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Raman lidar with for geocological monitoring

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Abstract. Application of CCD array photodetector technology is shown to provide record synchronously hundreds of spectral intervals, increase essentially the relative aperture and intensity of echo-signals in the input optical path as well as to reduce the mass – dimension parameters of hyperspectral Raman LIDAR as a whole for geocological monitoring by aerial and underwater unmanned vehicles.

1. Introduction

The detection of methane gas is extremely important for health and safety reasons and its monitoring is required in many areas, such as water-treatment plants, the oil and gas industry, landfill sites, and commercial or domestic environments. There is increasing need to quantify methane being lost in production processes, so analytical detection methods will become important if public policies on climate change and greenhouse gas emissions are tightened to combat global warming.

As a consequence of the increasing amounts of methane in the atmosphere posing an environmental and health hazard, many researchers have focused their attention upon quantifying the amount of methane in a sample of air. There is a plethora of analytical techniques available to detect methane, ranging from infrared (IR) spectroscopy to electrochemistry, through to gas chromatography (GC); each technique carries its own advantages and disadvantages.

The authors of article propose to use hyperspectral anti-Stokes Raman spectrometry for geocological monitoring. Raman LIDAR allows to register simultaneously a wide composition of chemical substances under sensing at one lasing wavelength. LIDAR s with ultraspectral polycromator are used in geocology for studying the dangerous gases of technogenic origin that appear in atmosphere under disposing of wastes, trash, poisonous and explosive substances, and for searching the growth of narcotic plants. CARS technique is able to measure the concentration on level of 3-10 molecules and determine hydrocarbons under presence of impurities in real atmosphere and hydrosphere [1,2].

2. Experiments and results

A few ultraspectral Raman LIDARs detecting an iodine radionuclides, heavy hydrocarbons as well as methane leaks on the gas pipelines are elaborated and tested [3,4]. The sensing is carried out at wavelength of 261.7 nm by 7ns - pulses with energy of 10 mJ and 200 Hz repetition rate of Nd:ILF laser. The installed optical head provides the combined scanning of space by laser beam linearly through the movable mirror as well as in spiral trajectory using deflector. Polycromator have ensured spectral resolution $\Delta \nu=0.6$ cm$^{-1}$ and selectivity $\nu/\Delta \nu>>1000$. The swing speed of mirror in angle of ±10o at
frequency of 20 Hz allows to track the items space on inclined courses. Deflector scans in narrow angle field (±5°) with 15’ sensitivity during 1 ms. Background noises on receiving canal are eliminated practically to naught due to the detection of echo-signal at the anti-Stoks frequencies.

Figure 1. Functional diagram KARS lidar

Unfortunately application of conventional photodetectors (PMT, photodiodes or streak tubes) limits the input lens relative aperture (f/4÷f/3) and number of recorded spectra in receiving channels of Raman LIDAR. Photodetectors should be located at a distance to each other in polychromator. Therefore a small aperture is disadvantage of Raman LIDAR. The authors propose the use of highly sensitive matrices. Modern progress in the technology of CCD array photodetector with high sensitivity in wide spectral range provides to record synchronously hundreds of spectral intervals, increase substantially the intensity of echo-signals in the input optical path (f/2÷f/1.5) and to reduce the mass and dimensions of LIDAR system as a whole. Fig. 2 presents some frequency shifts of the molecules-indicators for hydrocarbon gases.

Figure 2. Raman shifts for hydrocarbon gases

For example, the model of S10140-1109-01Back-thinned type CCD area (2048 × 122; 2048 × 506 pixels (table 1)) ensures a high UV sensitivity and stable characteristics under UV light irradiation (Fig.3) [5].
Figure 3. CCD area sensor
Table 1. The matrix parameters

| Parameter                  | Value                        |
|----------------------------|------------------------------|
| Image size                 | 24.576 x 6.072 mm            |
| Pixel size                 | 12 x 12 μm                   |
| Pixel pitch                | 12 μm                        |
| Number of effective pixels | 2048 x 506 pixels            |
| Package                    | Metal                        |
| Line rate (typ.)           | 40 line/s                    |
| Line rate (max.)           | 60 line/s                    |
| Spectral response range    | 200 to 1100 nm               |
| Dark current (typ.)        | 30 e-/pixel/s                |
| Readout noise (typ.)       | 4 e-r ms                     |

Back-thinned type CCD area image sensors deliver high quantum efficiency (90% or more at the peak wavelength) in spectral range up to VUV region, and have great stability for UV region (Fig.4). Moreover, these also feature low noise and are therefore ideal for low-light level detection.
Figure 4. Spectral response
The authors develop a hyperspectral Raman LIDAR for geoeconomic monitoring for both unmanned and unmanned underwater vehicle. A polychromator with $\lambda/\Delta \lambda > 1000$ is used to ensure the registration of a wide range of pollutant substances in the lidar receiving channel. The application of the matrix receiver enables the use of more than 100 spectral channels. Information about the intensity of each spectral channel is extracted as a TTL signal from a group of pixels of the matrix with a frequency of at least 10 MHz by means of a multichannel deserting head C10150 or C10151. The detection head converts the spectrum image into an analogy video signal, which is transmitted via the C7557-01 controller to the PC via a USB interface. The resulting sequence of frames is stored on the PC and period is decrypted by specialized software.

3. Conclusion
Studies have shown the prospects of Raman spectroscopy and, in particular, coherent anti-Stokes Raman spectroscopy as a highly sensitive method of remote detection and recognition of a wide class of radionuclides contaminants in the environment. The matrix is used as a photodetector in Raman LIDAR. So it will allow us to achieve extremely high sensitivity and selectivity with a possibility of registration the spectrum of more than 100 indicator substances on-line. It should be noted that the results given in the article are preliminary. Therefore, the authors propose to continue their research to develop the technology of hyperspectral anti-Stokes Raman spectrometry.

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