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Experimental Study on Micro Laser Fluorescence Spectrometer

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Abstract. This paper presents a kind of miniature handheld laser fluorescence spectrometer, which integrates a laser emission system, a spectroscopic system and a detection system into a volume of 100×50×20 mm^3. A USB interface is connected to PC for data processing and spectrum display. The emitted laser wavelength is 405 nm. A spectral range is 400~760 nm and 2 nm optical resolution has been achieved. This spectrometer has the advantages of compact structure, small volume, high sensitivity, and low cost.

Keywords: spectrometer, laser, fluorescence,

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1 Introduction

Comparing with traditional detection methods, laser-induced fluorescence(LIF) technology is a kind of molecular fluorescence spectrometry with high precision, large measuring range and fast measuring speed. Currently it has become a very important and effective means on spectrum analysis and detection. The application range covers the fields of industry, agriculture, life science, environmental science, material science, and food science etc. [1-6]. The tendency of its development is intelligence, miniaturization, integration, chip module and system engineering, which meets the on-site rapid detection and civilian needs.

However, most popular laser-induced fluorescence detection instruments in the market are large in size and high in price [7-9]. In addition, these instruments commonly used in the laboratory are not suitable for on-site rapid detection, and thus the instrument application was greatly confined. Recently a variety of miniaturized and light-weight spectral detection instruments have been reported[10-11]. In this paper, we presented a low-cost miniature laser fluorescence spectrometer with high sensitivity. In the experiments we carried out on-site spectral detection on various solids and liquids without opening the transparent packages or containers. The tested solids and liquids also included the ordinary family cooking oils, liquors, pesticides and foods. In addition to the civil use, our spectrometer also has wide application prospect in areas of scientific research, industrial production, environmental monitoring, etc.

2 The structure of the instrument

As is shown in Fig. 1, the miniature handheld laser fluorescence spectrometer is composed of four parts: the laser emission system, the spectroscopic system, the detection system, and the data processing system. The laser emission system consists of a laser diode and a driver. A small low-cost 405 nm semiconductor laser is chosen as the excitation source, which output the laser beam in either a continuous or pulsed manner with the computer-controlled laser driver. A long wave pass filter is placed in front of the small transmission grating to avoid the disturbance of reflected laser during detection. To ensure clear image formation of the spectrum on the CCD surface of the detection system, a lens is placed behind the spectroscopic system. The data acquisition card captures the CCD imaging data, followed by data processing and spectrum display on the computer screen. To avoid the disturbance of the packaging materials, a certain angle is designed between the laser emission path and the optical axis of the receiving system. The main parameters are shown in Table 1. The spectral range is 400-760 nm. The Laser power output is 100 mW. The minimal precision of the spectral resolution is 2 nm.

The main features of the spectrometer are as follows:

(1) Our optical spectrometer applies a real-time background subtraction technology to reduce the external light interference which limits the florescence detecting sensitivity. The pulsed laser

is half the frame rate of CCD data acquisition. In other words, the adjacent two frames acquired signal of the CCD are detected either with the background spectrum or with LIF adding the background spectrum. The former frame contains the background spectrum and instrument noise signal, while the latter contains the laser-induced fluorescence spectrum signal in addition to the signals of the former. The external light interference can be greatly reduced by subtracting the two adjacent frame signals, and thus improve the instrument sensitivity and signal-to-noise ratio.

(2) The spectrometer is suitable to detect liquid and solid targets of different shapes. The angle between the laser emission direction and the optical axis will ensure that the detected light is the fluorescence from the liquid sample instead of the fluorescence from the bottle surface.

(3) The system of the spectrometer is quick in response and real-time spectral curves can be displayed.

(4) The spectrometer is of small size (100 mm×50 mm×20 mm) and low cost (less than 500 $). It is portable and easy to operate.

3. Experimental detection

3.1 Edible oil spectrum detection

The edible oil samples were bought from the supermarket, including soybean oil, olive oil, sunflower oil, peanut oil, and corn oil, etc. The fluorescence from the samples can be directly measured by the spectrometer contacting the surface of the plastic bottle as shown in Fig. 2. The results are not affected by the fluorescence from the bottle surface or the ambient light. The detecting results of the edible oil samples with our spectrometer are analyzed and the spectrum curves are shown in Fig. 3. The fluorescence from different samples are discriminative. The two fluorescence peaks around 500 nm and 680 nm were detected for Jinlongyu soybean oil, Hujihua blend oil and Jinlongyu blend oil. However, the peak shapes and relative intensities of these three samples are different. As for the olive oil, only one obvious spectrum peak appears. These results show the spectrometer can discriminate fake or substandard edible oil products.

3.2 Water quality detection

Currently the laser-induced fluorescence technique has been applied in the detection of chlorophyll, dissolved organic matter (DOM), and petroleum pollutants [12-15], etc. It can also be applied to dynamic monitoring of water pollution. We measured the laser fluorescence in water with the miniature spectrometer. Fig. 4 shows the laser-induced fluorescence and Roman spectrum of tap water and mineral water. It can be seen that the fluorescence peak of the tap water is relatively strong (around 525 nm) because of the high content of organic soluble matter in it, while the mineral water and pure water have only obvious Raman peak and very weak fluorescence peak. The water quality can be calculated by comparing the Raman peak and the fluorescence peak. In addition, the Raman peak of the water is obvious and high compared with that of the noise at the figure bottom. The result shows the spectrometer has high sensitivity.

3.3 Solid Target Spectrum Detection

In addition to water, oil, alcohol and other transparent or translucent liquid substances, the spectrometer can also test solid targets such as fruits, vegetables, gemstones, paint, etc. In the experiment, we measured the fluorescence spectra of the holly leaves and surfaces of the apples. As is shown in Fig. 5, the 685 nm characteristic fluorescence peak intensity of the leaves is stronger than that of the apples. The chlorophyll content of plants can be evaluated by suitable algorithms in future research based on the 685 nm peak value.

4. Conclusion

In this paper, the miniature laser fluorescence spectrometer we designed is reported. It has the advantages of small size, low cost and high sensitivity, and can be applied to the detection of a variety of solid or liquid substances. In order to test the performance of the spectrometer, experiments on the laser induced fluorescence spectra of edible oil, water and plants have been carried out. The minimal precision of the spectral resolution is 2 nm.

In the process of the water quality detecting, the laser-induced fluorescence is relatively weak and strong noise spectrum can be detected. Nevertheless, the Raman peak of water (3300 cm^{-1}) is more obvious, which is a proof that the spectrometer has high sensitivity.

In addition to scientific research, industrial production, and environmental protection, the application of the spectrometer can be extended to the quality and safety testing on ordinary family cooking oils, liquors, pesticides and foods, etc. This experimental study on the spectrometer means to promote its civil applications.

Acknowledgments

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Biographies

Zhaoshuo Tian is a professor at the Harbin Institute of Technology at Weihai. He received PhD degree in physical electronics from the Harbin Institute of Technology in 2001. His current research interests include laser radar, spectrum and optoelectronic systems. He is a member of IEEE.

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Erdan Gu is a research team leader in Institute of Photonics, University of Strathclyde, Glasgow, U.K., He received the Ph.D. degree in thin-film physics from Aberdeen University, Aberdeen, U.K., in 1992. His research interests include micro/nano photonic materials and devices, optoelectronics, diamond optics and photonics, hybrid organic/inorganic optoelectronic devices and micro-systems.

Table

Table 1 Main parameters and performance index

Parameter	**Performance**
Spectral range	400-760 nm
Excitation wavelength	405 nm
Spectral resolution	2 nm
Laser power output	100 mW (peak)
Integration time	100 ms-60S
Size	100 mm×50mm×20mm

Caption List

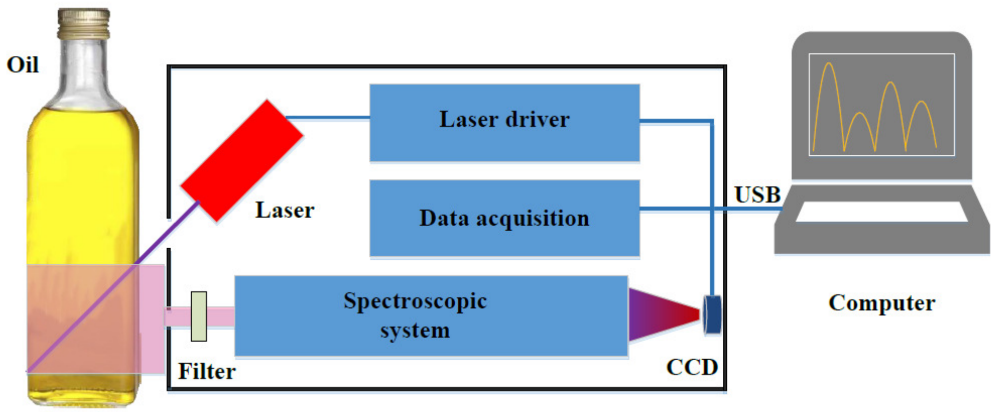


Fig. 1 Structure of the miniature laser fluorescence spectrometer.

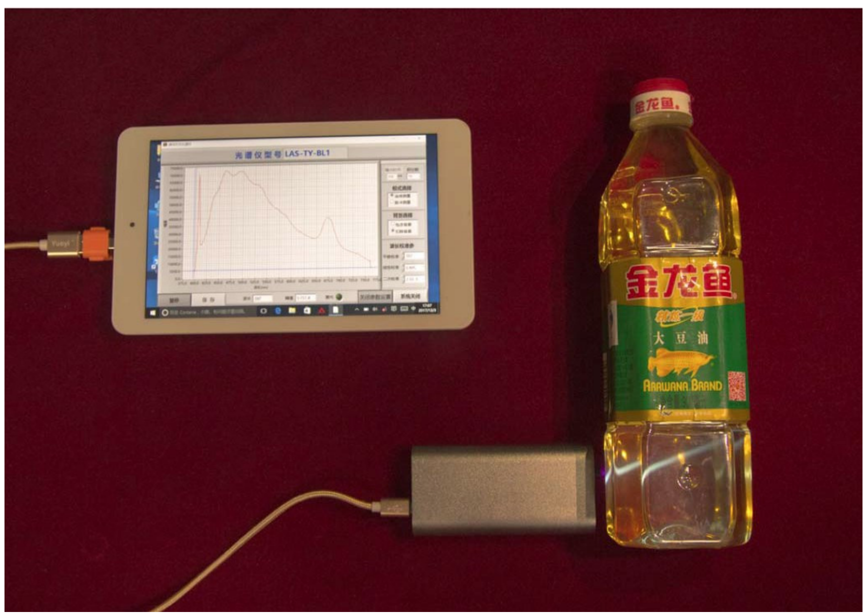
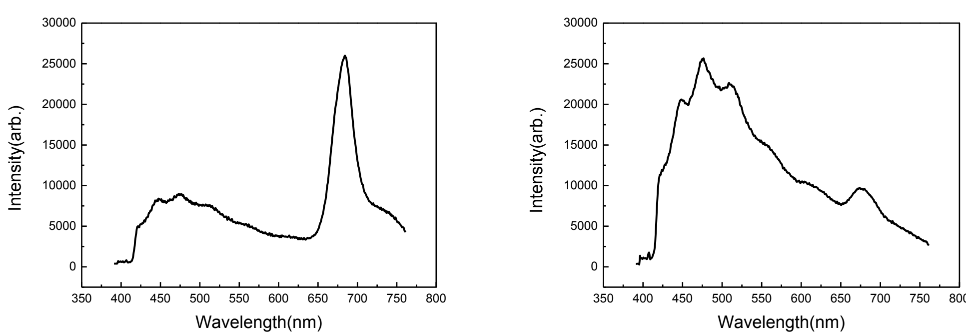
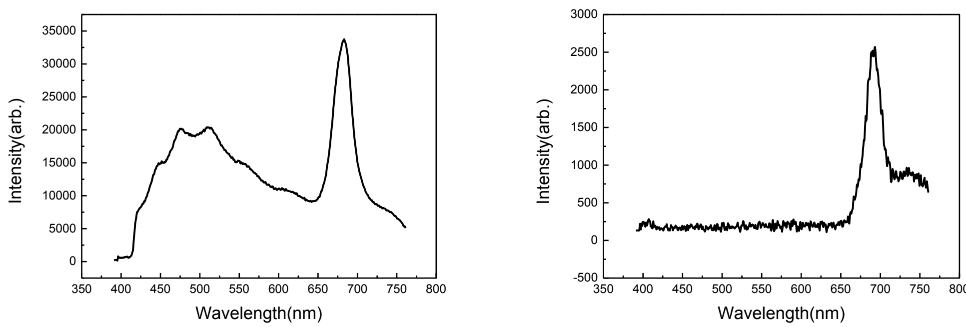


Fig. 2 Picture of testing of edible oil by micro laser fluorescence spectrometer

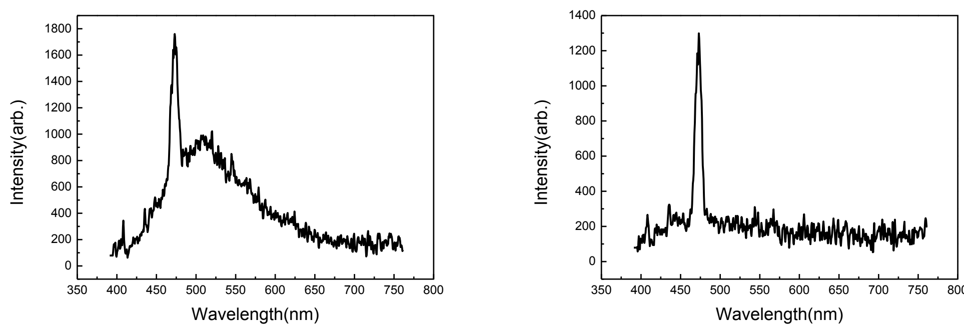


(a) (b)



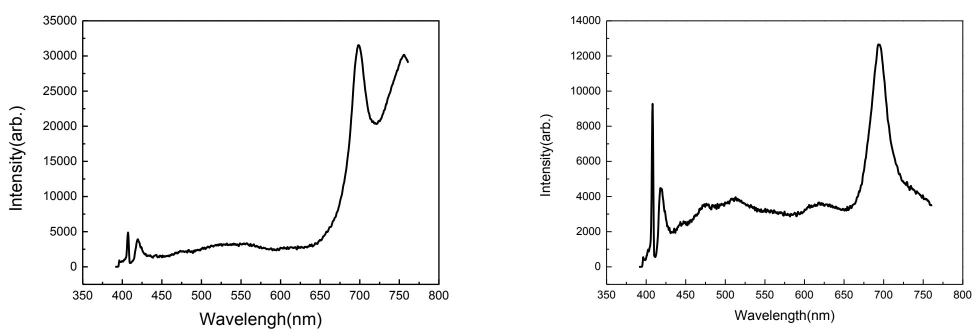
(c) (d)

Fig. 3 Results of spectral measurement of different oil species: (a) Jinlongyu soybean oil, (b) Hujihua blend oil, (c) Jinlongyu blend oil, (d) olive oil



(a) (b)

Fig. 4 Comparison of laser induced fluorescence and Raman spectrum of tap water with mineral water: (a) tap water, (b) mineral water



(a) (b)

Fig 5 Comparison of LIF spectra of leaves and apples: (a) holly leaves, (b) apple