Fraunhofer UK

Fraunhofer Centre for Applied Photonics

Hydrogen Sensing

The remote sensing of hydrogen, both concentration and the location, is a challenge in several sectors including nuclear energy and the wider hydrogen economy. Fraunhofer CAP has developed a stand-off hydrogen detection system that relies upon the interaction of pulses of laser light with hydrogen and uses sensitive time-resolved sensors to detect the returned signal giving both concentration and location.

A proof of concept system is capable of detecting hydrogen at 0.1% at 100 m

Remote Sensing using Lasers

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 a large number of 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.

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.

When excited by ultraviolet light the presence of hydrogen is characterised by blue Raman scattered photons. Therefore, by analysing the wavelength of the returned Raman scattered photons the presence of hydrogen can be detected. The amount of hydrogen can be established through the number of returned Raman scattered photons.

LIDAR

The principle of LIDAR is similar to 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.

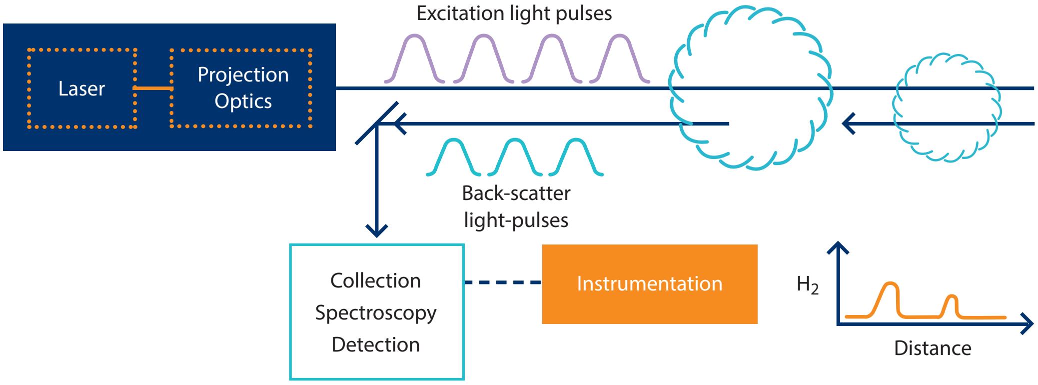
SPAD Photodetectors

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.

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.



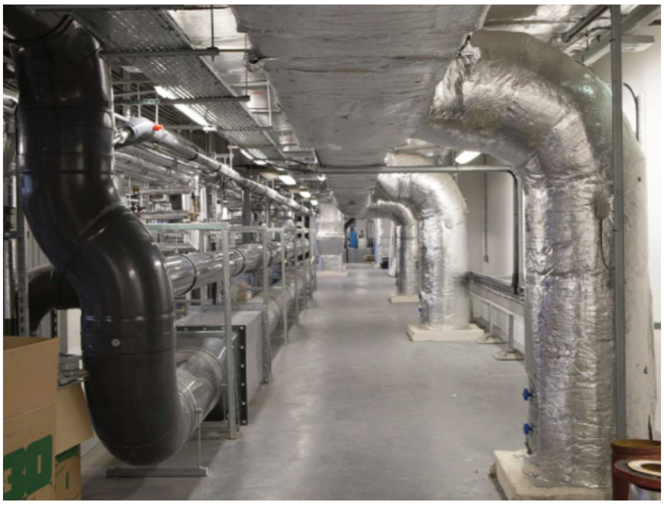
System Description

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.

A mixture of various concentrations of hydrogen and dry air could be released into several open-ended plastic tubes placed at various points along the beam path. This was to assess whether the system could “see” beyond a cloud of hydrogen and detect concentrations further along the beam path.

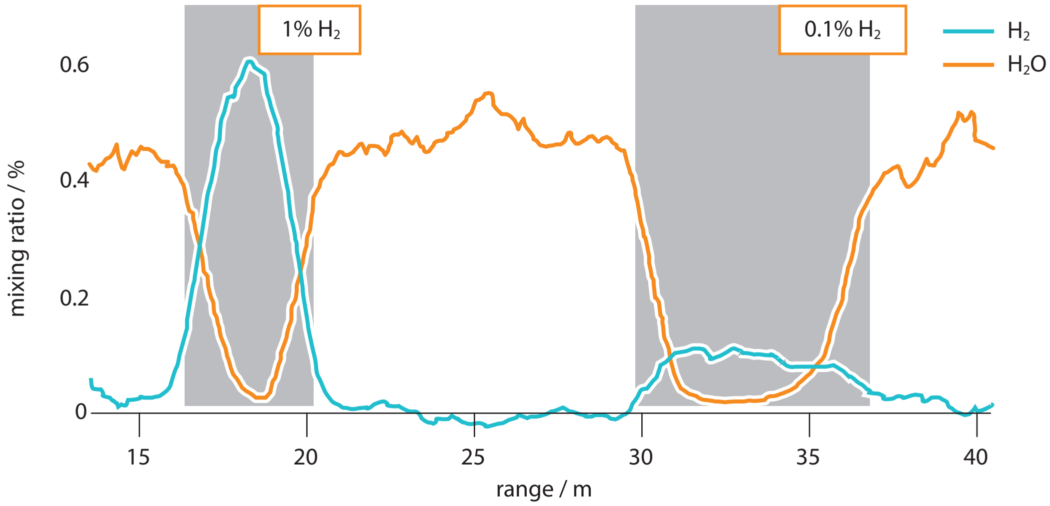


Results

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.

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.

0.1 % H_2 concentration can be detected at >30 m even in the presence of a higher concentration H_2 zone in front of the low concentration.



Limit of Detection and Location Accuracy

The detection system relies upon counting individual Raman scattered photons generated by the interaction with hydrogen which will be received at a low rate. Therefore, the photon counts are allowed to build up over some time to give statistical confidence. The limit of detection is a function of several factors, including excitation power, laser pulse repetition rate, and averaging time. The greater the energy contained in each pulse of light the greater the Raman scattering that occurs thereby increasing signal strength. The higher the number of pulses emitted by the laser each second (pulse repetition rate) the more rapidly the detection systems can build up the statistics of returned Raman scattered photons.

The limit of detection is dictated by the interplay of laser characteristics, range and integration time.

The ability to locate the origin of the hydrogen will be in part determined by the excitation laser pulse duration. A pulse of light, even short in terms of duration will correspond to a significant physical length which will be a source of uncertainty in terms of the origin of Raman scattered photons. For example, a pulse duration of 5 ns will correspond to a length resolution of 75 cm.

Field Deployed System

Having established the proof of concept Fraunhofer CAP developed a much more compact field-deployable system. This system was used to make hydrogen measurements in a nuclear store area on-site at Sellafield, UK

Both the deployed and proof of concept systems were subjected to rigorous assessment of ignition risk

Contact

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About Fraunhofer CAP

Fraunhofer CAP (Centre for Applied Photonics) is a not for profit research and technology organisation (RTO) offering industry a professional development capability in the field of photonics. Based in the UK, Fraunhofer CAP is an affiliate of Europe's leading independent research organisation. Our expertise lies in the development of a wide variety of laser sources and optical systems. We engage with industry through funded projects or direct contracts.

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