# In-Situ Fuel Concentration Measurement with Optical Spark Plug Sensor by 3.39 μm Infrared Laser Absorption Method

**Atsushi Nishiyama*, Nobuyuki Kawahara, Eiji Tomita, and Masahiro Shigenaga**

Atsushi NISHIYAMA, Ph.D. Candidate
Graduate School of Natural Science and Technology
Okayama University
3-1-1 Tsushima-Naka, Okayama 700-8530 JAPAN
E-mail: nisiyama@power.mech.okayama-u.ac.jp

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## INTRODUCTION

There have been intensive efforts at developing thermal efficiency of internal combustion engines. It is very important to promote better understanding of in-cylinder combustion phenomena that include mixture formation process. For spark ignition engines, initial stage of combustion has strong influence on subsequent main combustion so that fluctuation of the initial flame kernel formation causes the cycle-to-cycle fluctuation of combustion. The fluctuation of the fuel concentration near the spark plug is one of the main factors that cause the cycle-to-cycle fluctuation of combustion [1]. Therefore, it is very important to measure fuel concentration near the spark plug at the spark timing. Recently, infrared absorption method has been noticed to measure in-cylinder concentration measurement [2-7]. This method can be applied to actual engines to make optical set-up into sensor and acquire time-sequence data. In this work, fuel concentration in the vicinity of the spark plug was measured using in-situ infrared absorption method with optical spark plug sensor in actual spark ignition engine.

## EXPERIMENTAL PROCEDURE

When light with only one wavelength, such as a laser, is used and the intensity of the light, $I_0$, decays to the value of $I$ through a gas along measurement length, $L$, the transmissivity, $I/I_0$, is expressed from Lambert-Beer's law as follows:

$$log\left(I/I_0\right) = -\varepsilon CL \tag{1}$$

where $\varepsilon$ and $C$ denote the molar absorption coefficient and molar concentration of the gas absorbing the light, respectively. When the measurement length, $L$, is constant, the concentration of the gas can be determined by measuring the transmissivity. When hydrocarbons exist in the test section, light around 3.4 μm is absorbed strongly, owing to C-H bonds in the hydrocarbon. The molar absorption coefficient depends on the pressure and temperature in the test region. The absorption coefficient of isooctane used as fuel in this study was measured in advance by using a constant-volume vessel and matching engine conditions [6, 7].

An optical sensor with double-pass measurement length was used. Figure 1 shows the optical arrangement and schematic diagram of the experimental apparatus. The light source with wavelength of 3.392μm was introduced into an optical fiber and guided to a spark plug. This optical sensor was constructed by modifying a commercially available instrumented spark plug. The fiber guides the light to the measurement volume where the light leaves the fiber, traverses a gap, reflects off a concave mirror, traverses back through the gap and into the second fiber. The second fiber guides the light into a collection system, which focuses the light into an IR detector through a band-pass-filter. The measurements were done in a 4-cycle spark-ignition engine fuelled with isooctane. The bore and stroke were 89 and 96 mm, respectively. The compression ratio was 9.2:1.

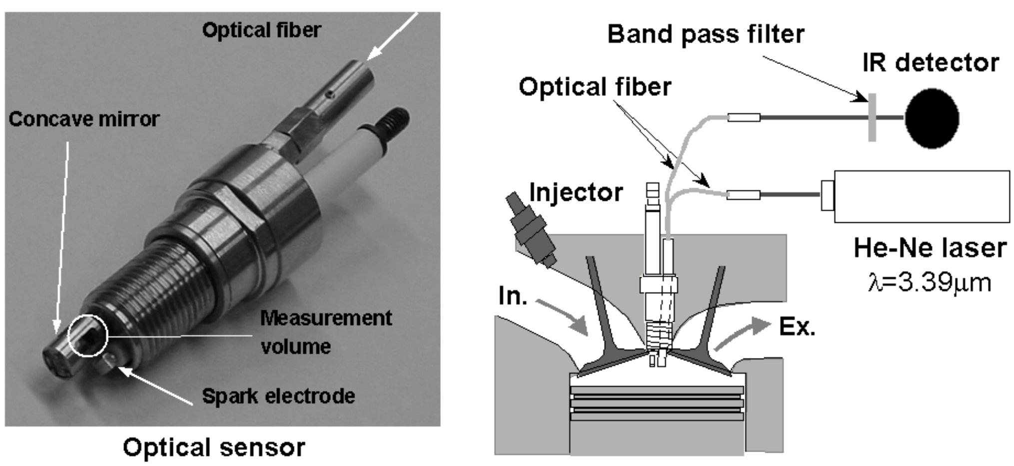


Fig.1 Optical arrangement for measurement

**RESULTS**

Figure 2 shows the in-cylinder pressure of consecutive 50 cycles at n = 800 rpm. Average air/fuel ratio was determined by the mass flow of air and fuel consumption measured by the laminar flow meter and burette, respectively. In Fig.2, average air/fuel ratio was 17.7. The cycle-to-cycle variation of combustion was very large under this condition. Figure 3 shows the transmissivity of the IR signal recorded simultaneously. The solid and dotted lines denote the average and RMS results, respectively. In the initial stage of the intake stroke, the transmissivity decreased rapidly as the rich fuel-air mixture that built up behind the intake valve flew into the cylinder and passed near the spark plug after opening the intake valve. Then, the transmissivity increased gradually. During the latter part of the compression stroke, the transmissivity decreased again owing to compression of the mixture. After the spark, the transmissivity increased, because the flame propagated through the measurement region and removed hydrocarbons. During the exhaust stroke, the transmissivity remained constant at unity. Fig.4 shows the molar concentration calculated by Lambert-Beer's Law. After combustion, the molar concentration and air/fuel ratio were evaluated qualitatively. The molar concentration increased until the spark and then decreased. Fig.5 shows the air/fuel ratio calculated from molar concentration. The dashed lines indicate the average air/fuel ratio. The air/fuel ratio near the spark timing was almost constant and close to the average air/fuel ratio.

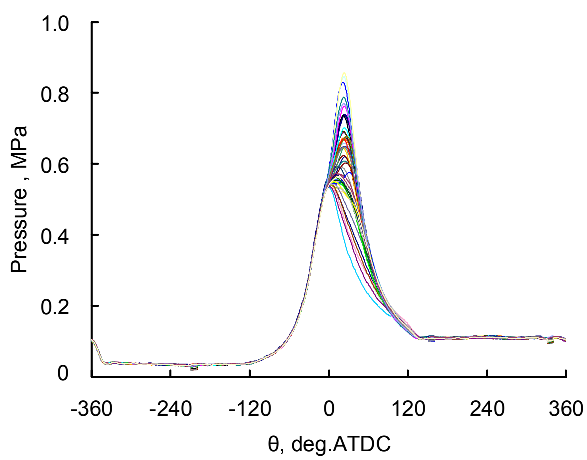


Fig.2 In-cylinder pressure

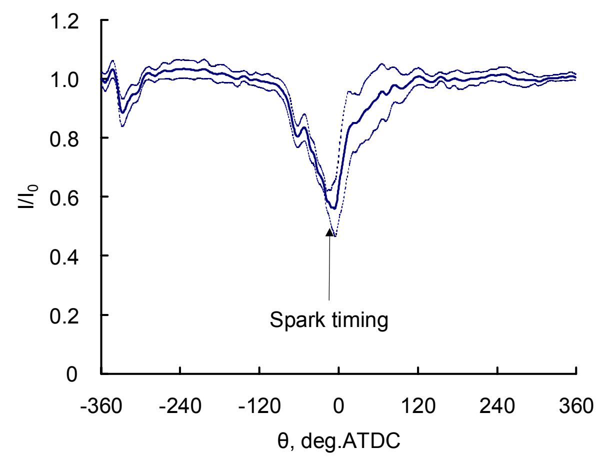


Fig.3 Transmissivity

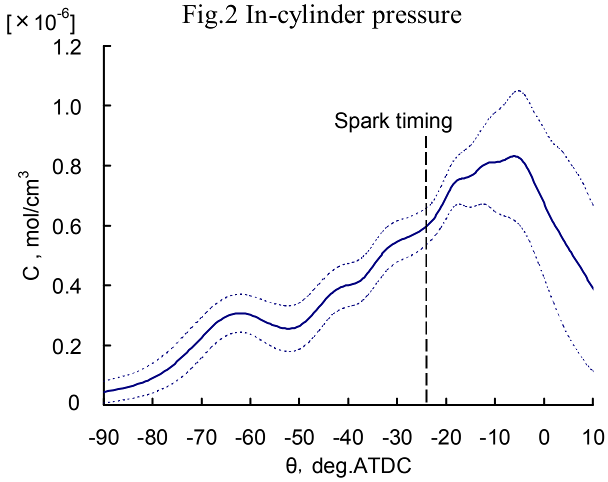


Fig.4 Molar concentration

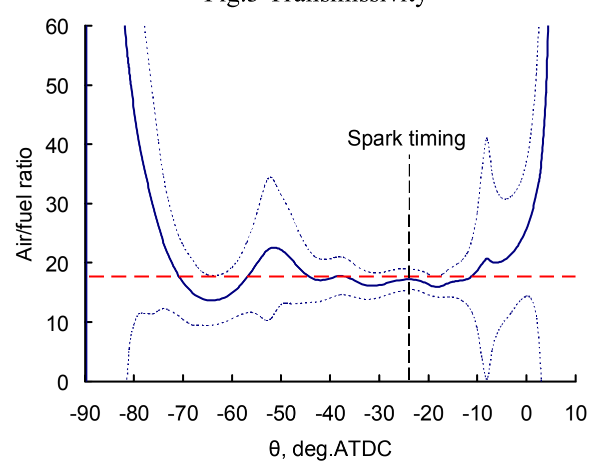


Fig.5 Air/fuel ratio

**SUMMARY**

The *in-situ* fuel concentration near a spark plug was measured with an optical spark plug sensor using a laser infrared absorption method. The fuel concentration near the spark plug was measured in a four-stroke cycle port injection spark-ignition engine, using isooctane as fuel. The fuel concentration history near the spark plug was measured and the air-fuel ratio near the spark plug agreed with the average air/fuel ratio at the spark timing. This spark plug sensor can be used to understand mixture formation process near the spark plug. Furthermore, the sensor has feasibility to provide better understanding of cycle-to-cycle fluctuations in combustion.

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