Design and Construction of Optical System to Detect of Ammonia Gas

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Abstract: The idea of research is the detection of gases using the transmitter and receiver system for electromagnetic radiation in the IR region using the optical absorption method. As a result of the interaction of the light with the gas molecules can be detect and measure gas pressure adoption absorption method. It was chosen best absorption band between (1.4-1.6) μm at the wavelength 1.5 um to build a sensor for accurate measurement of ammonia gas which is characterized by precision, where he was the measuring pressure range (1-6) bar. The importance of the oil industry has been focusing on this kind of scientific research for the detection of ammonia gas.

Keywords: Ammonia Gas Sensing, Gas Analysis, Spectroscopy

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Introduction

Ammonia (NH₃) is colorless gas composed of nitrogen and hydrogen with a sharp, penetrating dour. Sensitive and continuous monitoring of NH₃ is relevant in several applications such as environment monitoring to quantify NH₃ emissions from coal waste piles in combustion (Viveiros et al., 2014), DeNOx processes, which are widely used in power plants and incinerators to reduce NOx emissions (Busca et al., 1998) or in medicine to analyses breath NH₃ levels as a diagnostic tool (Narasimhan et al., 2001). The main optical gas sensor technologies are based on absorption spectroscopy of fundamental bands in the 3-25 μm spectral region, near infrared vibration overtone and combination bands from 1-3 μm (Viveiros et al., 2015). Various NH₃ analysers and measuring methods have been developed, including the differential optical absorption spectrometer (Mount et al., 2002), tunable diode laser absorption spectrometer (Sickles et al., 1990), photoacoustic spectroscopy (Schmohl et al., 2002) and cavity ring-down spectroscopy (O’Keefe and Deacon, 1988). Fourier Transform infrared spectroscopy (Galle et al., 2000; Wyers et al., 1993). NH₃ has a rich spectrum in the near infrared region, in the spectral range from 1450 nm to 1560 nm. Recently, several works have been developed which use the absorption lines at 1532 nm and 1512 nm as the operating wavelength for NH₃ sensing (Claps et al., 2001). The Wavelength Modulation Spectroscopy (WMS) technique has also been demonstrated in a system using a Distributed Feedback (DFB) laser diode with an emission wavelength at 1532 nm in conjunction with hollow optical waveguides (Fetzer et al., 2002). Such waveguides were used as long-path sample cells (optical path length of 3 m) which were coiled to reduce the physical extent of the system. A portable diode-laser-based sensor for NH₃ detection, using vibration overtone absorption spectroscopy at 1532 nm (optical path length of 36 m), was described using a fiber-coupled optical element that made a trace gas sensor rugged and easy to align (Huszár et al., 2008). The gas sensor was used primarily for NH₃ concentration measurements. An NH₃ sensor based on the combination of resonant photo acoustic spectroscopy and direct absorption spectroscopy techniques with a DFB laser diode operating at 1532 nm, was also described (Besson et al., 2006).
bonding strength of oscillated composition atom, but is unrelated with composition atom. Figure 1 is a vibration mode of NH₃ gas. 2 parallel mode that is \( v_4, v_1 \) and \( v_2 \) increased symmetrical, on the other hand, \( v_3 \) and \( v_4 \), 2 right angle modes, have degeneration style of asymmetry. These four vibration modes have four absorption bands in core infrared rays area (0.78~2.5 um) by association each other as appear in Table 1 (Claps et al., 2001).

**Infrared Absorption**

If the molecule absorbs infrared rays, the molecule must occur essence change of dipole moment by vibration and rotational motion. When molecule oscillates, change amount of dipole moment is the more, infrared absorption is the stronger. In the case of uniformity nucleus species molecule such as N, H, O molecules do not absorb because essence change of dipole moment does not happen by vibration or rotational motion of molecule. NH₃’s dipole moment is 1.471D. So, we can know that infrared absorption occurs Fig. 2 shows that NH’s absorption spectrum in 1.5, 2.0, 2.3 um. Absorption spectrum in 1.5 um and 2.3 um is strong and effect of interference for other gas such as H₂O or CO₂ is less (Claps et al., 2001; Webber et al., 2001).

**Table 1:** Assignments for NH₃’s NIR spectra, listed roughly in order of contribution to the band (Claps et al., 2001)

| NIR region | Band assignment |
|------------|-----------------|
| 1.5 µm     | \( v_1 + v_3, 2v_3, v_3 + 2v_4, v_1 + 2v_4, 2v_1 \) |
| 1.65 µm    | \( v_2 + v_3 + v_4 \) |
| 2.0 µm     | \( v_3 + v_4, v_1 + v_4 + 2v_2 + v_3, 4v_2 + v_4, 2v_2 + 2v_4 \) |
| 2.3 µm     | \( v_2 + v_3, v_2 + 2v_4, v_1 + v_2 \) |

Fig. 1: H₃’s vibration modes (Claps et al., 2001)

Fig. 2: NH₃’s absorption bands in the NIR (Chomsky, 2012)
**Theory**

The fundamental theory that governing absorption spectroscopy for narrow-line width radiation sources is embodied in the Beer–Lambert law, Equation (1) and is described thoroughly in Ref. 3. The ratio of the transmitted intensity $I_t$ and initial (reference) intensity $I_0$ of laser radiation through an absorbing medium at a particular frequency is exponentially related to the transition line strength $S_i$ [cm$^{-2}$atm$^{-1}$], line-shape function $\phi$ [cm], total pressure $P$ [atm] of the medium, mole fraction of the absorbing species $x_j$ and the path length $L$ [cm] through which the radiation passes (Claps et al., 2001; Webber et al., 2001):

$$\frac{I_t}{I_0} = \exp\left(-S_i \phi P x_j L\right)$$  \hspace{1cm} (1)

The two laser intensities can be converted to absorbance $\alpha(v)$ and related to the transition parameter by:

$$\alpha(v) = \ln\left(\frac{I_t}{I_0}\right) = S_i \phi P x_j L$$  \hspace{1cm} (2)

Absorption coefficient, $\varepsilon(v)$ is defined with (3):

$$\varepsilon(v) = S_i \phi(v) P$$  \hspace{1cm} (3)

Absorption, $\alpha(v)$ can appear in simple form with way(4) from way(2):

$$\alpha(v) = \varepsilon(v) x_j L$$  \hspace{1cm} (4)

Here, absorbance $\alpha(v)$ is proportional in concentration ($x_j$) of measurement gas.

**Experimental Setups**

The basic elements of an experiment for measuring absorption spectra of the NH$_3$ gas by sensor system is shown in Fig. 3 and 4. The main block of the system consists an Electrical lamp source whose radiation is directed pass through an absorbing gas medium of known path length and monitored with a detector. The Electrical lamp source with optical filter at 1.5\,$\mu$m is wavelength-tuned across the absorption transition and the transmitted intensity is recorded with the detector (THORLAB PDA30G - EC type PbS Amplified Detector 1.0-2.9\,$\mu$m) or analyzed spectrometer (Zolix – monochromatic – omni - 500) to determine the integrated area of the absorption line shape. Two modes can be chosen IR transmitter lamp at wavelength 1.5\,$\mu$m connected with driver modulated circuit by the square mode of (1-3) Hz frequency and CW mode. Optoelectronic receiver includes Indium Gallium Arsenide (InGaAs) photodiode with a low noise amplifier circuit for monitor signal detection were chosen because of their good stability and responsively for 1.5\,$\mu$m radiation. The sensor was comprised of a single pass cell with 34 cm optical path length. The pressure monitored by gauges at the entrance and exit of NH$_3$ gas at pressure (1-6) bar. The cell was heated to a temperature of 30°C to minimize ammonia adsorption on its glass walls and to prevent potential water condensation on the cell mirrors, as monitored with thermocouple at cell.

![Fig. 3: Ingle Path NH$_3$ gas sensor with Zolix - monochromator (omni - 500)](image-url)
Results and Discussion

It has been monitoring the absorption band through spectral scanning ammonia gas in the infrared region between (700-1700 um), this is illustrated in Fig. 4. It has been focusing only on the strong absorption band between (1400-1600 um) in ammonia gas detection.

It was built optical sensor for measuring the ammonia gas pressure without spectral analyzer and with minimal optical noise; Using optical filter type (THORLABS – FB1500 -12 -1500 nm FWHM =12 nm) is compact with photodiode (PbS) is coupled to gas sensor cell and the second end of the gas sensor cell provider optical light source works continuous and pulse mode. In the case of a small amount of water vapor inside the ammonia gas cell. The optical filter was used to separate the overlap spectrum between the ammonia gas and water vapor. The first part: to examine the optical system for measuring the ammonia gas sensor at different pressures in (1-6) bar under temperatures constant (T = 30°C), with optical spectrum analyzer and filter at 1.5 um. Figure 5 shows the light intensity levels as a function of gas pressure was record. Then intensity peak of the spectra is at around 1500 nm and the intensity of light passing through the gas decreases with increased gas pressure, due to increased absorption.
The proposed sensing system shows line responses in the gas ammonia range from 1 to 6 bar.

Second part: Detector has been replaced with optical filter instead of the spectral analyzer. And make the same previous tests for pressure and temperature as shown in Fig. 3. It was measured and recorded output voltages values as a function of ammonia gas pressure as shown in Fig. 6a-6f. These results were compared with pressure gauge used to obtain accurate results for measuring the ammonia gas pressure. This system could be developed for measuring the highest pressure gas.

**Conclusion**

In this study, we have been designing and building a system for measuring the ammonia gas pressure in the infrared region. The work includes two parts: The first measurements uses spectral analyzer to see stronger absorption regions between (700-1700 um) and the focus was exclusively on the 1.5um region.

The second parts, the sensing system of gases using the transmitter and receiver system in the IR region (1.5 um). Work the system for measuring the
ammonia gas limits (1-6) bar. The advantages of this sensor system is high accuracy and easy in laboratory and industrial applications.

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Author’s Contributions

Mohanad M. Azzawi and Mohammed Jabbar Hussein: Work experimental and write manuscript.
Nibras K. Jebur and Halla F. Saad: Check crammer.

Ethics

Authors should address any ethical issues that may arise after the publication of this manuscript.

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