Radially and axially resolved optical emission observed during the initial phase of nanosecond discharge in liquid water

P. Bílek[1*], G. Arora[1], P. Hoffer[1], V. Prukner[1] and M. Šimek[1]

[1] *Institute of Plasma Physics of the Czech Academy of Sciences, Prague, Czech Republic*
[(*)] bilek@ipp.cas.cz

Electric discharges in contact with or directly in liquid water produce reactive species that are of interest for many biological and medical applications [1]. The simplest mechanism of the discharge initiation in liquids is associated with the local evaporation of liquid due to Joule heating in the discharge gap, followed by gas breakdown. However, in the case of (sub)nanosecond high-voltage pulses, the heating and vaporization of the liquid is not fast enough to enable the onset of the discharge. The mechanism that controls the initiation of discharge in such short timescales is still under investigation. Therefore, basic characteristics and signatures of the direct and bubble-assisted mechanism are still the subject of focused diagnostic studies. An experimental study [2] pointed out that a nanosecond discharge is composed of nonluminous and luminous phases, see Figure 1. The non-luminous dark phase, which created bush-like structures made of thin hair-like filaments, occurs with a delay of a few nanoseconds after the onset of the HV pulse, and the propagation of every single filament is accompanied by GPa shock waves [3]. In contrast, the luminous phase has a simple tree-like morphology and is characterised by broadband continua extending from ultraviolet to near-infrared (NIR) wavelengths [4]. The onset is delayed by about 600 ps with respect to the onset of the dark phase.

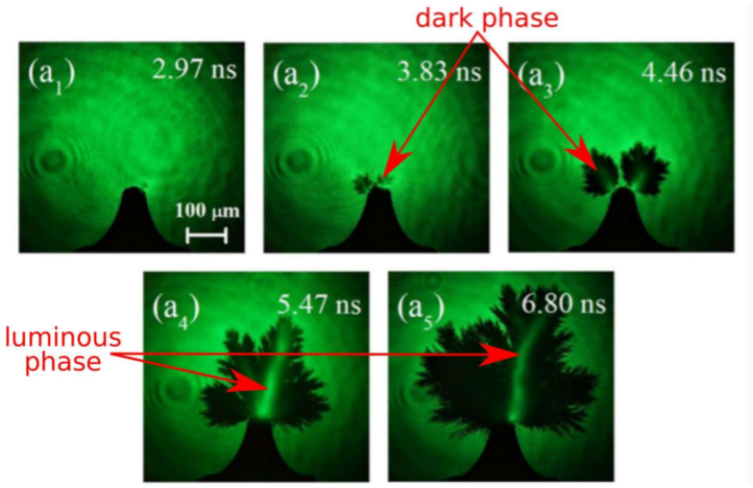

Fig. 1: Morphology of the nanosecond discharge in liquid water. Credits on [2].

Recently, we obtained temporally and spatially resolved emission spectra of the nanosecond discharge together with images registered using a four-channel ICCD imager [5]. This enabled us to connect the morphology of the luminous discharge phase with the specific characteristics of the plasma-induced emission in the vis-NIR region, as shown in Figure 2 [6]. We discovered that the initial diffuse morphology of the discharge is associated with broad-band emission spectra, whereas the subsequent filamentary morphology is linked to spectra featuring broadened hydrogen and oxygen atomic lines.

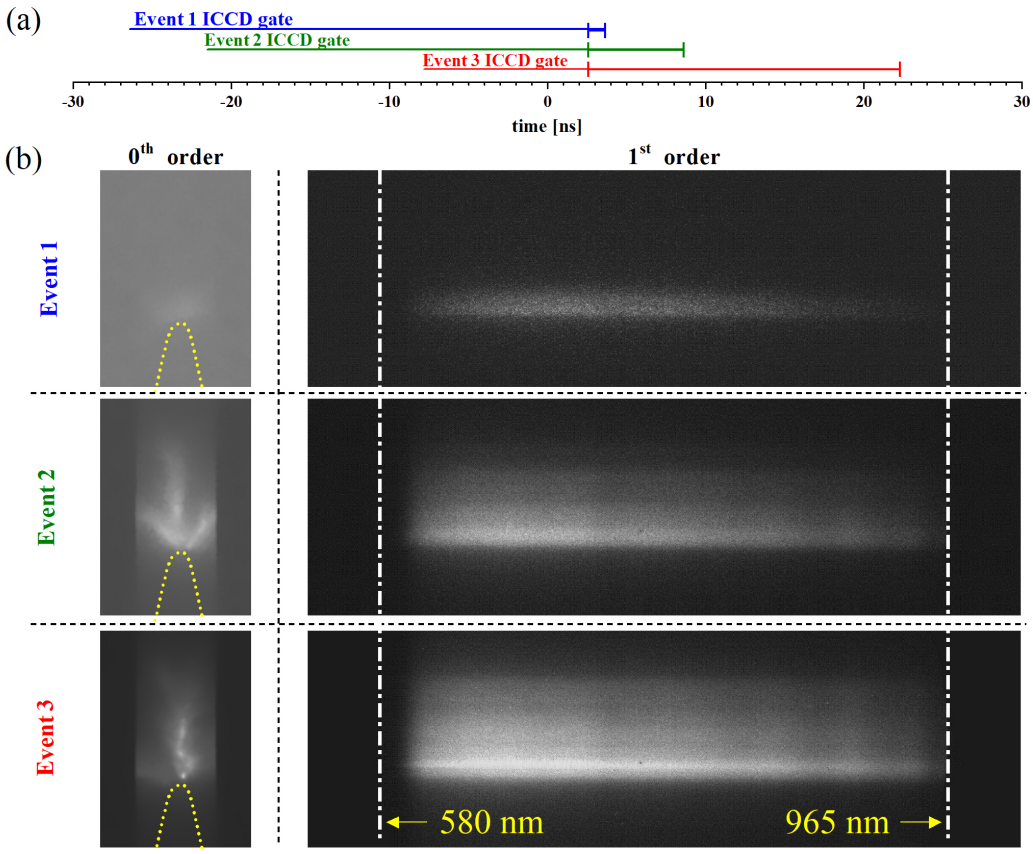

Fig. 2: Selected ICCD spectrometric images acquired in 0th and 1st diffraction orders using ICCD gate of 30 ns. Horizontal bars in (a) illustrate the timing of the MCP gates with respect to the onset (time t=0 ns) of the HV pulse. Images in panel (b) show the plasma-induced emission of selected events during the primary HV pulse.

In this work, we investigate the origin of the broad-band emission spectra captured in the first nanoseconds of the luminous phase by comparing them with model spectra obtained through three different methods:

(i) electron–neutral bremsstrahlung generated by a bell-like energy distribution of the electrons, which is coherent with the concept of electric field emission into electrostriction-induced nanovoids [7],

(ii) considering the electron–neutral bremsstrahlung due to electron energy distribution derived from state-of-the-art cross-section sets for H_2O [8],

(iii) considering high-pressure (GPa) broadening of hydrogen and oxygen atomic lines.

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