# LASER IGNITION FOR INTERNAL COMBUSTION ENGINES

Shantanu M. Khandebharad[1], Rahul S. Benade[2]

1Student, Mech. Dept.,MET Adgaon/UOP, Nashik, khandebharadshantanu97@gmail.com

2Student, Mech. Dept.,MET Adgaon/UOP, Nashik, benaderahul09@gmail.com

***Abstract*-Laser ignition has become an active research topic in recent years because it has the potential to replace the conventional electric spark plugs in engines compared to conventional spark ignition. Laser ignition allows more flexible choice of the ignition location inside the combustion chamber with the possibility to ignite even inside the fuel spray .Modern engines are required to operate under much higher compression ratios, faster compression rates, and much leaner fuel-to-air ratios than gas engines today.Experiments with the direct injection engine have been carried out at the fundamental wavelength of the Nd:YAG laser as well as with a frequency doubled system.The purpose of this paper is to prove that laser induced spark ignition can be used in gasoline direct injection engines.**

## I. INTRODUCTION

Economic as well as environmental constraints demand a further reduction in the fuel consumption and the exhaust emissions of motor vehicles. At the moment, direct injected fuel engines show the highest potential in reducing fuel consumption and exhaust emissions. Unfortunately, conventional spark plug ignition shows a major disadvantage with modern spray-guided combustion processes since the ignition location cannot be chosen optimally. It is important that the spark plug electrodes are not hit by the injected fuel because otherwise severe damage will occur. Additionally, the spark plug electrodes can influence the gas flow inside the combustion chamber.

It is well know that short and intensive laser pulses are able to produce an ”optical breakdown” in air. Necessary intensities are in the range between 1010-1011W/cm2.1, 2 At such intensities, gas molecules are dissociated and ionized within the vicinity of the focal spot of a laser beam and a hot plasma is generated. This plasma is heated by the incoming laser beam and a strong shock wave occurs.

The expanding hot plasma can be used for the ignition of fuel-gas mixtures.

## II. CONVENTIONAL SPARK IGNITION

### *A. DRAWBACKS OF CONVENTIONAL SPARK IGNITION*

1.Location of spark plug is not flexible as it require shielding of plug from immense heat and fuel spray.
2.It is not possible to ignite inside the fuel spray.
3.It require frequent maintenance to remove carbon deposits..
4.Leaner mixtures cannot be burned.
5.Degradation of electrodes at high pressure and temperature.

All the above drawbacks are overcome in laser ignition system explained as follows.

## III. LASER IGNITION SYSTEMS

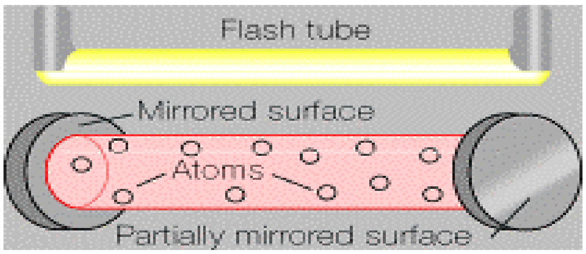
### *A. WHAT IS LASER?*

Lasers provide intense and unidirectional beam of light. Laser light is monochromatic (one specific wavelength). Wavelength of light is determined by amount of energy released when electron drops to lower orbit. Light is coherent; all the photons have same wave fronts that launch to unison. Laser light has tight beam and is strong and concentrated. To make these three properties occur takes something called “Stimulated Emission”, in which photon emission is organized.

Main parts of laser are power supply, lasing medium and a pair of precisely aligned mirrors. One has totally reflective surface and other is partially reflective (96 %). The most important part of laser apparatus is laser crystal. Most commonly used laser crystal is man made ruby consisting of aluminum oxide and 0.05% chromium. Crystal rods are round and end surfaces are made reflective. A laser rod for 3 J is 6 mm in diameter and 70 mm in length approximately. Laser rod is excited by xenon filled lamp, which surrounds it.

Both are enclosed in highly reflective cylinder, which directs light from flash lamp in to the rod. Chromium atoms are excited to higher energy levels. The excited ions meet photons when they return to normal state. Thus very high energy is obtained in short pulses. Ruby rod becomes less efficient at higher temperatures, so it is continuously cooled with water, air or liquid nitrogen. The Ruby rod is the lasing medium and flash tube pumps it.

FIG1 Laser in its non lasing state.




*B RUBY LASER :( TWO ENERGY LEVEL):*

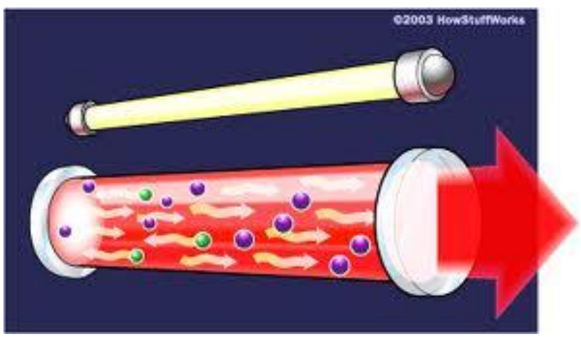



FIG2 Working of ruby Laser

*C GAS LASERS*

The Helium-neon laser (HeNe) emits 543 nm and 633 nm and is very common in education because of its low cost. Carbon dioxide lasers emit up to 100 kW at 9.6 µm and 10.6 µm, and are used in industry for cutting and welding. Argon-Ion lasers emit 458 nm, 488 nm or 514.5 nm. Carbon monoxide lasers must be cooled but can produce up to 500 kW. The Transverse Electrical discharge in gas at Atmospheric pressure (TEA) laser is an inexpensive gas laser producing UV Light at 337.1 nm.

Metal ion lasers are gas lasers that generate deep ultraviolet wavelengths. Helium- Silver (HeAg) 224 nm and Neon-Copper (NeCu) 248 nm are two examples. These lasers have particularly narrow oscillation line widths of less than 3 GHz (0.5 picometers) [6] making them candidates for use in fluorescence suppressed Raman spectroscopy.

*D CHEMICAL LASERS*

Chemical lasers are powered by a chemical reaction, and can achieve high powers in continuous operation. For example, in the Hydrogen fluoride laser (2700-2900 nm) and the Deuterium fluoride laser (3800 nm) the reaction is the combination of hydrogen or deuterium gas with combustion products of ethylene in nitrogen trifluoride.

*E EXCIMER LASERS*

Excimer lasers produce ultraviolet light, and are used in semiconductor manufacturing and in LASIK eye surgery. Commonly used excimer molecules include F2 (emitting at 157 nm), ArF (193 nm), KrCl (222 nm), KrF (248 nm), XeCl (308 nm), and XeF (351 nm).

*F SOLID-STATE LASERS*

Solid state laser materials are commonly made by doping a crystalline solid host with ions that provide the required energy states. For example, the first working laser was made from ruby, or chromium-doped sapphire. Another common type is made from Neodymium-doped yttrium aluminium garnet (YAG), known as Nd:YAG. Nd:YAG lasers can produce high powers in the infrared spectrum at 1064 nm. They are used for cutting, welding and marking of metals and other materials, and also in spectroscopy and for pumping dye lasers. Nd:YAG lasers are also commonly doubled their frequency to produce 532 nm when a visible (green) coherent source is required.

Ytterbium, holmium, thulium and erbium are other common dopants in solid state lasers. Ytterbium is used in crystals such as Yb:YAG, Yb:KGW, Yb:KYW, Yb:SYS, Yb:BOYS, Yb:CaF2, typically operating around 1020-1050 nm. They are potentially very efficient and high powered due to a small quantum defect. Extremely high powers in ultrashort pulses can be achieved with Yb:YAG. Holmium-doped YAG crystals emit at 2097 nm and form an efficient laser operating at infrared wavelengths strongly absorbed by water-bearing tissues. The Ho-YAG is usually operated in a pulsed mode, and passed through optical fiber surgical devices to resurface joints, remove rot from teeth, vaporize cancers, and pulverize kidney and gall stones. Titanium-doped sapphire (Ti:sapphire) produces a highly tunable infrared laser, used for spectroscopy.

Solid state lasers also include glass or optical fiber hosted lasers, for example, with erbium or ytterbium ions as the active species. These allow extremely long gain regions, and can support very high output powers because the fiber's high surface area to volume ratio allows efficient cooling and its wave guiding properties reduce thermal distortion of the beam.

### *G SEMICONDUCTOR LASERS*

Laser diodes produce wavelengths from 405 nm to 1550 nm. Low power laser diodes are used in laser pointers, laser printers, and CD/DVD players. More powerful laser diodes are frequently used to optically pump other lasers with high efficiency. The highest power industrial laser diodes, with power up to 10 kW, are used in industry for cutting and welding. External-cavity semiconductor lasers have a semiconductor active medium in a larger cavity. These devices can generate high power outputs with good beam quality, wavelength-tunable narrow-line width radiation, or ultra short laser pulses.

Vertical cavity surface-emitting lasers (VCSELs) are semiconductor lasers whose emission direction is perpendicular to the surface of the wafer. VCSEL devices typically have a more circular output beam than conventional laser diodes, and potentially could be much cheaper to manufacture. As of 2005, only 850 nm VCSELs are widely available, with 1300 nm VCSELs beginning to be commercialized [7], and 1550 nm devices an area of research. VECSELs are external-cavity VCSELs.

## IV. LASER IGNITION

Laser ignition, or laser-induced ignition, is the process of starting combustion by the stimulus of a laser light source.Basically, energetic interactions of a laser with a gas may be classified into one of the following four schemes as described in [5]:

• thermal breakdown
• non-resonant breakdown
• resonant breakdown
• photochemical mechanisms

In the case of thermal interaction, ignition occurs without the generation of an electrical breakdown in the combustible medium. The ignition energy is absorbed by the gas mixture through vibrational or rotational modes of the molecules; therefore no well-localized ignition source exists. Instead, energy deposition occurs along the whole beam path in the gas.

According to the characteristic transport times therein, it is not necessary to deposit the needed ignition energy in a very short time (pulse). So, this ignition process can also be achieved using quasi continuous wave (cw) lasers.

Another type, resonant breakdown, involves non-resonant multi-photon dissociation of a molecule followed by resonant photo ionization of an atom. As well as photochemical ignition, it requires highly energetic photons (UV to deep UV region). Therefore, these two types of interaction do not appear to be relevant for this study and practical applications.

In these experiments, the laser spark was created by a non-resonant breakdown. By focusing a pulsed laser to a sufficiently small spot size, the laser beam creates a high intensity and high electric fields in the focal region. This results in a well localised plasma with temperatures in the order of 106 K and pressures in the order of 102 MPa as mentioned in [6,7].

## V. EXPERIMENTAL

This section describes the experimental setup. Laser ignition experiments were carried out in a constant volume vessel (0.9 l) and an internal combustion engine.

The constant volume vessel, also termed the combustion bomb, was used to conduct basic studies of laser ignition in homogeneous fuel/air mixtures. The sustainable fuels hydrogen and biogas were used. The biogas was obtained from a municipal water purification plant. It was composed of 50.5% $CH_4$, 31.7% $CO_2$ and 80 ppm $H_2S$. Schlieren photography was used for accompanying optical diagnostics.

The engine, a one-cylinder research engine, was deployed for the investigation of sprayguided combustion initiated by a laser. Gasoline was used as a fuel here. The focus of sustainability is on laser ignition for enhanced combustion and efficiency.

## VI. LASER IGNITION IN AN INTERNAL COMBUSTION ENGINE

A one-cylinder research engine was used as a test engine. The research engine was equipped with a four-valve DOHC cylinder head with a spray-guided combustion system of AVL List GmbH [20]. In a double-overhead-camshaft (DOHC) layout, one camshaft actuates the intake valves, and one camshaft operates the exhaust valves. Gasoline was used as a fuel.

In following table the key technical data of the test engine are listed.

| Research engine | | Q-switched Nd:YAG | |
|---|---|---|---|
| No. of cylinders | 1 | Pump source | Flash lamp |
| No. of valves | 1 | Wavelength | 1064 or 532 nm |
| Injector | Multi-hole | Max. pulse energy | 160 mJ |
| Stroke | 85 mm | Pulse duration | 6 ns |
| Bore | 88 mm | Power consumption | 1 kW |

| | | | |
|---|---|---|---|
| Displacem ent vol. | 517 cm 3 | Beam diameter | 6 mm |
| Compressi on ratio | 11.6 | Type | Quan tel Brilliant |

Table1 Engine parameters

Engine test runs were carried out with two different approaches.First, a plane window was inserted into the cylinder head of the engine. A focusing lens was placed in front of that window in order to focus the laser beam down into the combustion bomb ("separated optics").

Second, a more sophisticated window was deployed. A lens-like curvature was engraved directly into the window. By using such a special window, no further lens was required ("combined optics").

This is depicted schematically in Fig. 3

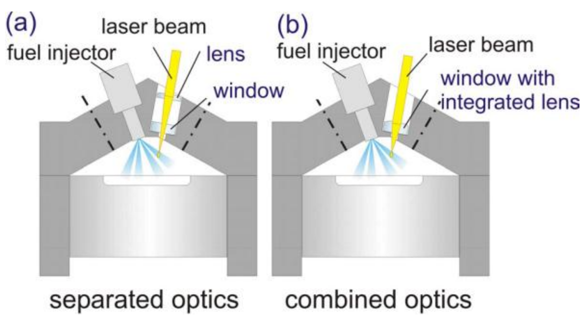



Fig3 Schematic cross section of the engine for laser ignition test runs. Two window/lens configurations were tested: Fig. 2(a) shows the separated optics, Fig. 2(b) the combined optics.

## VII. Results

It shows that laser ignition has advantages compared to conventional spark plug ignition. Compared to conventional spark plug ignition, laser ignition reduces the fuel consumption by several per cents. Exhaust emissions are reduced by nearly 20%. It is important that the benefits from laser ignition can be achieved at almost the same engine smoothness level .Additionally, a frequency-doubled Nd:YAG laser has been used to examine possible influences of the wavelength on the laser ignition process. No influences could be found. Best results in terms of fuel consumption as well as exhaust gases have been achieved by laser ignition within the fuel spray. As already mentioned, it is not possible to use conventional spark plugs within the fuel spray since they will be destroyed very rapidly. Laser ignition doesn't suffer from that restriction.

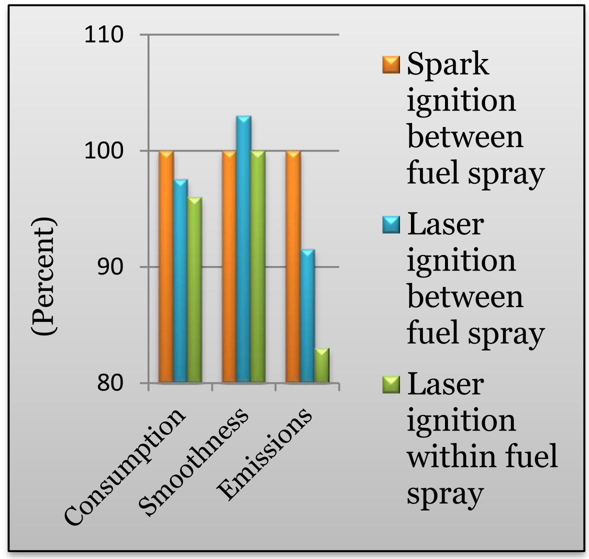



Fig4 Result comparison.

## VIII. Advantages

1. A choice of arbitrary positioning of the ignition plasma in the combustion cylinder
2. Absence of quenching effects by the spark plug electrodes
3. Ignition of leaner mixtures than with the spark plug , lower combustion temperatures => less NOx emissions
4. No erosion effects as in the case of the spark plugs => lifetime of a laser ignition system expected to be significantly longer than that of a spark plug
5. High load/ignition pressures possible => increase in efficiency
6. Precise ignition timing possible
7. Exact regulation of the ignition energy deposited in the ignition plasma
8. Easier possibility of multipoint ignition.
9. Shorter ignition delay time and shorter combustion time.
10. Fuel-lean ignition possible.

## IX. Disadvantages

1. High system costs
2. Concept proven, but no commercial system available yet.

## X. Conclusion

The applicability of a laser-induced ignition system on direct injected gasoline engine has been proven. Main advantages are the almost free choice of the ignition location within the combustion chamber, even inside the fuel spray. Significant reductions in fuel consumption as well as reductions of exhaust gases show the potential of the laser ignition process.

At present, a laser ignition plug is very expensive compared to a standard electrical spark plug ignition system and it is nowhere near ready for deployment. But the potential and advantages certainly make the laser ignition more attractive in many practical applications.

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