Fufurin I.L., Morozov A.N., Kareva E.R., Tabalina A.S.

**Infrared spectroscopic system for human breath analysis.**

Kaliningrad, 2020.

# INFRARED SPECTROSCOPIC SYSTEM FOR HUMAN BREATH ANALYSIS

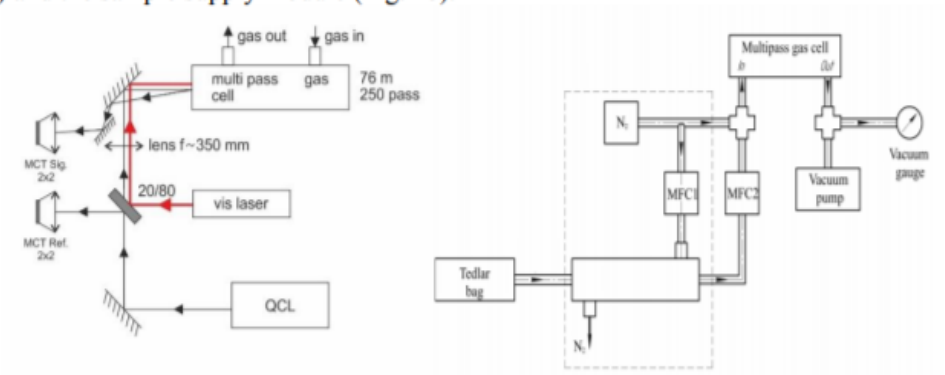
*Igor L. Fufurin, Andrey N. Morozov, Elizaveta R. Kareva, Anastasiia S. Tabalina*

*Bauman Moscow State Technical University, Moscow, Russia*

**Introduction.** The development of fast non-invasive screening systems that enable pathology to be detected at an early stage of evolution is one of the important scientific and technological problems in the field of medicine. One of the approaches that can ensure non-invasive diagnosis of diseases in real time is an express analysis of human exhaled air [1]. The development of laser technologies in the field of creating widely tunable quantum cascade lasers (QCLs) provides new opportunities for creating fast, relatively compact and effective systems for diagnosing diseases according to the composition of exhaled air.

**1. Prospects of using QCL.** As exhaled air is a complex gas mixture, analysis of its microstructure requires high selectivity for the detection of target substances; insensitivity to nitrogen and oxygen, the concentration of which are tens of percent; selectivity for water vapor and $CO_2$. The mid-infrared range, which contains the spectral lines of vibrational-rotational transitions, is very informative [2]. A wide range of QCL rearrangements will make it possible to analyze simultaneously a large number of different biomarker molecules.

**2. Experimental setup.** It is proposed to use an experimental setup, the circuit diagram of which is shown in Fig. 1. Two main modules can be distinguished in the scheme: the radiation analysis module (Fig. 1a) and the sample supply module (Fig. 1b).




a) b)

**FIGURE 1.** Schematic diagram of the experimental setup. a) radiation analysis circuit b) flow pattern of the test sample: MFC – mass flow gas controller.

The following main technical solutions are proposed to achieve the highest possible sensitivity: use of a reference photodetector; study of the sample inside an astigmatic multi-pass gas cell with an optical path length of up to 76 m; removal of water from the test sample; evacuation of a gas cell to eliminate the possibility of any atmospheric fluctuations.

**3. Experimental results.** Using QCL spectra of test membranous simulators and gas mixtures were recorded in a multi-pass cell. Experimental sensitivity-estimations for certain chemical compounds,

including biomarkers, were performed for setup based on QCL and multi-pass gas cell (table 1) [10]. These results were obtained for the optical path length of 6 m.

**TABLE 1.** The sensitivity of the experimental setup based on QCL with a multi-pass cell. [10].

| Substance | Detection limit |
|---|---|
| Methane | 0.5 ppm |
| Formaldehyde | 2.1 ppm |
| Ammonia | 0.9 ppm |

**4. Expected results.** A number of computational experiments were performed to test methods for processing experimental data. A simplified model of a drained sample of exhaled breath was considered (Fig. 2). The main component of model mixture (carbon dioxide) had nominal concentration 300 ppm.

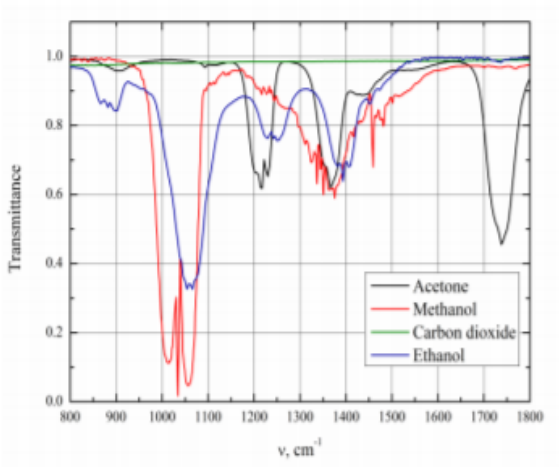
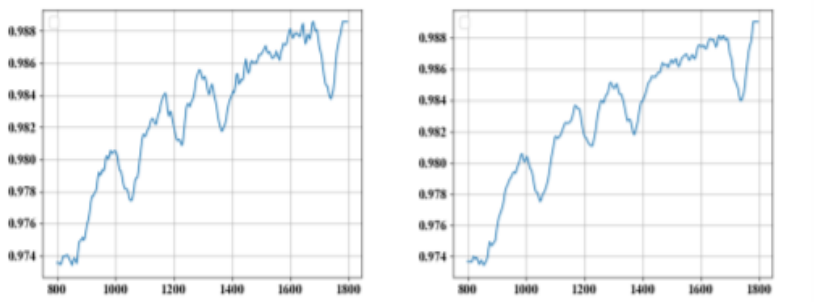



**FIGURE 2.** Base spectra of mixture components (NIST).

Examples of model mixtures are shown on Fig. 3. In this work for mixture analysis we considered 3 methods: method of Bayes estimation, parametric optimization and double parametric optimization. Table 2 shows results of model mixtures analyzing for the test spectral database for SNR=100.




a) b)

**FIGURE 3.** The spectra of the model mixture for various SNR: a) SNR = 50; b) SNR = 100.

**TABLE 2.** Results of computational experiments.

| SNR | Bayes estimation | Parametric optimization | Double parametric optimization |
|---|---|---|---|
| 100 | Acetone c = 0.14 ppm δ = 93%; Ethanol c = 0.08 ppm δ = 92%; | Acetone c = 1.53 ppm δ = 23%; Ethanol c = 0.32 ppm δ = 68%; | Acetone c = 1.65 ppm δ = 18%; Ethanol c = 0.68 ppm δ = 32%; |

| | Methanol c = 0.04 ppm δ = 59% | Methanol c = 0.06 ppm δ = 40% | Methanol c = 0.03 ppm δ = 71% |
|---|---|---|---|

**Conclusions.** The main goal of medical diagnostic systems is to provide a practicing doctor with a tool for effective diagnosis and monitoring of the course of the disease. Methods of absorption spectroscopy, which are the basis for the design of the radiation analysis module, will ensure the operation of the system in real time.

*The reported study was funded by RFBR according to the research project №18-29-02024.*

1. M. Phillips, Breath tests in medicine, *Scientific American*, 1992, 267(1), pp. 74-79.
2. L. A. Wallace, E. D. Pellizzari, T. D. Hartwell, C. M.Sparacino, L. S.Sheldon, H. Zelon,. Personal exposures, indoor-outdoor relationships, and breath levels of toxic air pollutants measured for 355 persons in New Jersey, *Atmospheric Environment (1967)*, 1985, 19(10), pp. 1651-1661, doi: 10.1016/0004-6981(85)90217-3.
3. E.V. Stepanov, Diode laser spectroscopy and analysis of biomarker molecules. *M.: FIZMATLIT*, 2009, 416 p.
4. C. Wang, P. Sahay, Breath analysis using laser spectroscopic techniques: breath biomarkers, spectral fingerprints, and detection limits, *Sensors*, 2009, 9(10), pp. 8230-8262, doi: 10.3390/s91008230.
5. M. R. McCurdy, Y. Bakhirkin, G. Wysocki, R. Lewicki, F. K.Tittel, Recent advances of laser-spectroscopy-based techniques for applications in breath analysis, *Journal of breath research*, 2007, 1(1), pp. 014001.
6. D.A. Samsonov, A.S. Tabalina, I.L. Fufurin, QCL spectroscopy combined with the least squares method for substance analysis, *Journal of Physics: Conference Series*, 2017, 918(1), pp. 012034, doi: 10.1088/1742-6596/918/1/012034.
7. I. L. Fufurin, A. S. Tabalina, A. N. Morozov, I S. Golyak, S. I. Svetlichnyi, D. R. Anfimov, I. V. Kochikov, Identification of substances from diffuse reflectance spectra of a broadband quantum cascade laser using Kramers-Kronig relations, *Opt. Eng.*, 2020, 59(6), pp. 061621, doi: 10.1117/1.OE.59.6.061621.
8. I.L. Fufurin, O.A. Nebritova, A.S. Tabalina, Methodology for identification biomarker molecules in human expired air, *Acoustooptical and radar methods for measuring processing information. Ser. "Materials of the 12th international scientific and technical conference"*, 2019, pp. 89-92.
9. A. N. Morozov, I. L. Fufurin, A. S. Tabalina, Technique of substances identification by scattering spectra, acquired by quantum cascade laser (QCL), *Proc. of ARMIMP-2018*, 2018, pp. 93-7.
10. I. S. Golyak, A. N. Morozov, S. I. Svetlichny, A. S. Tabalina, I. L. Fufurin, Identification of chemical compounds by scattered radiation spectra in the wavelength range of 5.3-12.8 microns using a tunable quantum cascade laser, *Russian Journal of Physical Chemistry B*, 2019, 38(7), pp. 557-564, doi: 10.1134/S1990793119040055.