Filament-driven Lasing Action for Combustion Diagnosis

Huailiang Xu[1,3], Wei Chu[1,2], Helong Li[1], Jielei Ni[2], Bin Zeng[2], Jinping Yao[2], Haisu Zhang[2], Guihua Li[2], Chengrui Jing[2], Hongqiang Xie[2], Kaoru Yamanouchi[3], Ya Cheng[2]

[1]State Key Laboratory on Integrated Optoelectronics, College of Electronic Science, and Engineering, Jilin University, Changchun 130012, China
[2]State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China
[3]Department of Chemistry, School of Science, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo,113-0033,Japan
huailiang@jlu.edu.cn and ya.cheng@siom.ac.cn

Abstract: We report on the lasing action for the combustion intermediate of CN in an ethanol/air flame by femtosecond laser excitation. It is confirmed that the lasing action results from amplified spontaneous emission with the population inversion achieved in the femtosecond-laser-induced plasma filament.

OCIS codes: (020.4180) multiphoton processes; (120.1740) combustion diagnostics.

1. Introduction

Ultrafast femtosecond laser-induced lasing actions via amplified spontaneous emission (ASE) or seed amplification in the plasma filaments have been a subject of increasing interest in recent years because of its potentials for remote applications in standoff spectroscopy and remote sensing [1-3]. In air, it was shown that when an plasma filament is formed by a powerful femtosecond laser pulse, population inversion of neutral nitrogen molecules (i.e., N_2) for the $C^3\Pi_u$-$B^3\Pi_g$ transition and that of nitrogen molecular ions (i.e., N_2^+) for the $B^2\Sigma_u^+$-$X^2\Sigma_g^+$ transition could be established although their underlying mechanisms are totally different [4,5]. It was further demonstrated that the population inverted N_2 and N_2^+ systems in ambient air can be seeded by self-generated white light continuum or harmonics during the filamentation of the pump laser beams [2,5,6]. Based on such approach, the μJ output energy of the self-seeded laser has been reported [5].

In the current contribution, we show that when a femtosecond filament is formed in a laminar ethanol/air flame on an alcohol burner, clean fluorescence emissions from free radicals CH, CN, NH, OH, and C_2, as well as atomic C and H, can be obtained, and their intensities vary as functions of the position of interaction of the filament with the flame along the vertical axis of the central combusting flow, showing the fluorescence signal intensity can be used to characterize the concentration of combustion intermediates [7]. Furthermore, it is found that the fluorescence emission from some specific species such as CN can be amplified by observing the backward fluorescence intensity as a function of the plasma length in the flame, opening up a new way to enhance the signal-to-noise ratio in combustion diagnosis by using fluorescence techniques [8].

2. Experimental results and discussion

Experiments were performed with 1 kHz and 800 nm Ti:Sapphire femtosecond laser pulses. The laser beam with a 0.5 mJ pulse energy was focused by a lens of 20 cm into the ethanol/air flame on an alcohol burner to generate a single filament with the length of ~1 cm. A moving stage was used to raise or lower the alcohol burner to control the position of interaction of the flame with the short filament. The fluorescence emitted from the filament was collected at a right angle to the laser propagation direction, and focused onto the entrance slit of a spectrometer (Andor Shamrock SR-303i) and detected by a gated intensified charge coupled device (ICCD, Andor iStar). Figure 1(a) shows the filament-induced spectrum of the ethanol/air flame in ambient atmosphere measured from the side of the filament. The spectral bands are assigned to free radicals of C_2, CH, CN, N_2, NH and OH, and atomic species of C and H. As can be seen in Fig. 1(b), we examined the intensities of the four species of C, CH, CN, and C_2 as a function of the filament position in the flame, and found the signal intensities of all the four species vary, which reflects the concentration distribution of the four intermediate species in the flame.

Furthermore, we generated the filament in the flame on an alcohol burner array by focusing the laser beam with an f = 40 cm lens. The laser energy was 1.6 mJ/pulse. The total length of the alcohol burner array with five burner wicks was approximately 40 mm. As can be seen in the photos in Fig. 2(a), the length of the filament in the flame became longer as the flame length became longer. In this measurement, the fluorescence emitted from the filament was collected and collimated in the backward direction. It was noticed that the main features of the measured backward spectrum were consistent with that measured previously from the side of the laser-induced flame filament. However, the emission at ~388 nm for CN was strikingly enhanced when compared to the spectral bands of other species. By changing the length of the filament interacting with the flame by moving the burner array along the

filament direction, we plotted the dependence of the peak intensities of CN at 388 nm and C_2 at 474 nm on the interaction length of the filament in the flame in Figs. 2 (b). It can be seen that the signal intensity of CN increases exponentially, but that of C_2 increases linearly when the length of the filament interacting with the flame becomes longer, confirming that there exists gain only for CN in the flame filament.

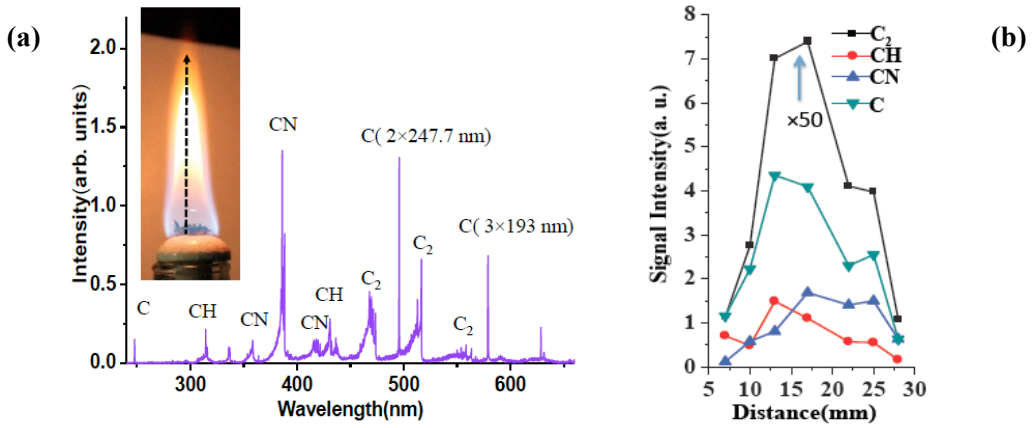

Fig.1. (a) Spectrum of the ethanol/air flame on an alcohol burner by the excitation of a femtosecond filament. Inset: Picture of the flame and the interaction positions marked by the dash lines; (b) The signal intensities of the four species, C_2, CN C, and CH, obtained at the different positions of the flame along the dash line in the inset picture.

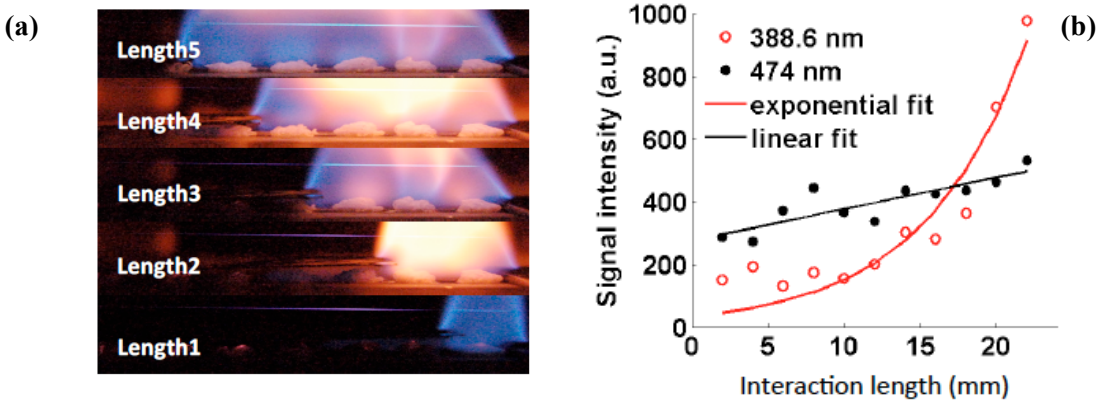

Fig.2. (a) The photos of the flame and the filament taken for the five different flame lengths; (b) Measured (circle) and fitted (solid line) dependence of the emission intensity of CN at 388.6 nm and that of C_2 at 474 nm on the length of the filament in the flame.

3. Summary

We have demonstrated the generation of ASE lasing action for the spectral band of CN at ~388 nm in the ethanol/air combustion flame. This finding shows that lasing actions triggered by femtosecond laser filaments can be employed for sensing specific species in combustion and explosion processes.

4. References

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