UTILIZATION OF PULSED GAAS DIODE LASERS TO COMPLEX LIDAR REMOTE SENSING

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Abstract

We report application of powerful multichip-stack (In)GaAs/AlGaAs diode lasers feasible for complex atmospheric monitoring. An original method is developed for spectral remote sensing employing this type of pulsed diode lasers of broad radiation line. Mie- scattering lidar signal over 15km range is accessible by the power-characteristics of the developed lidar system. Water vapour absorption spectrum of third oscillatory molecular overtone of 894-904nm, is considered with relevance to the potential for DIAL remote sensing of tropospheric humidity. A specialized digital filter in the accumulation and processing of the lidar information acquires essentially higher sensitivity of the analytical system.

Keywords: *atmospheric spectroscopy, remote sensing, diode lasers, DIAL lidar*

1. MONITORING OF THE ATMOSPHERIC AEROSOL EMPLOYING POWERFUL (In/Al;)GaAs LASERS

In search of new development of lidar systems and their wider application, essential part is attributed to the laser source. Tendency in various areas of optoelectronics is marked by the implementation of diode lasers (DL). Except compact size, the advantages of DL focus on the large efficiency and the uniqueness of the direct pumping and spectral modulation of radiation. Of major importance is the great choice of compounds for laser active media emitting in a broad spectral band from 0,3 to 30μm. Infrared DL dominate in spectroscopic applications, implementing the different frequency modulation and detection techniques and high coherence properties of radiation for investigation of most of the high- resolution atmospheric molecular spectra[1-3]. Still, there is certain limitation to the laser power of DL determined by thermal and optical degradation, which prevents efficient remote sensing applications. By comparison of the operational regimes of radiation, the class of pulsed lasers yields higher power, simultaneously utilizing a simple and efficient

method of pulse-frequency modulation[4,5]. Two types of pulsed multi-chip-stack DL suggest a solution, combining the advantage of highest power of radiation with the opportunity for development of relevant methodology of spectral atmospheric analysis utilizing these powerful diode lasers of broad radiation line, and presenting a new aspect of their application.

We refer to complex atmospheric monitoring, based on a portable, highly stable at transportation lidar system employing pulsed DL. The energetic characteristics of the lidar enable acquisition of aerosol profiles and detection of hard targets at distances over 10 km. It comprises the most powerful pulsed chip-stack (In)GaAs/AlGaAs DL, formed of a number of heterostructures capable of emitting up to 120 W power. Determined by structure, these lasers possess higher threshold and can be operated only in pulse- mode at prescribed duty factor of 10^{-3}- 10^{-4}. On the other hand, the characteristics of the chip-stack DL, with the number of p-n junctions of large emitting surface generally lead to considerable broadening of the laser line, so far, compensating the spectral application of the great laser power of such structures.

The principle scheme of the lidar on Fig.1 is designed prospectively, to realize an original methodology for DIAL analysis.The collinear optical source/detector tract is developed on a multimode gradient optical fiber, directing the output radiation (or coupling two lasers in DIAL method) towards a collimator body in the telescope. This construction greatly simplifies the optical tuning of the system, preserving its parameters at mounting procedures and varying conditions by the priciple "plug and play". Continuous measurements of the backscatter lidar signal of the atmospheric aerosol by this method were conducted in experiments, testing the system parameters (Fig.2). The vertical profile on the figure is referred to a path tilted by 30^0 to the horizon, when the actually measured tracking distance is twice greater. Data acquisition time is 1-10 min at standard application of a computer operated boxcar, with the excess noise limited by the narrow frequency band of its low-pass filter.

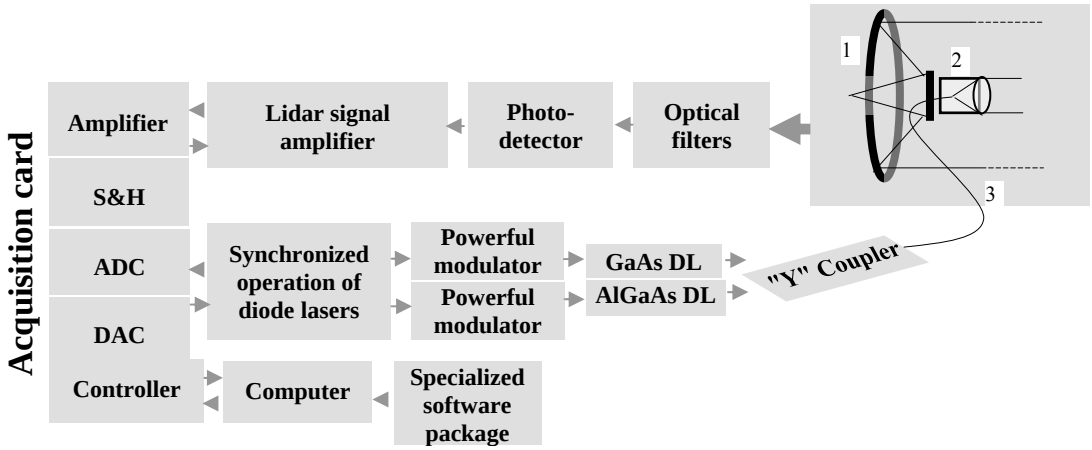

Figure 1. Design of a DIAL scheme based on powerful pulsed GaAs/AlGaAs diode lasers:

(1) Cassegrain telescope (2) collinear collimator (3) gradient optical fiber corning 100/140μm.

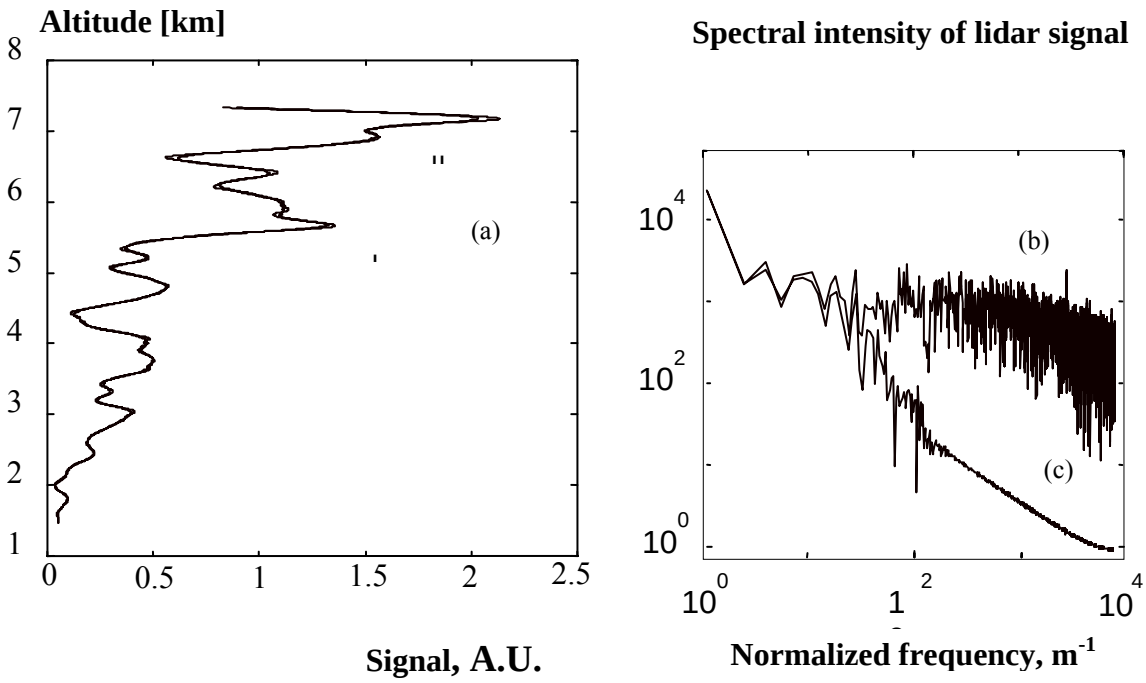

Figure 2. (a) Profile of backscatter signal exposing stratification of clouds, employing GaAs DL in the lidar investigation of the atmospheric aerosol on a path tilted by 30^0 to the horizon;

(b) Noise characteristics of the lidar signal at the direct boxcar output; (c) processed by adaptive digital filter.

Analyzing the spectrum of the lidar signal for the purpose to increase the sensitivity of the lidar system, we have developed a method of its efficient processing. A quasi-optimal nonlinear adaptive digital filter of high order and a number of characteristic system functions are chosen, on the basis of the available prior information of the apparatus and the available models of an atmospheric channel. The best results are acquired by a characteristic function set to preserve the spacial resolution of the digital filter of the system, when the signal to noise ratio is ultimately improved by 40dB of additional noise suppression.

2. DIAL METHOD OF ATMOSPHERIC ANALYSIS EMPLOYING PULSED DIODE LASERS OF BROAD RADIATION LINE

The principle of DIAL sounding by differential absorption of radiation on two wavelengths of DL modulation range with reference to our methodology, is expressed by the comparison of nonresonance and the resonance absorption of (In)GaAs/AlGaAs DL radiation in the back- scatter lidar signal. An essential achievement is to make use of the spectral characteristics of the radiation of (In)GaAs DL, which matches an overtone spectrum of water vapour in the region of 0.9μm of absorption coefficients of 0.5-5km^{-1}, containing appr. 155 resonance lines in the profile of the laser line. This feature should be of major attention for atmospheric applications of these lasers, directed to measurements of humidity in the boundaries of troposphere. The reference wavelength of AlGaAs laser is situated in the atmospheric window of 0.85μm of negliible absorption by water vapour, in this way, enabling direct transition to DIAL measurements based on the lidar scheme on Fig.1 Based on Beer's law of the laser extinction and spectral data on linestrength, the mathematical consideration serves for callibration of the measurements of the atmospheric humidity. The expression developed for masurement of atmospheric gas concentration by linestrength data[6] undergoes a change, as here is presumed that the profile of the resonance absorption line is not resolved, which is induced by the characteristics of the powerful pulsed (In)GaAs/ AlGaAs DL, employed in the lidar scheme.

Considering only water vapour resonance absorption in Beer-Lambert's law of propagation of laser radiation in open atmosphere, an algorithm for DIAL analysis by

pulsed broad- line DL radiation line is developed, based on available linestrength data. The relevant transformations are:

$$\frac{I(\nu, L) - I_0(\nu, L)}{I_0(\nu, L)} = -\sigma(\nu)NL \tag{1}$$

where, $I_0(\nu, L)$, $I(\nu, L)$ stand for the absorption-free and the absorbed intensity at differential absorption of laser radiation;

$\Delta\nu$ is laser line-width; $\sigma(\nu)$ is cross-section of resonance absorption; N- concentration of the selected gas molecule; L- resolved spatial interval with reference to the differential absorption signal;

Proceeding to integration in the limits of a Gaussian laser line:

$$N = \frac{\Delta\nu}{2}\left(\frac{\pi}{\ln 2}\right)^{1/2} \frac{1}{LS_l} \frac{B_0(L) - B(L)}{B_0(L)} = 1{,}06 \frac{\Delta\nu}{LS_l} \frac{B_0(L) - B(L)}{B_0(L)} \tag{2}$$

$$B(L) = \int_{\Delta\nu} I(\nu, L) d\nu \tag{3}$$

and inserting the normalizing relation for Gaussian laser line:

$$I_0(\nu, L) = I_0(L) q(\nu) \tag{4}$$

$$\frac{2}{\Delta\nu}\left(\frac{\ln 2}{\pi}\right)^{1/2} \int_0^\infty q(\nu) d\nu = 1 \tag{5}$$

The linestrength of the vibration- rotational transition modulated by the form-factor of the laser line is given by:

$$S_l = \int_{\Delta\nu} q(\nu)\sigma(\nu) d\nu \tag{6}$$

Explicitly, assuming Gausian laser line and Lorentzian profile of the absorption lines we get:

$$S_l = \int_{\Delta\nu} \exp\left[-\left(\frac{\nu-\nu_0}{\Delta\nu/2}\right)^2 \ln 2\right] \sum_n \sigma_n \frac{1}{\pi\Delta\nu} \frac{\Delta\nu^2/4}{(\nu-\nu_n)^2+\Delta\nu^2/4} d\nu \tag{7}$$

With the great number of absorption lines filling closely the frequency interval of the laser line, its form-factor varies much less than that of the absorption line. Thus, the following approach is applicable, replacing the integration for summation by the number of absorption lines:

$$S_l = \sum_n \exp\left[-\left(\frac{\nu_n-\nu_0}{\Delta\nu/2}\right)^2 \ln 2\right] \int_{\Delta\nu} \sigma_n \frac{1}{\pi\Delta\nu} \frac{\Delta\nu^2/4}{(\nu-\nu_n)^2+\Delta\nu^2/4} d\nu =$$

$$= \sum_n S_n \exp\left[-\left(\frac{\nu_n-\nu_0}{\Delta\nu/2}\right)^2 \ln 2\right] \tag{8}$$

where, S_n stands for the linestrength of an individual line in the spectrum.

$B(L_n)$ integral is noted to be invariant with atmospheric pressure. The relevant spectrum depicted on Fig.4 is evaluated on the basis of Beer's law and known parameters of the laser line and the absorption lines broadened by atmospheric pressure. The selected, experimentally derived spectroscopic data on linestrength[6] are applied for calibration of the catalogue data with reference to the explicit spectrum[7-9].

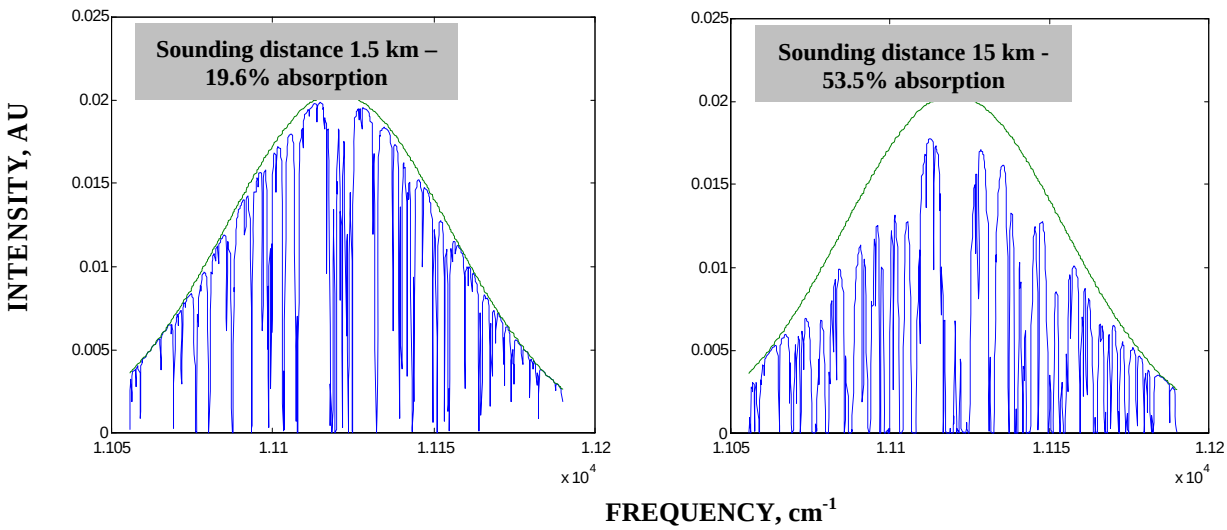

Figure 4. Outline of the selected spectrum of back- scattered GaAs diode laser radiation at open-path propagation and fixed atmospheric conditions: 70% humidity, 740 Torr and 16^0C.

Approbation of the suggested method for DIAL monitoring of humidity is considered, exploring the lidar profile derived by a computer simulation depicted on Fig.5 with reference to sonde data (Table 1), for selected conditions of comparatively dry atmosphere. The graphs are normalized by the laser extinction due to factors other than resonance absorption. As a consequence of the essential difference of extinction by over 30 times acquired by fine tuning of radiation of both DL, the zero-absorption line can approximate the extinction of AlGaAs DL radiation. Assessment of the measurements of the atmospheric humidity up to 6km-altitude by this profile shows that maximal system error should be in the limits of 10%.

Table 1. NIMH Sofia - Belgrade surface data, 15August 1998; Sofia surface data, 15December 1998

H [km]	0.6	1.3	1.5	3.1	5.8	5.9	7.5	9.5
T [C]	15	18	16.2	5.4	-10.7	-11.5	-22	-38.9
U [%}	49	45	55	65	19	30	16	42

(1)

H [km]	0.6	1.5	3	5.5	7	9	10.2	11.6
T [C]	1.2	-5.9	-12.7	-25.7	-38.5	-48.3	-52.5	-52.5
U [%}	82	92	88	68	52	43	41	41

(2)

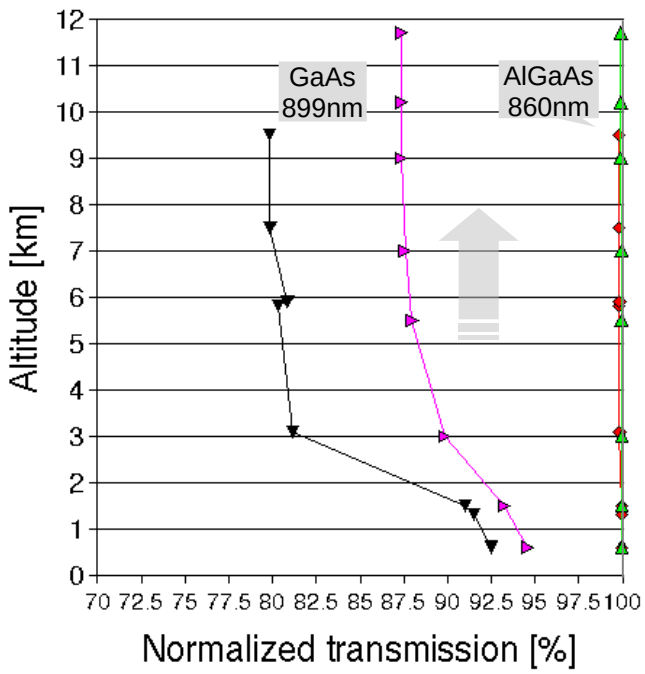

Figure 5 Evaluated lidar profile of resonance absorption of GaAs and AlGaAs DL radiation, referred to sonde data on Table 1, 2: (1) 15August 1998; (2) 15December 1998 referred to corrective azimuth angle of lidar sounding.

3. CONCLUSION

In conclusion, a mobile lidar employing powerful pulsed (In)GaAs/AlGaAs diode lasers of the near infrared region is constructed, based on an original method of DIAL monitoring of atmospheric humidity and other gas constituents. The latter is developed for, and employs diode lasers of broad radiation line. Lidar measurements of aerosol profiles, hard targets and cloud strata up to 15- km distance in open atmosphere were conducted, confirming the efficiency and high sensitivity of the lidar system. The spectrum of the lidar signal was analyzed, and a digital filter was developed for optimal noise suppression, widening the area of application. Further development is close to control of emissions of industrial gas pollutants, esp. petrol products, and prognostics of potentially hazardous zones in gas transport tubes.

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