Coal Mine Low Power Laser Methane Detection and Alarm Instrument

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ABSTRACT

At present, the portable carrier catalytic methane detection and alarm instrument for coal mine generally has many problems, such as high power consumption, short standby time, low detection accuracy, few parameters and single function, which can not meet the rapid development needs of mine safety. In this paper, a low power portable laser methane detection and alarm instrument based on tunable laser absorption spectroscopy (TDLAS) is designed. The instrument can detect methane concentration, ambient temperature and ambient pressure at the same time. It has the functions of sound and light alarm, historical data storage and query, and integrates Wi-Fi to realize data wireless transmission. The instrument can work continuously for 36 hours, and the response time is less than 15 seconds. It has the function of self-diagnosis. The overall performance of the instrument has been greatly improved compared with the traditional mine methane portable instrument. A mobile methane alarm Internet of things(IOT) system for coal mine based on portable instrument has been developed, which realizes real-time upload of data and cloud analysis, makes the traditional mine gas monitoring and control system powerfully supplemented, greatly improves the detection level of coal mine gas, and has broad application prospects.

Keywords: TDLAS; portable; detection and alarm instrument; low power; wireless; methane; Wi-Fi; Internet of things

1. INTRODUCTION

Prevention and control of gas accidents is the key point of coal mine safety production. Traditional catalytic and non-fractional infrared methane detection alarms have some problems such as small detection range, short standby time, short life, easy poisoning, frequent calibration, etc[1-4]. It is of great significance to develop laser methane detection alarms with high reliability, high stability and full range detection[5]. Laser methane detection and alarm instrument based on tunable semiconductor laser absorption spectroscopy (TDLAS) has many advantages, such as high detection accuracy, wide measurement range, no cross-interference, no need for constant calibration, temperature and pressure compensation, etc. It is very suitable for gas detection and alarm in oil, gas, coal and other industrial fields [6-7].

With the maturity of wireless communication system in mine and storage area, wireless networking of methane detection and alarm has become a new development trend. However, in many industrial applications, such as coal mines, the

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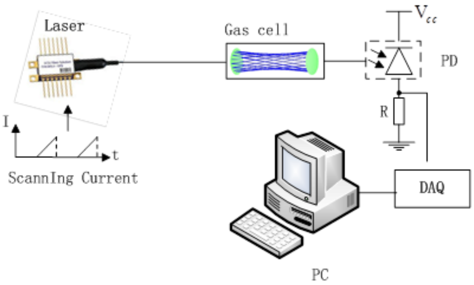
power consumption of methane detection and alarm devices has more stringent requirements. Low-power systems are more suitable for various inflammable and explosive scenarios, and have significant advantages of intrinsic safety. At present, the existing laser methane detection and alarm devices based on tunable semiconductor laser absorption spectroscopy often use light source driver module with temperature control, and its power consumption has been high. When the wireless module is further integrated in the system, the power consumption of the system will be further increased, which seriously restricts the TDLAS methane detection and alarm equipment. Application and promotion in industry [8-11]. In this paper, a low-power portable laser methane detection and alarm instrument based on VCSEL laser and a mobile methane alarm Internet of Things system for coal mine are developed. The corresponding system is analyzed experimentally, which will be a great complement to the existing coal mine gas monitoring and control system, and will greatly improve the level of coal mine gas detection .

2. THE BASIC MEASUREMENT PRINCIPLE

Absorption of light energy by certain gases (e.g. methane) in the infrared band follows Lambert-Beer's law.

$$\ln\left(\frac{I}{I_0}\right) = -PS(T)\phi(\nu)CL \qquad (1)$$

Among them, I_0 is the light intensity without gas absorption, I is the light intensity after gas absorption,$S(T)$is the characteristic line intensity of the gas, $\phi(\nu)$is the linear function, which determines the characteristics of the absorption line of the measured gas component, P is the total pressure of the gas medium, T is the total light path of the gas absorption, and C is the concentration of the gas.The basic system schematic diagram is shown in Figure 1.Figure 2 shows the absorption line of methane gas obtained from HITRAN database at 1653 nm wavelength, where 1653.722 nm is selected as the target absorption line.



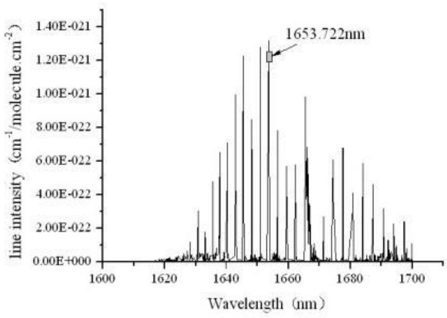


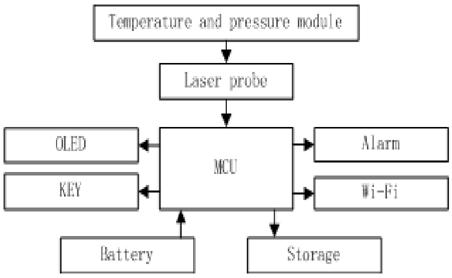
Figure 1.The basic system schematic diagram Figure 2.Selection of Methane Gas Absorption Lines

As shown in Figure 1, the laser diode is driven and controlled by wavelength scanning. The output wavelength of semiconductor lasers is determined by temperature and driving current. When a semiconductor laser operates at a constant temperature, its output wavelength is linearly related to the injection driving current. The distribution of scanning current in time domain includes sawtooth wave, triangular wave and trapezoidal wave. The output beam of the semiconductor laser is transmitted to the gas absorption cell through optical fibers. The gas in the cell is absorbed and then transmitted through optical fibers to the photosensitive surface of the photodetector. The photoelectric detector generates the corresponding photocurrent and gets the corresponding voltage signal through the conversion circuit. The absorption spectrum data is acquired after further analog-to-digital conversion acquisition by the data acquisition card, and is finally sent to the computer for analysis, storage and display. In actual gas detection, the type of gas can be identified by the position of the central wavelength of the characteristic spectral line, and the concentration of gas can be calculated accurately and quantitatively by the height of the peak value of the characteristic spectral line.

3. THE SYSTEM DESIGN

The TDLAS methane detection and alarm instrument proposed in this paper uses VCSEL laser as light source and adopts a multi-stage scanning laser spectrum technology without temperature control. It realizes the spectral pre-processing of fast automatic identification of characteristic peaks and fast locking of jumping peaks by laser, which significantly reduces the power consumption of the whole instrument. While the power consumption of the system is reduced, the volume and weight of the system are also significantly reduced. The system can integrate various functional modules, such as Wi-Fi module, which greatly extends the system's extension function.

The system is highly integrated with microcontroller and laser system. Its functional block diagram is shown in Figure 3.



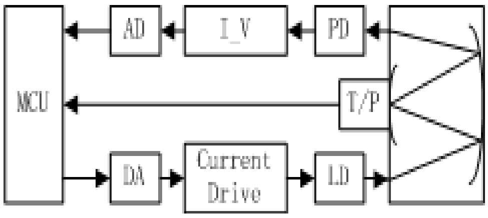


Figure 3. Function block diagram of alarm instrument   Figure 4.Principle block diagram of laser gas detection modul

Laser gas detection module as the core component, real-time detection of methane gas concentration, ambient temperature and ambient pressure, methane gas concentration through TTL signal transmission to MCU, and then through OLED display detection information. When the concentration of methane exceeds the set threshold, an acousto-optic alarm will be issued. Wi-Fi can also be connected to the underground Wi-Fi ring network to transmit data to the monitoring room in real time. The battery uses 1500 mAh lithium manganate battery with over-charge and over-discharge protection circuit. The storage unit can store real-time information such as time, methane concentration, ambient temperature, ambient pressure and so on. At the same time, it can keep 7-day historical records for inquiry. The alarm device has the function of fixed-point data storage and reading, so as to facilitate the security personnel to store the methane gas concentration information at a specific location.

Laser gas detection module adopts tunable semiconductor laser absorption spectroscopy technology. The principle block diagram is shown in Figure 4. Under the modulation of voltage controlled constant current source, the laser outputs a specific wavelength beam. After the beam passes through the measuring chamber, it passes through PD, photoelectric conversion circuit and AD to convert the optical signal into digital signal. The methane gas concentration to be measured is processed and analyzed by single chip computer. At the same time, the ambient temperature and pressure are measured, and the temperature and pressure compensation for measuring methane gas concentration is carried out.

4. PERFORMANCE TESTING

The standard methane gases with concentration of 0.5%, 1.5%, 8.5%, 19.6% and 85% were put into the alarm in turn, and the measured results were transmitted to the computer through Wi-Fi. The measurement results are shown in Figure 5. when the methane standard gas concentration is less than 1%, the measurement error of the system is 0.01%. When the concentration of methane standard gas is more than 1%, the measurement error of the system reaches the maximum when the concentration of methane standard gas is 8.5%, and the error is 1.76%. In summary, the measurement error of the system is controlled within 1.76%, which is better than the measurement error requirement stipulated in standard AQ6211 and meets the technical requirements of industrial application.

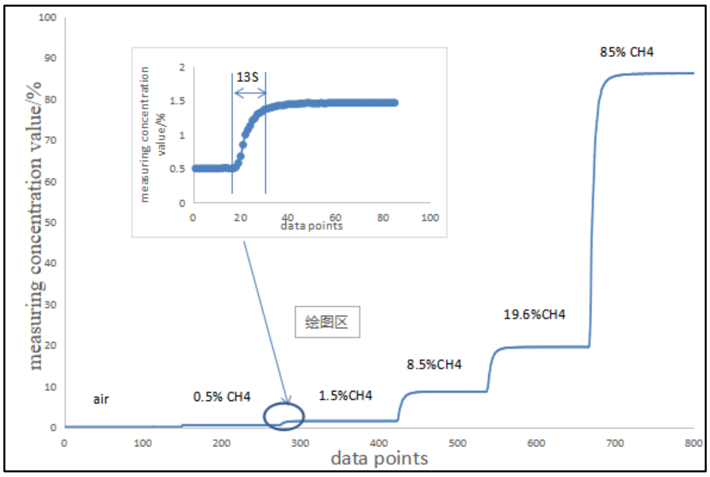


Figure 5. The measured results of portable laser methane detection and alarm instrument

The response time of the mine methane alarm is 90% of the time required for the detection concentration to reach the standard gas concentration,which is called "T90". 1.5% methane standard gas is injected into the alarm, and the response curve of the alarm is tested as shown in Figure 5. According to the data analysis, the response time is 13 s, which is better than 20 s stipulated in the traditional sensor standard of coal industry.

When the alarm is powered by 3.7V DC power without battery power supply, the average consumption current is about 38mA. The lithium battery with 1500 mAh power supply can theoretically work continuously for 39 hours. Five prototypes of battery-charged alarm are tested, and the running time is not less than 36 hours, which meets the design requirements. If calculated according to the normal working time of 8 hours, it can be used continuously for 4 to 5 days without charging, which is much longer than the working time of the existing portable sensors.

Laser methane detector is compared with AQ 6207-2007 standard of portable gas detector in coal mine industry as shown in Table 1.

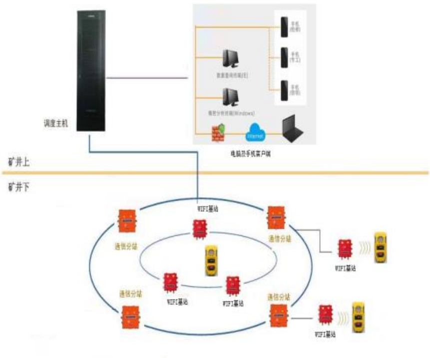
Table 1.Performance comparison

<table>
<tr><th>Specifications</th><th>Laser methane detector</th><th>AQ 6207-2007</th></tr>
<tr><td>Measurement range of methane</td><td>0~100%CH_4</td><td>0~4%CH_4</td></tr>
<tr><td rowspan="3">Basic error</td><td>0~1%： ±0.05%</td><td>0~1%： ±0.1%</td></tr>
<tr><td rowspan="2">1~100%： ±%5 of truth value</td><td>1~3%： ± 10% of truth value</td></tr>
<tr><td>3~4%： ±0.3%</td></tr>
<tr><td>response time</td><td>Less than 15s</td><td>Less than 20s</td></tr>
<tr><td>Measuring Environmental parameters</td><td>Temperature, Pressure and Humidity</td><td>No</td></tr>
<tr><td>fault self-diagnosis</td><td>Laser 、gas cell、battery etc key components and device status monitoring;</td><td>No</td></tr>
<tr><td>Wireless</td><td>Wi-Fi</td><td>No</td></tr>
<tr><td>Data memory</td><td>Continue memoring 7 days</td><td>No</td></tr>
<tr><td>Operating time</td><td>36 hours</td><td>10 hours</td></tr>
</table>

The portable laser methane detector has realized the functions of low power consumption, high precision, multi-parameter, fast response, fault self-diagnosis and real-time networking. Compared with the traditional portable instrument, it has great advantages and can better meet the application requirements of coal mine environment.

5. INTERNET OF THINGS SYSTEM BASED ON PORTABLE LASER METHANE DETECTOR

Based on mine Gigabit Ethernet and underground WiFi base station, the mine methane Internet of things system of portable laser methane detector is established. The mobile data is uploaded to the cloud in real time for data release and further forecasting and warning analysis. As shown in Figure 7, the data of the laser methane alarm detector is uploaded to the cloud service center in real time through the Internet. The service center processes and analyses the data, and pushes the data to the user's PC and mobile APP. Users can manage their own devices through PC or APP. At the same time, they can view real-time data, equipment status, historical data and predictive analysis conclusions. The mobile methane alarm Internet of things system in Coal Mine Based on portable instrument will be a great complement to the existing monitoring and control system of coal mine gas, and will greatly improve the level of coal mine gas detection.



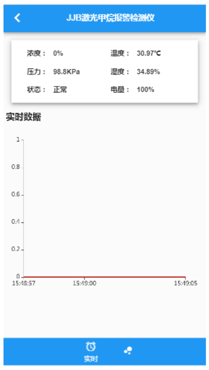


Figure 7. Topology diagram of coal mine mobile methane alarm IOT system   Figure 8 .Mobile phone APP display interface

6. CONCLUSION

The new generation of laser methane detection and alarm instrument has the advantages of ultra-low power consumption on the premise that it has the leading performance indicators of the whole range of detection, high detection accuracy and fast response time. In addition, the system proposed in this paper also has the functions of continuous data storage and fixed-point data storage, and integrates a wireless transmission module, which can realize long-distance data wireless transceiver. The new generation of laser methane detection and alarm instrument has strong field adaptability due to its unique technical advantages, industry-leading performance indicators and highly integrated functional architecture. It is suitable for monitoring and alarming applications of methane gas in various industrial scenarios. Based on mine Gigabit

Ethernet and underground WiFi base station, the mine methane Internet of things system of portable laser methane detector is established, which will be a great supplement to the existing coal mine gas monitoring and control system, and will greatly improve the level of coal mine gas detection.

ACKNOWLEDGMENTS

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