Passively Q-switched Nd:YAG/Cr^{4+}:YAG laser with multiple-beam output

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Abstract: We report on the design and output performances of a diode pumped, high-peak power Nd:YAG/Cr^{4+}:YAG laser with four-beam output. The system posses the ability to chose independently the focus of each laser beam, being seen as a solution for a laser spark with multiple-point ignition.

The laser ignition of a gasoline direct injected engine has several advantages in comparison with ignition by electrical spark plugs, like absence of quenching effect during the developing flame kernel, ability in positioning the ignition point inside the engine cylinder or the possibility to ignite leaner air-fuel mixtures [1]. Based on extensive research, the first report on an automobile that was fully ignited by laser sparks was presented in 2013 [2]. Recently, a Renault automobile engine was also run only by laser sparks [3]. Several key parameters were measured at various engine speeds and loads, proving the advantages of laser ignition in comparison with classical ignition, such as better engine stability or reduced CO and HC emissions. The laser sparks were built using diode-pumped Nd:YAG laser media that were passively Q-switched by Cr^{4+}:YAG saturable absorbers. This configuration, which was proposed by Koefler et al. in 2007 [4], was further improved such to make it more compact (i.e. comparable to an electrical spark plug), as well as robust and resistant to vibrations and high temperatures [5]. The best solution for the laser medium was then a diffusion-bonded Nd:YAG/Cr^{4+}:YAG composite structure (of single-crystal or polycrystalline nature), whereas monolithically scheme was adopted for the laser resonator. These lasers delivered one output beam.

Ignition by a laser device opens the possibility to obtain ignition in multiple points [6,7] aiming better and more uniform combustion in comparison with ignition by electrical spark plugs. Several experiments were devoted to this subject, showing improved combustion for the ignition in two points [6]. A diode-pumped Nd:YAG/Cr^{4+}:YAG laser spark with three-beam output was also developed for laser ignition [8].

In this work we are reporting on the realization of a laser device that delivers four independent beams with performances suitable for ignition. The laser medium is a composite Nd:YAG/Cr^{4+}:YAG polycrystalline structure (10-mm diameter, 1.1-at.% Nd of ~9-mm length); monolithically resonator was obtained by coating the high-reflectivity mirror on Nd:YAG input side and the out-coupling mirror on the exit surface of Cr^{4+}:YAG. The pump was made by four fiber-coupled (400-µm or 600-µm diameter fibers, numerical aperture NA= 0.22) diode lasers (JOLD-120-QPXF-2P; Jenoptik, Germany) in quasi-continuous wave regime. A compact optical system was design in order to transfer the pump radiation into Nd:YAG/Cr^{4+}:YAG, keeping the compactness of the device and assuring mm-order distance between each laser beam. Typically, the laser pulse energy for every beam was up to 3 mJ with duration shorter than 1 ns. The focusing system was designed for various purposes, aiming focusing and air-breakdown realization in four points (in the same plane or at different distances from the laser) or in a single point. This laser device could be used for multiple-point ignition of an automobile engine.

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