Measurement system of gas density based on spectrum absorption

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A novel measurement system for the gas density based on spectrum absorption is studied in details. Based on the theory of Beer-Lambert, the technology of nonlinear laser diode (LD) spectrum is used to perform the polluting gases monitoring on line. The peak wavelengths of LD are changed with the applied voltage and temperature, so the technology of wavelength modulating or frequency modulating can be used at perform the measurement in wide scope. In this paper, the low density of the polluting gases, is detected by the method of harmonic detection in order to increase the detection sensitivity.

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Many countries have paid more attention to the problem of the environment protection. The traditional sample analysis method has certain limit in space and time. So the long distance monitoring based on optical technology highly is anticipated. For monitoring the flue, optical technology is simple and has high anti-interference power. The main methods of gas detection include chemical material test, fluorescence detection, gas chromatography and spectrum absorption detection. At present, long distance monitoring instruments, which include the non-diffusion infrared meter (NDIR) and Fourier transformation infrared (FTIR), can perform the gas detection in wide spectral region including infrared, visible light and ultraviolet. In addition, difference absorption spectrum technology (DAOS) and novel infrared technology (LASAIR) are new methods in foreign countries these years. In the paper, laser diode (LD) spectrum technology is used to measure characteristic spectrum of the pollution gas on line.

Harmonic detection is wide applied to the detection of the weak signal. It scans the measured parameter by high frequency that modulates certain signal changing with the frequency. In signal processing system, the reference signal is attained by modulating the frequency or double frequency. Then the phase-locked amplifier records the information which constituted of a series of harmonic information of modulating signal. The configuration is shown in Fig. 1.

The absorption peak value of NO_2 in the low-loss window of quartz optical fiber is 0.8 μm, so InGaAs/AlGaAs LD is used as the light source. In the design, distributing feedback LD (DFBLD) is selected to make the light frequency change with temperature or the drive current of the diode array. Here $\delta\lambda_s$ is defined as the wave spectrum of the narrow-band light source, which is far less than the bandwidth of the gas absorption ($\delta\lambda$). For DFBLD, the most convenient method of modulating frequency is to modulate the injection current. In actual measurement, the system environment is near to a atmospheric pressure, so the rorate vibration spectral line of the gas in infrared area is influenced mainly by the collision widening not Doppler widening. Now, the reasoning formulae based on Lorentz absorption curve are given as follows.

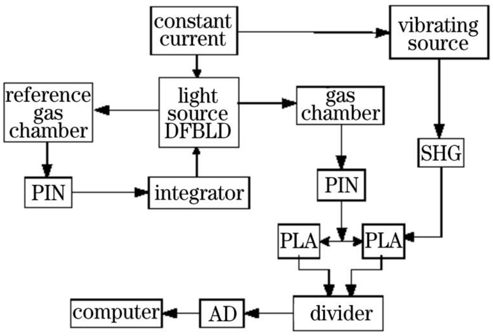

Fig. 1. Schematic of second harmonic gas detection system.

When the injection current is modulated according to $mi_0 \sin\omega t$, the homochromy energy density is given by

$$\rho(\lambda) = \rho_0 \delta(\lambda - \lambda_{os})(1 + m \sin\omega t). \quad (1)$$

where ρ_0 is the total energy density of the monochrome light wave field. The central wavelength (λ) changes with the modulating signal:

$$\lambda_{os} = \lambda_{DC} + \frac{1}{k} sm\rho_0 \sin\omega t, \quad (2)$$

where λ_{DC} is the static wavelength of the light source; λ_{os} is the output wavelength of the light source; k is the ratio factor of output optical power and injection current; s is electricity modulating rate; and m is depth of modulation.

Considering the spectrum distribution and the linetype of gas molecule, the law of Beer-Lambert can be given as

$$I(\lambda_0) = \int_{-\infty}^{+\infty} \rho(\lambda) \exp[-\alpha_0 g(\lambda - \lambda_0) CL] \mathrm{d}\lambda, \quad (3)$$

where $g(\lambda - \lambda_0)$ is the function of the absorption linetype of the gas. Because of $\alpha_0 g(\lambda - \lambda_0) CL \ll 1$, Eq. (1) is rewritten as

$$I(\lambda_0) = \int_{-\infty}^{+\infty} \rho(\lambda)[1 - \alpha_0 g(\lambda - \lambda_0) CL] \mathrm{d}\lambda. \quad (4)$$

According to the quality of the δ function and the Eq. (1–4),

$$I(\lambda_0) = \rho_0(1 + m \sin\omega t) - \rho_0(1 + m \sin\omega t)\alpha_0 CLg(\Delta\lambda + nm\rho_0 \sin\omega t), \quad (5)$$

where $\Delta\lambda = \lambda_{\rm DC} - \lambda_0$, the difference between static working wavelength of the linear spectrum and the peak wavelength of the absorbed gas. The formula of Lorentz absorption linetype of the gas is given as

$$g(\lambda - \lambda_0) = \frac{\delta\lambda}{2\pi[(\lambda - \lambda_0)^2 + (\delta\lambda/2)^2]},$$

so

$$I(\lambda_0) = \rho_0(1 + m\sin\omega t) - \rho_0(1 + m\sin\omega t)$$
$$(2\alpha_0/\pi\delta\lambda)LC/[4(\Delta\lambda + nm\rho_0\sin\omega t)^2/(\delta\lambda)^2 + 1] \quad (6)$$

Because the modulating point is in the neighborhood of the absorption peak, that is $\lambda_{\rm DC} \approx 0$, so $\Delta\lambda \approx 0$, and $4[(\Delta\lambda + nm\rho_0\sin\omega t)/(\delta\lambda)]^2\sigma \ll 1$, here $\sigma = \frac{2}{\pi\delta\lambda}$, according to the spread formula of the frequency modulating,

$$I(\lambda_0) = D + A_{\rm p}\sin\omega t + B_{\rm p}\cos 2\omega t + C_{\rm p}\sin 3\omega t, \quad (7)$$

where D is the component of the direct current; $A_{\rm p}, B_{\rm p}$, and $C_{\rm p}$ are respectively the coefficients of first, second, and third harmonics, where

$$A_{\rm p} = [1 - \alpha_0\sigma CL(1 - 2\theta\Delta\lambda n\rho_0 - (3/4)\theta n^2m^2\rho_0^2 - \theta\Delta\lambda^2)]m\rho_0, \quad (8)$$

where $\theta = \frac{4}{(\delta\lambda)^2}$. According to the Eq. (8), even if the wavelength of the source aims at the centra wavelength of the absorption peak value ($\Delta\lambda = 0$), $A_{\rm p} \neq 0$, namely the first harmonic is not zero, and

$$A_{\rm p} = [1 - \alpha_0\sigma CL(1 - \frac{3}{4}\theta n^2m^2\rho_0^2)]m\rho_0. \quad (9)$$

From Eq. (2), it can be known that $mn\rho_0$ is the modulating depth of the LD and proportional to $\delta\lambda$ which is the half width of the gas. Adjust the current modulating depth of the light source to make $1 - \frac{3}{4}\theta n^2m^2\rho_0^2 = 0$, so the first harmonic is that $A_p = m\rho_0$, which is a constant error. Introduce a signal that has the equal value but reverse symbol with the intensity modulating signal to compensate the difference. Then the signal passes through integration circuit to control the center wavelength of the laser. The detection system uses the first harmonic as the error signal, and detects the second harmonic to attain the information of the density of the gas. In the signal processing system the second harmonic generator (SHG) is applied to make the ratio of the 2nd and 1st as the system output so as to eliminate the common mode noise generated by the fluctuation of optical intensity.

In conclusion, a novel measurement system on the gas density is analyzed in detail, which uses the technology of the laser spectrum to detect the density of the pollution gas. In addition, it also can be used in reconnaissance of the mineral resources, the quality analyzing of the industrial production and the area of the medical treatment based on this theory.

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