A high-peak power passively Q-switched Nd:YAG/Cr^{4+}:YAG compact laser with multiple-beam output

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Abstract: A diode-pumped, passively Q-switched, compact and monolithic Nd:YAG/Cr^{4+}:YAG ceramic laser with four-beam output is presented. The energy of each laser pulse could be increased up to 5.9 mJ at pulse duration around 1 ns. The system is seen as a solution for a laser spark with multiple-point ignition.

In comparison with ignition by electrical spark plugs, the laser ignition of a gasoline direct injected engine offers several potential benefits; often discussed are the no quenching of the combustion flame kernel, the ability to focus a laser beam at any location of interest in the combustion chamber, or the possibility to deliver beams in different positions, simultaneously or with temporal control. The first report on an automobile that was fully ignited by laser sparks was presented in 2013 [1]; also, a Renault vehicle was run only by laser sparks recently, in 2015 [2]. Better engine stability and reduced CO and HC emissions were measured for the engine ignited by laser sparks.

A laser device offers the possibility to induce ignition in more than one location of the engine, for better and more uniform combustion in comparison with ignition by electrical spark plugs. This technique of multi-point ignition can shortens the distance that a flame covers during the combustion process. The combustion time reduces and the flame will lose less heat than in the case of single-point ignition; consequently, higher temperatures and pressures could be reached, leading to improved thermal efficiency and increased power of the engine. In addition, there is increased probability to fire lean air-fuel mixtures.

The influence of two-point laser ignition on combustion characteristics of different hydrogen- or methane-air mixtures was studied, showing improved combustion in comparison with single-point ignition [3-5]. Moreover, the potential of a two- and three-point laser ignition system to improve the lean operation limit was investigated [6]. Decreased fuel consumption and lower NO_x emissions were the main findings for multi-point ignition of a one-cylinder engine [6]. Furthermore, a technique that proved to be successful for generation of several (up to three) sparks with arbitrary spatial location was developed, based on variable diffraction of a pulsed, single-beam laser with a spatial light modulator [7]. This method was applied to a single-cylinder automobile research engine; much stable combustion was obtained when the engine was operated with lean air-fuel mixtures.

A laser configuration aimed to be used for building of a compact laser spark was proposed in 2007 [8]. The scheme consisted of a solid-state Nd:YAG medium, passively Q-switched by a Cr^{4+}:YAG saturable absorber (SA); in addition, the Nd:YAG was optically pumped at 808 nm by a fiber-coupled diode laser operated in quasi-continuous wave (quasi-cw) mode. Further investigations concluded that the best choice for the device integration is a diffusion-bonded Nd:YAG/Cr^{4+}:YAG composite structure with a monolithic scheme for the laser resonator [9]. Based on this concept and using multiple pump lines, spark-plug like, composite, all-ceramic Nd:YAG/Cr^{4+}:YAG monolithic laser with two- and three-beam output were realized [10,11].

Recently we have proposed a diode-pumped high-peak-power passively Q-switched Nd:YAG/Cr^{4+}:YAG laser with four-beam output [12]. Each laser line could deliver pulses with energy around 3 mJ and 0.9 ns duration. In this work we report on further improvements of this scheme and realization of an integrated spark plug like laser device.

The experimental set-up is shown in Fig. 1a. The laser medium is a composite Nd:YAG/Cr^{4+}:YAG ceramic (1.1-at.% Nd, total length of 11 mm); the monolithic resonator was obtained by coating the high-reflectivity mirror on the input side S1 of Nd:YAG and the out-coupling mirror on the exit surface S2 of Cr^{4+}:YAG SA. The pump was made by four fiber-coupled (600-μm diameter fibers, NA= 0.22) diode lasers DL (JOLD-120-QPXF-2P; Jenoptik, Germany) in quasi-cw regime. For each line the pump beam was focused with a single lens L and then a combination of two right-angle prisms (PP) was used to direct the corresponding pump beam toward Nd:YAG. The management of the thermal effects in Nd:YAG/Cr^{4+}:YAG was obtained by choosing the laser medium with a hole drilled along its center and by proper cooling. Focusing of each laser beam was realized with a single lens (FL).

The laser pulse energy is shown in Fig. 1b. While the between each optical fiber (DL) and a lens L was fixed (around 5 mm), the laser pulse energy could be varied by adjusting the distance between the lens L and side S1 of Nd:YAG/Cr^{4+}:YAG. Thus, laser pulses with energy between 1.7 mJ and 5.9 mJ could be obtained by increasing this distance from 13.5 mm to 18.5 mm, respectively. Maximum energy of the pump pulse was nearly 50 mJ. The laser pulse duration was around 1 ns. The laser was designed to operate up to 60 Hz repetition rate. In addition, multiple-pulse emission was obtained for each line by adjusting the pump pulse duration. Results on several characteristics of a laser pulse, like stability, pulse jitter or standard deviation will be presented.

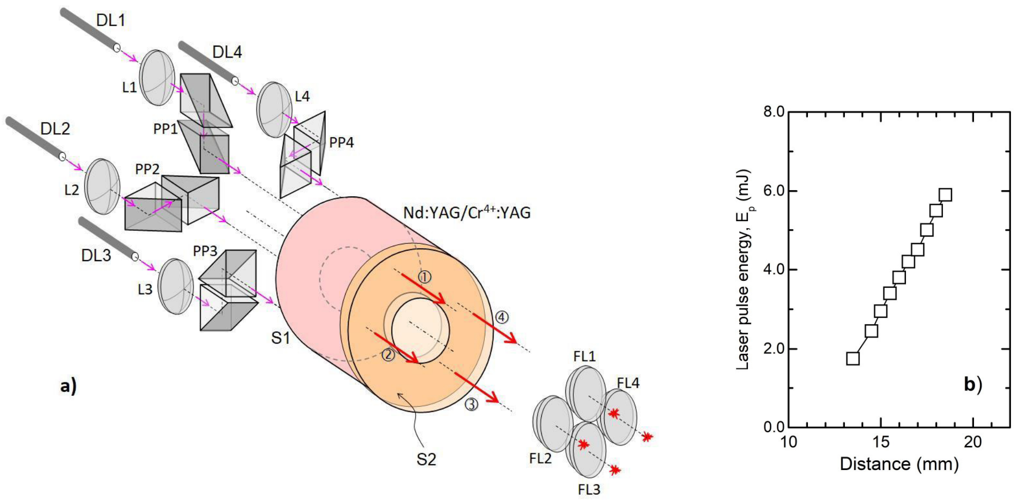

Fig. 1. a) A sketch of the laser device with four-beam output is shown. DL: diode laser; L: lens; PP: prisms; FL: focusing lens. **b)** The laser pulse energy E_p versus distance between a lens L and surface S1 of the Nd:YAG/Cr^{4+}:YAG medium.

Such a laser device can be used for studies of combustion characteristics in a closed chamber or for multiple-point ignition of an automobile engine.

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