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Development of the Raman lidar system for remote hydrogen gas detection

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1. Introduction

Detection of hydrogen (H_2) gas leakage is very important for safety of the nuclear power plant because H_2 gas is very flammable and explosive. H_2 gas is generated by oxidizing the nuclear fuel cladding during the critical accident and generated H_2 gas leads to serious secondary damages in the containment building of nuclear power plant. Thus, various H_2 gas detection techniques are used in the nuclear power plant such as catalytic combustion sensors, semiconducting oxide sensors, thermal conductivity sensors and electrochemical sensor. However, these are point sensors. Therefore, a large number of the sensors are needed to cover the area of the nuclear power plant. [1]

Alternatively, a Raman lidar (Light Detection And Ranging) system for remote detection of the H_2 gas can cover the area in the containment building of a nuclear power plant. H_2 gas has a very strong Raman Effect, and H_2 Raman cells have been widely used for laser wavelength conversion. In this study, Raman lidar system was developed for H_2 gas detection used in the containment building of nuclear power plant.

2. Principle and Measuring system

2.1 Raman scattering

The Stokes Raman spectrum line is shifted toward longer wavelength relative to the pump light and the quantity of the shift wavelength depends on the molecular species. The table 1 indicates the Raman scattering wavelength and Raman backscattering cross section when the third harmonic of a Nd:YAG laser (wavelength 354.7 nm) is irradiated to some gases. 416.1nm Raman scattering wavelength shift are generated by using the 354.7 nm laser light irradiated to the H_2 gases. [2], [3]

Table 1: Raman scattering wavelength and Raman back scattering cross section when the third harmonic of Nd:YAG laser (wavelength 354.7 nm) irradiated to some gases.

	Raman scattering wavelength [nm]	Cross section [$10^{-30}cm_2sr^{-1}$]
O_2	375.4	2.68
N_2	386.7	2.28
CH_4	395.6	26.2
H_2	416.1	7.07

2.2 Measuring system

A hydrogen Raman lidar system was developed for detecting concentration of H_2 gas. A schematic diagram of the hydrogen Raman lidar system is shown in Fig 1. The Raman scattering light is collected by Plano-convex lens and split into the two beams by a beamsplitter (BS). Each beam through a narrow band pass filter and directed to a photomultiplier tube (PMT) to measure the N_2 and H_2 gas signal. The 355 nm Nd:YAG laser specification was shown in Table 2.

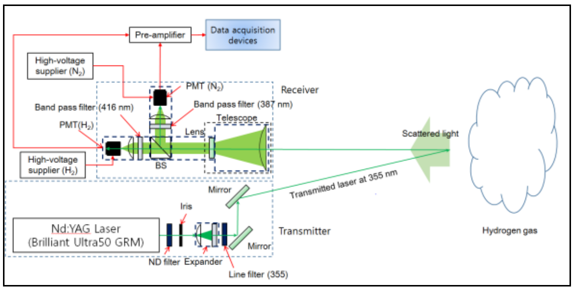

Fig. 1. Schematic diagram of the Raman lidar for measure the N_2 and H_2 Raman scattering signal.

Table 2: Specification of the Nd:YAG laser used in the Raman lidar system

Nd:YAG laser (Brilliant ultra 50)	
Wavelength	355 nm
Energy per pulse	12 mJ at 355 nm
Repetition rate	20 Hz
Pulse duration	6 ns at 355 nm
Energy stability	< 6 % at 355 nm
Jitter	< ± 2 ns

2.3 Signal processing system

The measuring algorithm of the Raman scattering signal is shown in Fig 2. The N_2 and H_2 Raman scattering signals have a low Signal to Noise Ratio (SNR). Therefore, cumulative-mean method is used to enhance a SNR. The Raman scattering signals of the N_2 and H_2 gas were collected by using the OKOS data acquisition board with digitizing rate 1GS/s and Q-switched signal of the Nd:YAG laser was used for the data acquisition board trigger. The PMT amplifies all of the signal and noise. Therefore, cumulative mean method was used to enhance the signal to noise (SN) ratio. Interface of the implemented Raman lidar measuring algorithm by using the LabVIEW programing platform was shown in Fig 3.

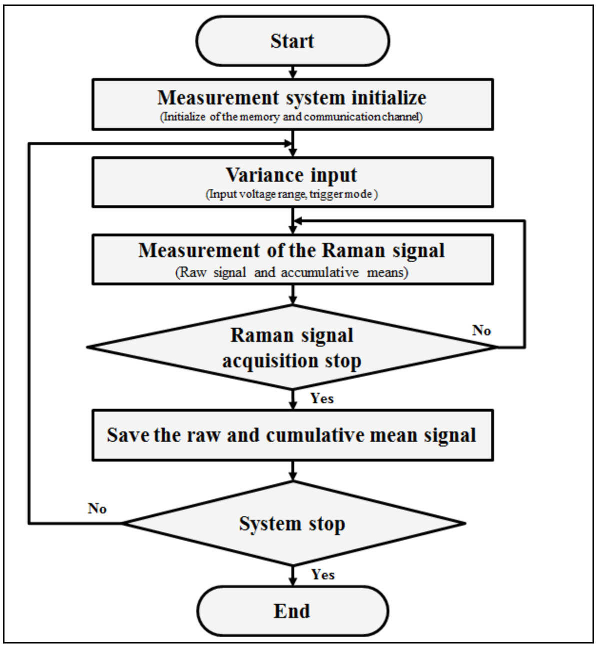

Fig. 2. Measuring algorithm of the Raman lidar

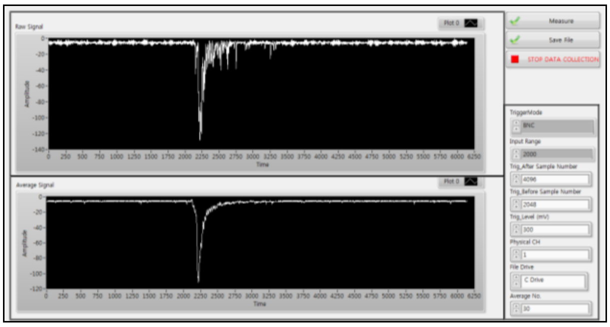

Fig. 3. Interface of the Raman lidar measurement program

3. Experimental setup and results

Figure 4 shows the Raman lidar system to measure the N_2 and H_2 gases. The H_2 gases were released into the air when the nozzle of the H_2 gas chamber, located at the 30m from the Raman lidar system.

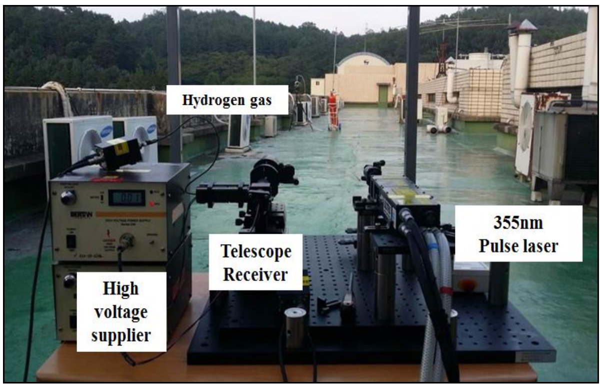

Fig. 4. Photography of Raman lidar system for measuring the N_2 and H_2 Raman scattering signal

The Raman scattering signals of N_2 and H_2 gas were simultaneously measured by using the developed Raman lidar system and an oscilloscope and DAQ system. The Figure 5 shows N_2 and H_2 gas Raman scattering signal by using the developed Raman lidar system. The intensity of H_2 Raman scattering signal is lower than that of N_2 Raman scattering signal. Even if pure H_2 gases blow out the nozzle into the air, the volume percent of the H_2 gas was lower than volume percent of the N_2 gas into the air. Therefore, the results of N_2 and H_2 gas Raman scattering signal by using the developed Raman lidar system are reasonable.

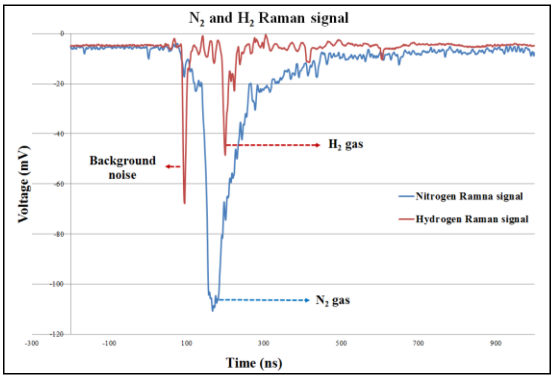

Fig. 5. The graph of the N_2 and H_2 Raman scattering signal using the developed Raman lidar system

4. Conclusion

Hydrogen gas detection is very important in nuclear industry because it is very flammable and explosive. Therefore, a hydrogen gas measuring method was needed to safely operate the nuclear power plant.

In this study, remote hydrogen gas detection devices and measuring algorithm are developed by using the Raman lidar method. Through the experiment, we proved that our developed Raman lidar system was possible to measure the N_2 and H_2 gas scattering signal remotely.

ACKNOWLEDGMENT

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