STAND-OFF DETECTION OF HYDROGEN CONCENTRATION

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ABSTRACT

The ability to remotely monitor hydrogen and map its concentration is a pressing challenge in large scale production and distribution as well as other sectors such as nuclear storage. We present a photonics-based approach for the stand-off sensing and mapping of hydrogen concentration capable of detecting and locating <0.1% concentrations at 100m distance. The technique identifies the wavelength of light resulting from interaction with laser pulses via Raman scattering [1] and can identify a range of other gas species, e.g. hydrocarbons, ammonia, by the spectroscopic analysis of the wavelengths present in the return signal. LIDAR, Light Detection and Ranging – analogous to Radar, is used for ranging. Laser-based techniques for the stand-off detection of hydrocarbons frequently employ absorption of light at specific wavelengths which are characteristic of the gas species. Unfortunately, Hydrogen does not exhibit strong absorption, however, it does exhibit strong Raman scattering when excited in the UV wavelength range. Raman scattering is a comparatively weak effect. However, the use of solid-state detectors capable of detecting single photons, known as SPADS (Single Photon Avalanche Photodiode), enables the detection of low concentrations at range while making use of precise time-of-flight range location correlation. The initial safety case which necessitated our development of stand-off hydrogen sensing was the condition monitoring of stored nuclear waste, supported and funded by Sellafield and the National Nuclear Laboratory in the UK. A deployable version of the device has been developed and hydrogen characterisation has been carried out in an active nucelar store. Prior to deployment a full ignition risk assessment was carried out. To the best of our knowledge this technique is the strongest candidate for the remote, stand-off sensing of hydrogen [2][3].

1.0 REMOTE SENSING USING LASERS

1.1 Laser Sensing Introduction

The use of lasers for remote sensing and identification of a variety of substances is well established. The characteristics of a laser (a narrow beam with many photons interacting with the substance) lend itself to remote sensing. Typically, a laser can be selected with an emission wavelength which is matched to a part of the spectrum with maximises the generated signal.

1.2 Raman Spectroscopy

Stand-off sensing using lasers frequently uses the absorption of light at specific wavelengths to identify a substance through its unique absorption spectrum. For example, many hydrocarbons absorb infra-red light at specific wavelengths allowing the use of absorption spectroscopy for stand-off detection. In this regard, the sensing of hydrogen presents a challenge as it only weakly interacts with light via absorption. However, hydrogen does display relatively strong interaction with light via Raman excitation. In Raman excitation, incident photons are scattered inelastically by a molecule to a different wavelength. The shift in wavelength between the incident photon and scattered photon is characteristic of the molecule.

1.3 LIDAR

The principle of LIDAR is like Radar and Sonar except that pulses of light are used rather than radio or sound waves. Distance can be calculated by measuring the time of flight of a returned photon. Here, the returned photons are generated via the Raman scattering from a hydrogen cloud rather than the reflection from a hard target.

1.4 SPAD Photodetectors

Although the Raman effect associated with hydrogen is relatively strong, the number of photons returned to the detector is small, requiring sensitivity down to the single-photon level. For example, if a pulse of excitation laser consists of 10^{17} photons then the returned Raman scattered photons might only amount to around 10 or so. However, one advantage of using a pulsed laser source is the ability to average over many pulses and build a statistical picture of the signal.

Furthermore, time of flight measurements of pulses traveling at the speed of light requires excellent time resolution. Fortunately, the dual challenges of sensitivity to low photon levels plus time resolution can be met using a new type of photo-detector, the Single Photon Avalanche Photodiode, SPAD, which is employed in the system.

2.0 PROOF OF CONCEPT SYSTEM

A proof-of-concept system was developed as part of the Game Changers open innovation program in conjunction with Sellafield and the National Nuclear Laboratory, UK.

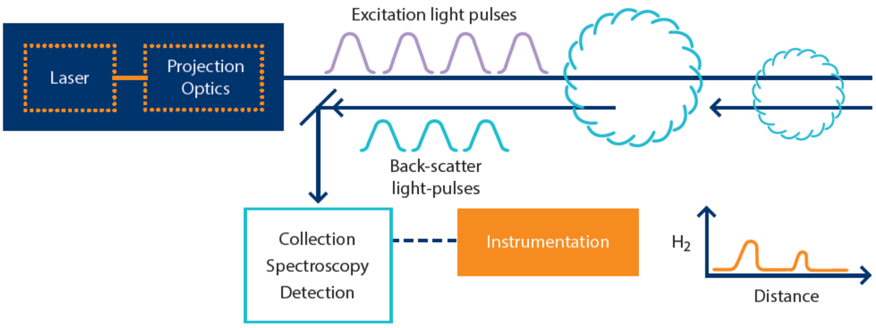

Figure 1. Schematic of proof-of-concept system

The complete system consists of:

- The laser source, an at hand commercial laser was used in the feasibility system, generating pulses of light in the UV with up to 20 mW average power used in this study.
- Projection optics, taking the laser beam and collimating it with a suitable beam diameter and with beam pointing control.
- Collection telescope, a reflective telescope gathers the returned light from the beam line and collects it for delivery to the spectroscopy module and sensors.
- Spectroscopy module, the light collected by the telescope will comprise photons of different wavelengths originating from various processes including backscattered laser excitation photons, fluorescence, reflection from hard surfaces, and the Raman scattered photons of interest. A series of optical filters separates these wavelengths into individual SPAD sensors.
- Instrumentation, comprising the collection of photon counts from the various channels plus time-of-flight analysis.

A suitable non-laboratory test space was identified, and the detection system set up at one end with a series of hydrogen sources arranged along the beamline. The overall length of the beam path was limited by the space and was ~50 m.

Figure 2. Test space used for proof-of-concept demonstration. A mixture of dry air and hydrogen was released into the horizontal pipes. The laser beam line is along the horizontal and through the horizontal pipes.

3.0 RESULTS

The figure below shows H_2 and H_2O as a function of distance. In this case, a mixture of dry air and hydrogen was released at two points along the beamline (illustrated by grey shading), the concentrations were 1 % and 0.1%. The excitation laser beam first passes the high concentration before encountering the lower concentration.

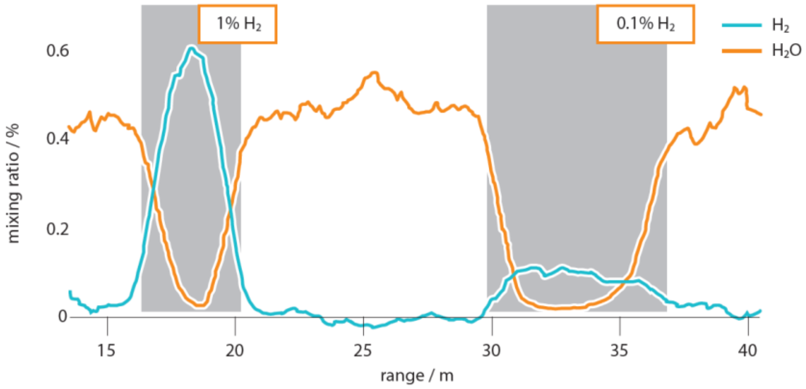

Figure 3. H2 and H2O concentration as a function of range along the beam path.

Based upon analysis of the measured data and bearing in mind this was a non-optimised proof-of-concept system, Fraunhofer CAP believes that the detection of sub 0.1 % concentrations of hydrogen at 100 m is feasible.

3.0 FIELD DEPLOYED SYSTEM

Having established the proof of concept a more compact field-deployable system was developed for a specific use-case in a nuclear store. This system has conducted hydrogen measurements at the nuclear facility in Sellafield, UK

Figure 4. Field deployed hydrogen sensing system.

4.0 CONCLUSION

An optical method for the stand-off detection of hydrogen is presented. Raman scattering from a plused excitation lasre is detected using time correlated single photon detectors in a LIDAR configuration. Less than 0.1% concentrations have been detected at many tens of meters.

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