Multi-point, pulse-train laser ignition of methane-air mixtures by a high-peak power passively Q-switched Nd:YAG/Cr^{4+}:YAG compact laser

Nicolae-Tiberius Vasile, Gabriela Croitoru, Ciprian Dumitrache, Nicolaie Pavel
National Institute for Laser, Plasma and Radiation Physics, Laboratory of Solid-State Quantum Electronics, Magurele 077125, Romania
nicolaie.pavel@inflpr.ro

Laser ignition (LI) of various fuel mixtures is a research topic that seeks to address mankind's concern for the environment and natural resources through a number of specific features [1]. In the case of LI there is no electrode placed in the combustion chamber and therefore the flame kernel develops freely. Moreover, using proper focusing optics, LI can be initiated at any point in the engine cylinder, thus providing a possibility to optimize engine performance. Furthermore LI is a suitable technique for igniting lean fuel mixtures, thus reducing emissions without decreasing engine power [2-4]. A laser beam offers also the possibility to control the ignition spatially, by simultaneous ignition in several points [5,6], as well as temporally, by using a train of laser pulses for a single ignition event. In the case of LI at several points, the combustion time is reduced and the flame can lose less heat, resulting in higher temperatures and higher pressures. All experiments conducted so far on LI at several points have used large commercial lasers, and the laser beams have been directed to and then focused in a static combustion chamber or in the engine cylinder using various optical systems [6]. In addition, there are very few reports of multi-pulse laser ignition [7]. In this work, we report on the realization of a compact, diode-pumped passively Q-switched Nd:YAG/Cr^{4+}:YAG laser with four beams, operating in single-pulse as well as in burst mode (yielding trains of up to five pulses). This device was used to study LI of CH_4-air mixtures in a combustion chamber, employing spatial ignition control as well as temporal ignition control mode.

A composite Nd:YAG/Cr^{4+}:YAG ceramic medium (1.1-at.% Nd) was used to build the laser, considering a monolithic resonator design. The Nd:YAG/Cr^{4+}:YAG laser was pumped with four fiber-coupled laser diodes; the pump pulse duration was chosen so that each laser beam contains trains of up to five pulses at a set repetition rate. The energy of an individual laser pulse was 3.2 mJ with duration of 0.9 ns. LI of CH_4-air mixtures was done in a spherical combustion chamber, properly equipped for such experiments [8].

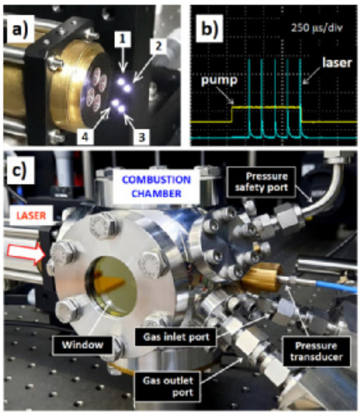

Fig. 1 a) The laser with four points of ignition and **b)** a train of five pulses is shown. **c)** The combustion chamber is presented.

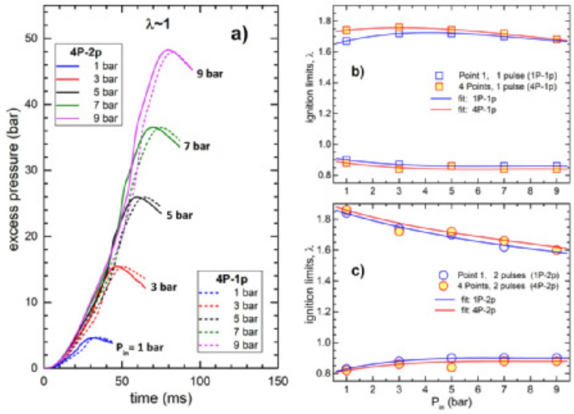

Fig. 2 a) Pressure vs. time for LI in four points of CH_4-air stoichiometric mixtures (λ~1) at various initial pressure, P_{in}. Limits of ignition for λ, considering ignition with **a)** a laser pulse and **b)** trains of two laser pulses.

LI of CH_4-air mixtures with different values of relative equivalence ratio, λ was investigated considering four ignition schemes: ignition in point 1 with one laser pulse (1P-1p) and with train of two laser pulses (1P-2p); four-point ignition with one laser pulse (4P-1p) and with two laser pulses (4P-2p). Maximum pressures and the combustion times were obtained from the pressure curves recorded during LI (Fig. 2a); an analysis is made for each ignition scheme, considering initial pressures in the combustion chamber up to 9 bar. Ignition limits for λ have been determined (Fig. 2b, Fig. 2c) and a discussion of these results is presented. The advantages of multi-point LI with trains of laser pulses are analyzed compared to LI at one location. Multi-point LI with burst-mode train pulses is a feasible technique for igniting lean fuel-air mixtures and for increasing the combustion speed.

Financing Projects PN-III-P4-PCE-2021-0519 and NUCLEU-LAPLAS V 16N/2019, Ministry of Research and Innovation, Romania.

[1] P.D. Rooney, Opt. Eng. **33**(2), 510-521 (1994).
[2] J. D. Dale, P. R. Smy, and R. M. Clements, SAE Technical Paper 780329 (1978).
[3] T. Taira, S. Morishima, K. Kanehara, N. Taguchi, A. Sugiura, M. Tsunekane, "World first laser ignited gasoline engine vehicle," in: 1st Laser Ignition Conference, Yokohama, Japan, 2013 paper LIC3-1.
[4] N. Pavel, M. Bärwinkel, P. Heinz, D. Brüggemann, G. Dearden, G. Croitoru, O. V. Grigore, Prog. Quantum Electron. **58**, 1-32 (2018).
[5] T. Phuoc, Combust. Flame **122**(4), 508-510 (2000).
[6] P. Patane, M. Nandgaonkar, Opt. Laser Technol. **130**, 106305 (2020).
[7] S. Lorenz, M. Bärwinkel, R. Stäglich, W. Mühlbauer, D. Brüggemann, International Journal of Engine Research **17**(1), 139-150 (2016).
[8] N.-T. Vasile, N. Pavel, Opt. & Laser Techn. **141**, 107169 (2021).