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Low-cost NDIR based sensor platform for sub-ppm gas detection

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A R T I C L E   I N F O

A B S T R A C T

We report on a new low-cost non-dispersive infrared (NDIR) based sensor platform for sub-ppm gas detection. The aim of the sensor platform development was to create a cost-effective, mass-producible and highly accurate device. Due to its sensitivity, the platform is well suitable for measuring and detecting gases like carbon dioxide, methane, dinitrogen oxide, ammonia, ethanol vapour, refrigerants, etc. The sensor is based on the White-cell NDIR approach and realizes a path length of 1.28 m in a device with an external length of less than 10 cm. High mechanical accuracy of the optical system, temperature controlled optics, highly stable electronics and an optimized mirror surfaces allow a detection level as low as 0.007 ppm.

1. Introduction

There is a large range of applications where accurate gas sensing might be of importance, such as alarms, process control and ventilation. In many cases the levels needed to be detected are very low. In general, several different techniques exist (Liu et al., 2012) where IR absorption is one of the simplest and most economical (Zosel et al., 2011). Several methods and device construction techniques are available that use IR absorption in some way (Corman et al., 2000). The non-dispersive infrared (NDIR)

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gas sensing is one of the most widely used for low-level gas detection, and there is a wide range of cell designs in commercial manufacture (Hodgkinson et al., 2012; Martin, 1997). NDIR analysis attributes high precision, relatively short response time, moderate sample consumption rate, low cross-sensitivity, no poisoning and easiness of operation. It is reported that the common NDIR analyzer can provide accurate measurements with an uncertainty of less than 0.1 ppm, if carefully calibrated (Tohjima et al., 2009). Here we present a new low-cost NDIR based sensor platform that is capable of detecting carbon dioxide levels as low as 0.007 ppm.

2. Material and methods

2.1. IR-absorption

In a molecule, absorption or emission of energy can occur in transitions between different energy levels (Mohan, 2002). In the infrared spectral region, these transitions can be associated with changes in vibrational and rotational energy levels of the molecule. Such internal energies are quantized, so that the molecule can exist only in certain discrete energy levels. Each vibrational level is associated with a set of rotational levels, which results in several closely spaced energy levels existing within a frequency band in the infrared spectrum of the molecule (Barrow, 1962). The fundamental frequencies at which the bands exist are functions of the particular bond and the mode of vibration, e.g. stretching or bending (Mohan, 2002).

When a molecule is exposed to infrared radiation with an energy equivalent to an allowed vibrational transition, the radiation is absorbed and the molecule undergoes the energy transition. The strength of this absorption is used as the means to determine the amount of target gas molecules present (Svanberg, 2004). As far as the absorption wavelengths for different species are well separated, the absorption due to different gas mixing in the sample gas can be resolved by the instrumentation (Willard et al., 1988). Hence, very exact and reliable sensing of the target gas often can be realized by IR spectroscopy, without any cross interference between different gases. Absorption bands of four example gases are shown in Fig. 1.

The relationship between optical absorption and gas concentration at a specific wavelength is determined by the over 160 years old Lambert–Beer law (first published in 1852 (Beer, 1852)),
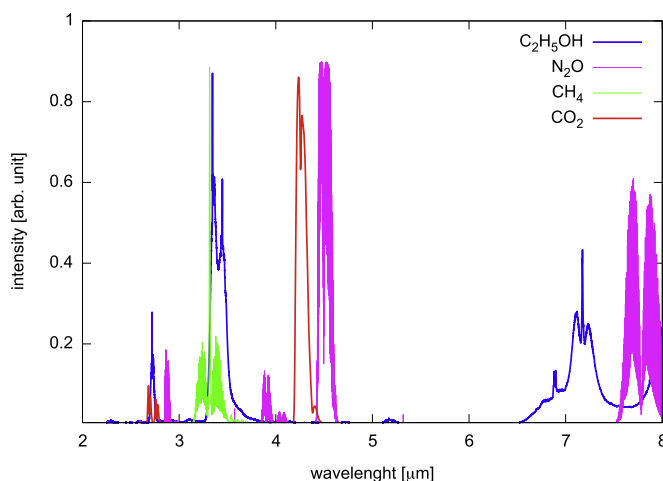
Fig. 1. Absorption bands for ethanol vapour, dinitrogen oxide, methane and carbon dioxide. Methane have absorption bands that are less dense than the other gases. Spectra of ethanol vapour, methane and carbon dioxide are obtained with Fourier transform infrared spectroscopy, while the dinitrogen oxide spectrum is simulated using data from HITRAN (http://hitran.iao.ru/).