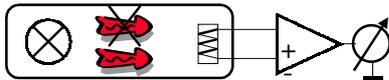


APPLICATIONS OF THERMOELECTRIC INFRARED SENSORS (THERMOPILES): GAS DETECTION BY INFRARED ABSORPTION; NDIR

Jürgen Schilz PhD

PerkinElmer Optoelectronics GmbH, P.O. Box 3007, D-65020 Wiesbaden, Germany
Tel: +49-611-492493; Fax: +49-611-492199; e-mail: juergen.schilz@perkinelmer.com

Abstract



Since silicon micromachined thermopiles have commercially entered the infrared detector scene in the beginning of the 1990's, there has been a rapid decrease in price with its excessive increase in demand and market volume. Number one in driving force for volume expansion is still low-cost pyrometry for consumer applications (see e.g. [1]), but other fields of utilization are advancing. Number two in thermopile employment is certainly gas detection by infrared absorption for industrial usage. Thermopile devices dedicated for this application field are in rapid development, since the micromachining techniques allow a comparatively easy tailoring of the product. This gives the possibility for a thorough adaptation to the desired application while at the same time maintaining the capability for low-cost mass production.

The current paper provides an overview on PerkinElmer's thermopile technology as far as infrared based gas detection is concerned. After a brief review on the gas detection method and a summary on applications, the specifics of the PerkinElmer thermopile detectors and components are discussed.

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1 Introduction

From the “greenhouse effect”, which is due to the constant supply of carbon dioxide (CO₂) and other gases into the atmosphere we are aware that heat (which is indeed infrared radiation) can be absorbed by gases. In fact, most gases are able to absorb infrared (IR) light. These are gases consisting of two different kinds of atoms, such as the mentioned CO₂, but also CO, NO_x and all carbon hydrogens (HC) such as methane, propane or other natural gases employed for heating.

The IR light is capable to excite higher energy levels (excited states) of the molecules (rotational or vibrational excitations) by coupling to the dipole moment of the heteroatomic assembly. Heat energy from the IR light is therefore transferred into the gas – it heats up. Concomitantly, the intensity of a beam of IR light, which passes through a gas volume, diminishes. The intensity loss is a function of the number of active gas molecules in the volume, which means a function of the gas concentration.

Together with the fact that the interaction only occurs with IR light of certain wavelengths, one gains a powerful tool to measure the concentration of a certain gas even in the presence of other gases. One can thus, for example, measure and monitor the concentration of important gases in the atmosphere, such as CO₂, CO, or NO_x.

➡ The intensity loss of an IR light beam of initially known intensity in a specific spectral region is a direct measure of the concentration of the matching gas.

It has to be noted that monoatomic gas molecules, such as nitrogen, N₂, or oxygen, O₂, are not affected by IR radiation and can therefore not be detected by this means. Otherwise the mentioned atmospheric greenhouse effect would be extremely severe and probably we would not exist in the current life form.

The aim of this paper is to give a brief explanation about the principle of gas detection by IR absorption with the focus on the application of PerkinElmer’s thermopile and IR technology.

2 Principle of gas detection by infrared absorption

2.1 Single beam IR absorption gas detector

As touched in the introduction, one can detect a gas and measure its concentration by monitoring the absorption of an infrared light beam. A respective equipment capable for this task consists of an IR light source, a measurement volume, in which the gas to be detected is confined, an element, which allows to pick out the desired wavelength region, and a detector that measures the intensity of radiation.

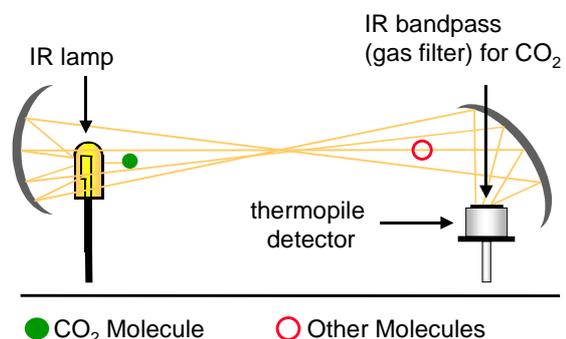


Figure 1: Schematic sketch of an infrared absorption gas detector. The to be detected gas is CO₂ in this example.

If an IR photon with the right frequency to interact with the given gas, flies through a thin slice with thickness Δx of the measurement volume, the probability to “get caught” by a molecule is proportional to that thickness and to the concentration c of the absorbing gas. The proportionality constant, k , is called the absorption or extinction coefficient. Thus a beam of intensity I passing through this slice will undergo an decrease in intensity given by

$$\Delta I = -kIc\Delta x. \quad (1)$$

Through summing (integrating) up over all slices of the measurement volume with length l , one receives the fundamental law of absorption

$$I = I_0 \exp(-kcl). \quad (2)$$

This relation is called Beer’s law. It can be seen that with given measurement length l , the important quantity to be determined by a gas detector is the intensity ratio I/I_0 . This ratio is a measure for the gas concentration. (It has to be noted that the concentration c here is the particle concentration of the given gas and thus given in molecules per unit volume.)

It was already mentioned that the infrared activity of the gas only occurs at those wavelengths, which can excite higher energy states of the molecules. This makes the absorption coefficient k a strong function of the IR wavelength. The Figure 2 shows some prominent examples of absorption spectra. As common for spectroscopists, the abscissa axis is partitioned in wavenumbers instead in wavelength units. The two measures are directly related through

$$\lambda \text{ in } \mu\text{m} = 10^4 / (\text{wavenumber in } \text{cm}^{-1}).$$

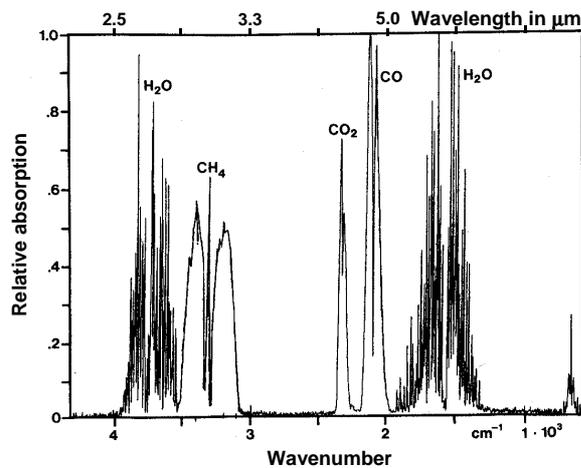


Figure 2: Absorption bands of water, methane, carbon dioxide, and carbon monoxide. The ordinate axis is scaled in arbitrary units for the absorption.

Due to the physical fact that different gases exhibit different absorption spectra, one can therefore dedicate the gas detector to a specific gas by introducing a respective wavelength selective element into the optical path. In industrial applications this is mostly accomplished by an optical filter in front of the detector.

2.2 Improving the gas detector by a reference channel

In Figure 1 the principle setup of a gas detector was already shown: An infrared light source is collimated by an optic onto an infrared detector with the IR bandpass filter in front. The filter transmission is matched to the absorption band of the gas of interest. If a thermopile IR detector is used, the DC output signal decreases with increasing gas concentration. Without absorption, the detector voltage amounts to U_0 , which is a measure for the incoming intensity I_0 as occurring in Beer's formula. With gas present, the resulting voltage ratio U/U_0 equals the quantity I/I_0 occurring in equ. (2).

The difficulty, however, is the determination of the null (zero) signal I_0 , i.e. U_0 . One can of course calibrate the detector, but during long term operation the source intensity may deteriorate due to aging processes. Also if there is a change in the optics due to e.g. contamination, the zero value will inevitably change and lead to incorrect readings.

Therefore, often a dual beam version is employed, where a second detector senses the source in an IR range, where almost no absorption occurs. This is e.g. an IR band of $4.00 \pm 0.02 \mu\text{m}$. In Figure 3 the principle is sketched. For this dual beam application, PerkinElmer features dual detectors in a single housing, with one thermopile carrying the reference filter and the other one the active measurement channel (see paragraph 4.1). This allows a still compact design and because the two detectors are so close to each other, the two light paths are almost identical.

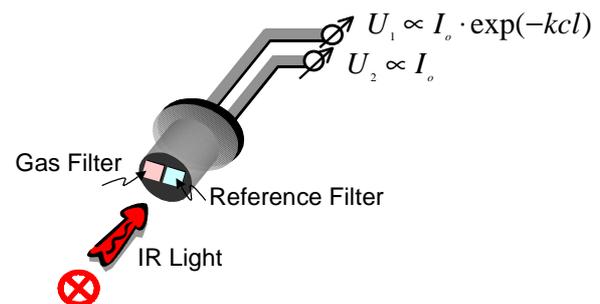


Figure 3: A dual beam arrangement makes the gas detector insensitive to source performance deterioration.

In a dual beam arrangement the measurement value that determines the gas concentration is U_1/U_2 with U_1 being the voltage of the gas channel and U_2 that of the reference channel.

Before we have a closer look into the single components (chapter 4 – with emphasis on the PerkinElmer technology), we will first confer to applications in various fields.

3 Applications in industrial and domestic gas detection

The 'traditional' domain of optical gas detection has always been the high precision industrial instrument market. Because this type of detectors are noted for their extreme reliability and accuracy, IR absorption techniques are the preferred choice in the safety and analytical fields. Many countries have even regulations that vehicle exhaust gas analyzers must be IR-based as long as

Thermal facts



What is NDIR?

The acronym NDIR stands for non-dispersive infrared. It originally refers to a detector type, which employs so-called opto-acoustic sensors. Here, the sensing element is a closed chamber which houses a microphone and the gas to be detected. IR light, which falls into the chamber will heat up the gas due to absorption processes. This heating is accompanied by a pressure increase, which can be sensed by the microphone. The distinctive gas filling in the housing ensures, that only those IR wavelengths generate a signal which correspond to the characteristic absorption lines of the gas.

Thus, any signal loss due to the same gas absorption processes between the IR source and the opto-acoustic sensor will result in a change of the signal in the sensing chamber.

Such type of sensor is based on a true material comparison and does not need any IR selecting (dispersing) elements. Therefore the name NDIR method was chosen.

Today's IR gas sensors mostly feature IR bandpass filters as the gas sensitive elements. Though such a filter is indeed a dispersive element (dispersive in the physical sense means a wavelength dependent transmission characteristics), the technical term NDIR is still featured. In this article, however, the more general term 'IR absorption gas detector' is used throughout.

the analysis of IR active gases are concerned. Instruments which are carried by workers to warn them of explosive gas build up or to check the atmosphere of sewers, tanks and other vessels prior to entry also generally employ the IR gas absorption method. These instruments invariably are "multigas". They have 3 or even 4 sensors included in the package.

New fields are emerging rapidly. Currently, the largest growth is observed in the building technology business. Air quality monitoring by measuring the CO₂ content in public and office rooms becomes more and more an issue and will continue to grow together with the expected decrease in equipment expenses.

The largest potential market, however, is CO detection in households with the purpose for smoke and fire detection. This field is currently covered by solid state sensors, which change their conductivity in the presence of CO (and – mostly unwanted – other gases). This technology is cheap, but the sensors are subjected to steady aging processes, which make a frequent check and replacement necessary. Due to these drawbacks, the IR absorption technology is certainly the better choice, but it needs development in terms of cost and production technique issues.

The following paragraphs which list established and potential applications for thermopile-based IR gas detection are certainly not complete, but provide a glimpse into the power of this technique.

3.1 Industrial applications

3.1.1 Safety market

The following industrial usages of IR absorption gas detectors in the safety market are well ascertained. They mostly need portable, battery powered and lightweight equipment. The devices often feature an alarm signal. Applications:

- confined space entry,
- hazardous area working ,
- gas leak detection,
- landfill gas monitoring.

3.1.2 Analytical instruments

Larger analytical instruments are required for industrial test and measurement applications. These are mostly established and well proven applications:

- measurement of flue gas and automobile exhaust emissions: control of CO₂, CO and unburnt hydrocarbons in stacks or automotive exhausts,
- CO₂ and hydrocarbon content of landfill or digester biogas.

3.1.3 Food processing and farming

Applications of IR gas analysis in food and farming have been showing a continuous growth since several years. In Germany, this growth was mainly triggered by a regulation (TRSK 313, Schankanlagenverordnung), that obligates the employment of a CO₂ detector in rooms, where

pressure devices for beer or other CO₂ containing beverages are located. This indeed affects every bar and restaurant. Due to the regulation, a first alarm level has to be released when the CO₂ level in the room reaches 1.5 vol%. A second alarm level is due when the level comes to 3 vol%.

Other applications in these fields are particular:

- brewing and fermentation,
- measurement of CO₂ levels in food packaging applications (e.g. mineral water or soft drink CO₂ content – this is even possible through the glass bottle),
- mushroom farming,
- monitoring of the CO₂ level in horticulture greenhouse crop production.

3.2 HVAC, IAQ

HVAC stands for heating, ventilation and air conditioning and IAQ for indoor air quality. To hold energy losses low, mostly closed heating and air conditioning systems are employed. Dependent on the number of people in the room or due to other activities (e.g. cooking with gas), the air quality goes down which can be verified by measuring the increase in CO₂ level. Lack of proper ventilation is often associated with the accumulation of other pollutants which may have more harmful effects on building inhabitants or persons in vehicles or other confined areas.

Appropriate ventilation is not only important for personal comfort but as well to economical operation of the heating and air conditioning systems. The USA OSHA (Occupational Safety & Health Administration) lists a STEL (maximum short term exposure limit, 15 minutes) of 30,000 ppm and a TWA (Time Weighted Average exposure limit, 8 hours) of 5000 ppm for CO₂.

There are recommendations by the OSHA indoor air quality rule as of 1995, which require a fresh air supply, if the CO₂ level exceeds 800 ppm.

CO₂ monitoring, as the tracer for air quality is **the** domain of IR absorption detectors. When employing multiple elements, such a detector can at the same time sense the amount of water vapor in the air, because humidity is as well a parameter for air quality.

- Up to now, the market for air quality control equipment was mainly that of large public or office buildings having elaborated air condi-

tioning systems. Thus, CO₂ detector prices were not under too severe price pressure.

- Recently, in Europe, so-called low energy houses are becoming more and more important. Especially Germany with the highest restrictions on house energy consumption (in order to meet the 1997 Kyoto agreement on CO₂ reduction) has a high interest to induce controlled ventilation systems into small office and even private buildings. For these applications, however, lower investment costs are needed.
- In countries, where air conditioning (cooling) in cars is an issue, there are increasing interests to introduce air quality systems into vehicles. This especially helps in the initial stage of cooling down the vehicle's interior, to hold losses due to air supply to a minimum. An air quality sensor in a car can also be employed to sense unhealthy gases entering the air supply channel and close it in that event.

3.3 Medical applications

There is a number of medical applications, where optical gas detection is well established. These cover especially breath control, e.g.

- alcohol content in exhalation breath ,
- patient monitoring of CO₂ content in exhaled breath,
- prenatal supervision by supervising inhaled/exhaled gases.
- In operation areas: monitoring of anaesthetic gases.

3.4 Household applications

To date, IR absorption techniques have not found their way into domestic applications, due to their still high price level. But as prices continue to decrease, the following applications possess an extensive market volume:

- monitoring of CO₂ levels for indoor air quality (IAQ) monitoring (see above),
- detection of natural gas caused by leakages of gas supply systems,
- CO monitoring for smoke and fire alarm. (Here the prerequisite, a low cost IR radiation source for 4.6 μm, needs to be developed and brought into market.)

One can imagine that the future will bring a heater or air conditioning control device, which will not only sense temperature, but at the same time CO₂ level and humidity. Additionally, it will act as a detector and alarm for a gas leakage. The PerkinElmer quad detector TPS 4339 can be the heart of such a system. It employs four gas filters and a temperature sensor.

3.5 Environmental protection

It is the nature of IR absorption gas detection, that the most easiest gases to measure are the greenhouse gases which contribute to the global warming of the atmosphere.

Greenhouse gases include water vapor, carbon dioxide, methane (CH₄), nitrous oxide (N₂O), chlorofluorocarbons (CFCs), and other compounds such as hydrofluorocarbons (HFCs) and perfluorinated carbons (PFCs).

To hold the incorporation especially of the human-made CFCs, HFCs, and PFCs low, precautions must be undertaken, to measure and monitor the concentrations at the location of usage. The semiconductor industry for example, employs a number of HFCs which may go into the atmosphere.* There are restrictions on released concentrations, which are usually measured by means of IR absorption detectors. Only this method allows the proper gas specific measurement.

4 PerkinElmer's thermopile-based gas detector technology

4.1 Thermopile characteristics

PerkinElmer offers a wide range of silicon micromachined thermopile sensors of different types. For an overview on their function please refer to [1].

PerkinElmer thermopiles are CMOS-based devices, which makes them compact and rugged with long lifetimes. PerkinElmer's thermopile technology is one of the industry's most technically advanced.

* For the production of thermopiles, PerkinElmer employs HFCs for its unique etching processes. It is made sure, however, that those gases are not released into the atmosphere, but cracked by an appropriate burning process and subsequently washed out.

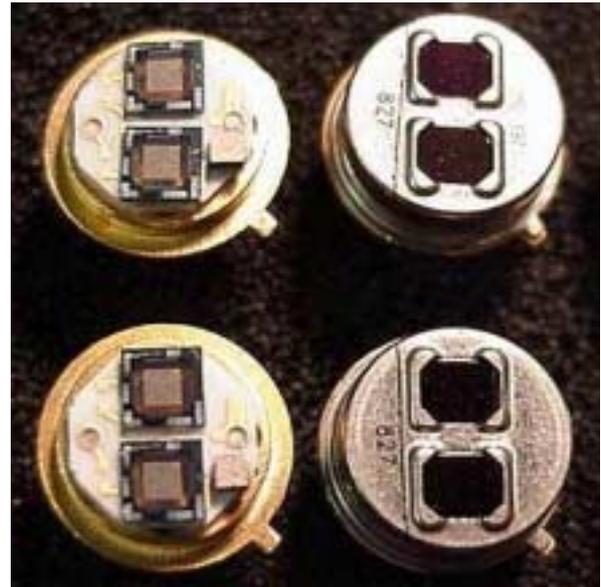


Figure 4: Photo of PerkinElmer dual-thermopile detectors. The left side shows open detectors. Clearly the two thermopiles can be seen. The brown squares in the middle of each sensor chip are the absorber areas, which collect the IR light to be measured. The small cube near to the lower chip is the thermistor which senses the ambient temperature. The right side shows the detectors covered by a cap holding the two different IR-filters.

A thermopile senses IR light through a number of tiny thermoelements placed below an absorber area. The IR light that strikes the absorber heats it up and generates a voltage at the output leads. The output is thus a DC voltage which is a direct measure of the incident radiation power, P_{rad} . Thus, if there is a gas matched IR bandpass filter in front of the thermopile, the decrease in output voltage is directly related to the amount of IR absorption by the respective gas.

Due to the narrow wavelength range, the output signal, U , is typically in the several 10 μ V range and needs amplification. The height of the voltage is determined by the so-called sensitivity of the thermopile, S , which is defined as

$$S = \frac{U}{P_{rad}} \quad (3)$$

and measured in V/W. In datasheets, either the sensitivity without any filter or with a longpass filter is stated. In fact, only the sensitivity without any filter represents the real sensor performance and allows a comparison between different types of devices.

For PerkinElmer thermopiles, the sensitivity without filter is usually in the range of several 10 V/W (please refer to the datasheets for de-

Thermal facts

Regarding the choice of the "right" detector

It is the specific detectivity D^* , which determines the detector limited gas sensitivity or the resolution of an IR absorption detector. D^* contains the absorber area of the detector. Therefore, people tend to simply compare detectors by their area, which indeed should be as large as possible, but is in fact a too simple approach.

For a thermopile, a larger area often means an increased sensor resistance and concomitantly, a larger noise signal and thus a smaller signal-to-noise ratio. Also, other properties of the sensor, namely the sensitivity, may either be higher or lower, when comparing detectors with different areas.

Therefore, one should refer to the specific detectivity D^* and here preferably to the value without IR filter for a better comparison.

tailed values). With the narrow IR bandpass gas filter in front, and when taking the radiation, which incidences the filter as a base, it decreases typically slightly more than an order of magnitude.

It has to be noted, that the sensitivity not solely determines the lower detection limit for a gas or the resolution of the gas measurement. To discuss this, consider the following: For a given radiation power density p_{rad} (in W/m^2) the output signal U of the detector will be $U = p_{rad} \cdot A_D \cdot S \propto A_D S$. This output signal is however distorted due the noise u_{noise} (in W/\sqrt{Hz}) generated by the detector. Of course, the lower the noise signal the better. Therefore we can define a figure of merit for the resolution of an IR gas detector by $A_D \cdot S / u_{noise}$. For some reasons, the square root of the detector area will be used leading to

$$\frac{\sqrt{A_D} \cdot S}{u_{noise}} \equiv D^* \quad (4)$$

This quantity D^* is referred to as specific detectivity and is usually measured in $cm\sqrt{Hz} / W$. D^* is applicable for the comparison of thermopile performances, but also when relating between different types of detectors, such as pyroelectric

sensors or photoconductive/-voltaic (photonic) semiconductors.



Figure 5: The quad thermopile sensor TPS 4339 houses four thermopile chips in a single TO 5 case. The open detectors in the lower row show clearly the internal aperture, that suppresses successfully any crosstalk between the four channels. Even this sensor type employs a thermistor (the small cube in the upper right position) to provide an internal temperature reference. The upper row shows closed sensors carrying four different IR bandpass gas filters.

A typical D^* value for a thermopile is $10^8 cm\sqrt{Hz} / W$, which equals to the specific detectivity of pyroelectric sensors, but is about an order of magnitude lower than a good photonic detector.

The large advantage of thermopiles over photonic detectors is their almost constant sensitivity and specific detectivity over the IR spectrum. Therefore the thermopile is an excellent detector choice for gas absorption instruments. Because of its broad spectral response, it can, when combined with the proper IR bandpass filter, measure virtually any gas.

Table 1 provides a list of PerkinElmer thermopiles which are appropriate for gas detection. Besides the classical single elements and the already referenced dual thermopile, there is a quad sensor listed. This is a new device, which features four thermopiles in a single TO5 housing (the cap has a diameter of 8.3 mm) together with a thermistor as temperature reference. The quad thermopile can thus sense four different IR bands. In a standard version, the detector is equipped with a reference filter and filters for CO_2 , CO and methane.

Series	Type of sensor	Housing	Absorber size [mm ²]	Sensit., S w/o filter [V/W]	D* w/o filter [cmHz ^{0.5} /W]
TPS 3xx	single	TO18	0.7 · 0.7	65	1.4 · 10 ⁸
5xx	single	TO5	1.2 · 1.2	42	2 · 10 ⁸
2534	dual	TO5	1.2 · 1.2 each	42 each	2 · 10 ⁸ each
4339	quad	TO5	0.7 · 0.7 each	65 each	1.4 · 10 ⁸ each

Table 1: Selection of PerkinElmer thermopiles applicable for gas detection by infrared absorption. The dual detector houses two single TPS 5xx and the quad detector four TPS 3xx sensors in a single TO5 case. Single detectors are available in TO5 as well as in even smaller TO18 housings.

 To summarize, PerkinElmer thermopiles for gas detection are characterized by:

- a fast response time in the 10...40 ms range,
- a high sensitivity of several 10 V/W,
- being DC radiation sensitive, which allows flexible signal evaluation techniques,
- their self generating signal behaviour, which makes any additional power connection unnecessary,
- an extremely low temperature coefficient,
- an almost constant response behaviour over the IR spectrum,
- the absence of any microphonic noise effects,
- low susceptibility to electromagnetic pulses (EMP) due to the low internal resistivity (< 100 kΩ),
- having a built-in ambient temperature reference (thermistor),
- having a low crosstalk between individual channels,
- being rugged, featuring a long duration lifetime due to modern CMOS silicon micro-machining technology.

4.2 Characteristics of IR gas filters

In IR absorption gas sensors, an infrared optical filter with a narrow band of transmission is selected to overlap with the absorption band of interest. The transmission characteristics of the filter determine the gas to be measured and the amount of absorption determines the gas concen-

tration present. The infrared filter is chosen to ensure that the sensor is totally gas specific.

An IR bandpass filter consists of a number of dielectric layers on a substrate [2]. PerkinElmer usually employs silicon as substrate material. The thickness and the number of deposited layers on the silicon determine the transmission characteristics of the filter. In Figure 6 those parameters are visualized, which are important measures for the filter specifications.

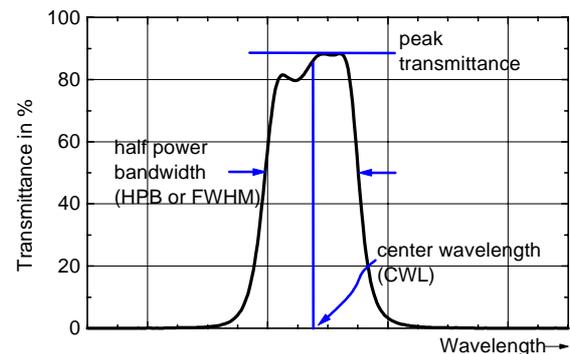


Figure 6: Visualization of characteristic IR bandpass filter parameters.

The most significant value is the center wavelength, CWL, since it determines the position of the filter. It is usually specified in micrometers. The width of the filter curve at the half power point is often called the “half power bandwidth” (HPB) or the “full width at half maximum” (FWHM). This value is also specified in wavelength units, i.e. micrometer or nanometer.

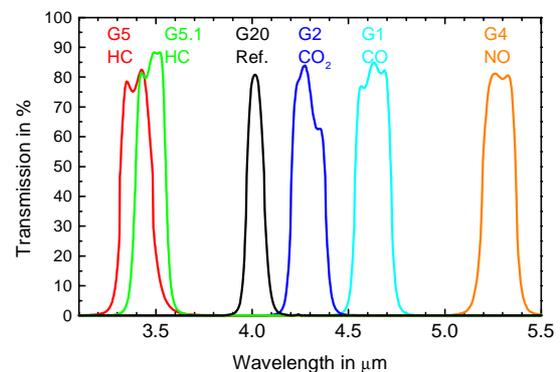


Figure 7: Bandpass characteristics of PerkinElmer IR gas filters. Filters are identified by a “G” number. The respective matching gas is marked.

The quality of a filter is often stated by the quotient HPB/CWL, which gives the relative open-

ing of the filter on the wavelength scale. This opening ranges typically from 1% to 6% of the center wavelength. Thus, often a filter is referred to as e.g. a 4% 4.6 μm filter (this refers to a filter with 185 nm half power bandwidth).

The third important characteristics is the peak transmittance. This ranges for normal filters from about 70 to 80%.

Identifier	Matching gas	HPB/CWL	center wavelength (CWL) [μm]	half power bandwidth (HPB, FWHM) [nm]
G5.3	HC	5.2%	3.09 ± 0.030	160 ± 20
G5.2	HC (CH ₄)	4.8%	3.30 ± 0.033	160 ± 20
G5	HC	5.3%	3.40 ± 0.070	180 ± 20
G5.1	HC	4.7%	3.46 ± 0.050	163 ± 10
G20	Reference	2.3%	4.00 ± 0.080	90 ± 20
G2	CO ₂	4.2%	4.26 ± 0.043	180 ± 20
G2.3	CO ₂	2%	4.30 ± 0.033	85 ± 10
G2.2	CO ₂	1.4%	4.43 ± 0.040	60 ± 5
G1	CO	3.9%	4.64 ± 0.047	180 ± 20
G4	NO	3.4%	5.30 ± 0.053	180 ± 20

Table 2: Selection of PerkinElmer standard IR bandpass filters for gas analysis. All filters are silicon based.

Figure 7 shows typical transmittance curves of PerkinElmer standard bandpass filters and Table 2 lists the specifications of those and some additional filters.

 It has to be noted that the transmission characteristics for an IR bandpass filter are only valid and specified for normal radiation incidence and for a temperature of 300 K.

4.2.1 Non-normal radiation incidence

If, in an application, the IR beam onto the filter is not well collimated, which means that a bundle of rays within a certain cone angle incidences the filter, the center wavelength, the bandwidth, and the peak transmittance will change.

The changes are [3]:

- The center wavelength will shift towards lower values. (For a 30° half cone angle a typical shift amounts to 40 nm, which in

many cases already exceeds the tolerance of the CWL position.)

- The bandwidth will slightly increase. (Again for 30° half cone angle it increases typically by 10%).

To hold any errors and changes negligible, which are due to the shifting of the filter characteristics, one should make sure that the incidence half cone angle will not exceed about 20°. This means one must either make sure that the total field of view of the sensor is at a maximum of 40° or the incident radiation from the IR source must be collimated appropriately.

4.2.2 Temperature shift

When the temperature varies, the optical thickness of the filter layers change due to thermal expansion and due to the changes in the refractive indices. This leads typically to CWL shifts of about 0.01 %/K.

The filter shifts towards longer wavelengths when the temperature increases. Concomitantly, the peak transmittance decreases. When lowering the temperature, the CWL shifts into the opposite direction as well as the peak transmittance may increase. In both cases out of band peaks may develop.

These changes lead to a signal alteration when the temperature varies, which – dependent on the desired accuracy – have to be taken into account. Since the temperature dependence can be very complicated, these corrections have to be performed empirically.

4.2.3 Positioning of the IR filter in respect to the absorption lines

When employing a multigas detector like the quad device TPS 4339, the length of the absorption chamber has to be adapted to that gas, which shows the weakest absorption (either due to its low absorption coefficient or due to a low concentration value to be detected). The most prominent example is the concomitant measurement of CO and CO₂.

In automobile exhaust gas checks, the CO measurement range lies in the percent region, whereas that of CO₂ may far exceed 10%. Unfortunately, the absorption coefficient of CO₂ is about a magnitude larger than that of CO. When placing both IR bandpass filters in the middle on the strongest absorption lines, respectively, one will receive

extremely different signal characteristics. If in this case the chamber length is adjusted for the weak CO absorption, the CO₂ signal will already saturate at very low concentration values. A measurement into the several percent region of CO₂ is not possible in that case, because the respective IR wavelengths are already fully attenuated. Making the chamber shorter to adjust for the CO₂ signal, the CO measurement will become impossible because of the resulting weak signals.

This situation occurs when e.g. employing the filters G1 for CO and G2 (or G2.3) for CO₂ as sketched in the Figure 8.

Therefore, in such a situation, where large CO₂ concentrations have to be measured together with weak absorbing CO, a CO₂ filter should be employed, which is placed on the shoulder of the spectral absorption region. The G2.2 CO₂ filter is the right choice in this case. It has its transmission window in a region, where the CO₂ absorption occurs already at the same strength as that of CO. This positioning adjusts for the large differences.

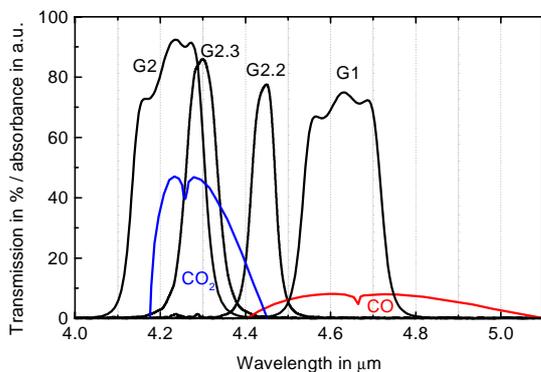


Figure 8: CO₂ and CO absorption regions (schematically sketched for high concentrations) together with the position of some PerkinElmer IR filters for these gases. The relatively broad G2 filter covers most of the CO₂ absorption region. G2.3 is placed on the strongest lines. The filter G2.2 is located in a region, where the absorption strength already approaches that of CO.

The placement of the CO₂ filter on the upper edge of the 4.18...4.44 μm absorption spectrum (G2.2) is a well established method. It has, however, some points to consider in practical application.

- If the CO concentration is large, as occurring in vehicle exhaust gas measurements, a crosstalk in the CO₂ channel appears, which

has to be corrected. This crosstalk is in all practical cases purely additive and can be easily determined.

- Every filter has inevitable tolerances in CW position and bandwidth. Since the G2.2 filter is placed on a region where the absorption characteristics vary considerably over the wavelength, the resulting detector signal may vary as well between different filter batches. This has to be taken into account for the design of the detector amplifier.

4.3 Characteristics of infrared sources

The IR absorption gas detector needs an infrared source for the excitation of the gas molecules. Thermal radiators are usually employed for this task. Their operation temperature should be as high as possible to obtain a large radiation power and concomitantly a large detector output signal.

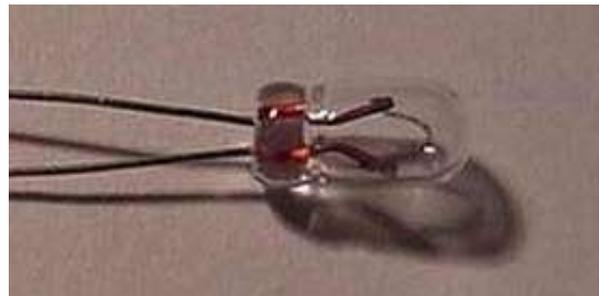


Figure 9: Glass housed thermal radiator as IR source for the range 2 to 4.6 μm (PerkinElmer IRL 715).

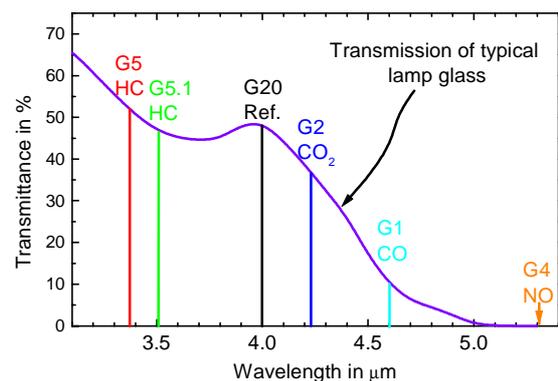


Figure 10: The curve shows the transmission characteristics of a typical lamp glass together with the center position of some gas absorption bands. The intensity of the IR light decreases above 4 μm with a cutoff wavelength, which is located at 5 μm. The CO₂ absorption is still well within a high intensity region, whereas the detection of CO is already extremely difficult due to the limited IR output.

Since often a protective encapsulation of the heated filament is needed, one has to make sure that the housing is transparent for the desired radiation wavelength. For example, a glass encapsulated IR source as shown in Figure 9 (PerkinElmer IRL 715) is only applicable for wavelengths below $4.6\ \mu\text{m}$, because of the limited glass transmission characteristics (cf. plot in Figure 10).

Such a lamp-like thermal source is indeed very economic in terms of costs, but it has the stated drawback of the limited accessible IR range. For CO_2 and HC detection it is however still a perfect choice. When employing a lamp for this purpose, one has to select a type which exhibits

- a long lifetime,
- a high IR output efficiency,
- geometric accuracy in filament position, and
- a low thermal time constant (high modulation depth).

The last listed parameter is an important characteristic, since the source is mostly modulated (switched on and off) during detection operation. Since the lifetimes are typically in the several hundred millisecond range, the resulting AC output at – let’s say – 1 Hz modulation frequency is therefore greatly dependent on this parameter (cf. Figure 11).

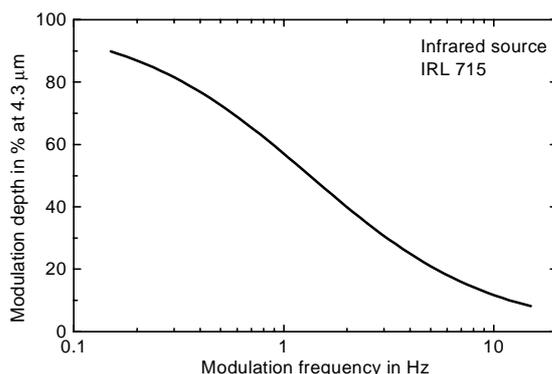


Figure 11: Modulation depth at $4.2\ \mu\text{m}$ as a function of modulation frequency of the IR source IRL 715. The resulting curve shows a typical low pass behaviour with a thermal time constant of 290 ms. (Remark: the time constant for radiation in the visible spectrum as sometimes stated in data sheets is considerably shorter.)

The PerkinElmer IRL 715 has been proven to be a reliable and efficient source for the stated IR

range, which means it is especially suited for the detection of CO_2 and HC.

5 Summary and contact address

The article’s scope was to assist the reader in employing PerkinElmer Optoelectronics’ thermopile technology for the design and development of optical absorption gas detectors (NDIR technology). Please feel free to ask for further details and component characteristics, offered by PerkinElmer for thermopile-based IR gas detectors. These are namely

- thermopile sensors (single, dual, quad elements),
- IR filters, and
- IR sources.

In addition, PerkinElmer assists customers in the development of gas detector solutions by

- providing technical consultancy,
- aiding in the development of special components (e.g. optical IR parts).

Contact

Please contact PerkinElmer Optoelectronics directly in Wiesbaden, Germany, or through one of the various offices worldwide. Their addresses together with additional information are obtainable from our websites:

<http://www.perkinelmer.com> or contact directly:

Dr. Helmut Kriz,
 tel: +49-(0)611-492-500,
 fax: +49-(0)611-492-228,
 e-mail: helmut.kriz@perkinelmer.com

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