An integrated optical gas sensor with improved sensitivity and time response

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A novel integrated optical ammonia sensor can be fabricated using refined waveguides, a highly-stable electronic comparison scheme, and computerized data storage and processing.

The ability to detect gases such as CO, NO₂, NH₃, SO₂, and O₃ is important in several different fields ranging from environmental monitoring to ecology, medicine, chemistry, defense, and homeland security. Different types of sensors have been designed based on various physical and chemical properties.⁴ Environmental monitoring and physical ecology, in particular, require the development of sensors that can determine parameters such as temperature, pressure, humidity, composition of mixtures, and gas concentration. Progress in this area is closely related to advances in opto-chemical sensor technology. The interest generated for these new sensors is related to their advantages: high sensitivity, fast response, potential for remote sensing, simplicity of signal multiplexing, and applicability to integrated technologies.

The most promising are the integrated opto-chemical sensors.¹,³ Their operating principle is based on detecting the variation in the laser radiation intensity transmitted by the gaseous or liquid sample at characteristic wavelengths. The well-known Bouguer-Lambert-Beer law can then be used to determine concentrations.³ The challenge lies in building an easy-to-use, compact, accurate, and reliable sensor with a fast signal response that can measure ultra-low atmospheric concentrations of various substances.

The purpose of our work is to demonstrate that the development of integrated optical sensors¹–⁴ is a promising trend for environmental and, particularly, atmospheric monitoring. Their sensitivity can be significantly increased and their signal response times decreased if measurements are performed using analog-to-digital converters, with a stable electronic comparison scheme linked to computerized data storage and processing.

Our integrated optical sensor is a diffuse waveguide fabricated by doping a glass substrate with PbO₂. For the substrate plates, we use K₈ glass with a 14th-class surface finish roughness. The cell length, i.e. the distance between the input and output prisms, is 4cm. The measured attenuation in the refined waveguide is on average no greater than 0.1cm⁻¹ for the fundamental transverse-electric mode (TE mode) with an effective refractive index of 1.521. The coupling prisms are made of TF-5 glass with a refractive index of 1.7497 (at a wavelength of 632.8nm).

Figure 1 shows the schematics of the measurement setup. The 632.8nm line of a helium-neon laser, which coincides with one of the ammonia absorption bands, is used as radiation source. The incident beam is split into reference and sensor beams. The sensor beam is directed into the integrated optical waveguide at an angle that corresponds to the resonant excitation of the TE mode. The radiation emerging from the waveguide is measured

Figure 1. Scheme of the integrated opto-chemical sensor measurement setup. PD: photodetector.
with photodetector 1 (PD 1), whose signal is fed to the comparison scheme. The reference beam signal, measured with photodetector 2 (PD 2) is also channelled to the comparison scheme. After analog-to-digital conversion, the signal is recorded and processed with a computer. In our measurements, we recorded a signal-to-noise ratio (S/N) of approximately 15 with a sensor time response of 0.2s. Figure 1 shows that when ammonia is detected by the sensor cell, the output laser light power decreases.

The experimental value of the ammonia concentration (~2ppm) measured with this sensor was close to the minimum ammonia concentration detected with sensors of this type.\(^1,3\)

Several approaches have been proposed to increase the sensitivity of the sensor.\(^1-3\) For instance, the length of the absorbing cell can be increased. Its configuration can also be modified, for example by using Bragg mirrors or a cylindrical rod substrate. The S/N can also be increased. Finally, sensor elements such as radiation source, absorbing cell, and photodetector could be integrated on a single substrate.

To achieve high sensitivity and optimal signal response, we use refined waveguides, highly stable electronics for the comparison module, computerized data storage and processing, and also decreased the laser light scattering resulting from bulk heterogeneities in the waveguides. Computer modeling has shown that the theoretical value of the minimum ammonia concentration measured with this sensor can be less than 0.1 ppm with a S/N exceeding 20. This ratio can be further increased using a substrate with lower roughness surface. We did not analyze the effect of waveguide light scattering due to irregularities, since this issue has already been addressed in detail.\(^4-8\)

In conclusion, we have characterized an integrated optical ammonia sensor. The device exhibits high metrological performance (sensitivity, accuracy, linearity, reproducibility of results, fast response, absence of hysteresis, and relatively high S/N). It is also reliable and easy to manufacture.

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