Open-path gas detection using terahertz time-domain spectroscopy

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Abstract. We report on the development of an experimental setup for remote sensing of gas atmosphere in open air conditions using broadband terahertz pulses. Terahertz time-domain spectroscopy technique is used to solve the problems of gas detection and recognition in the presence of water vapor absorption lines. Acetonitrile vapors were detected and gas concentration was successfully estimated. Organic crystal with a 2% conversion efficiency pumped with near-infrared femtosecond laser pulses was used to generate single-cycle terahertz pulses with energies up to 10 µJ. Application of a novel high-power source of broadband terahertz radiation (0.2–3 THz) opens up new perspectives for further increasing the open space distances in remote sensing problem.

1. Introduction
Many materials have characteristic absorption lines in the terahertz frequency region (mostly in the region of 0.1–6 THz); in particular, there are many absorption lines due to rotational transitions in polar molecules [1, 2] and vibrational and rovibrational transitions in large molecules, including organic ones. Absorption of gases in the terahertz region is 10^3–10^6 times stronger as compared with absorption in the microwave region [3]. In contrast to the vibrational spectra in the infrared region, the use of rotational spectra helps to achieve higher selectivity and to study the molecules, absorption lines of which in other spectral regions are weak. Thus, terahertz spectroscopy is considered to be a promising tool for rapid and direct analysis of gaseous mixtures.

Application of terahertz spectroscopy for detection of gases is of importance in many areas. Dynamic analysis of the combustion gases to increase the efficiency of combustion processes is of interest in terms of ecology and energy conservation. Another field of application is a real-time diagnostics of toxic, hazardous, and flammable gases in smoke to avoid secondary accidents in cases of fire. The majority of the existing methods have limitations. In particular, the gas chromatography has high sensitivity but does not allow for analysis in real time. The method of infrared absorption spectroscopy is quite express, but its efficiency decreases in case of strong scattering in aerosols. Taking into account the relation between the standard wavelengths of terahertz radiation and the size of particles in aerosols, this radiation is less subjected to scattering [4, 5]. Thus, terahertz spectroscopy is considered to be a promising method for dynamic analysis of molecular gases in media containing aerosols like smoke, soot, dust, mist, fog, haze, fumes, and so on.
In general, the atmosphere, whether it is an open space track or a climate controlled room, contains nitrogen, oxygen, argon, carbon dioxide, and other gases, with concentration not exceeding a hundredth of a percent. In addition to the considered components, there are water vapors in the atmosphere with strong absorption lines in the terahertz frequency range. In connection with the foregoing, remote sensing of the atmosphere assumes the solution of both problems—detection and recognition of certain chemical compounds in the presence of water vapor. In most experimental studies [4, 6–8], the detection of gases has been carried out in a specialized dried box. A terahertz source, a gas cell, and a detector are installed inwards that ensures the absence of water vapor absorption lines in the recorded spectrum. This approach allows achieving low values of the minimum detected concentrations of chemical compounds and is applicable to fundamental research but is hardly appropriate for applied sciences and engineering.

Therefore, the studies of the propagation of broadband coherent terahertz radiation in the atmosphere at various humidity levels are of great significance. A review of terahertz spectroscopy techniques for remote express analysis of gases is given in [9]. The propagation of ultrashort terahertz pulses in a 100-m-long path at 10% relative humidity was studied in [10]. Later, the system based on terahertz time-domain spectroscopy (THz-TDS) with optoelectronic antennas was used to study the absorption in the 0.2–2 THz region in the presence of water vapor in a 6.2-m-long path [11]. The authors of [12] proposed and implemented a scheme for propagation of terahertz radiation (in the 0.1–1.6 THz region) in a 167-m-long path.

In this paper we report on the development of an experimental setup for remote open-path gas sensing using new high-power laser-based source of broadband terahertz pulses. Organic crystal with conversion efficiency of 2% was used to generate single-cycle terahertz pulses with energies up to 10 µJ.

2. Peculiarities of terahertz time-domain spectroscopy technique for open-path gas detection
The propagation of terahertz radiation in the atmosphere and its absorption by water vapor have been of interest for several decades. There have been several attempts to develop effective technology for remote broadband terahertz spectroscopy. Terahertz time-domain spectroscopy has an important advantage since it enables studying spectral amplitude of the signal passing through relatively long distances in several atmospheric transparency windows at the same time.

Two fundamental parameters of the discrete Fourier transform—the minimally allowed frequency interval \( \delta \omega \) and the range of recorded frequencies \( \Omega \) are determined as follows [13]:

\[
\delta \omega T = 2\pi, \\
\delta t \Omega = 2\pi,
\]

where \( T \) is the length of the recorded temporal profile (time window for recording the signal), \( \delta t \) is the time step of the delay (time resolution).

According to (1), the spectral resolution \( \delta \omega \) can be improved by increasing the length of the recorded temporal profile \( T \), and the maximum frequency obtained in the terahertz spectrum is inversely proportional to step \( \delta t \). In practice, the operating spectral range is limited by the emission spectrum of the source, so the decrease of \( \delta t \) is meaningful only up to a certain limit. The value of \( T \) is limited by the geometric dimensions of the optical setup only. The terahertz spectral fingerprints of gas molecules are concentrated below 3 THz. The absorption linewidth is on the order of a few GHz at atmospheric pressure and on the order of several MHz at low pressure.

Recently developed nonlinear organic electro-optic crystals for generation of terahertz pulses by optical rectification make it possible to obtain a high conversion efficiency in a simple collinear synchronism scheme. The maximum energy of terahertz radiation pulse of 0.9 mJ with a
conversion factor of 3% was obtained by using optical rectification of a femtosecond laser pulse of a chromium forsterite laser system [14] in a nonlinear 4-N,N-dimethylamino-4′-N′-methyl-stilbazolium 2,4,6-trimethylbenzenesulfonate (DSTMS) organic crystal [15]. However, depending on the requirements for the spectral range of the terahertz source, 2-(3-(4-hydroxystyryl)-5,5-dimethylcyclohex-2-enylidene)malononitrile (OH1) and 4-N,N-dimethylamino-4′-N′-methyl-stilbazolium tosylate (DAST) nonlinear organic crystals can be used as well [16]. Figure 1 demonstrates the spectra for the corresponding crystals, and table 1 shows their comparative characteristics.

The spectral range of 0.1–3 THz shown in figure 2 contains a large number of water absorption lines (see databases HITRAN [1], CDMS [17], NIST Physical Reference Data [18], JPL Molecular Spectroscopy catalog [19] or GEISA [20]), which cause distortions in the spectrum of the terahertz pulse, propagating in the atmosphere containing water vapors. There are nine major transparency windows between absorption peaks of the terahertz radiation in the atmosphere in the 0.1–3 THz region: 0.1–0.55 THz; 0.56–0.75 THz; 0.76–0.98 THz; 0.99–1.09 THz; 1.21–1.41 THz; 1.42–1.59 THz; 1.92–2.04 THz; 2.05–2.15 THz; 2.47–2.62 THz [10] (the measurements were carried out at 23 °C and humidity of 26%). Therefore, it is reasonable to select a crystal that has a smooth generation spectrum in this frequency range, like OH1.

3. Time-domain spectroscopy setup
A scheme and a photo of the experimental setup are shown in figure 3. It is assembled in a special case divided into two parts. The right part is a non-drying one—all the elements are located at the natural humidity of room atmosphere. The left part of the scheme highlighted in grey in figure 3(a) contains a crystal for generating terahertz radiation and other guiding optical components for its propagation. This part is supplied with dry air for spectral calibration.
purposes using an oil-free compressor (SB4/C-50.OLD20) and a cyclone separator (ARIACOM ACS-AD020).

Laser radiation (wavelength is 1240 nm, pulse duration is 80 fs, energy is up to 2 mJ, and repetition rate is 100 Hz) is directed to the THz-TDS setup. A wedge-shaped plate divides laser beam into two ones. Reflected laser pulse with energy of 4% is used for probing (red line in figure 3), and the rest 92% of pulse energy serve as a pump (blue line). Iris diaphragms are used to align optical axes of the laser beam and the terahertz spectroscopy scheme. To adjust the energy of laser pulses, polarization attenuators, consisting of a half-wave plate and a polarizer (Glan–Thomson prism), are used in both pump and probe beams.

A motorized translation stage (PI M-413.32S) in the pump beam serves as a delay line. The translation length of the stage is 300 mm, which corresponds to a maximum delay between terahertz and probe laser pulses of 2 ns. The minimum displacement step is 5 µm, which corresponds to temporal resolution of 33.4 fs. Optimum conversion of laser radiation to terahertz one in organic OH1 crystal occurs at laser fluence of about 3 mJ/cm². To obtain the desired value, an expanding telescope is assembled in the pump beam with a magnification factor of 1 : 1.5. The output laser beam 6 mm in diameter provides a complete filling of the terahertz crystal aperture, resulting in generation of 10 µJ terahertz pulse ∼1 ps in duration. A bandpass terahertz filter in the frequency range of 0.1–10 THz cuts-off laser radiation. To reduce the divergence of the terahertz radiation and match beam diameter with clear aperture of the gas cell, a mirror telescope is assembled with a magnification factor of 1 : 6.

Gas cell is developed to enable maximum volume of interaction of terahertz radiation with a gas medium in a single-pass scheme. Poly(4-methyl-1-pentene) (TPX) windows transparent in both optical and terahertz spectral regions are chosen to simplify experimental setup assembly. Terahertz radiation passing through the gas cell is focused by an off-axis parabolic mirror in GaP electro-optic crystal (EOC) 200 µm thick. The off-axis parabolic mirror has a through hole with an axis parallel to the focused beam. The probe beam is focused through the hole by lens 8. The lens with a focal length of 250 mm is mounted on a linear mechanical translation stage to enable precise alignment of waist position of both terahertz and probe laser beams along the optical axis in the EOC.

Figure 2. Water absorption lines [1].
Figure 3. (a) Terahertz time-domain spectroscopy scheme using the pump-probe and electrooptic sampling techniques and (b) photo of the experimental setup: 1, 3, 10—iris diaphragms; 2—wedge-shaped plate; 4, 7—polarization attenuators; 5—delay line; 6—expanding telescope; 8, 16—lenses; 9—second harmonic generation crystal; 11—organic OH1 crystal; 12—mirror telescope; 13—gas cell; 14—off-axis parabolic mirror; 15—GaP electro-optic crystal; 17—electro-optic detection circuit; 18—balanced photodiodes; 19—oil-free compressor; 20—cyclone separator.

A balanced detection technique is applied in the setup with the use of photodiodes (Thorlabs PDB210A/M). Since sensitivity of silicon photodiodes is in the wavelength range of 320–1060 nm, the probe laser radiation at fundamental frequency of 1240 nm is converted to radiation at a wavelength of 620 nm in a second harmonic generator (SHG) crystal (deuterated potassium dihydrogen phosphate, DKDP). The narrow bandpass filter (passband of 10 ± 2 nm full width at half maximum (FWHM) at 620 nm mounted right after the crystal is used to block the fundamental radiation. Electro-optic crystal is also mounted on a linear mechanical translation stage (travel length of 25 mm) to determine the position, corresponding to the maximum electric-field strength of the terahertz pulse. Passed through the EOC, laser probe pulse bears information about the change in its polarization induced by the terahertz pulse field. After collimation in lens 16, probe radiation is detected in the electro-optic detection circuit, consisting of a quarter-wave plate and the Wollaston prism.

The birefringence induced by the terahertz pulse in the EOC is proportional in certain limits to the amplitude of the electric field. Thus, by recording rotation degree of the polarization as a function of the delay between the terahertz and the probe laser pulse, it is possible to obtain information on temporal profile of the electric field of the terahertz pulse. The registration of both the difference signal and individual signals from photodiodes is carried out using a digital oscilloscope (Tektronix TDS 3054) with a bandwidth of 500 MHz. Custom NI LabView software is used to control motorized elements and to read the data from the oscilloscope.
4. Mathematical processing and analysis of the temporal profile

Raw temporal profiles are typically processed prior to the fast Fourier transform in order to enhance the quality of the final spectrum. Two common preprocessing methods are apodization and zero-filling. An apodization step can be carried out with the time-domain signal immediately before transformation to the frequency domain. However, caution is required because extreme apodization can lead to distortion of the spectral features and loss of spectral information [21]. The impact of different apodization functions can be seen in figure 4 that presents the resulting absorption spectra computed by applying some of the apodization functions to the temporal profile of terahertz pulse, propagating in the open air with humidity of 35%. Curves 3–7 are equidistantly offset over curve 2 by 5 \times 10^{-4} for better representation.

When temporal profile is recorded, the amplitude of the signal gradually decreases in time. After a certain moment, the signal-to-noise ratio falls down to a value of 2 when continuation of recording the profile has no sense since it leads to additional noise in fast-Fourier-transform spectrum. Averaging technique over laser shots in each point of temporal profile can significantly extend its useful length, but leads to long data acquisition times. Due to low repetition rate in our setup, the desired length of temporal profile \( T = 1 \text{ ns} \), corresponding to spectral resolution \( \delta w \) of about 1 GHz, is unreachable. Zero-filling, also known as “zero-padding”, is a technique that is commonly used to provide more spectral data points within a given spectral range. In our experiments we apply the Welch windowing function and zero-filling up to 1 ns. Achieved spectral resolution of the setup is about 7 GHz.

Analysis of the temporal profile of terahertz pulse, passing through a gas medium, can serve as an additional source of information for gas detection and recognition. The terahertz pulse of subpicosecond duration causes coherent molecular rotations through resonance interaction of “field–dipole” type [22]. On such coherent excitation, a phased array of dipole oscillators is formed in time and space, which emits simultaneously and coherently at different frequencies according to excited rotational transitions. The frequency of these oscillations can be calculated.
Table 2. Rotational constants and time period values of the free induction decay signal for various gases.

| Gas     | Rotational constant $B$, GHz | Time period of FID, ps | References |
|---------|-----------------------------|------------------------|------------|
| CH$_3$CN | 9.2                         | 54                     | [24–26]    |
| CD$_3$CN | 7.8                         | 7                      | [24]       |
| N$_2$O  | 12.5                        | 40                     | [27]       |
| CH$_3$Cl | 13.15                       | 38                     | [28]       |
| OCS     | 6.1                         | 82.2                   | [29]       |

by the formula

$$\nu = 2B(J + 1) - 2D_{JK}K^2(J + 1),$$  \hspace{1cm} (2)

where $J$ and $K$ are the rotational quantum numbers, $B$ is the rotational constant, and $D_{JK}$ is the centrifugal extension constant (at high rotational energies, when the length of the coupling gradually increases, the rotator is no longer considered to be “rigid”).

In gases, the absorption of terahertz radiation occurs on rotational transitions within a single vibrational band. The reemission, which is observed after such excitation of a set of rotational transitions in molecules, is denoted by the term Free Induction Decay (FID). The FID signal is a series of periodically located subpicosecond pulses. As a rule, the amplitude of such FID signals is on the order of 0.025–0.1 of the amplitude of the original terahertz pulse; it depends on both the molecular collisions and the pressure inside the gas cell and gradually decays in time.

As distinct from asymmetric molecules like water, for which the temporal profile is quite complicated [23], free induction decay can be observed in all symmetric molecules with a dipole moment (polar molecules) [6]. In this case, the FID signal can be used to detect gases without transition to the frequency domain [6, 24]. The method of direct gas identification consists in determining the time localization of a given FID echo. Such a gas as acetonitrile (CH$_3$CN) and its deuterated analogue (CD$_3$CN), nitrous oxide (N$_2$O), methyl chloride (CH$_3$Cl), carbon monoxide (OCS), etc. can be successfully detected using the temporal profile analysis. Table 2 contains the values of the rotational constant and the period of the free induction decay signal for these gases.

5. Determination of gas concentrations

In order to determine gas concentration, gas identification problem initially has to be solved. This is performed by comparison of absorption line frequencies in the recorded spectrum with database values [1, 17–20]. Once identified, the concentration of the gas can be quantified by determining the line area of a single transition. The line area is obtained by fitting the measured transition profile to theoretical one, depending on absorption line broadening. Gases at low pressure (below 1 mbar) exhibit only a Doppler linewidth and are fitted with a Gaussian function. At pressures above 10 mbar, the linewidth is dominated by molecular collisions, so a Lorentz profile can be applied. Intermediate pressures require both regimes to be accounted for, so a Voigt profile and a convolution of the Gaussian and Lorentzian profiles are used [30].

For atmospheric pressure, line area $A_\nu$ under absorption line is calculated using the profile:

$$\alpha(\nu)L = \frac{A_\nu}{\pi} \left[ \frac{\Delta\nu}{(\nu - \nu_0)^2 + \Delta\nu^2} \right],$$  \hspace{1cm} (3)

where $\nu_0$ is the central frequency of transition, $\Delta\nu$ is the half width at half maximum of transition, $L$ is the interaction length.
After determining the constants in (3), the species concentration \( n \) (cm\(^{-3}\)) may be directly calculated using \( A_\nu \), the interaction length \( L \) and the line intensity \( S \):

\[
n = \frac{A_\nu S L}{L}.
\]  

(4)

Tabulated values for transition line intensities of numerous species may be found in the literature or spectroscopy databases listed above.

6. Results and discussion

Acetonitrile has been chosen as a test gas to be detected and the experiment is carried out as follows. A droplet of 10 \( \mu \)l of acetonitrile is placed in the gas cell at atmospheric pressure and ambient humidity of 35%, using a special dispenser (Discovery 10 ml, Comfort). After a predetermined time the droplet evaporates completely, filling the cell with acetonitrile vapor. The temporal profile of the terahertz pulse recorded with a time step of \( \delta t = 66 \) fs with a duration of \( T = 180 \) ps is shown in figure 5. The signal is registered with averaging over 16 laser pulses at each point. Windowing and zero-padding procedures described above have been applied consecutively.

As noted earlier, gas detection can be performed via analysis of the recorded temporal profile. FID signal is clearly seen 54 ps after the main pulse in figure 5. Time period of reemission \( T = 54 \) ps corresponds to a gas, rotational constant of which is equal to \( B = (2T)^{-1} = 9.2 \) GHz, i.e. acetonitrile.

Figure 6 demonstrates normalized spectrum of terahertz signal passed through the cell with both acetonitrile and water vapors. Normalized spectrum of terahertz pulse passing through a dry air (humidity is less than 2%) inside and outside the gas cell is used as reference. Acetonitrile gas is easy to recognize due to periodic absorption lines in the range between 0.1 and 1.2 THz with 18.4 GHz period that are clearly seen in signal spectrum.

Theoretical estimation of acetonitrile concentration in the gas cell is performed as follows:

\[
n = \frac{N}{V},
\]  

(5)

Figure 5. Temporal profile of terahertz pulse after gas cell with acetonitrile vapors at natural humidity of 35%.
where \( N \) is the number of gas molecules, \( V = 450 \text{ cm}^3 \) is the gas cell volume. The number of gas molecules is estimated in the following way:

\[
N = \nu N_A = \frac{m}{M} N_A = \frac{\rho V_{\text{drop}}}{M},
\]

where \( \nu \) is the amount of a substance, \( N_A \) is the Avogadro number, \( m \) is the mass of the substance, \( \rho = 0.786 \text{ g/cm}^3 \) is the density of the substance (acetonitrile), \( M = 41.09 \text{ g/mol} \) is the molar mass, \( V_{\text{drop}} = 10 \mu l = 10^{-2} \text{ cm}^3 \) is the volume of acetonitrile drop in the experiment.

After inserting the data above in (5), we obtain the number of molecules \( N = 115.19 \times 10^{18} \), and acetonitrile concentration \( n = 2.56 \times 10^{17} \text{ cm}^{-3} \). Similar calculations for a doubled volume of acetonitrile droplet give us \( n = 5.12 \times 10^{17} \text{ cm}^{-3} \).

To determine the acetonitrile vapor concentration from the experimental data, two arbitrary absorption lines in the spectrum corresponding to rotational transitions \( 39 \rightarrow 38 \) and \( 40 \rightarrow 39 \) are analyzed. Approximation result of the experimental data by the Lorentz profile is shown in figure 7. The line intensities for the selected transitions are taken from the molecular spectroscopy catalog of Jet Propulsion Laboratory [19].

The first term in (2) corresponds to a set of absorption lines equally spaced by \( 2B \) (with respect to acetonitrile \( 2B = 18.39 \text{ GHz} \)). The second term in (2) corresponds to the fact that each absorption line includes a series of closely spaced lines of decreasing amplitude separated by a value of \( 2D_{JK} \) (for acetonitrile \( 2D_{JK} = 35.34 \text{ MHz} \)). Since the measurements are carried out at atmospheric pressure, the closely located K components in the spectrum are considerably broadened, overlapped, and therefore indistinguishable. For clarity, figure 7 shows the positions of all K components, reconstructed from known tabular data of spectral databases.

For the \( J = 39 \leftarrow 38 \) rotational transition, the sum of line intensities corresponding to the quantum numbers \( K = 0, \ldots, 21 \) is \( S = 0.2255 \), and for the \( J = 40 \leftarrow 39 \) transition, \( S = 0.2168 \).

Experiment with both droplets volumes evaporated in the gas cell is repeated 5 times. After each experiment the gas cell is blown with the air of room temperature and humidity for 5 minutes to eliminate the residual acetonitrile vapors. A comparison of the experimentally
Figure 7. Fitting the experimental data with the Lorentz profile: 1—experimental data; 2—database values; 3—fitted Lorentz profiles.

Table 3. Comparision of the measured and calculated acetonitrile concentrations.

| Drop volume, µl | Calculated concentration, cm⁻³ | Concentration, cm⁻³ | 39 ← 38 | 40 ← 39 |
|----------------|-------------------------------|-------------------|---------|---------|
| 10             | 2.56 \times 10^{17}         | 0.01597           | 2.39 \times 10^{17} | 0.01352 | 2.31 \times 10^{17} |
| 20             | 5.12 \times 10^{17}         | 0.02978           | 4.46 \times 10^{17} | 0.02754 | 4.69 \times 10^{17} |

measured values of acetonitrile vapor concentrations for 10 and 20 µl drops with theoretical calculations are given in table 3.

Comparison of the calculated and experimental values shows quite good agreement. Depending on the chosen rotational transition and the volume of the droplet, the error in determining the concentration is within 6–10%. The discrepancy obtained can be explained both by the error in formation of a drop of a given volume and by the error in determining the spectral amplitude of the gas line absorption.

According to the Beer–Lambert–Bouguer law, intensity of radiation decreases exponentially when travelling in an absorption medium. The case of terahertz radiation, propagating in the atmosphere containing water vapors, is more complicated since absorption occurs at a series of lines only and depends strongly on gases and water vapors concentrations. Terahertz signal propagation database [31] contains information on propagation of terahertz radiation...
(0.1–2 THz) in the air at ambient conditions (21 °C and 42% humidity) for various distances. Exponential character of signal decrease along with the distance is also observed. Speaking about practical applications, a threefold increase in the distance from 0.3 m in our case to 1 m, for example, requires to scale up radiation energy by a factor of 2; however, a distance increase from 0.3 m to 10 m requires energy 3 orders of magnitude greater. These rough estimations are given for the same value of signal-to-noise ratio as in our experiments. Some optimizations could possibly be performed to increase it for lower terahertz pulse energy values especially for high repetition rates (1 kHz and higher). Our observations show that increasing the number of signal accumulations $N_{ac}$ in each point of delay line results in growth of signal-to-noise ratio by a factor of $\sqrt{N_{ac}}$. Taking into account the aforesaid, detection of acetonitrile gas in normal ambient conditions is expected to be successful for terahertz pulse energies of several hundreds of microjoules. Thus, practical applications impose additional limitations and require both thorough optimization of experimental setup and proper component choice.

7. Conclusions

Open-path detection and recognition of gases is possible by various methods. As noted earlier, terahertz spectroscopy technique enables rather rapid registration, high sensitivity to rotational transitions in polar molecules and does not suffer from scattering in aerosols. The techniques currently applied for spectral studies in the terahertz range are generally determined by the type of sources and detectors. For the sources, the main selection criteria are the power, generation mode (continuous or pulsed), operating frequency range (broadband or narrowband), and frequency tuning capability. Besides, additional limitations should be taken into account when choosing devices and methods. For example, the highest efficiency of photodetectors on a quantum well is achieved at cryogenic temperatures. Likewise, quantum-cascade lasers, along with compactness and high output power, need to be cooled with liquid nitrogen or helium; besides, they have a limited range of frequency tuning.

Real conditions (atmospheric pressure and natural humidity) also impose limitations on the solution of the problem of gas detection and recognition. In particular, one limitation is the need to work in the atmospheric transparency windows. From this point of view, application of broadband coherent terahertz radiation appears as the most promising method, since it allows simultaneous measurements in several spectral regions, which increases the quality of recognition of the gas mixture composition. In connection with the foregoing, development of methods for remote gas detection and recognition on the basis of high-power sources of coherent broadband terahertz radiation appears to be a promising direction. One of the actively developing approach of generating the considered terahertz pulses is an optical rectification of laser pulses in nonlinear crystals.

In this paper, we report on development of terahertz time-domain setup on the basis of a new source of high-power terahertz radiation. A pulse of coherent terahertz radiation with an energy of about 10 $\mu$J and about 1 ps in duration is generated in organic OH1 crystal, with a spectral range of 0.2–3 THz. Open-path experimental studies of terahertz pulse spectrum are carried out. Using a gas cell makes it possible to simulate different parameters of ambient conditions, including pressure and humidity. Spectral calibration of the setup is performed in both wet (natural humidity of the room is 35%) and dry (humidity is about 2%) air. Experiments on gas sensing are performed in real conditions (atmospheric pressure and natural humidity). The achieved spectral resolution of the technique is about 7 GHz. Acetonitrile has been chosen as a test gas to be detected and its concentration has been estimated.

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