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LASERS IN TRANSPORTATION

Laser ignition quantitatively improves performance of gasoline engines

Only by quantitatively improving performance (and cost) compared to electric spark plugs (ESPs) will laser ignition (LI) of gasoline engines be considered for adoption by major automobile manufacturers. Researchers from the National Institute for Laser, Plasma and Radiation Physics and Renault Technologie Roumanie (both in Ilfov, Romania), and from University Politehnica of Bucharest (Bucharest, Romania) have achieved such advances in their design and quantifiable demonstration of an LI system using fiber-coupled, compact neodymium- and chromium-yttrium-aluminum-garnet (Nd:YAG/Cr^{4+}:YAG) laser spark plugs.[1]

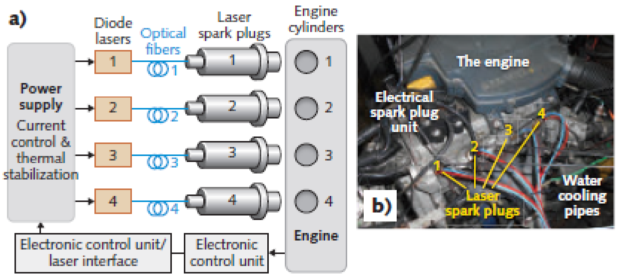
Compared to ESP ignition, LI has several advantages: 1) LI is delivered through an optical window on the engine cylinder wall, removing the ESP protruding electrode and allowing the flame to develop freely without quenching; 2) any internal part of the cylinder can be accessed and the fuel can be ignited at various spatial locations; and 3) multiple laser beams can be used to insure redundancy of ignition and potentially higher ignition efficiency through burst-mode operation.

Quantifying performance

The use of a 10.6 μm CO_2 laser and a 1.06 μm Nd:YAG laser for LI have already shown increased peak engine pressure and higher brake power, as well as improved engine combustion stability. However, these were large, tabletop-sized laser systems and obviously not amenable to commercial implementation.

The Romanian researchers instead used a compact LI system that consisted of four Nd:YAG/Cr^{4+}:YAG compact lasers pumped by 807 nm laser diodes, which were fiber-coupled using 600-μm-diameter fibers with a numerical aperture (NA) of 0.22 and operated in quasi-continuous-wave mode (see figure). With 250 μs pump-pulse duration and varied repetition rate from a few up to 100 Hz, laser pulses at 1.06 μm wavelength were delivered with 4 mJ energy and about 0.8 ns duration—corresponding to a peak pulse power of 5 MW from 40 mJ pump pulse energies.

The laser beam delivered by each laser spark plug (LSP) was collimated and then focused inside the corresponding cylinder of the engine. It is worthwhile to mention that the focusing position was chosen to match the point where ignition is made by the classical spark plug.



A block diagram shows the experimental setup for a LI system (a); the physical configuration is shown for a gasoline engine equipped with the LI system (b). *(Image credit: National Institute for Laser, Plasma and Radiation Physics)*

A sapphire window was used as the interface between an LSP and the corresponding engine cylinder. All optical elements (the Nd:YAG/Cr^{4+}:YAG medium, lenses, and the sapphire plate) were embedded in the LSP metallic body with an epoxy adhesive resistant to temperature variations from -70° to 170°C and with high shear and peel strength.

Ignition experiments on a Renault multipoint fuel injection passenger car engine with four cylinders were completed using standard 30 mJ ESPs and LI using only one laser pulse per cycle (not in burst mode) to establish ignition equivalency. For a stoichiometric air-fuel ratio (meaning a ratio where, if the reactants burned completely, there would be no leftover fuel or air) operation, results showed 7.9% higher engine brake power, 7.4% decrease in brake-specific fuel consumption (BSFC), and 20% fewer carbon monoxide (CO) emissions with LI compared to conventional ESP ignition. Furthermore, LI of lean (a nonstoichiometric ratio of approximately 1.25, leaving excess air left over after combustion) air-fuel mixtures improved the engine brake power by 29% relative to ignition by ESP (of the same type of fuel), while BSFC decreased by 21% and CO was reduced by 30%.

"Vehicles powered by internal-combustion engines must be continually improved as human concerns about environmental impacts rise," says professor Radu Chiriac from the Faculty of Mechanical Engineering at the University Politehnica of Bucharest. "Our laser spark plugs, with similar dimensions as classical electrical spark plugs, were used to operate a real car engine at stoichiometric air-fuel mixture [normal operation], but also at lean air-fuel mixtures, where less fuel is used. Improved engine performance and fewer exhaust emissions were obtained by laser ignition; faster ignition and more robust combustion initiation are thought to explain the improvements seen with laser ignition."—*Gail Overton*

REFERENCE

1. N. Pavel et al., *Opt. Express*, 27, 8, A385–A396 (2019).

REMOTE SENSING

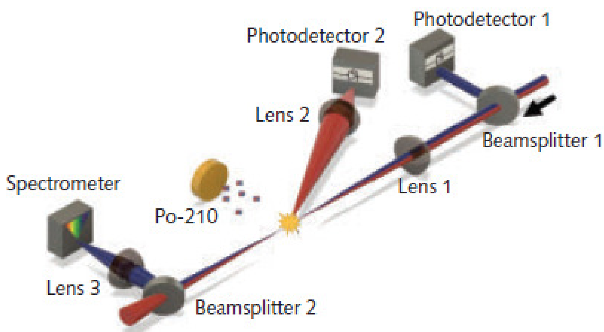
Radioactive material detected remotely using laser-induced electron avalanche breakdown

Physicists at the University of Maryland (UMD; College Park, MD) have developed a new laser-based method to remotely detect radioactive material.[1] Based on using an infrared (IR) laser beam to induce an electron avalanche breakdown near the material, the new technique is able to detect shielded material from a distance. A mid-IR (3.9 μm) laser induces avalanche breakdown in air, which is sensitive to "seed" ionization produced by radioactivity. The method improves upon current technologies that require close proximity to the radioactive material.

In the simplest version, the result is an on-off detection sensitivity. The researchers have also developed a more-sophisticated version that measures the shift of the temporal onset of avalanche and relates that to the degree of ionization from the radioactive source.

"Traditional detection methods rely on a radioactive-decay particle interacting directly with a detector," says Robert Schwartz, a physics graduate student at UMD. "All of these methods decline in sensitivity with distance. The benefit of our method is that it is inherently a remote process. With further development, it could detect radioactive material inside a box from the length of a football field."

As radioactive material emits decay particles, the particles strip electrons from nearby atoms in the air, creating



A laser-based instrument for remote detection of radioactivity uses a mid-IR laser to induce avalanche breakdown in air, but only when radioactivity is present, and a probe beam to detect the breakdown. In the setup, a 3.9 μm pulsed pump laser beam copropagates with a 1.45 μm chirped pulsed probe laser beam (both produced by an optical parametric amplifier, and thus proportional to each other in power), passing through beamsplitter 1 to send part of the probe light to reference photodetector 1. Driven by the pump light focused by lens 1, ionizing radiation from a polonium source seeds avalanche ionization (yellow spark). Speed of breakdown is proportional to radioactivity density. The increasing plasma density blocks the chirped probe light after the breakdown time (in this version, speed of breakdown is proportional to radioactivity density), resulting in the detection, measured by a spectrometer.