Investigation of the Initial Stage of Nanosecond Discharges in Water: Morphology and Emission Characteristics

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Abstract: In this contribution, we detail the temporally and spatially resolved spectra of nanosecond discharge in deionized water acquired using a vis-NIR ICCD spectrometer. We discuss the origin of broad-band emission continua occurring during the first few nanoseconds after the discharge onset and analyze the observed spectra in relation to electron-neutral bremsstrahlung.

1. Introduction

Electric discharges in contact with or directly within liquid water generate various reactive species of interest for numerous biological and medical applications [1].

The simplest mechanism for discharge initiation in liquids involves local evaporation due to Joule heating in the discharge gap, followed by gas breakdown. However, in the case of (sub)nanosecond high-voltage (HV) pulses, heating and liquid evaporation, which facilitate discharge onset on sub-nanosecond timescales, are not feasible. Consequently, the fundamental characteristics and signatures of both direct and bubble-assisted discharge mechanisms remain active research areas.

A recent experimental study [2] revealed that nanosecond discharges consist of a non-luminous and a luminous phase. The non-luminous (dark) phase, forming bush-like structures composed of thin, hair-like filaments, emerges a few nanoseconds after the onset of the HV pulse. The propagation of each filament is accompanied by gigapascal (GPa) shock waves [3]. In contrast, the luminous phase exhibits a simple tree-like morphology and is characterized by a broadband continuum spanning ultraviolet to near-infrared (NIR) wavelengths [4]. This phase begins approximately 600 ps after the onset of the dark phase.

2. Methods

We systematically investigated (see Fig. 1) synchronized ICCD images of the discharge luminosity together with imaging spectra of the discharge events produced in liquid DI water under single (nonperiodic) HV pulse conditions around anode needle. We combined time-resolved four-channel ICCD microscopy, single-channel ICCD images, and emission spectra with the basic electro-optical discharge characteristics [6]. This enabled us to connect the morphology of the luminous discharge phase with the characteristics of the plasma-induced emission in the vis-NIR region (registered up to 1050 nm).

3. Results and Discussion

We found out that the initial diffuse morphology of the discharge is associated with broad-band emission spectra, while the subsequent filamentary morphology shows broadened hydrogen and oxygen atomic lines. The origin of the broad-band emission spectra captured at the first nanoseconds of the luminous phase is quantified by comparison with the model spectra obtained in different

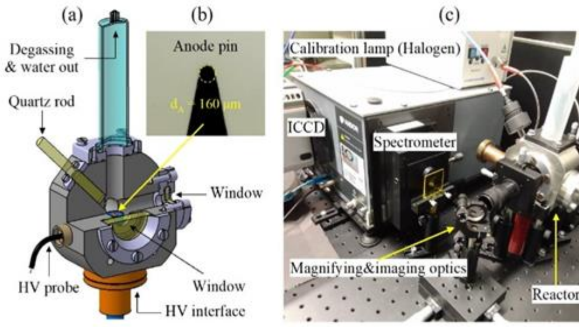

Fig. 1. Sketch (a) of the reactor chamber. Microscopic image (b) shows tungsten anode tip. Snapshot (c) of whole NIR spectrometric setup based on imaging

ways: (i) electron–neutral bremsstrahlung produced by a bell-like energy distribution of the electrons, which is coherent with the concept of electric field emission into electrostriction-induced nanovoids [5] (ii) considering the electron–neutral bremsstrahlung due to energy distribution of the electrons springing from the state-of-the-art cross sections for H_2O. All these findings provide important feedback for understanding the mechanisms of direct nanosecond high-voltage discharge in liquid water.

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