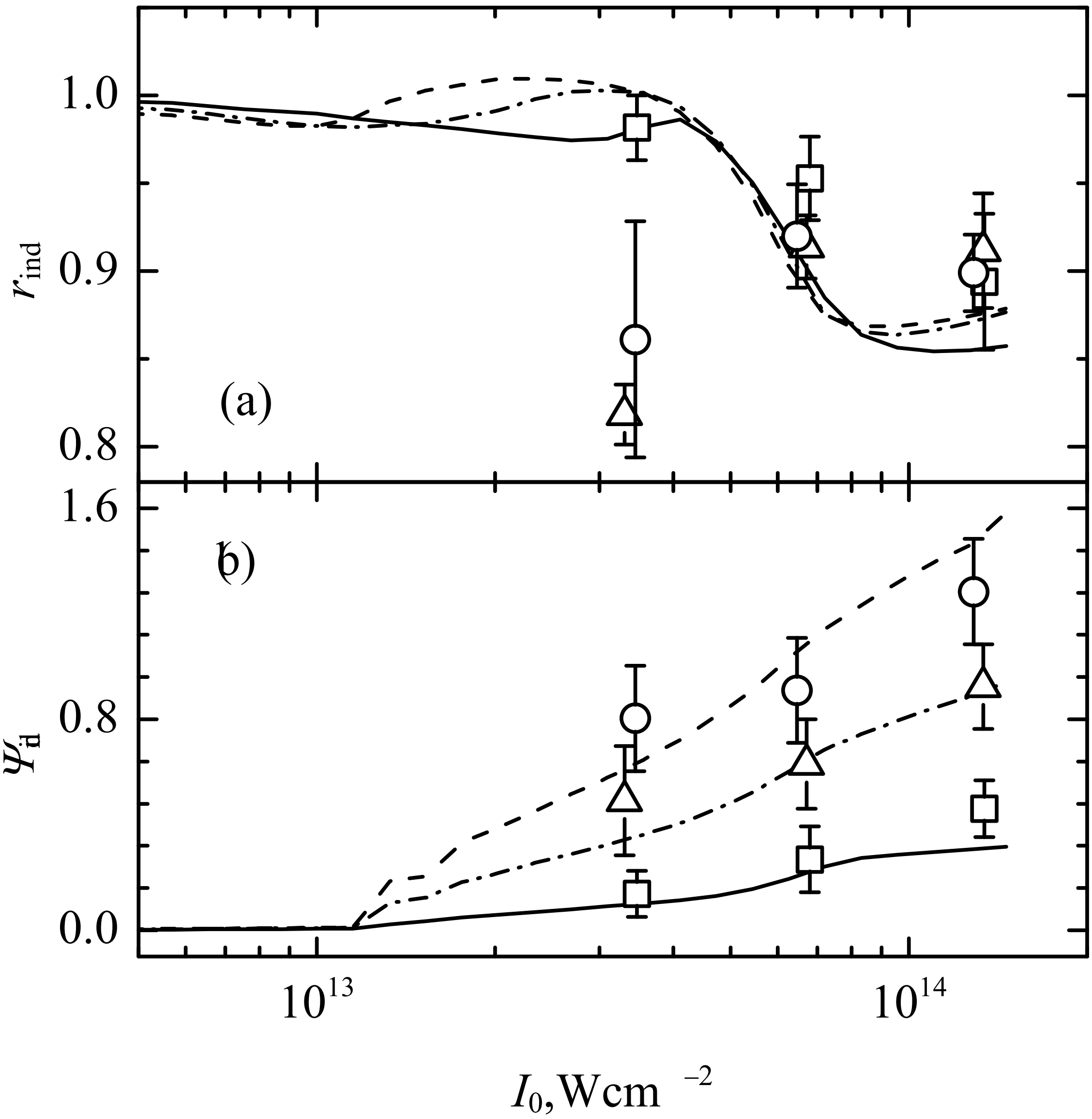

Figure 1: Experimental points and calculated curves for (a) r_{ind} and (b) Ψ_{ind} vs. the intensity I_0 of the heating laser pulse for delay times $\Delta t =$ (□ and solid line) 130, (△ and dash-dotted line) 530 and (◯ and dashed line) 930 fs.

When processing the interference patterns by the Fourier transform algorithm [3, 4], laser-induced changes in r and Ψ are determined, $r_{\text{ind}}(x,y) = r_{\text{t}}(x,y)/r_{\text{i}}(x,y)$, $\Psi_{\text{ind}}(x,y) = \Psi_{\text{t}}(x,y) - \Psi_{\text{i}}(x,y)$. Here, r_{i} and Ψ_{i} are the absolute value and phase of the complex reflection coefficients of the target before the action of the heating laser pulse, respectively, r_{t} and Ψ_{t} are the corresponding parameters of the irradiated target.

Figure 1 shows r_{ind} and Ψ_{ind} as functions of the maximum intensity I_0 of a heating laser pulse for various delay times ($\Delta t = 130$, 530 and 930 fs) of the probe pulse with respect to the heating pulse. Each experimental point is a result of averaging over $5 \div 10$ measurements.

A hybrid two-temperature hydro-electro-ionization numerical code [5, 6] with a new two-temperature equation of state is elaborated and used for numerical simulation of processes of the pump-probe measurements [1]. Values of parameters in expressions for the kinetic coefficients of plasma, which are used in the code, are chosen so as to ensure the best agreement between results of experimental measurements and theoretical calculations of r_{ind} and Ψ_{ind} over the investigated range of pump-pulse characteristics, see Fig. 1.

After such a choice of the numerical parameters, we can use the elaborated code as a reliable tool for calculation of properties of the plasma generated on the surface of a solid target under an action of powerful femtosecond laser pulses.

This work was supported in part by the Russian Foundation for Basic Research (project No. 06-02-17464) and the Council of the President of the Russian Federation for Support of Young Russian Scientists and Leading Scientific Schools (project No. NSh-3683.2006.2).

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