

LETTERS

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Features of the explosive boiling up of water irradiated by a *Q*-switched erbium laser

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***Abstract*. Subnanosecond pressure pulses were observed on the surface of water irradiated by 200-ns, 2.94-μm, 0.65 – 0.8-J cm^{-2} pulses from a *Q*-switched erbium laser. The pulses can be related to the development of explosive boiling up in a thin subsurface layer of the overheated water.**

Keywords: *laser, laser irradiation, explosive boiling up.*

We report the first observation of short (subnanosecond) pressure pulses which can be explained by the development of explosive boiling up in a thin submicron subsurface layer of water discussed in [1].

The water surface was irradiated by 2.94-μm pulses from a Er : YAG laser passively *Q*-switched by using a Fe^{2+} : ZnSe crystal *Q* switch with the initial transmission 86 %. The ZnSe crystals were doped with Fe^{2+} ions by the diffusion method under conditions of the thermodynamic equilibrium of phases [2]. The laser energy was 5.6 ± 0.25 mJ, the pulse FWHM was 200 ns, and the transverse radiation intensity distribution was close to that in the TEM_{00} mode. The absorption coefficient of the 2.94-μm laser radiation in water was $\sim 10^4$ cm^{-1} [3].

A broadband (no less than 300 MHz) Shapr-13M lithium niobate piezoelectric transducer, which was also used in papers [4, 5], was located under the water layer of thickness 2 – 3 mm. The absolute calibration of the transducer for the geometry of our experiment was not performed. The temporal shape of output signals of the acoustic transducer was recorded with a 2.5-GHz Tektronix DPO 7254 oscilloscope, laser radiation was detected with a D-125 photodetector with a time resolution of ~ 1 ns.

Figures 1 and 2 show the output signals of the acoustic transducer for different laser energy densities *E* and a fixed area (0.7 mm^2) of the radiation spot on the water surface. The maximum energy density was $E_m = 0.8$ J cm^{-2}. The incident laser energy was varied with the help of optical filters, other experimental conditions being invariable. The signal shape observed for $E/E_m = 0.4$ (Fig. 1a) can be partially related to the photoacoustic effect caused by a change in the liquid density (without the phase transition) upon exposure to laser radiation [6, 7].

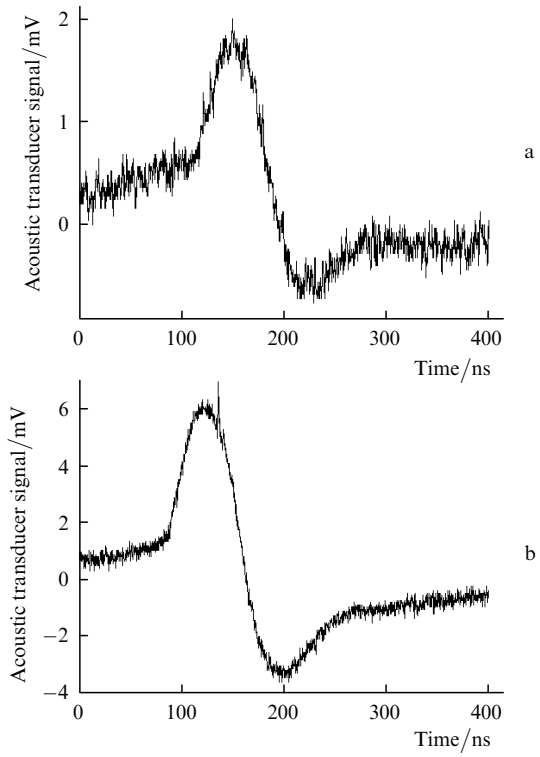

Figure 1. Acoustic transducer signals for the relative laser energy density $E/E_m = 0.4$ (a) and 0.8 (b) ($E_m = 0.8$ J cm^{-2}).

The separation between the maximum and minimum of the photoacoustic signal is in qualitative agreement with the distance 200 ± 80 ns between the extrema of the derivative of the laser-pulse intensity (determined by numerical differentiation). Note that the first extremum (maximum) of the photoacoustic signal in Fig. 1a is observed for $t \sim 100$ ns directly before the onset of the subsequent rapid pressure build-up caused by another physical process (surface evaporation).

The additional pressure pulse located between these two extrema can be caused by the nonstationary surface evaporation of water according to its position and rapid increase with increasing *E* (see, for example, [6, 8]). The bipolarity of the evaporation pressure pulse observed in our experiments (whereas this pulse should be monopolar on the irradiated surface) is probably explained by acoustic diffraction effects [7].

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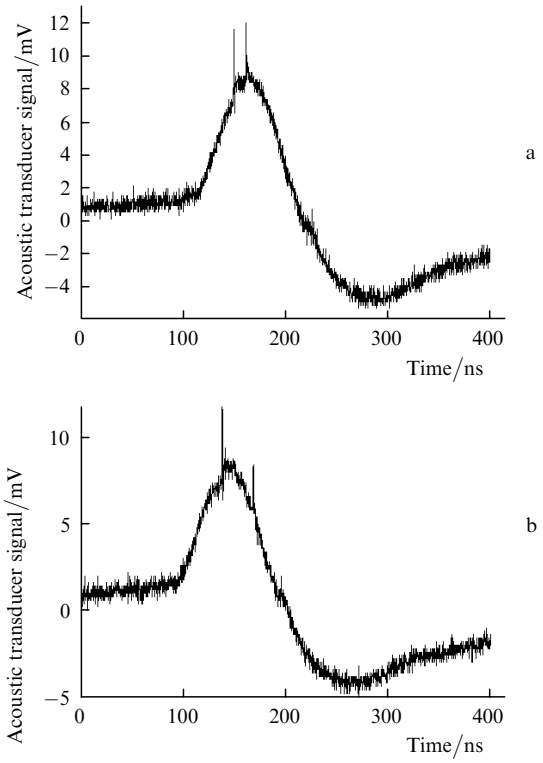

Figure 2. Acoustic transducer signals for $E/E_m = 1$. The different shapes of signals in Figs 2a and 2b demonstrate the random nature of explosive boiling up.

The stationary regime of surface evaporation is not realised under the conditions of volume absorption considered here because before the establishment of this regime the maximum of the temperature profile under the water surface achieves the boundary of the absolute thermodynamic instability (spinodal) near which the process of volume explosive boiling up should be initiated by the homogeneous nucleation or spinodal decomposition.

At the initial state of this process, separate sharp pressure peaks can appear. The rise time of these peaks is determined by the rate of appearance of a new phase, while their decay time is determined by the cooling rate of a newly formed interface and the flying-away dynamics of a near the surface film, which prevents free vapour expansion.

We assume that it is this mechanism that is responsible for the appearance of subnanosecond (FWHM of the ~ 0.8 ns) pressure peaks against the background of an evaporation pulse for $E/E_m \approx 0.8$ (Fig. 1b) and $E/E_m \approx 1$ (Fig. 2). The difference of signals in Figs 2a, b demonstrates some stochasticity of explosive boiling up under our experimental conditions. Note that due to a short duration of the signal, its acoustic diffraction distortions can be considerably smaller than in the case of the longer surface evaporation signal if the surface area in the region of explosive boiling up is not too small compared to the area where surface evaporation occurs.

Note also the threshold energy density below which short acoustic pulses were not observed exceeds by several times the theoretical value estimated from the volume heating of water up to the ultimate overheating temperature $\sim 300\,^{\circ}$C. This discrepancy can be explained by the fact that dissipation caused by the heat conduction and hydrodynamic motion was neglected in calculations, as well as by an increase in the heat capacity near the ultimate overheating temperature and a decrease in the absorption coefficient of water upon heating. The decrease in the absorption coefficient of water irradiated by an erbium laser was reported, for example, in [9].

The assumed mechanism of formation of short pressure pulses observed in our experiments does not contradict the known data on the behaviour of a thin 100-nm liquid film during its explosive boiling up on a substrate heated by laser pulses [10]. An alternative mechanism of formation of short pressure pulses caused by cavitation effects, i.e. by the appearance and subsequent collapse of bubbles in liquid, seems unlikely because such a process can occur only at much longer irradiation and observation times [11].

We emphasise in conclusion that the study of possible spinodal and nearly critical features of the phase transitions of the first order under nonstationary nonequilibrium conditions is of interest, in particular, for the search for appropriate pulsed methods of measuring these important characteristics of the equation of the nonequilibrium state of matter.

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