APPLICATION NOTE NDIR Gas detection

Molecules like CO_2, CO, CH_4, NO, N_2O and many others show strong absorption lines in the mid IR region. The absorption of infrared radiation causes transitions between the vibrational- rotational energy levels of the molecule. The typical structure of such an absorption line can be seen in the calculated CO_2 spectrum of figure 1.

The NDIR gas measurement set-up consists of an infrared radiation source, the gas sample cell including optical components, a gas specific filter which transmits only radiation corresponding to an absorption line of the gas in question and a suitable infrared sensor to detect this radiation.

The function is similar to a light barrier. If there is none of the specific gas between source and detector the measured signal remains stable and high. If gas molecules of the specific gas passes the area between source and detector the signal drops proportional to the gas concentration. The transmitted intensity is described by the law of Lambert and Beer, where I_0 is the initial intensity, k is the gas specific absorption coefficient, c is the gas concentration and l is the length of the absorption path.

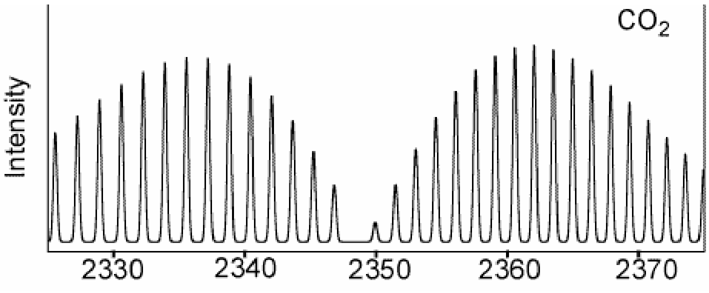

Fig.1:Calculated CO_2 absorption spectrum
(4,30 µm – 4,21 µm)

$$I = I_o \cdot e^{-k \cdot c \cdot l} \quad (1)$$

The infrared source can be a simple infrared lamp, a blackbody radiation source or an infrared diode-laser. The choice depends on the spectral characteristics and costs of the source in relation to the necessary resolution and sensitivity of the gas measurement.

The gas cell can be a single path cell of length l with reflective walls and additional optical components to concentrate the source radiation into the cell. Another possibility would be a “White-cell” where the path length is increased by folding the rays with different mirrors or a multipass cell with an even higher number of reflections.

The infrared filter and filter specification (CWL = center wavelength at normal incidence, FWHM = full width at half maximum) are important parameters of the gas measurement set-up. In most of the cases this filter is integrated as window into the infrared sensor, making the sensor a gas specific sensor.

If filters are used at other than normal angle of incidence the shift in spectral characteristics has to be considered. All interference filters will shift to shorter wavelenth as the angle of incidence deviates from normal. The effect can be approximately calculated by the following formula with n being the index of refraction.[3]

$$\lambda_\Theta = \lambda_0 \cdot \frac{\sqrt{n^2 - \sin^2 \Theta}}{n} \quad (2)$$

With increasing temperature the interference filter transmission will shift to longer wavelength and with decreasing temperature to shorter wavelength. The temperature effect can be approximated by the following formula and is normally small (0.01-0.2nm/°C). [3]

$$\lambda_T = \lambda_0 + \Delta T \cdot \frac{\Delta \lambda}{1°C} \quad (3)$$

Thermopile infrared sensors create a voltage signal proportional to the received radiation. In addition, the signal voltage depends on the sensors own temperature. Equation 4 describes the basic function. T_{source} is the source or object temperature, T_{amb} the ambient or sensor temperature, K an apparatus constant and the exponent n depends on the actual filter characteristics (n=4 for a perfect “black” characteristic and unlimited wavelength range).

$$U \approx K \cdot (T^{n}_{source} - T^{n}_{amb=sensor}) \qquad (4)$$

There are different NDIR methods used in practical applications, the two most important are single beam – single wavelength and single beam-dual wavelength. Figure 2 shows the schematic arrangements.

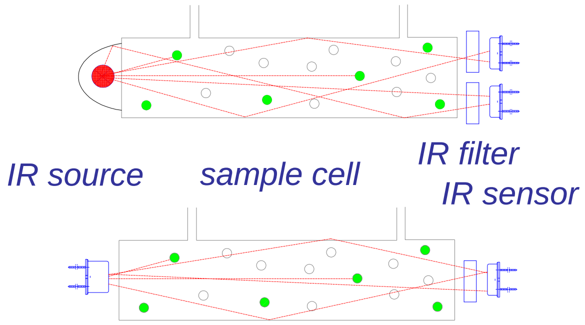

Fig 2: Schematic NDIR set-ups

In the dual wavelength set-up the spectral reference channel is normally well outside of the gas absorption wavelength, therefore the ratio of the two signals will be proportional to the gas concentration but independent of source variations or aging effects. In order to match the two wavelength channels further, the two sensor chips and two filters can be integrated together in one sensor housing. An example for such a dual channel infrared sensor is the Heimann Sensor HTS E21 F4.0/4.26 where “E” denotes the sensor type, “2” the sensor chip size, “1” a thermistor reference of 100kΩ and the two numbers following the letter F give the center wavelength of the the two gas filters.

A next approach to increase the sensor stability and ease the application for our customers was to integrate a sensor chip with an ASIC into the same TO housing (Fig 5). This ASIC has been specially developed to fit to the sensor chip parameters. The thermopile sensor acts as a voltage source with an internal resistance of about 85kΩ when the contact points of the thermoelements are heated by absorbed radiation energy. In a position close to this voltage source the sensor signal is then amplified to a level of several Volt. Of course the ASIC can be combined with different thermopile chip sizes and the TO39 header can be welded to different filter caps (“A” = round aperture 2.5mm, “B” = round aperture 3.8mm, “C” = square aperture 3.5 mm). In addition, the ASIC carries a temperature reference that delivers a linear output signal, e.g. 15mV/°C, for the ambient temperature. The voltage of this temperature reference and the radiation signal can be combined on chip to create a net output signal independent from ambient temperature. Table 1 summarizes typical output signals for the cases that the sensor faces a large blackbody source or the micromachined source EMIRS 200. Alternatively the knowledge of the ambient temperature can be used to calculate the effects of signal variation or filter wavelength shifts associated with changes of the ambient temperature. Since several ASIC parameters can be controlled externally there are different options how to use the ASIC. The integrated thermopile sensor can either be used with pre-set parameters, giving the system manufacturer a better and easier access to the gas-concentration proportional sensor signal and providing additional information on ambient temperature. The gas dependent signal output and temperature reference output are in a range that allows a direct connection to standard low-cost ADC and µC without further analog circuitry.

HIS integrated Sensor			fov 180° large blackbody 500K ambient 298K	dist. micromachined source to sensor =13 mm no optics source supply 5V
type	filter	gain	net output signal / V	
A11	CO2	900	1.39	
B11	CO2	900	3.32	
C11	CO2	900	3.41	
A11	CO2	3000		0.155
B11	CO2	3000		0.155
C11	CO2	3000		0.155
A21	CO2	300	1.18	
B21	CO2	300	2.71	
C21	CO2	300	2.91	
A21	CO2	3000		0.42
B21	CO2	3000		0.42
C21	CO2	3000		0.42

Table 1: Sensor output for different sources (no gas)

More Informations in: Simon, Leneke, et al.: “Thermopile Sensors and IR Sources for Gas Detection with Improved Functionality”; Proceedings of Sensors Conference, Section B8.5; Nürnberg, 10.-12.05.2005