The Potential for Development of an NH₃ Optical Fibre Gas Sensor

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Abstract. This paper describes the potential for the future development of comparatively low cost ultra-violet optical fibre ammonia gas detection systems. The potential for the construction of these systems using low-cost optoelectronic components is described. By experiment, it is shown that sub-ppm limits of detection that can be realised.

1. Introduction
There is a need for ammonia (NH₃) detection equipment addressing the needs of several different industries. This paper reviews NH₃ gas detection methods and discusses how Ultra-Violet (UV) fibre-optic sensors can complement existing NH₃ sensors. Experimental results are also included indicating the likely performance of low-cost NH₃ fibre optic sensors. Existing NH₃ gas sensing technologies are deployed in semiconductor, agricultural, medical, petrochemical, refrigeration and meat processing industries and this paper gives a description of where an NH₃ fibre-optic gas sensor could complement existing technologies.

The issues surrounding a number of important applications areas are highlighted below.

1.1. Agricultural Industries
Accurate NH₃ gas monitoring is required in agricultural environments. For example, concentrations of 10s of ppm of NH₃ can be present within, or in the emissions from, Feed Operations (AFOs) [1]. This presents an environmental pollution danger and poses risks for human and animal health. Existing established micro-meteorological diffusion ammonia sensors for agricultural application are mostly cumulative chemical sensors that measure NH₃ exposure over a set time period [2] and consequently require regular onsite service. A present optical fibre NH₃ sensor technology uses the evanescent field to detect the presence of NH₃ in the near-mid infrared [3].

1.2. Semiconductor Industries
The difficulties that NH₃ gas, or other amine gases can lead to in a clean room environment, are channel deformations or T-topping [4]. Currently available clean room ammonia sensors are typically gas diffusion conductivity sensors, which are located in the ventilation ducts of clean...
rooms. Typically the NH₃ gas Limit of Detection (LoD) requirement in this field is of the order of parts-per-billion (ppb). Gas diffusion sensors, which are currently deployed in clean room environments, attain this LoD. However, the response time is slow. An UV fibre-optic direct absorption fibre-optic sensor would offer a fast response time, and if a distributed measurement was made it would locate the source of the contamination.

1.3. Other Applications of NH₃ Detection

NH₃ gas is recognised as an irritant. It is recognised that long term exposure to concentrations exceeding 8ppm and short term exposures to concentrations exceeding 35ppm may be harmful to human health [5]. NH₃ gas is used frequently in petrochemical plants, as a refrigerant and within meat processing plants. Low-cost optical fibre ammonia detection systems would also be of use for monitoring process performance and health and safety monitoring.

The gas spectral absorption data for NH₃ at around 200nm is included in the Mainz Spectral Atlas of Gaseous Molecules [6] and was originally measured by Chen et al. [7]. This will allow comprehensive evaluation of a UV NH₃ gas detection system.

2. Experimental Arrangement

An evaluation of the NH₃ detection system developed for this work was conducted and a schematic of the apparatus used is shown in Figure 1.

![Schematic of the utilised NH₃ gas detection system](image)

Figure 1: Schematic of the utilised NH₃ gas detection system

The apparatus used is described in terms of four major sections, which are:

1. The optical source shown in Figure 1 is a DH2000 deuterium optical source. Currently this is the most readily available deep UV source, which emits down to approximately 190nm, enabling interrogation of the NH₃ gas absorption located at around 200nm. For this reason this deuterium source was chosen as the UV NH₃ demonstration source. In the longer term a suitable replacement for this could be a super-continuum source that would allow access to the deep UV. LED based sources are not currently available below 250nm in the deep UV.

2. The gas cell employed for the experiment was a stainless steel cylinder, with appropriate gas couplings (605mm long and 8mm Inner Diameter). This was suitable for previous experiments at
higher wavelengths. However, for the NH$_3$ experiment it exhibited a high optical power loss. In the future it is proposed to construct a similar gas cell with higher optical power transmission.

3. An Ocean Optics HR2000 spectrometer was used as the Optical Detection equipment. In the design of an NH$_3$ sensor from discrete components this could be replaced with discrete optical photodiodes and UV optical filters.

4. In this experiment the computational analytical software used was an installation of LabView™. Equally, a custom application could have been implemented.

3. Experimental Results

Figure 2 shows a deep-UV spectrum that was recorded using the equipment. This shows that with 100ppm NH$_3$ gas present in the gas cell and a measurement integration time of 1s, a relatively low noise UV absorption spectrum was measured. A Limit of Detection (LoD) of the order of 1ppm was obtained.

![NH$_3$ Absorption Spectrum](image)

Figure 2: Graphical representation of NH$_3$ absorption spectrum between 200nm and 220nm. The measurement was taken using the apparatus shown in Figure 1

Future optimally designed gas cells and optimised calibration wavelengths in a DOAS system are likely to allow the detection of at least 100s of parts per billion of NH$_3$. 


4. Conclusion

This paper has shown that, with future optimisation of low-cost UV optical fibre sensors, the detection of NH$_3$ at sub-ppm LODs will be achievable. This will enable the widespread deployment of high resolution optical fibre based sensors into semiconductor plant and agricultural environments. Work is continuing in this area.

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References

1. The Scientific Basis for estimating Emissions. 2000, Committee on Air Emissions from Animal Feeding Operations, Division on Earth and Life Studies, National Research Council, National Academy Press: Washington, D.C.
2. Meyers, T.P. and D.D. Baldocchi, Current Micrometeorological Flux Methodologies with Applications in Agriculture, in Micrometeorological Measurements in Agricultural Systems. 2005, American Agronomy Society. p. 381--396.
3. MacCraith, B.D., et al., Sol-gel coatings for optical chemical sensors and biosensors. Sensors and Actuators B, 1995. 29: p. 51-57.
4. Sun, P. and C. Ayre. Characterization of organic components outgasses from materials used in semiconductor (FABS)/processing. in Frontiers of Characterization and Metrology for Nanoelectronics. 2007. Gaithersburg, Maryland: National Institute of Standards and Technology.
5. Gases, B., Ammonia safety datasheet. 2000, BOC Gases.
6. Keller-Rudek, H. and G.K. Moortgat, MPI-Mainz-UV-VIS Spectral Atlas of Gaseous Molecules.
7. Chen, F.Z., et al., Low and room temperature photoabsorption cross sections of NH$_3$ in the UV region. Planetary and Space Science, 1999. 47: p. 261-266.