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Technical note

Towards a two-dimensional laser induced breakdown spectroscopy mapping of liquefied petroleum gas and electrolytic oxy-hydrogen flames ☆

Seok Hwan Lee [a], H. Thomas Hahn [a,b], Jack J. Yoh [a,*]

[a] School of Mechanical and Aerospace Engineering, Seoul National University, 1 Gwanakro, Gwanakgu, Seoul 151-744, South Korea
[b] Mechanical & Aerospace Engineering Department, UCLA, Los Angeles, CA 90095, USA

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ABSTRACT

Two-dimensional mapping of the laser-induced breakdown spectroscopy (LIBS) signal of chemical species information in liquefied petroleum gas (LPG) and electrolytic oxy-hydrogen (EOH) flames was performed with in situ flame diagnostics. Base LIBS signals averaged from measurements at wavelengths of 320 nm to 350 nm describe the density information of a flame. The CN LIBS signal provides the concentration of fuel, while the H/O signal represents the fuel/air equivalence ratio. Here, we demonstrate the meaningful use of two-dimensional LIBS mappings to provide key combustion information, such as density, fuel concentration, and fuel/air equivalence ratio.

1. Introduction

Laser induced breakdown spectroscopy (LIBS) is based on the optical spectroscopy of laser-induced plasma generated by the breakdown of a target gas, liquid, or solid. There have been several successful applications of LIBS to combustion analyses, which include the identification of industrial exhausts [1,2], the determination of fuel equivalence ratio in off-gas and flame [3–5], and the composition measurements of hydrocarbons [6].

The chemical species in the flame have also been evaluated by LIBS. Eseller et al. used LIBS with an ungated detector for the LIBS-based diagnosis of methane and biodiesel flames [7]. They also used N, O, and H LIBS signals from a CH_4/air flame to determine the equivalence ratio. Mansour et al. evaluated a turbulent premixed flame using double pulse LIBS method [8]. Kiefer et al. evaluated methane and DME (dimethyl ether) flames using LIBS [9]. They provided the optimal laser energy to generate laser plasma, and the fuel/air equivalence ratio according to the flame radial position. Rai et al. measured the metallic particles in a hydrocarbon flame for rocket engine health monitoring using LIBS [10]. Kotzagianni and Couris conducted combustion diagnostics using a femtosecond LIBS with varying delay time and laser energies [11]. Do and Carter confirmed that the short-gated LIBS signal of the H/N ratio can provide fuel concentration with good accuracy in an unsteady reacting flow [12]. Tripathi et al. demonstrated that LIBS-based calibrations perform better in equivalence ratio predictions for premixed atmospheric methane–air flames compared to chemiluminescence-based equivalence ratio measurements [13]. Michalakou et al. used LIBS to measure the equivalence ratios in methane–air, ethylene–air, and propane–air mixtures [14]. They demonstrated that the LIBS signal ratios of H(656.3 nm)/O(777 nm) and C(833.5 nm)/O(844.6 nm) from Bunsen burner laminar flames showed good correlations with the reference equivalence ratio.

Thus far, the application of LIBS to combustion diagnostics has focused on the measurement of chemical species in small local volumes or along a one-dimensional line. No regional information or multi-dimensional mapping of the chemical species by LIBS-based methodology has been attempted until now. For the illustration of such 2-D mapping of a flame via LIBS, we consider a gas mixture of hydrogen and hydrocarbon. Hydrogen is a potential fuel for generating clean energy without pollution, and researchers have continued to study its flame [15,16]. However, severe flashback and unstable flame propagation in lean burning conditions limit its use in most practical combustors. Hydrogen also explodes easily because of its wide flammability limits (4.65% – 93.9%), and thus requires special handling for safety. An approach to overcome these drawbacks is to use a mix of hydrogen and hydrocarbon fuels. The combustion mechanisms of hydrogen–hydrocarbon mixtures have been studied rather extensively in the past [17,18]. Electrolytic OxyHydrogen (EOH) gas is a stoichiometric mixture of hydrogen and oxygen produced from water through electrolysis [19]. As water electrolysis is quite instantaneous, EOH can be produced on demand without the need for storage. Nonetheless, the

* Corresponding author. Tel.: +82 2 880 9334.
E-mail address: jjyoh@snu.ac.kr (J.J. Yoh).

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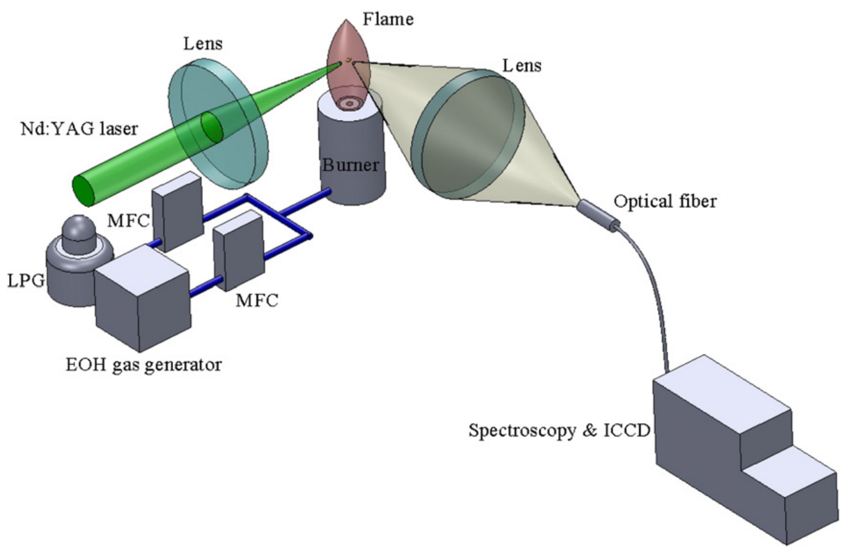

Fig. 1. Experimental setup.

combustion mechanism of the EOH–hydrocarbon mixture has not been studied in detail.

In this work, we consider a liquefied petroleum gas (LPG)–EOH flame for chemical analysis via LIBS. Two-dimensional mapping allows for spatial dimensionality in a conventional LIBS point measurement. Information about the dissociated chemical species (gas phase) and soot (solid particle phase) unattainable via any other means is provided by the present system. We present both atomic

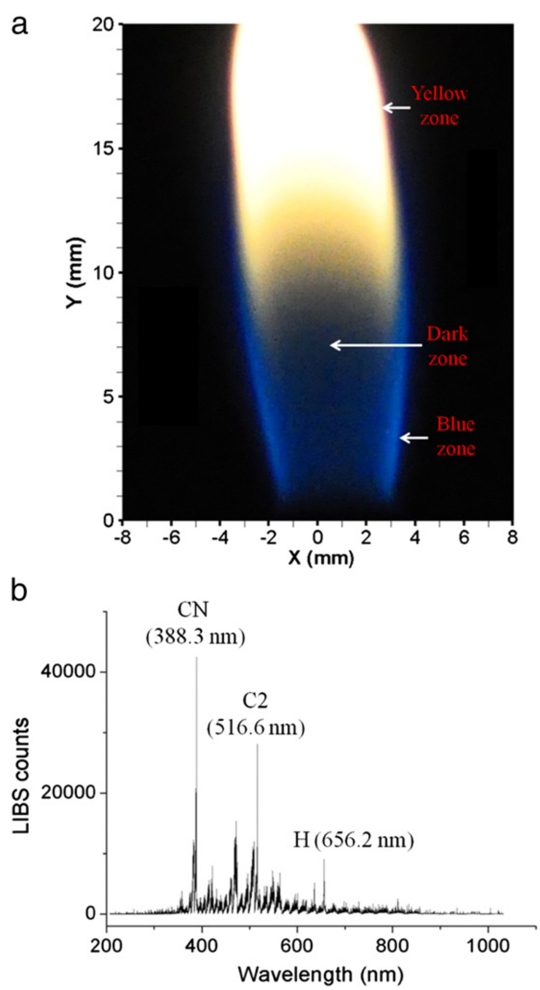

Fig. 2. (a) Flame image of LPG 50 ccm, (b) spectrum of LPG flame at 2 mm above the burner from 200 mJ laser energy at 2 μs delay time. Three peaks of CN (388.3 nm), C_2 (516.6 nm) and H (656.2 nm) are identified.

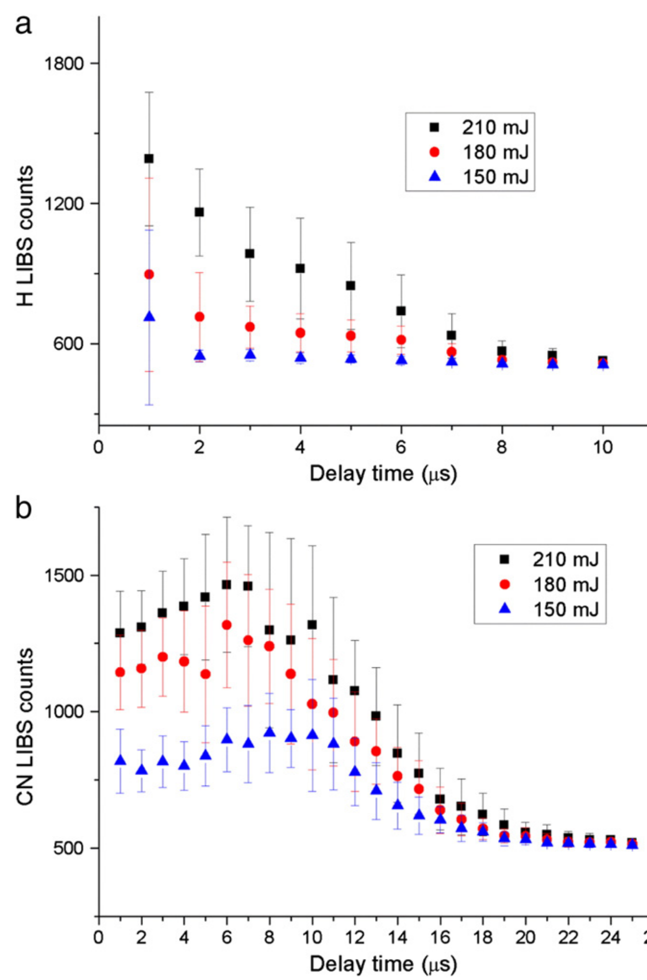

Fig. 3. LIBS signal according to delay time for different laser energy (a) H atomic peak (656 nm) and (b) CN molecular band (388 nm).