Mid-infrared pumped laser-induced thermal grating spectroscopy for flame thermometry and gas sensing

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KEY WORDS: Gas sensing, Laser-induced grating diagnostics, Flame temperature

The non-linear laser techniques of combustion diagnostics, based on four-wave mixing light-matter interactions, enable non-intrusive remote measurements of gas parameters in reactive flows with a high spatial resolution [1]. Laser-induced thermal grating spectroscopy (LITGS) is a versatile laser diagnostics technique that has demonstrated the possibility to perform highly sensitive, quantitative, spatially and temporally resolved measurements of various gas parameters, including temperature and pressure (e.g. [2]). Degenerate four-wave mixing (DFWM) is a resonant four-wave mixing technique that enables remote and zero background measurements with high sensitivity, and mid-infrared DFWM excitation scans of water absorption spectra have been widely applied for temperature measurements (e.g. [3]).

In this work, we demonstrate combined LITGS and DFWM measurements in premixed laminar $CH_4/O_2/N_2$ flames (equivalence ratios: 0.6 to 1.5) to achieve precise thermometry across various flame conditions [4]. Using laser wavelength around 3 μm enables the excitation of the ro-vibrational transitions of nascent water in flames. In fuel-lean flames, where variations in the mass-to-specific-heat ratio are minimal, LITGS provides high-precision temperature data. In fuel-rich flames, where the increased H_2 concentration in the flame introduces uncertainty in gas constants thus affecting the accuracy of LITGS thermometry, DFWM is instead employed for temperature measurement since it is less sensitive to the gas composition within the measured volume. Thus, the combined use of DFWM and LITGS demonstrates its potential for accurate thermometry and diagnostics of other thermodynamic parameters across diverse flame conditions. In addition, using different wavelengths, we demonstrate how LITGS signals can be generated using the vibrational transitions of CO_2 around 2 μm, to perform thermometry in the range of 293 K–420 K and measure the vibrational energy relaxation times of CO_2 in this vibration mode [5].

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