Systematic characterization of pulsed laser breakdown in water

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We have studied spatial, spectral, and temporal aspects of plasmas in water produced by 10 ns pulses from a Nd:YAG laser operating at 1064 nm. Emission lasts about 100 ns and is dominated by a continuum and an exceptionally broadened hydrogen Balmer-α line. We report on the dependence of spatial and spectral properties on water impurity concentrations as well as laser power and repetition rate.

1. Introduction

Laser produced breakdown in liquids offers the opportunity to study processes that are both of fundamental interest (such high-pressure shock-waves, light emission under extreme conditions etc.) and have relevance for applications (e.g. water treatment and plasma medicine). Recently, experimental investigations on nanosecond laser breakdown in water have illuminated aspects such as breakdown and early expansion stage [1], re-collapse of laser- produced bubbles attached to underwater surfaces [2], and evidence of atomic hydrogen in post-breakdown bubbles [3]. At the conference, we will present results of a systematic investigation of the spatial, temporal, and spectroscopic characteristics of laser breakdown events at different repetition rates and power in water of different particulate concentrations.

2. Experimental setup

A Nd:YAG laser (1064 nm, 250 mJ, 10 ns) is focused by a 10 cm lens into a stainless steel cell equipped with antireflection coated laser entrance and exit ports and wide quartz viewing windows. Time resolved images along the plasma axis are obtained with two intensified CCD cameras (Andor iStar 334 and 734) that are capable of 2-5 ns gating times. Laser-camera synchronization is achieved with a digital delay generator (SRS DG645). Two spectrometers are used: the first (OceanOptics HR2000) for spatially and temporally integrated surveys, the second (Jobin Yvon SPEX 1000M) in conjunction with one of the CCD cameras for time and space resolved spectra.

3. Results

3.1. Spatial emission patterns and repetition rate

Depending on the particulate concentration, the breakdown region extends from about 3mm for highly filtered water to tens of millimeters in tap water somewhat larger than the estimated Rayleigh length. The center of emission intensity shows distinct time dependence (see Fig. 1). Within a single pulse, it first moves towards the laser, then

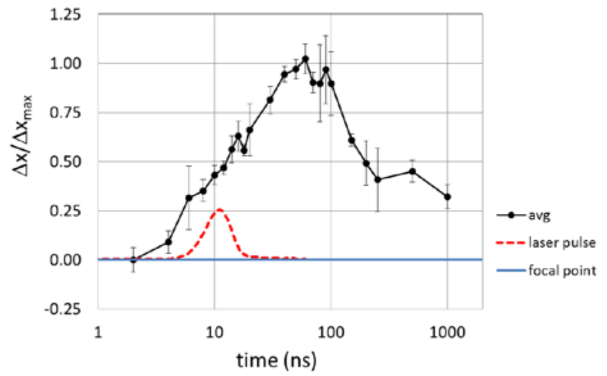

Fig. 1 Apparent motion of centre of emission intensity as a function of delay time. Position is in units of the maximum displacement from the focal point (Δx_{max}=1.1 / 2.2 / 2.4 mm for ultrapure, distilled, and tap water, respectively). Line to guide the eye. Laser direction top to bottom; laser pulse (dashed line) shown for time reference only.

reverses direction in a way that within measurement errors is the same for all types of water samples but differs in magnitude, with the largest change observed for the highest particulate concentration. Upon increasing repetition rate, the emission center moves generally in the direction of the laser beam (as if "drilling" into the water) well beyond the Rayleigh range, which suggests possible filamentation.

3.2. Emission spectra and super continuum

Compared to laser produced plasma in gases, emission from water breakdown is weak and lasts not much longer than about 100 ns. So far, we have identified the hydrogen Balmer-α line as the only line feature in an otherwise continuous spectrum. The width of the H-α line diminishes with delay time until about 100 ns when the spatially resolved intensity becomes too small for reliable detection. A large full width at half maximum (FWHM) of about 8 nm at the latest delay times indicates that probably both Stark and van der Waals broadening are important. Time integrated spectra show a FWHM of the H-α line of ca. 50 nm.

3.3. Shockwaves and bubble dynamics

Finally, using white light illumination of the breakdown region we have observed shockwaves that separate from the luminescent plasma centers at around 200 ns. The instantaneous shock speed diminishes with time from almost 2000 m/s to below 1500 m/s providing information on local conditions of the water in the plasma region. Shadowgraphy reveals complex dynamics of both single and “colliding” laser produced bubbles (see Fig. 2)

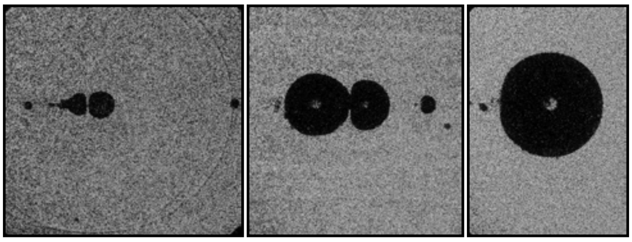

Fig. 2 Shadow graphs of laser produced underwater bubbles at delay times of 4, 20, and 50 μs (left to right panel). In the left panel the associated shockwave is still visible; at later delays it has moved beyond the field of view of the camera. Vertical scale of each image is 5.7 mm. The central bright spot in each shadow is due to a lensing effect of the bubble.

References

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