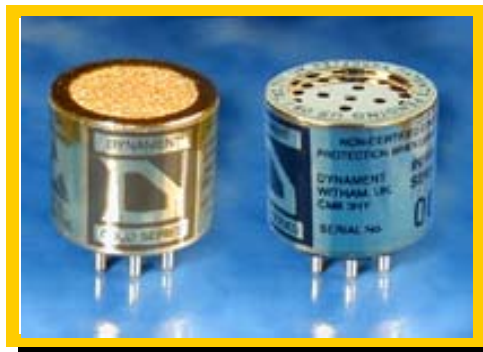


## Application Note AN3

### MINIATURE INFRARED GAS SENSORS GOLD SERIES

UK Patent App. No. 2372099A  
 USA Patent App. No. 09/783,711  
 World Patents Pending

### SIGNAL EXTRACTION



### Introduction

Light incident on a macroscopic system can be reflected, transmitted, refracted or absorbed. The fraction of incident light absorbed can be expressed by the relationship

$$-dl/l = bdx$$

where  $l$  is the intensity of light at a distance  $x$  from its entry into the medium and  $b$  is called the absorption coefficient. On integration with the boundary condition  $l = l_0$  at  $x = 0$  this leads to

$$l = l_0 e^{-bx}$$

In 1852, Beer showed that the coefficient  $b$  is proportional to the concentration of the absorber and thus led to Beer's Law:

$$\log(l/l_0) = -\epsilon cl$$

where  $c$  is the molar concentration,  $l$  is the pathlength and  $\epsilon$  is called the molar absorption coefficient or extinction coefficient.

However, this law is obeyed strictly only for monochromatic light.

The NDIR method views the intensity of a range of wavelengths within a passband defined by the optical filter employed in the detector, as opposed to viewing a single wavelength. Therefore the resulting intensity is a function of a range of extinction coefficients, one for each individual wavelength within the active passband used. One effect of this technique is that the initial boundary condition  $l = l_0$  at  $x = 0$  still applies but the other boundary condition  $l = 0$  at  $x = \infty$  does not since some wavelengths within the passband may not be absorbed.

Two main sources of non absorbing wavelengths are:

- Spectra where there are non absorbing wavelengths interspersed with absorbing wavelengths (eg carbon dioxide or methane)
- Where the passband of the filter is wider than the absorption peak of the target molecule, allowing non absorbing wavelengths at one or both sides of the absorption peak to contribute to the signal.

The effect of this is to modify the intensity law to the form:

$$I = I_0 * ((1-S) * e^{-bx} + S)$$

Where  $S$  is the contribution to the intensity caused by non-absorbing wavelengths. This maintains the boundary condition  $I = I_0$  at  $x = 0$  and defines the boundary condition  $I = SI_0$  at  $x = \infty$ , this being the contribution to the signal caused by non-absorbing wavelengths.

In addition, the exponential factor is modified by the fact that a passband monitors an integrated form of the product  $b \times$ . Since for each individual wavelength the product  $b \times$  is inseparable, the exponent of the summation can be converted into a useable form via the relationship:

$$\exp(-\sum\{b \times\}) = \exp(-\alpha x^\beta)$$

where  $\alpha$  is a constant related to a mean value of  $el$  in Beer's law and  $\beta$  is a spectrum related constant.

### Determining the gas concentration

The above discussion leads to the following modification to the intensity law:

$$I = I_0 * ((1-S) * \exp(-\alpha x^\beta) + S)$$

In order to use this relationship the individual components are defined as follows:

$I$  = Intensity of the detector signal. This is the peak-to-peak value of the detector output which is modified by the presence of target gas.

$I_0$  = Intensity of the detector signal in the absence of target gas. This can be determined from the peak-to-peak value of the reference output  $I_r$  and the peak to peak value of both the detector and reference outputs in the absence of target gas. This should be continuously monitored using the correlation  $I_0 = I_r * (I/I_r)_0$  where  $(I/I_r)_0$  is the ratio of detector output to reference output in the absence of target gas and can be denoted by the symbol  $Z$  which constitutes a zero level.

$S$  = Non absorbing wavelength contribution to the signal. The range of the absorbing contribution is defined by  $(1-S)$  which constitutes a span level.

$x$  = Target gas concentration in units defined by the units of  $\alpha$ .

$\alpha$  = Exponential constant that also defines the units of the target gas concentration

$\beta$  = Power constant dependent on the spectrum of the target gas.

Therefore in terms of the signals from the detector ( $I$ ) and the reference ( $I_r$ ) this results in the relationship:

$$(I/(Z * I_r) - S) / (1 - S) = \exp(-\alpha x^\beta)$$

and the gas concentration  $x$  can therefore be found from the rearrangement:

$$x = (-\ln \{ (I/(Z * I_r) - S) / (\alpha * (1 - S)) \})^{1/\beta}$$

where  $x$  is the gas concentration,  $Z$  is the zero factor equal to  $(I/I_r)_0$ ,  $S$  is the span factor equal to the asymptote of the ratio change with increasing gas concentration,  $\alpha$  is a constant and  $\beta$  is a constant.

The intensity law equation can also be rearranged to produce the equivalent relationship in terms of absorbance, where absorbance is defined as  $(1 - I/(Z^*I_r))$ :

$$(1 - I/(Z^*I_r)) = (1 - S) * (1 - \exp(-\alpha x^\beta))$$

and the gas concentration  $x$  can therefore also be found from the rearrangement:

$$x = (-\ln \{ 1 - (1 - I/(Z^*I_r))/(1 - S) \} / \alpha)^{1/\beta}$$

In this case the span factor is equal to  $(1 - S)$  and all other factors and constants are as described above.



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