文章编号　1674-2915(2011)01-0021-05

Electric signal generated under action of HF laser pulse on surface of a water column

ANDREEV S N[1], FIRSOV K N[1], KAZANTSEV S Yu[1], KONONOV I G[1], PASHININ P P[1], ZHANG Lai-ming[2], RUAN Peng[2]

(1. *Prokhorov General Physics Institute*, *Russian Academy of Sciences*, *Moscow* 119991,
2. *State Key Laboratory of Laser Interaction with Matter*, *Changchun Institute of Optics*, *Fine Mechanics and Physics*, *Chinese Academy of Sciences*, *Changchun* 130033, *China*)

Abstract: Generation of an electric signal under interaction of pulsed HF laser radiation with water column surface was investigated. It was found that the electric signal demonstrates pronounced a two-peak structure with time interval between peaks linearly depending on the laser energy. The second pike was determined to appear upon the collapse of the vapor cavity produced at the bottom of water column. It was also found that the amplitude of electric signal strongly depends on the presence of a thin water layer which is dilated and pressed in the process of the water column motion initiated by laser pulse. Tenfold increase of electric signal is achieved if the thin water layer is presented between the upper border of the cell and quartz plate which closes the cell and touches the upper surface of water column.

Key words: HF laser; vapor cavity; thin water layer; quartz plate; water column

HF激光脉冲与水柱表面相互作用产生电信号

ANDREEV S N[1], FIRSOV K N[1], KAZANTSEV S Yu[1], KONONOV I G[1], PASHININ P P[1], 张来明[2], 阮　鹏[2]

(1.俄罗斯科学院 普罗霍罗夫普通物理研究所,莫斯科 119991;
2. 中国科学院 长春光学精密机械与物理研究所,
激光与物质相互作用国家重点实验室,吉林 长春 130033)

摘要:研究了脉冲HF激光与水柱表面相互作用下电信号的产生过程。电信号显示了与激光能量线性相关的峰值间有时间间隔的两峰结构,且第二个尖峰在水柱底部的蒸汽腔塌缩后出现。实验还显示电信号的幅值和激光脉冲照射过程中是否存在膨胀和挤压的薄水层密切相关。如果在电池上边缘和石英平板(石英板紧邻电池,并与水柱上表面相接)之间存在一薄水层,电信号强度会增加10倍。

关　键　词:HF激光器;蒸汽腔;薄水层;石英平板;水柱

中图分类号:TN248.5　　**文献标识码**:A

收稿日期:2010-08-21;**修订日期**:2010-10-23

基金项目:Supported by Russian Basic Research Foundation(Grants No.09-02-00475, No.09-02-00581)

1 Introduction

The effect of generation of an electric signal (ES), when IR laser radiation ($\lambda = 2.92\ \mu m$, $\tau = 150$ ns, $E = 10$ mJ) with the intensity below the plasma-formation threshold interacts with a water surface, was discovered[1]. ES was detected with the amplitude up to 10 mV. Authors of paper [1] suggested that the ES is produced due to the growing of water dissociation degree in a thin (about 1 cm) overheated surface layer and charge separation in it caused by the difference in the diffusion rates of H^+ and OH^- ions.

High power pulsed HF laser and CO_2 laser were used to investigate the generation of ES in water and some other polar liquids[2]. ES with the amplitude over 15 V were detected upon interaction of laser radiation with both an open (free) water surface and a water surface that is in contact with a plate of a material transparent to laser radiation ('closed' water surface). The investigation made it possible to find a relation between the generation of electric signals and the explosive boiling of overheated water layer and to give explanation of the effect at a qualitative level.

The authors of paper [3] constructed a mathematical model of charge separation for the case when a laser pulse acts on a closed water surface. The model takes into account the processes of laser heating of water, explosive boiling of thin overheated water layer during which a vapour cavity is produced. The opposite sides of the cavity acquire charges of different signs because of diffusive separation of charges during heating. It follows from the calculations[3] that the potential difference at the boundaries of the vapour cavity contributes most to the observed ES.

The paper [4] investigated the effect of ES generation upon the interaction of radiation from a nonchain HF laser with the lower surface of a water column in a cell with a bottom transparent to laser radiation, while the upper surface of the water column remains open. It was found that the electric signal demonstrates pronounced two-peak structure with time interval between peaks (up to 1.3 ms) linearly depending on the laser energy. The second spike was determined to appear upon the collapse of the vapor cavity produced at the bottom of water column.

2 Experimental

The scheme of the experimental setup is given in Fig. 1. The cell was made of a fragment of a fused-quartz tube with the inner diameter of 37 mm, outer diameter of 42 mm and the length of 50 mm. A 9 mm thick window of IR-type quartz was welded to one end of the tube. The height of the water column was 50 mm. Radiation from a nonchain electric-discharge HF laser with pulse of 140 ns, maximal energy density on the water surface of 0.6 J/cm^2 penetrated into the cell from the bottom (closed surface irradiation conditions). Two ring-shaped electrodes with the width of 3 mm, one round being the bottom weld and the other round being the upper rim, were used to read out the electric signal. As in paper [3], the electric signal was fed to an oscilloscope through a voltage repeater.

In the first case of the experiment (see Fig. 1 (a)) water column surface opposite the irradiated one remains open, similarly to conditions of the experiment[4]. In the second case of the experiment (see Fig. 1 (b)) the water cell was covered by the quartz plane-parallel plate, the bottom surface of which contacts with the whole area of water column upper surface. At the same time there was a thin water layer (water contact) between the upper border of the cell and bottom surface of the plate. In the third case of the experiment (see Fig. 1 (c)) the plane-parallel plate was replaced by the spherical lens, which contacts with the water column by the

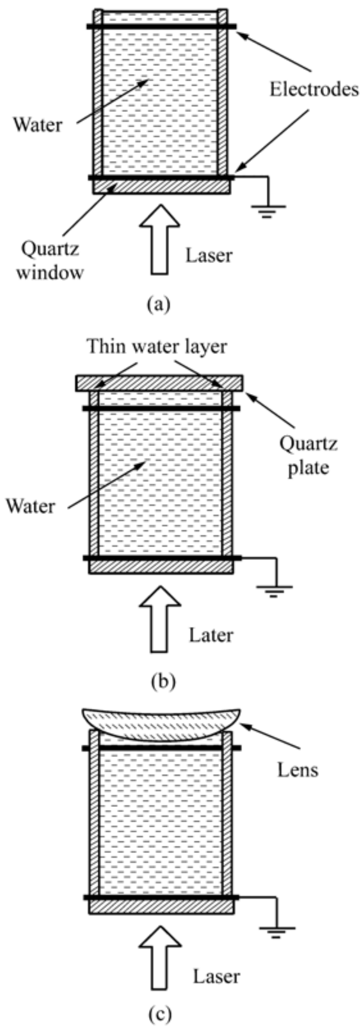

Fig. 1　Scheme of experimental setup

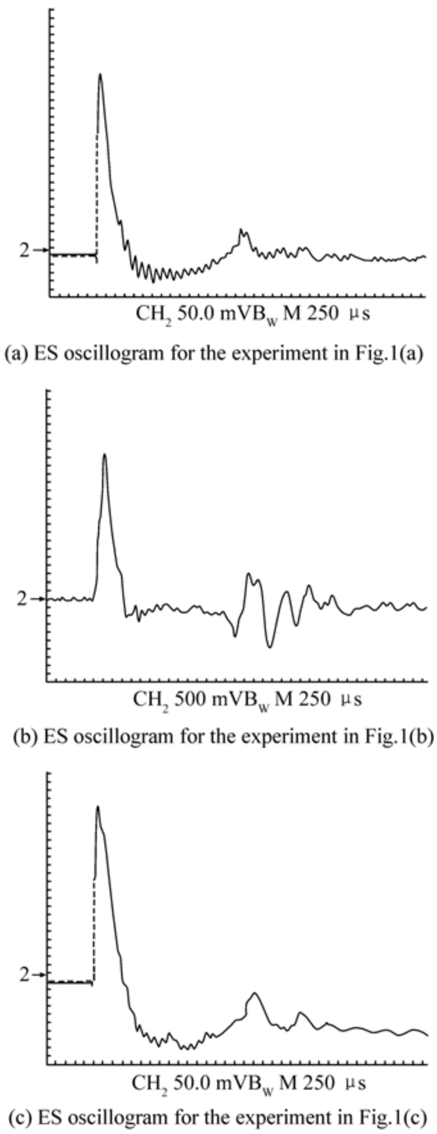

Fig. 2　ES oscillograms for the experiment in Fig. 1

convex surface. In this case, the area of water contact with the butt-end of the cell was distinctly smaller than in the former case.

3　Experimental results and discussion

Fig. 2 presents typical ES oscillograms for the conditions of the experiment in Fig. 1(a). ES demonstrates a pronounced two-peak structure. The time interval between peaks linearly depends on laser energy and it is equal to the time of inertial motion of the water column, accelerated during the initial stage of interaction of laser pulse with closed water surface. Generation of the second spike is related to the collapse of vapor cavity, which arises from explosive boiling of overheated water layer [4]. Fig. 2(b) presents ES oscillogram, for the conditions of the experiment in Fig. 1(b). The energy of laser pulse was the same as in the former case. One can see from Fig. 1(b), the ES retains two-peak structure, but peak amplitudes exhibit nearly tenfold growth. The schemes of experiments in Fig. 1(a) and Fig. 1(b) differs from each other only by the presence of thin water layer(water contact) between the upper border of the cell and bottom surface of the quartz plate in the latter case. One can suppose that the presence of water contacts in the experiment is the reason of the ES amplitude growth. The results of the experiment in Fig. 1(c) confirm this assumption.

Fig. 2(c) presents ES oscillogram for the conditions of the experiment in Fig. 1(c). It is shown from Fig. 2(c) that the amplitude and form of ES are nearly the same as in Fig. 2(a).

In Fig. 3, the first peak amplitude P(V) of ES as a function of laser pulse energy E(J) on a water surface is presented in the case of the presence of thin water layer between the upper border of the cell and bottom surface of the quartz plate (the conditions of the experiment in Fig. 1(b)). From Fig. 3, it follows the general tendency of amplitude growth with radiation energy increase, but large scatter of experimental points is observed. This large scatter is possibly conditioned by water contact thickness change from shots to shot, and also with uncontrolled presence of water droplets on water contact line on the outer side of the cell.

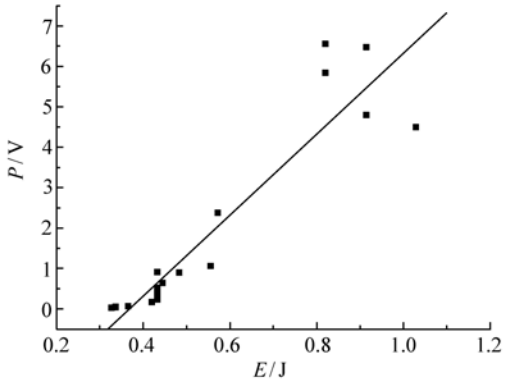

Fig. 3 Relation between peak amplitude of ES and laser pulse energy

Qualitatively the influence of thin water layers on ES one can explain as follows. During the motion of water column, accelerated on initial stage of laser action, thin water layers undergo straining (compression). At the same time the area of water contact between the upper border of the cell and bottom surface of the quartz plate will change. Therefore the energy of border surface tension will also change. Inasmuch as the border surface tension determines the electric potential drop on the boundary of two media[5], then the change of the energy of border surface tension can cause the generation of additional electric signal.

4 Conclusions

Generation of an electric signal under the interaction of pulsed HF laser radiation with closed water surface is investigated. The HF laser illuminates the lower surface of a water column in a cell with a bottom surface which is transparent to laser radiation, while the upper surface of the water column remains open. It is found that the amplitude of electric signal strongly depends on the presence of thin water layers which are dilated and pressed in the process of the water column motion initiated by laser pulse. Tenfold increase of electric signal is observed if a thin water layer is presented between the upper border of the cell and quartz plate which closes the cell and touches the upper surface of water column.

References:

[1] ILYICHEV N N, KULEVSKY L A, PASHININ P P. Photovoltaic effect in water induced by a 2.92-μm Cr^{3+}:Yb^{3+}:Ho^{3+}:YSGG laser[J]. *Quantum Electronics*, 2005, 35:959.

[2] ANDREEV S N, IL'ICHEV N N, Firsov K N, *et al.*. Generation of an electrical signal upon the interaction of laser radiation with water surface[J]. *Laser Phys.*, 2007, 17:1041.

[3] ANDREEV S N, KULEVSKY L A. Simulate the effect of electric signal generation in water by laser radiation[J]. PRYKL F., 2008, 4:30.

[4] ANDREEV S N, FIRSOV K N, KAZANTSEV S Y, *et al.*. Temporal structure of an electric signal produced upon interaction of radiation from a HF laser with the bottom surface of a water column[J]. *Quantum Electronics*, 2009, 39:179

[5] SALEM R R. *The Theory of Double Layer*[M]. Moscow: Fizmatlit, 2003: 104.

Author's biography: Sergey Kazantsev (1971—), Moscow, Russia, graduated from Moscow Engineering Physics Institute (State University) in 1998, His research interests are concerned with experimental investigation of volume self-sustained gas discharge phenomena, development of chemical and high-power electric discharge lasers, and investigation of high power laser beam interaction with matter, laser induced gas breakdown, laser lightning protection. E-mail: kazan@kapella.gpi.ru