# DEVELOPMENT OF A RAMAN LIDAR SYSTEM FOR HYDROGEN GAS DETECTION

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## 1. Introduction

Hydrogen is considered to be a clean energy source, and a possible alternative to fossil fuels for use in transportation, and power generation. Hydrogen fuel cell vehicles are expected to become widely used in the next decade or two, which necessitates the installation of a large number of hydrogen fueling stations. Since hydrogen is flammable and is fueled at high pressure in the order of several hundred atmospheres, detection of hydrogen leaks is important for safety. Various kinds of hydrogen gas detectors, such as catalytic combustion sensors, electrochemical sensors, semiconducting oxide sensors, and thermal conductivity detectors have been developed [1]. However, since these are point sensors, a large number is necessary to cover the area of a fueling station. Alternatively, a single laser-based or optical sensor could cover the entire area by spatial scanning.

Hydrogen has no absorption bands from the near ultraviolet to near infrared, which makes its optical detection difficult, as conventional methods such as laser-induced fluorescence, absorption spectroscopy, and FT-IR cannot be used. On the other hand, the hydrogen molecule exhibits a strong Raman effect, and hydrogen Raman cells have been widely used for laser wavelength conversion. Moreover, the technology readiness level of Raman scattering is considered to be highest among the remote sensing methods applicable to hydrogen gas detection [2]. By using a scanning Raman lidar, three-dimensional mapping of hydrogen is possible in principle.

## 2. System Description

A Raman lidar system for detection of hydrogen gas was developed. The system was designed to detect hydrogen gas at 8-30 m distance. The system uses a Q-switched, pulsed Nd:YAG laser operating at 355 nm. The Raman scattering wavelengths by hydrogen (1st order Stokes line) are shown in Table 1.

**Table 1.** Raman Scattering Wavelengths*

| | vibrational Raman scattering | | rotational Raman scattering | |
|---|---|---|---|---|
| laser wavelength [nm] | Raman shift [cm$^{-1}$] | scattering wavelength [nm] | Raman shift [cm$^{-1}$] | scattering wavelength [nm] |
| 355 | 4155 | 416.4 | 587 | 362.5 |

*1st order Stokes line

A schematic diagram of the lidar system is shown in Fig. 1, and the principal specifications are shown in Table 2. The beam from the Nd:YAG laser is transmitted along the axis of a Newtonian telescope of aperture 212 mm. The primary and secondary mirrors of the telescope are UV coated, with reflectivity >90% from 270 nm to the visible region. Laser backscatter is collected by the telescope, collimated, and split into two beams by a beamsplitter. Each beam passes through a narrowband interference filter and directed to a photomultiplier tube (PMT). In addition, a laser line edge filter is installed in front of the beamsplitter to reject stray laser light, Rayleigh scattering, and Mie scattering.

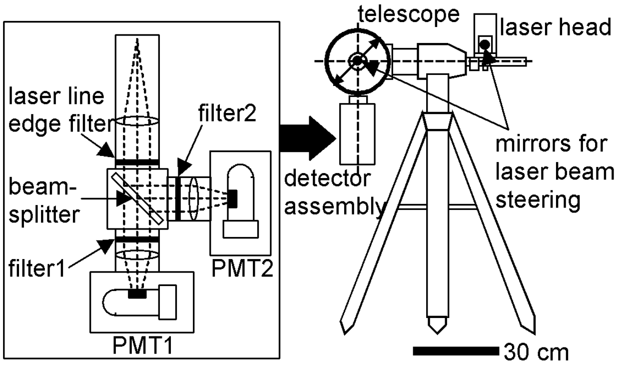

**Fig. 1.** Schematic diagram of the Raman lidar system

**Table 2.** Specifications of the Raman lidar system

| | |
|---|---|
| Laser | |
| type | Nd:YAG (THG) |
| wavelength | 355 nm |
| output energy | 60 mJ max. |
| repetition rate | 20 Hz |
| Telescope | |
| type | Newtonian |
| primary mirror diameter | 212 mm |
| secondary mirror diameter | 68 mm |
| focal length | 830 mm |
| mirror reflectivity | >90% at 362, 416 nm |
| Laser line edge filter | |
| laser light rejection ratio | $<10^{-6}$ at 355 nm |
| transmission | >98% at 362, 416 nm |
| Vibrational Raman filter | |
| center / FWHM | 416.5 nm / 0.9 nm |
| transmission | 29% |
| Rotational Raman filter | |
| center / FWHM | 362.5 nm / 1.6 nm |
| transmission | 21% |

## 3. Experimental Setup

Hydrogen detection experiments were conducted in daytime, outdoor conditions. Hydrogen gas was released from a burner (not ignited) at a distance of 10-30 m from the lidar system, as shown in Fig. 2. The flow rate of hydrogen gas was adjusted in the range 0-50 liter/min. The position of the laser spot (about 1 cm in diameter at 10 m, 3 cm in diameter at 30 m) was adjusted so that the bottom edge of the spot was 3-5 cm above the tip of the burner in order to prevent reflection from the burner.

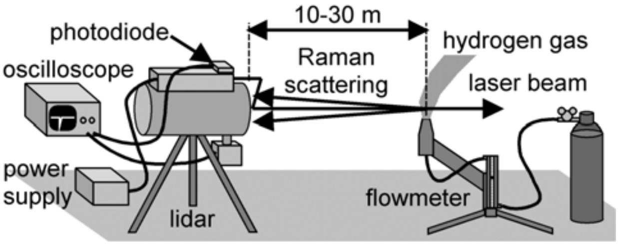

**Fig. 2.** Experimental setup for hydrogen gas detection

The PMT signals were measured and stored by a digital oscilloscope (digitizing rate 1 GS/s). A photodiode (PD) placed near the laser head detected the laser reflection from one of the beam steering mirrors, which provided the trigger signal for the oscilloscope.

## 4. Experimental Results

An example of vibrational and rotational Raman scattering signals from hydrogen gas is shown in Fig. 3. In this case, the release point of hydrogen gas was 11 m from the lidar system. The two signals were measured simultaneously by the two PMTs. The result shows that the system can detect hydrogen by either vibrational or rotational Raman scattering. Since the experiment was conducted during daytime, the background level is higher for the longer wavelength (416 nm).

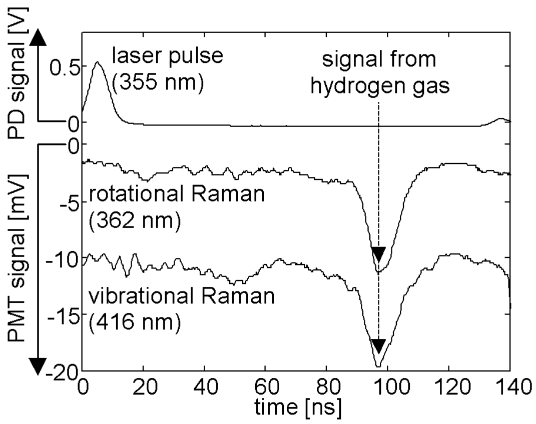

**Fig. 3.** Example of Raman scattering signals. Top trace: laser pulse measured by photodiode, middle trace: rotational Raman scattering signal (362 nm), bottom trace: vibrational Raman scattering signal (416 nm)

To test whether the system can detect hydrogen gas at greater distance, the Raman scattering signal was measured with the burner at different distance from the lidar system, and at different flow rate of hydrogen gas. The result is shown in Fig. 4. In Fig. 4(a), the telescope was adjusted so that the focus was at 30 m distance. As a result, the sensitivity exhibited a local maximum at this distance. In Fig. 4(b), the Raman scattering signal did not show any marked dependence on the flow rate.

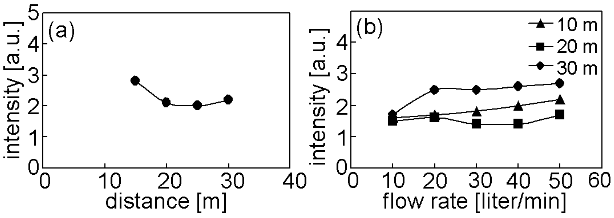

**Fig. 4.** Raman scattering signal intensity at (a) different distances and (b) different flow rates of pure $H_2$ gas

In order to investigate the sensitivity of the Raman lidar system as a function of distance *x*, Raman scattering by atmospheric $O_2$ was measured. The obtained signal *V*(*x*) is shown in Fig. 5(a). The portion for *x*=15-60 m is expanded and shown in semilog scale in Fig. 5(b). The dotted line shows the result of a least squares fit, which showed that the signal in this interval could be closely approximated by an exponential decay with an e-folding distance of about 25 m. The rapid decay of the signal is thought to be the result of the telescope focus being adjusted at 15 m distance.

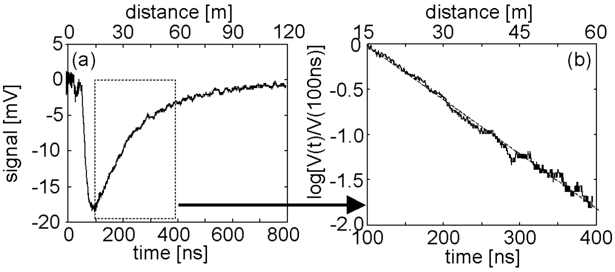

**Fig. 5.** (a) Raman scattering signal by atmospheric $O_2$, (b) semilog plot for distance 15-60 m

## 5. Conclusion

A Raman lidar system for detection of hydrogen gas was developed. The system could detect hydrogen gas in outdoor, daylight conditions up to a distance of 30 m, by either vibrational or rotational Raman scattering. Visualization of hydrogen gas by beam scanning within the telescope field of view is under development.

## References

[1] National Aeronautics and Space Administration, "Safety Standard for Hydrogen and Hydrogen Systems", NSS 1740.16, Washington DC (1997)

[2] R. G. Sellar, D. Wang, "Assessment of Remote Sensing Technologies for Location of Hydrogen and Helium Leaks, Phase 1 Final Report", Florida Space Institute, NAG10-0290 (2000).