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# INSIDE technique: INduced Spectroscopy for Ignition Diagnostics in Engines

A technique was developed based on spark-induced breakdown spectroscopy (SIBS) as a diagnostic tool to characterize homogenous methane-air mixtures composition at engine relevant conditions in a quiescent constant volume cell. Spectral fingerprints of different gas composition were identified to relate plasma emissions to combustion relevant parameters such as the local fuel-air equivalence ratio. Using an inductive ignition system, atomic emission lines of hydrogen ($H_\alpha$) at 656 nm, oxygen ($O_{777}$) at 777 nm, carbon ($C_{766}$) at 766nm and nitrogen ($N_{746}$) at 746 nm and the corresponding ratios can be directly related to the local fuel-air equivalence ratio. The technique was recently modify for investigating different ignition systems, including capacitive- and Nanosecond Repetitive Pulsed Discharge (NRPD) ignition. The INSIDE is thus a versatile tool to characterize the mixture composition at ignition timing in the spark plug location.

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## Introduction

Plasma emissions during the ignition process are a fingerprint of the local gas composition. The local fuel-air equivalence ratio ϕ is one of the main parameters for successful transition from an the ignition plasma to the early flame kernel.

$$\Phi = \frac{m_{fuel}/m_{air}}{(m_{fuel}/m_{air})_{st}}$$

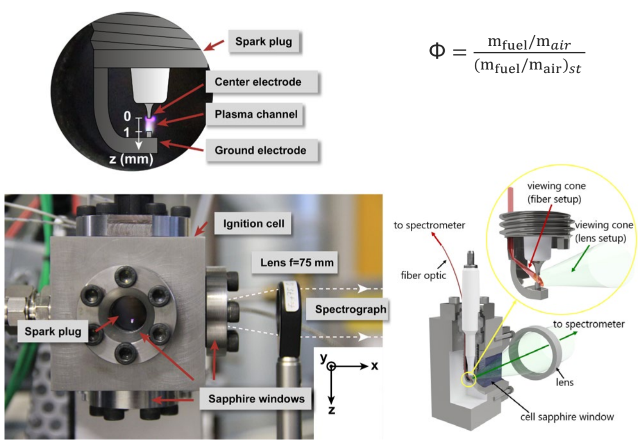


Figure 1: Experimental setup

## Methodology

Spark-induced breakdown spectroscopy (SIBS) was used to analyze the availability of different species during ignition. The impact of fuel composition, pressure, temperature and other cross-sensitivity on the spectral characteristics are investigated in an optically accessible constant volume cell (Fig. 1) at quiescent conditions. Experiments were performed for methane-air mixtures of different stoichiometry at an engine relevant pressure level of 10 bar. Plasma emissions were extracted via a lens-coupled spectrometer and compared with measurements via a fiber optic spark plug [1-2]. Atomic emissions from the mixtures main constituents can be used to characterize the mixture composition (Fig. 2). Comparing the emission line intensities of $H_\alpha$ at 656 nm to lines of oxygen $O_{777}$ at 777 nm, nitrogen $N_{746}$ at 746 nm and carbon $C_{766}$ at 766 nm allows characterizing the local mixture composition in terms of the fuel-air ratio ϕ.

## Results and discussion

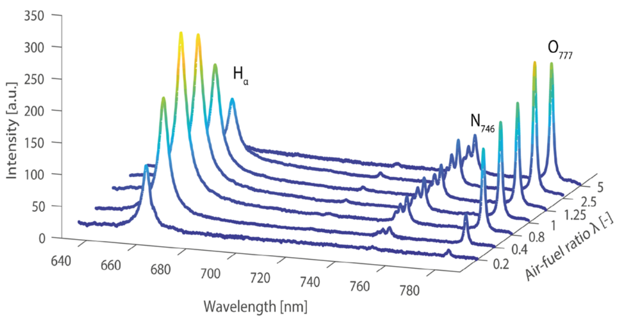


Figure 2: Spectral signature of methane-air mixtures at different air-fuel equivalence ratios.

A versatile SIBS-based technique (**INSIDE**) was developed for contributing to the understanding of the transitional phase from the plasma channel to the early flame kernel. **Spectral emissions** can be used to characterize the local mixture composition near the spark plug. The possible application to running engines and diluted mixtures was shown [3-4]. **Short duration, non-equilibrium plasmas** like those obtained using nanosecond repetitive pulsed discharge (NRPD) are a promising solution for a wide range of applications in which highly diluted, ultra-fast, low-temperature combustion need to be controlled [5].

Spectral emissions measured at 10 bar in a stoichiometric methane/air mixture diluted with EGR (Exhaust Gas Recirculation) addition show different features when using capacitive (Fig. 3) or nanosecond-ignition (Fig. 4), thus giving information on the different phenomena occurring.

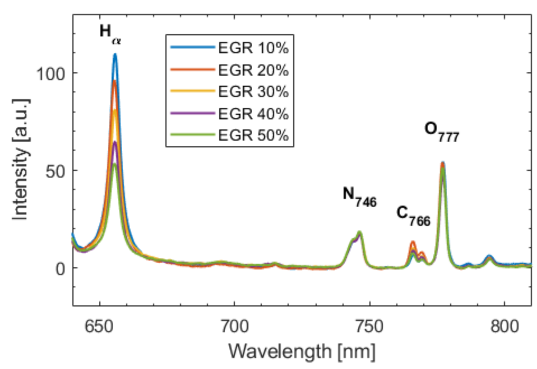


Figure 3: Spectral emissions for methane/air mixture diluted with EGR, capacitive ignition system.

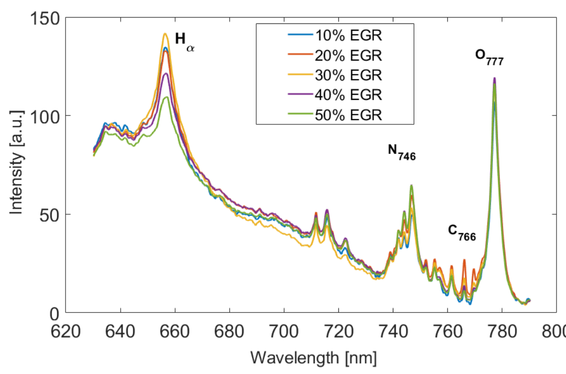


Figure 4: Spectral emissions for methane/air mixture diluted with EGR, nanosecond ignition system.

For real systems applications, understanding of plasma assisted ignition and combustion is needed. For the most interesting range of parameters for practical applications, such as gas temperatures below the self-ignition threshold, simulation of plasma-assisted ignition and combustion remains an open problem. INSIDE is thus a promising technique for improved understanding of the phenomena occurring at ignition, as well as for diagnostics.

## Expected impact

Significant advances in engine development are currently limited by a poor understanding of the details of ignition and flame development at the early stage of combustion. However, the formation and development of the flame at the early stage of combustion greatly influence the later flame propagation and thus the combustion process and stability.
The spectroscopic data of the ignition event enhances the understanding of the transition from the plasma to the early flame kernel and allows to further refine and validate CFD models of the ignition process. Integrating this method into an optical spark plug provides insight into the ignition process and can reveal important information on a cycle to cycle basis.

## References

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