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Nanosecond plasmas for detonability enhancement

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The interest in detonation as a substitute to the usual isobaric combustion process lies in its high characteristic pressure and short reaction times and lengths. One of the main issues is to ensure detonation ignition and propagation in a large range of initial conditions [1-2]. This work extends results of former experiments and calculations [3] which demonstrate that plasma enhances detonability. Our observations thus show the decreases of the deflagration-to-detonation (DDT) length and the detonation cell width.

Our work investigates (i) the links between the pre-dissociation of a gas mixture by plasma action and (ii) the decrease of the characteristic times and lengths of the combustion reactions.

For the DDT experiments, a nanosecond multichannel capillary discharge was used to ignite the flame. For the experiments on the cellular detonation regime, a nanosecond discharge homogeneously distributed was used to pre-dissociate the mixture before the detonation front.

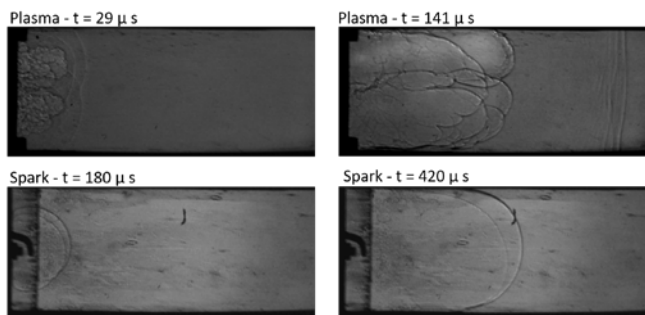


Figure 1. Ignition and evolution of the flame in $2\text{H}_2:\text{O}_2$ mixture at 600 mbar (Schlieren)

Figure 1 shows typical Schlieren pictures of the ignition and evolution of the flame in the $2\text{H}_2:\text{O}_2$ mixture at 600 mbar. The flame evolution is much faster and its front shows more structures, hence a larger combustion surface, with the nanosecond plasma discharge than with the automotive plug. For example, the second picture of the plasma sequence at $141 \mu\text{s}$ shows that the flame has reached half the field when this position is only reached at $420 \mu\text{s}$ with the ignition by the automotive plug. As a consequence, the push on the initial mixture is faster and stronger as indicated by the presence of compression waves ahead of the front (the dark vertical lines at the rightmost part of the picture at $141 \mu\text{s}$). The flame shows several combustion kernels, generated by the multiple-point electrode, hence a more turbulent front. In contrast, the flame front obtained with the automotive plug always shows a smooth surface in the frame time of the recordings. The plasma ignition thus leads to a faster and more turbulent flame that speeds up the transition to detonation.

For the detonation experiments, Figure 2 shows the soot recordings in the $2\text{H}_2:\text{O}_2$ mixture at 150 mbar diluted with 40% of argon. The decrease of the cell width is easily observed on the right recording by comparison with the cells on the reference recording (left).

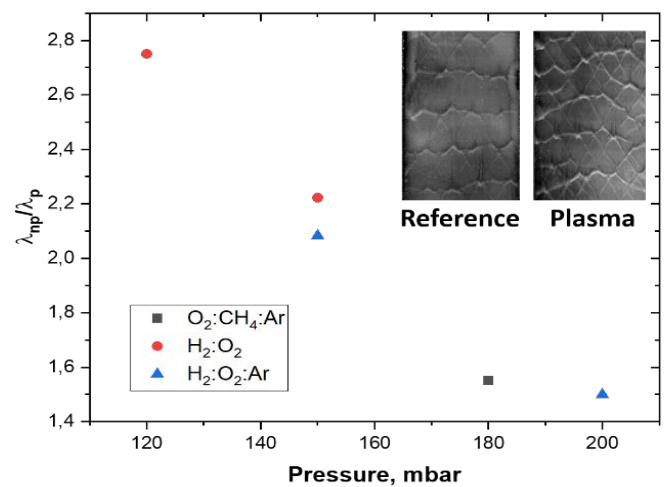


Figure 1. Measured cell sizes against initial pressure

Figure 2 also shows the cell width measured as function of the initial pressure for several mixtures in the form of the reduction ratio (n_p : no plasma, p : plasma) for several mixtures. The ratio increases with decreasing initial pressure which corresponds to the conditions that ensures a more homogenous plasma ahead of the detonation front.

The pre-dissociation effect of the plasma on the initial mixture was calculated. The results were used as input for a ZND code implementing a detailed chemistry of H_2 -based mixtures to obtain the temperature profiles in the detonation reaction zone. The plasma-case profile was calculated with 2% atomic oxygen added to the initial composition, a number given by the plasma OD calculations. We observe a reduction of the induction time by a factor of 2, a ratio that agrees with the experimental reduction of the detonation cell size. The results of the calculations will be shared and discussed.

This work thus demonstrates that the length of the DDT and the mean width of the detonation cell can be reduced by using high-voltage nanosecond discharges. Our experiments are fundamental in nature and performed in simple configurations. Nevertheless, we conclude that more specific devices implementing detonation as a combustion process could be made more efficient and compact by using plasma actions.

[1] Roy G. D., Frolov S. M., Borisov A. A., Netzer D. W. (2004), Pulse detonation propulsion: challenges, current status, and future perspective. *Progress in Energy and Combustion Science*, 30(6), 545-672.

[2] Shepherd J.E., Kasahara J. (2017). Analytical Models for the Thrust of a Rotating Detonation Engine, Tech. Report FM2017.001, Graduate Aeronautical Laboratories, California Institute of Technology

[3] Cherif, M. A., Shcherbanev, S. A., Starikovskaia, S. M., & Vidal, P. (2020). Effect of non-equilibrium plasma on decreasing the detonation cell size. *Combustion and Flame*, 217, 1-3

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