Diode-Laser-Based Portable Thermal Lensing Spectroscopy System with Optical Fiber

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Received August 2, 1996

In spectrometric analysis, the application of laser has been widely used for the light source. However, its maintenance and operation are often impractical due to the costs and the complexities. These problems could be circumvented by the use of a diode laser, which is compact and inexpensive. Diode lasers have already been applied to many analytical problems.[1-3] In previous paper[4], a simple and compact thermal lensing spectroscopy (TLS) system, only consisting of a diode laser and a photodiode, was reported. In the construction of portable TLS system, however, a serious problem still exists due to the long pathlength between sample cell and detector. The optical pathlength in TLS is generally varied from 2 m to 10 m.[4-7] Such a long pathlength is an obstacle to construct the system compact. The use of optical fiber can bypass the problem of the optical path length by coupling the sample cell and detector directly.

The optical fibers combined with laser system have been recently very efficient media for the light transmission in many areas of technologies such as telecommunication industry and analytical detection system. It can be applied for the samples remote from spectrometer, for hostile environments, and for coupling several spectroscopic instruments together to a single detection unit.[8-10] For the convenience of transmittance, the optical fiber has been developed in multimode with wide range of wavelength, and in single mode with a specific wavelength.[11] Multimode optical fiber was already used to combine the sample cell and detector in pump-and-probe type conventional laser TLS system.[12,13] But they are still voluminous and complicate. In those system, optical fibers were used just to improve directionality, not to construct the compact and portable system.

A single mode optical fiber, however, provides good transmittance at a specific wavelength and is simpler/or thinner than multimode one. The former has advantages over the latter when applying to a compact type spectroscopic system such as portable diode laser TLS system.[14] In this study, we developed the system, which consisted of a visible diode laser as a light source, a conventional quartz cell, a single mode optical fiber, and a photodiode. To evaluate the performance of the system, the thermal lensing signal intensity was measured with the concentration of Indophenol Blue in toluene. The sensitivity was then compared with that of previously reported non-fiber optic system.[4] In addition, to examine the possibility of further applications to the detection of samples being remote from spectrometer, the signal was monitored with optical fiber extended up to 10 m.

The apparatus used in this study for TLS system is shown in Figure 1. Since the detailed configuration was reported elsewhere[4], and the system is briefly described here.

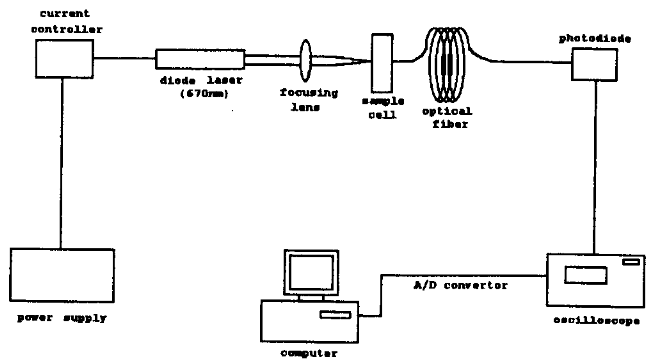

Figure 1. Experimental setup for portable diode laser thermal lensing spectroscopy using optical fiber.

A diode laser (MWK Industries, USA) emitting at 670 nm (output power, <5 mW) was adapted as a light source. The sample was contained in a 1 cm square quartz UV cell. The transmitted light was sent through a 2 m long optical fiber adjusted with a optical fiber positioner (FPH-S/FPHSR, Newport Co., USA). According to ref. 14, a single mode type optical fiber (F-SV, Newport Co., USA) was selected due to its large transmittance at the wavelength of 670 nm. The refractive indices of core and cladding were 1.4616 and 1.4157. Diameters of the core, cladding, and jacket were 4.8, 125, 250 μm, respectively. The TL signal was detected by a photodiode (Pin-6DP, UDT Sensors Inc., USA). The decay of signal was monitored by an oscilloscope (5802, Hung Chang Co., Korea) and aquisitioned by a PC (IBM AT compatible) through a A/D converter (PCL-711S, Adventech Co. Ltd., Tiwan). The system has the dimension of only 10 cm in width, 20 cm in length, and 20 cm in height excluding the data aquisition system (A/D converter board and PC). The thermal lensing system used in this study includes neither a monochromator nor a complicated photomultiplier tube. It consists of an inexpensive and simple diode laser, an optical fiber, and a photodiode. As far as we know, the design is the simplest type of TCL system that has ever been reported.

To evaluate the performance of the fiber-optic/diode-laser TLS system, the analytical curve for Indophenol Blue was investigated. Indophenol Blue, Acid Blue 25, and C_{70} were obtained from Aldrich Chemical Co. The stock solution of Indophenol Blue was prepared in toluene at the concentration of 1×10^{-4} M and diluted with toluene stepwise to 3.25×10^{-6} M. Acid Blue 25 and C_{70} were dissolved in 2-propanol and toluene to obtain the concentrations of 1.0×10^{-4} M and 2.0×10^{-4} M, respectively.

As shown in Figure 2, as the concentration of Indophenol Blue increases from 3.25×10^{-6} M to 6.5×10^{-5} M, the ther-

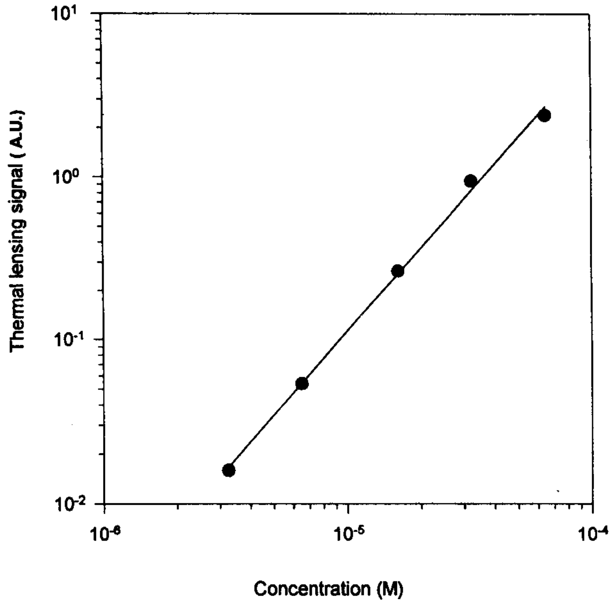

Figure 2. Calibration curve of Indophenol Blue dissolved in toluene.

Table 1. The thermal lening singnal with the optical fiber length of 2 an 10 m

Sample	Thermal lensing signal	
	2 m	10 m
Indophenol Blue in toluene	0.324	0.260
Acid Blue in 2-propanol	0.405	0.350
C_{70} in toluene	0.119	0.095

mal lensing signal also increases from 0.016 to 2.402. It represents a linearity with the regression coefficient of 0.990 in the range of given concentration and the minimum detectable amount of Indophenol Blue is found to be 3.25×10^{-6} M at the signal to noise ratio of 3. This shows the sensitivity as the comparable as the non-fiber optic system of previous study.[4]

As explained above, the recent interests concerning the optical fiber are its applicability to the remote detection from sample. In order to examine the possibility for the remote acquisition of spectrochemical data, the length of optical fiber was extended to 10 m. As shown in Table 1, the TLS signals at 2 m for Indophenol Blue in toluene, Acid Blue 25 in 2-propanol, and C_{70} in toluene are 0.324, 0.405, and 0.119, respectively. The corresponding TLS signals at 10 m are 0.260, 0.350, and 0.095, respectively. Even though the signal obtained at 10 m length was weakened, the detection has reached at the level of 70%. When the light propagates down to the optical fiber, the power loss would occur due to the attenuation by the fiber media such as glass and quartz. The decibel, *dB*, is the customary unit to designate ratio between two levels of power input, P_i, and power output, P_o.

$$dB = -10 \log \frac{P_o}{P_i} \quad (1)$$

The single mode optical fiber used in this report has the maximum attenuation of 12 dB/km at the wavelength of 670 nm,[14] which indicates that 0.05% of initial power is reduced when the light travels 2 m distance in the fiber. According to the equation 1, with the fiber length of 10 m, the power is reduced by 2.7% to its initial value. While the power of 10 m fiber is reached to the 98% level of 2 m fiber, the TL signal is reduced to two thirds. In the optical fiber, the signal reducing rate is higher than that of power attenuation. This phenomena is not explained clearly at this time. However, it still shows a possibility for the detection of samples, which are located at some distance from the spectrometer in hostile environments.

In summary, by coupling the sample cell to the photodiode detector with the single-mode optical-fiber, the system is free from the distance between the sample and the detector. It suggests a strong possibility for the construction of compact and portable fiber-optic/ diode laser TLS with the sensitivity as comparable as the non-fiber optic system. In contrast to the non-fiber optic TLS detection, which is very sensitive to the change of light intensity, the fiber optic/ diode laser TLS detection is not influenced by the surroundings, thus, it could be operated in the laboratory without dark room. The successful detection in the condition of the length of optical fiber extended up to 10 m indicates the possibility for a sensing of TLS signal for the samples remote from a spectrometer.

Acknowledgment. The author thanks to Dr. Jong Shin Yoo of KBSI and Prof. Jin Soo Hong at Department of Physics, Soonchunhyang University for their helpful discussions.

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