Temperature evolution of carbon-neutral fuel mixtures in a nanosecond discharge

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Abstract: Plasma-Assisted Combustion (PAC) is a promising technology for stabilization of lean flames in sustainable fuel/air mixtures. However, scaling PAC for industrial applications like aircraft engines involves challenges such as managing NOx emissions. Our study uses advanced optical diagnostics like fs/ps CARS to measure gas temperature, which plays a critical role in NOx formation.

1. Introduction

Plasma-Assisted Combustion (PAC) has been shown to be very effective for the stabilization of lean flames [1], thus providing a means of reducing emissions in aircraft engines and industrial burners. The next generation of combustors will likely use sustainable fuels such as sustainable aviation fuel (SAF), or carbon-neutral fuels such as hydrogen (H_2). Such options are CO_2 neutral but still result in NO_x emissions. Furthermore, the combustion stability of these fuels poses challenges that current technologies struggle to address [2]. Our overall goal is to study PAC technology in sustainable fuel/air and carbon-neutral fuel/air mixtures, with a particular focus on flame stabilization of lean mixtures and minimization of NO_x emissions.

The specific goal of this work is to measure the temperature evolution of a nanosecond discharge initiated in certain sustainable fuel mixtures. Our focus is on a reduced set of kinetics and, therefore, no air is introduced and there is no combustion. Nanosecond repetitively pulsed (NRP) discharges are initiated in the mixtures. High-voltage pulses of about 10 ns duration are used and applied with a repetition frequency of 10-100 kHz. Hybrid fs/ps CARS (coherent anti-Stokes Raman Scattering) will be used to measure the temporal evolution of the vibrational and rotational temperatures of N_2.

These measurements aim to capture some of the ultrafast processes associated with NOx formation. Such data is crucial for enhancing the scientific communities' understanding of complex chemical interactions in nanosecond discharges, addressing current limitations of PAC technology, and paving the way for its practical application in larger industrial systems.

2. Experimental setup

The experimental setup is shown on Fig. 1. It is centered around the Solstice Ace femtosecond laser system. The optical setup is similar to the one proposed by Miller *et al.* [3], with one significant change. Instead of using the diffraction grating, lens, slit, and mirror setup for generating the picosecond probe pulse, we employ a singular optical device – a Bragg reflective notch filter, as suggested by Scherman *et al.* [4]. These filters are commercially available, and this modification significantly simplifies the pulse shaping portion of the experimental setup.

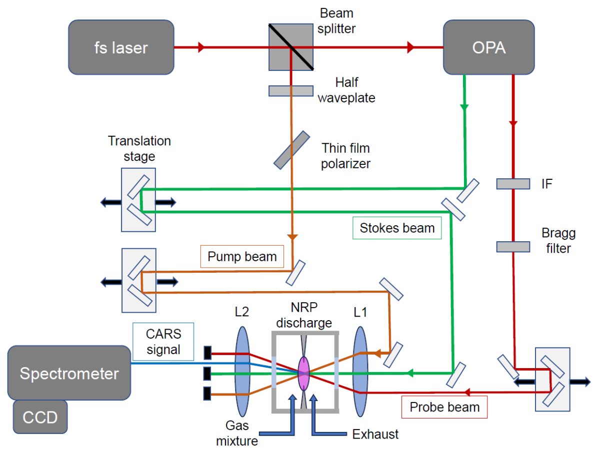

Fig. 1. Experimental CARS setup. OPA: optical parametric amplifier, IF: interferential filter, L1, L2: lenses, CCD: charge coupled device.

3. Results and Discussion

Initial findings from the rotational Coherent Anti-Stokes Raman Spectroscopy (CARS) optical system have been acquired. These measurements were taken under room temperature and atmospheric pressure conditions. However, the rotational CARS technique is better adapted for environments with low gas temperatures. In contrast, for assessing temperatures exceeding 1000 K, typical in fuel-air mixture combustion scenarios, vibrational CARS spectra will be required. Current work is focused on implementing these measurements.

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