High precision spectroscopy and imaging in THz frequency range

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Abstract. Application of microwave methods for development of the THz frequency range has resulted in elaboration of high precision THz spectrometers based on nonstationary effects. The spectrometers characteristics (spectral resolution and sensitivity) meet the requirements for high precision analysis. The gas analyzers, based on the high precision spectrometers, have been successfully applied for analytical investigations of gas impurities in high pure substances. These investigations can be carried out both in absorption cell and in reactor. The devices can be used for ecological monitoring, detecting the components of chemical weapons and explosive in the atmosphere. The great field of THz investigations is the medicine application. Using the THz spectrometers developed one can detect markers for some diseases in exhaled air.

1. Introduction and background

The terahertz (THz) region is attractive for many well-known applications (biology and medicine, ecology and security). Until recently, it was difficult to efficiently generate and detect THz radiation. Most THz sources were either low-brightness emitters such as thermal sources, or cumbersome, single-frequency molecular vapor lasers.

Recently, however, there has been a significant progress in THz generation and detection due to achievements in nanotechnology and small-scale semiconductor industry.

2. Results

The present paper reports on microwave methods, devices and applications of THz spectrometry. We present the unique family of synthesizers operating in $667 \div 857\,GHz$, $789 \div 968\,GHz$, $882 \div 1100\,GHz$ [1]. Application of quantum superlattice devices has also advanced microwave spectroscopy methods to THz frequency range and yielded a family of THz spectrometers, based on non-stationary effects [2]. Medical and biological problems for THz technology involve, first of all, studying of biological compounds (DNA, proteins, sugars, *etc*) in solid phase and liquids. Dielectric properties of biomolecules in THz range are formed by low frequency vibrations, which specify collective motion of big atomic groups, and intermolecular hydrogen bonds, thus, providing information about molecular geometry and conformational flexibility and its chemical activity. The THz technique can also be used for studying of biological tissues based on dielectric function analysis. The main scientific purpose of this paper is development of a spectroscopic complex designed for studying of various biological systems (biomolecules, tissues, human organism). The complex includes spectrometers, based on free-damping polarization and fast passing effect and operating in near and far wave zones. The periodic switching the phase (or frequency) of radiation interacting in

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resonance with the medium leads to rising the processes of transient radiation and absorption, periodic appearing and decaying the macroscopic polarization induced [3]. The new frequency tunable sources of subTHz, THz and MIR radiation based on solid state harmonics generator and QCLs with frequency set not worse than 10^{-8} and power $10\ mcW - 10\ mW$, which meet requirements of high – precision spectroscopic measurements, are developed. The subTHz radiation source is developed on the solid state harmonics generator. For THz and MIR ranges the QCLs are used. They have a high output power and can generate radiation in pulse and continuous modes together with fast tuning of frequency. The room temperature PLL of THz QCL was developed and elaborated. Detection of the radiation in all three frequency ranges (subTHz, THz and MIR) are realized by the unique receiver block based on quantum semiconductor superlattices. The developed radiation sources are used for design and development of high-precision THz-imaging system and THz spectroscopy of biological objects.

One of the most important applications of the spectrometer elaborated is non-invasive medical diagnostics based on the analysis of the exhaled air [4]. We can identify some diseases with using the measurement of the characteristic gas-marker concentration in the exhaled air. Monitoring the variation of the NO concentration at the radiotherapy course was carried out. The absence of nitric oxide in exhaled air of healthy people and its appearance in exhaled air of oncopatients with cancer of lung which had radiotherapy are determined at clinical tests [4]. The experimental set up for precise spectral measurements of DNA in THz frequency range was developed and realized. The preliminary measurements of DNA spectra were carried out.

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