Application of LIBS and CT-TDLAS to Industrial Processes

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Abstract: A new collinear long and short DP-LIBS method and CT-TDLAS method were proposed and applied to component measurement and 2D temperature distributions to improve the detection ability and measurement accuracy, which enable real-time measurements in various industrial processes, such as iron and steel making processes, engines, burners and so on.

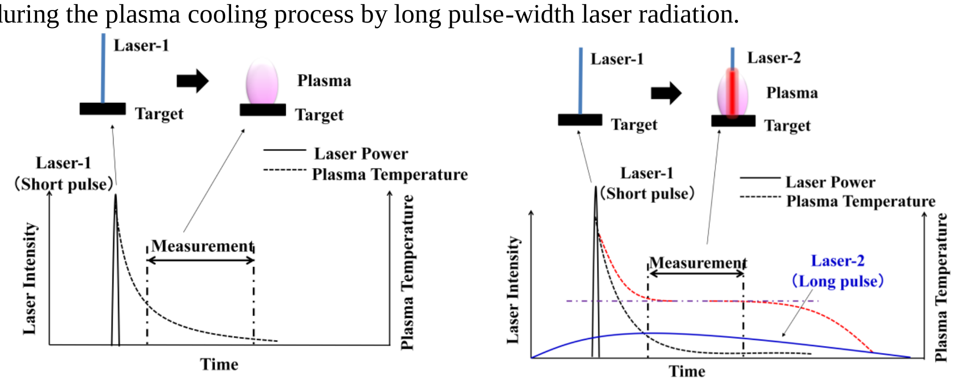
OCIS codes: (120.0120) Instrumentation, measurement, and metrology; (300.0300) Spectroscopy

1. Introduction

Recently, as a measurement technique with high sensitivity and fast response, laser diagnosis has been developed and applied to the actual industrial fields [1]. Laser-induced breakdown spectroscopy (LIBS) is an analytical detection technique based on atomic emission spectroscopy to measure the elemental composition, which has been widely applied in the various fields [2]. Most fundamental researches focus on the signal enhancement to improve the accuracy and detection ability of LIBS measurement, as well as understanding of the basic plasma physics. Various papers reported the signal enhancement by optimizing the experimental conditions to improve LIBS detection ability, such as pulse width, laser wavelength, laser power, gate delay time, lens-to-sample distances, atmospheric condition, etc.[3,4] Some improvement approaches of LIBS technique have also been developed[5,6]. DP-LIBS is an important way to enhance the emission intensities to improve LIBS analytical capability. In this study, a new collinear long and short DP-LIBS method was proposed to improve the detection ability and measurement accuracy by the control of the plasma cooling process using the long pulse-width laser radiation. Tunable diode laser absorption spectroscopy (TDLAS) has been developed for practical applications [7]. With these engineering developments, transient phenomena such as start-ups and load changes in engines have been gradually elucidated in various conditions. In this study, the fast response 2D temperature and concentration distribution measurement method was developed and applied to a high pressure constant volume combustor. The technique is based on a CT method [8,9] using absorption spectra of molecules such as H_2O. However the CT-TDLAS applications to high pressure combustion fields such as engines still remained as an important issue. In this study the CT-TDLAS method using 16-path laser beams was applied to measure 2D temperature distributions in a high pressure constant volume combustor. The novel CT algorism using the two dimensional polynomials for temperature and concentration distributions was developed to improve the CT reconstruction features. Since CT-TDLAS has a potential of kHz response time, this method enables real-time 2D temperature and species concentration measurements in various industrial combustion processes.

2. LIBS Applications

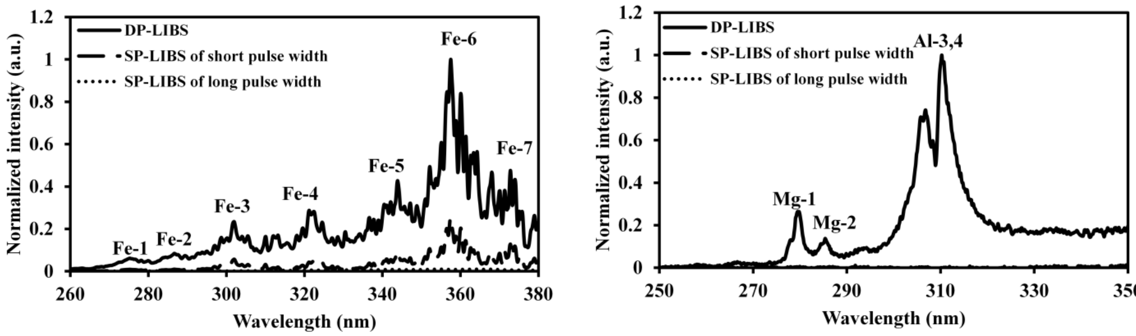
Fig.1 shows the notional comparison of laser-induced plasma processes of single-pulse LIBS (SP-LIBS) and long and short DP-LIBS. The plasma generated by the short pulse-width laser is stabilized and maintained at high temperature during the plasma cooling process by long pulse-width laser radiation.



(a) SP-LIBS (b) Long and short DP-LIBS.

Fig. 1 Laser-induced plasma processes of single-pulse LIBS (SP-LIBS) and long and short DP-LIBS.

Stainless steel in air was measured using SP-LIBS of short pulse width, SP-LIBS of long pulse width and DP-LIBS under different conditions. The Al sample in water was also measured using this method under various experimental conditions. Measured spectra of stainless steel and Al sample in different measurement conditions were shown in Fig.2(a) and Fig.2(b). The signals were normalized with respect to maximum signal using DP-LIBS. As is well known, there are numerous Fe emission lines. According to the measurement results, several representative wavelength ranges of Fe emission were determined in Fig.2(a). The distinct spectra were observed when using SP-LIBS of short pulse width and DP-LIBS, whereas the spectra cannot be identified from SP-LIBS measurement of long pulse width. It is recognized that the long pulse-width laser was unable to make plasma to generate LIBS signals. It can also be seen that the emission intensity was enhanced obviously when using DP-LIBS. Fig.2(b) shows the comparison of Al sample measurement results in water using SP-LIBS and DP-LIBS. The spectra were recognized using neither SP-LIBS of short pulse width nor SP-LIBS of long pulse width. However, the distinguishable emission lines were detected using DP-LIBS. It demonstrates the feasibility for underwater measurement.

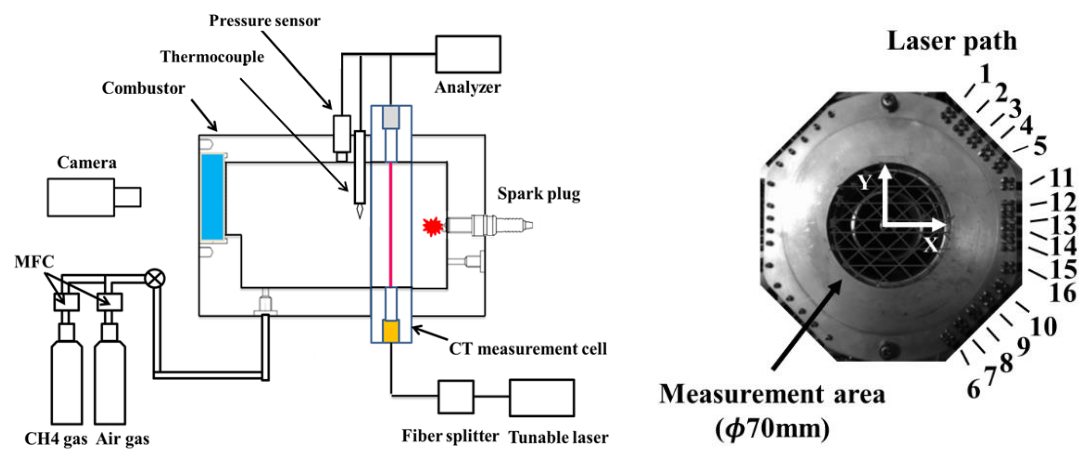


(a) Stainless steel in air (b) Al sample in water

Fig. 2 Measurement results of stainless steel in air and Al sample in water under different conditions.

3. CT-TDLAS Applications

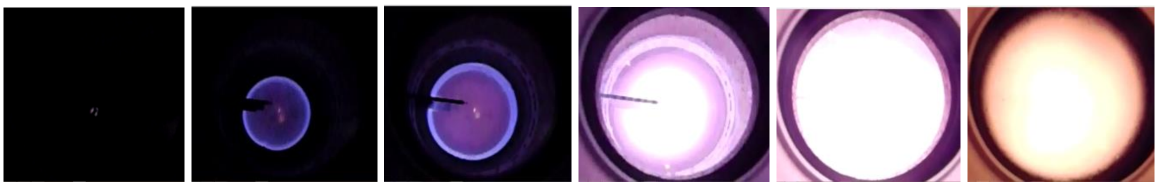
High pressure combustion has been widely used for varius indusrial field such as engines, boilers, and gas turbines. Time-series 2D temperature and concentration information is important to develop the efficient combustors. Fig.3 shows a schematic diagram of the experimental setup of a high pressure constant volume combustor. A constant volume combustion chamber was employed to evaluate the of 2D temperature measurement in high temperature and high pressure conditions using CT-TDLAS. The apparatus mainly consisted of a 16-path CT-TDLAS measurement cell, a pressure transducer, a spark plug, and an optical imaging system using a CCD Camera(Panasonic, HX-WA30-K). The experimental procedure was to set the chamber in a given temperature and then to fill the chamber with a fuel-air mixture. The initial pressure was 0.4MPa. The mixture was thermally equilibrated for 60 seconds and ignited to form the high pressure flames. Time resolved 2D temperature distributions in the combustion chamber were measured by CT-TDLAS using an external cavity diode laser (Santec, HSL-200-30-TD) with more than 50nm wavelength scan range at 33kHz. The two parameters, i.e. ignition trigger and pressure in the combustion chamber, were simultaneously measured. The combustion flame was also monitored by the CCD camera at 480fps to evaluate the flame characteristics.



(a) Experimental equipment (b) 16-path CT measurement cell

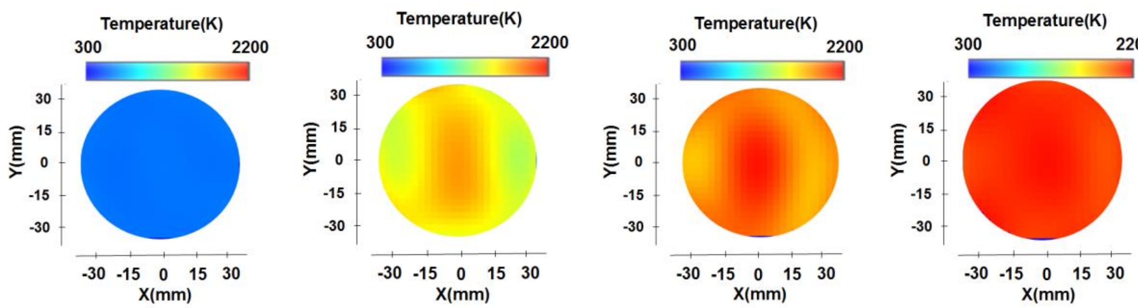
Fig. 3 Experimental apparatus of high pressure constant volume combustor measurement

Fig.4 shows the time-resolved of flame photograph in the high pressure constant volume combustion. Ignition by the spark plug occured at t = 0ms, while the flame reached to the CT-TDLAS measurement cell around t = 35-40ms. Temperature was determined by the spectral fitting method to minimize error. Fig.5 shows the time series 2D temperature distribution from t=30ms to 180ms. When pressure increases, absorption spectra broadens by the pressure broadning phenomina. Because the external cavity diode laser with more than 50nm wavelength scan range was used in this study, it was possible to evaluate the broadened absorption spectra and the temperature distrubution was reconstructed by the CT argorism in high pressure(5Mpa or more) fields. The temperature distribution at t=39ms showed the high temperature region at the center(X=Y=0mm) and high temretaure region expanded to the combustion wall with time.



(a) 0 ms (b) 17 ms (c) 25 ms (d) 41 ms (e) 75 ms (f) 200ms

Fig. 4 Photographs of high pressure flames



(a)30ms (b)42ms (c) 120ms (d) 180ms

Fig. 5 Time series 2D temperature distributions measured by CT-TDLAS.

5. Conclusions

Laser diagnostics are widely applied to industrial processes. The measurement methods were developed in this paper. A new collinear long and short DP-LIBS method was proposed to improve the detection ability and measurement accuracy. The CT-TDLAS method was applied to measure 2D temperature distributions in a high pressure constant volume combustor. The novel CT algorism using the two dimensional polynomials for temperature and concentration distributions was developed to improve the CT reconstruction features. These developed methods enable real-time measurements in various industrial processes.

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