X-ray, Terahertz Wave, and Sound Emission from Water Flow Irradiated by Intense Femtosecond Laser Pulses in Air

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Introduction: Intense femtosecond laser-matter interaction results not only in photon emission such as X-ray [1] or terahertz wave (THz) but also in sound/ultrasound emission, which are usually accompanied with macroscopic laser ablation. Mechanisms on such various types of emission induced by intense laser irradiation to water have not yet been fully uncovered though there may be potential applications from basic science to advanced one. This presentation demonstrated simultaneous detection of X-ray, THz, and sound emission from water flow irradiated by focused femtosecond laser pulses in air and we will try the discussion on the intense laser- matter interaction especially from the viewpoint of laser ablation.

Experiments: Single or double femtosecond pulses (800 nm, 35 fs, linearly-polarized) were tightly focused with an off-axis parabolic mirror (f = 50.8 mm, NA=0.25) onto a thin water flow (~15 μm thick). An automatic stage moved the water flow along the laser focus axis (z-axis) from the downstream side to the upstream. Intensities of audible sound (2 Hz - 20 kHz), X-ray, and THz emission were measured with a microphone, a Geiger counter, and with EO detection using a ZnTe (11) crystal as in the previous reports [2,3], respectively. Double pulse excitation was carried out with an automatic optical delay stage.

Results: Figure 1 shows intensities of X-ray, THz, and sound emission as a function of the flow position under the single and the double pulse excitations. The bandwidth of the profile in X-ray under the single pulse excitation is much narrower at 37 μm than the others in THz at 52 μm and in sound at 403 μm. However, the peak positions are the same among the three different emissions.

Under the double pulse excitation with the time delay at 4.6 ns, all the emissions are enhanced much but the enhancement factors change from 34 in X-ray and 21 in THz to 1.2 in sound emission. The pre-pulse irradiation induces plasma formation/decay in the picosecond delay and the initial processes of laser ablation in the sub-nanosecond delay afterward. At 4.6 ns, it is certain that the water flow surface starts to be rough for droplet formation as the initial process of the macroscopic laser ablation. Therefore, the emission enhancements observed are assigned to such transient surface modifications leading to further focusing of the incident main pulse.

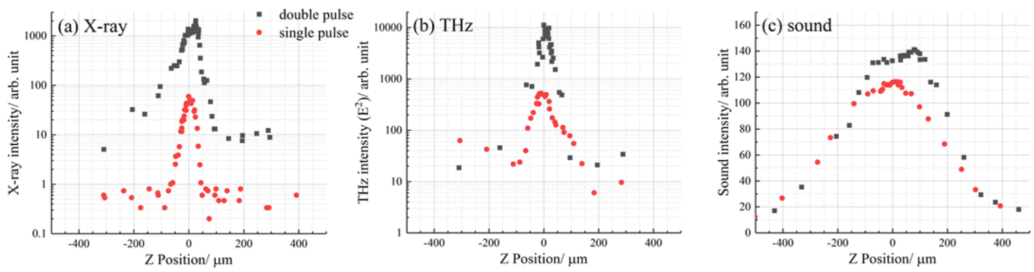

Fig 1. Intensities of (a) X-ray, and (b) THz, and (c) sound emission under the single and the double (4.6 ns) pulse excitations as a function of the flow position along the Z-axis. The laser intensity is 0.4 mJ/pulse (p-pol.) and 0.1 mJ/pulse (s-pol.) for the main and the pre-pulses, respectively.

References:

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[3] H.-H. Huang, *et al.*, “Correlated emission of X-ray and spound from water flow irradiated by femtosecond laser pulses”, *Appl. Surf. Sci.,* (2018), *under review for publication*.