

Emission spectra of plasma produced by laser ablation at water surface

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Synopsis Laser ablation was produced at the surface of liquid water, in air, by using a pulsed Nd-YAG laser (355 nm, 10 ns, 10 Hz). The plasma emission spectrum was analyzed by means of line assignment, Boltzmann plot, H- α line intensity and Stark broadening. The emission lines were mostly due to H, O and N atomic transitions, the excitation temperature was about 9000 K and the electron density was in the order of 10^{18} cm^{-3} .

Laser Induced Breakdown Spectroscopy was used to study laser ablation of water at the liquid-air interface. A Quantel Brilliant B laser beam (wavelength 355 nm, repetition rate 10 Hz, 10 ns pulsewidth) was focused by a 250 mm focal length positive lens to the surface of distilled water, in air. Laser pulse energy was varied, by changing the delay between pumping lamp and q-switching, from 20 to 150 mJ, which results in fluences varying from 0.37 to 2.82 kJ/cm² at the focal point. For every pulse a plasma was produced and its luminous emission was collected by a 25 mm positive lens and coupled, through an optical fiber, to an Ocean Optics HR4000 spectrometer, attached to a computer.

Three groups of experiments were performed, using: a-) distilled water, b-) solution of 0.5 g of NaCl in 150 ml of water and c-) 1.0 g of NaCl in 150 ml of water.

First the H- α , H- β , H- γ and H- δ lines were identified and used to calibrate the spectrum in wavelength, thus, other lines were assigned by comparing with NIST atomic transitions database. It was observed that all distinct peaks were assigned to H, O or N lines (atomic or molecular). Another observation was that, except for a scale factor, all spectrum are identical, with the same lines and same relative amplitudes.

Similar to the case of underwater discharge spectroscopy [1], H- α line profile is better fitted by a double Lorentzian function, instead of by a single one, i.e.,

$$I(\lambda) = A_0 + \frac{A_1}{1 + \left(\frac{\lambda - \lambda_0}{\Delta\lambda_1/2}\right)^2} + \frac{A_2}{1 + \left(\frac{\lambda - \lambda_0}{\Delta\lambda_2/2}\right)^2},$$

where the symbols have the usual meaning.

This profile is justified by assuming the superposition of two regions contribution: one internal with higher electron density (so, broader spectra) and one external with lower electron density. By fitting this equation, the amplitudes and the linewidths for the H₂O + NaCl mixtures mentioned above and for several different fluences were calculated.

The linewidths showed to be constant, independent on the NaCl presence in water and independent on fluence, with $\Delta\lambda_1 = (2.5 \pm 0.4) \text{ nm}$ and $\Delta\lambda_2 = (11.7 \pm 1.3) \text{ nm}$. This results suggest that there exist some kind of saturation mechanism, not identified in this work, which limits the electron density in this kind of plasma.

The amplitudes A_1 and A_2 increase with pulse fluence, tending to saturation values and the saturation values decrease with NaCl content. However, for each NaCl content, the ratio A_1/A_2 remains virtually independent on the fluence.

A Boltzmann-plot estimation for the electrons temperature was accomplished for O I lines, resulting in an electron temperature of $(8000 \pm 5000) \text{ K}$. Together with the measured linewidths and supposing the spectral broadening is dominated by Stark effect, electron density was estimated to be in the order of $ne_1 = 1.8 \times 10^{17} \text{ cm}^{-3}$ and $ne_2 = 4.1 \times 10^{18} \text{ cm}^{-3}$, corresponding to the two linewidths above.

References

- [1] Xiao, P., and Staack, D. (2014). Journal of Physics D: Applied Physics, 47, 355203.

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