Raman spectroscopy

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Rovibrational temperature determination of a plasma assisted premixed flame

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Introduction

To improve the lean flammability limit and combustion stability of premixed methane flames, plasma can be applied. Non-equilibrium plasma effects the flame through thermal, chemical and aerodynamic mechanisms. The thermal mechanism can be quantified by in-flame temperature measurements using Raman spectroscopy.

Experimental setup

- A flat flame burner with a high voltage electrode in the surface, which creates a nanosecond micro-discharge plasma in the gas channels has been designed by Elkholy [1], see Figure 1.
- Raman scattering induced by a Nd:YLF laser beam at 527 nm and is measured with an 2400 g/mm spectrograph and iCCD camera, see Figure 2.

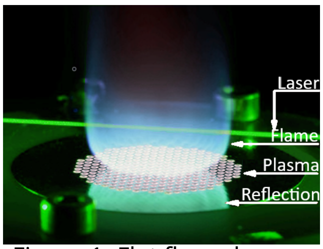

Figure 1: Flat flame burner

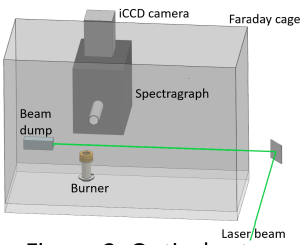

Figure 2: Optical setup

Temperature modelling

Raman spectrum intensity I can be modelled using a Boltzmann distribution (eq. 2) for the scattered population $N_{\nu,J}$ or a Treanor distribution (eq. 3) for a strong over-abundance of higher vibrational levels [2].

$$I_{\nu,J} = C\frac{h}{8\varepsilon_0{}^2\Delta\sigma_R}(\sigma_L - \Delta\sigma_R)^4\frac{d\sigma_R}{d\Omega}N_{\nu,J}P \quad (1)$$

$$N_{\nu,J} = \frac{g_J\exp(-\frac{hcE_{vib}(\nu)}{kT_{vib}} - \frac{hcE_{rot}(\nu,J)}{kT_{rot}})}{Q_{vib}(T_{vib})Q_{rot}(\nu,T_{rot})}N_T \quad (2)$$

$$N_{\nu,J} = \frac{g_J\exp(-\frac{hcE_{vib}(\nu=1)}{KT_{vib}} + \frac{hc(E_{vib}(\nu=1)-E_{vib}(\nu))}{KT_{rot}} - \frac{hcE_{rot}(\nu,J)}{kT_{rot}})}{Q_{vib}(T_{vib},T_{rot})Q_{rot}(\nu,T_{rot})}N_T \quad (3)$$

Symbol	Quantity	Unit	Symbol	Quantity	Unit
ν	Vibrational level	-	$\frac{d\sigma_R}{d\Omega}$	Scattering cross-section	cm^{-1}
J	Rotational level	-	P	Laser power	W
C	Calibration constant	-	g	Degeneracy	-
h	Planck constant	Js	k	Boltzmann constant	J/K
ϵ_0	Permittivity of vacuum	F/m	Q	Partition function	-
σ	Wavelength	nm	E	Internal energy of molecule	cm^{-1}

Results

The scattered emission of a $Q = 6$ L/min and $\phi = 0.83$ methane flame with and without a 3 kHz repetition rate plasma is measured in the centre of the flame at 3 mm above the burner, see Figure 3. Least squares fitting of the Boltzmann distribution model with variable T_{rot} and T_{vib} and measured Raman spectrum of N_2 has been used to determine the flame temperatures with and without plasma. The results are presented in Figure 4 and 5.

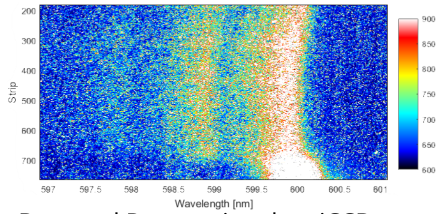

Figure 3: Detected Raman signal on iCCD camera of flame without plasma

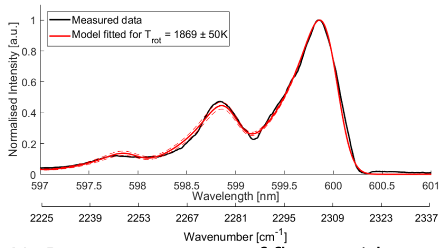

Figure 4: N_2 Raman spectrum of flame without plasma, captured in 1x1.000.000 gates

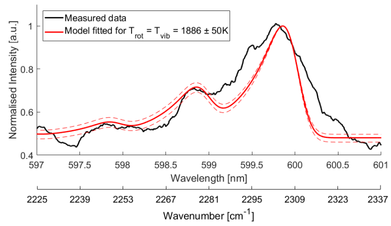

Figure 5: N_2 Raman spectrum of flame with plasma, captured in 5x100.000 gates

Conclusions

- With Raman spectroscopy temperature dependent scattered N_2 spectra can be measured and modelled using a Boltzmann and Treanor distribution with moderate accuracy.
- Signal quality is insufficient to measure significant change to the rotational and vibrational temperatures due to non-equilibrium plasma.

References

[1] A.H.E. Elkholy *et al* (2018). Characteristics of a novel nanosecond DBD microplasma reactor for flow applications. *Plasma Sources Sci Technol.* **27**, 055014.

[2] A. Lo *et al* (2012). Spontaneous Raman scattering: a useful tool for investigating the afterglow of nanosecond scale discharges in air. *Applied Physics B* . **107**, 229-242.

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