A proposed gas analysis apparatus (1) comprises a gas sample cell (10) having a gas inlet (11) and a gas outlet (12) allowing the input and output of gas to be analyzed and a radiation inlet (13) and a radiation outlet (14) allowing the input and output of electromagnetic radiation, said gas sample cell (10) employing rotational spectroscopy and comprising a hollow waveguide (15) containing said gas and guiding electromagnetic waves of said radiation. A radiation generator (20) generates frequency modulated radiation in a millimeter and/or submillimeter wavelength range. A radiation transmitter (3) transmits a radiation signal generated by said radiation generator (20) into said gas sample cell (10) via said radiation inlet. A radiation receiver (40) receives a radiation signal from said gas sample cell (10) via said radiation outlet (14) and mixes the received radiation signal with a delayed transmitted radiation signal to obtain an output signal for performing a spectral analysis. Finally, an output signal is output by said radiation receiver (40) for performing a spectral analysis.
Field of the Disclosure

[0001] The present disclosure relates to a gas analysis apparatus, a gas analysis system and a gas analysis method, in particular for analysis of exhaled breath. Further, the present invention relates to a replaceable gas sample cell.

Description of Related Art
[0002] Known instruments to analyze breath volatile organic compounds are gas chromatography (GC), selected ion flow tube (SIFT) mass spectroscopy (MS), proton transfer reaction (PTR) MS, and infrared spectroscopic instrumentation. GC can measure good sensitivities but it is a complex technique used by trained technicians in laboratories. GC cannot operate real time, breath samples should be sent to a laboratory. PTR MS and SIFT MS are mainly used for the breath analysis research community. They can provide real time measurements, but are large in size with high costs, requires consumables gases, many mixed gases cannot be analyzed easy. In PTR MS, if molecules have the same mass, they cannot be differentiated. In comparison to other methods, infrared laser spectroscopy uses frequency markers (lines) which are created by applying optical waves. In infrared laser spectroscopy, selectivity is not enough to distinguish many different VOCs in breath. It has low frequency resolution and uses mainly expensive detectors.

[0003] US 7,300,408 discloses a breath analysis apparatus. A cavity enhanced optical cavity, optical source and optical detector are used. Wavelengths are between 1607.634 nm / 1607.501nm (1.8648e+14 Hz / 1.865e+14Hz). Due to the very small wavelength, the apparatus can detect very limited specimen. Rotational spectroscopy cannot be exploited. It can only identify one or limited target components due to its cavity enhanced cavity structure which is optimized to certain components. Further, CO₂ is the target molecule. The apparatus cannot be used to distinguish many different compounds which are available in breath.

[0004] US 7,473,898 B2 discloses cryogenic terahertz spectroscopy. The goal of the idea is to increase spectral resolution of the spectrometers (time domain THz spectroscopy) in order to identify more species. Therefore, it is proposed that the spectroscopy system is enhanced by cooling and heating the gas samples in certain steps, taking absorption spectra and subtracting them to get third absorption spectra. This will require very long measurement time and consumable gases for cryogenic cooling resulting in an expensive system.
[0005] The report "Mission adaptable chemical sensor (MACS)" by Dr. Keith Reiss, Smart Transitions LLC, 27 March 2009, discloses a system that is thought for defense applications like detecting explosives etc. Solid state electronics circuits are used in the system. Rotational spectroscopy is exploited in the spectroscopy system. 10 mT pressure is needed for optimum sensitivity. The analysis is done at fixed intermediate frequency (IF). The issues of the system are the creation of a spur free signal (eliminate undesired mixer products) and to maintain the desired power levels throughout frequency. Furthermore, YIG tuned oscillator varies over time with changes in temperature, vibration, normal drift, etc.


[0007] Some of the known devices are expensive devices which should be operated by trained technicians and which don't give real time results. Further, they require consumables like carrier gases (gas chromatography, mass spectroscopy). There are also spectroscopy instruments which identify gases by inspecting the frequency response of molecules. They are mainly laser systems which do not have a sufficient frequency resolution to identify complex gases, and the frequency tuning speed is low.

[0008] Recently, solid state electronic THz spectrometers have been developed for purposes like defence applications. It can be modified to be used in breath gas analysis.
but the performance of these systems is not sufficient due to undesired effects at frequency generation and handling. (non-linearity, phase noise, spurs, etc.).

[0009] The "background" description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventor(s), to the extent it is described in this background section, as well as aspects of the description which may not otherwise qualify as prior art at the time of filing, are neither expressly or impliedly admitted as prior art against the present invention.

SUMMARY

[0010] It is an object to provide a gas analysis apparatus, a gas analysis system and a gas analysis method, in particular for analysis of exhaled breath, that are less expensive, enable a spectral analysis with high frequency resolution, are easy to build and use and provide a high accuracy of the analysis. Further, a replaceable gas sample cell shall be provided.

[0011] According to an aspect there is provided a gas analysis apparatus comprising
- a gas sample cell having a gas inlet and a gas outlet allowing the input and output of gas to be analyzed and a radiation inlet and a radiation outlet allowing the input and output of electromagnetic radiation, said gas sample cell employing rotational spectroscopy and comprising a hollow waveguide containing said gas and guiding electromagnetic waves of said radiation,
- a radiation generator that generates frequency modulated radiation in a millimeter and/or submillimeter wavelength range,
- a radiation transmitter that transmits a radiation signal generated by said radiation generator into said gas sample cell via said radiation inlet,
- a radiation receiver that receives a radiation signal from said gas sample cell via said radiation outlet and mixes the received radiation signal with a delayed transmitted radiation signal to obtain an output signal for performing a spectral analysis.

[0012] According to a further aspect there is provided a gas analysis method comprising
- generating frequency modulated radiation in a millimeter and/or submillimeter wavelength range,
- transmitting a radiation signal generated by said radiation generator into a gas sample cell via a radiation inlet, said gas sample cell having a gas inlet and a gas outlet allowing the input and output of gas to be analyzed and said radiation inlet and a radiation outlet allowing the input and output of electromagnetic radiation, said gas sample cell employing rotational spectroscopy and comprising a hollow waveguide containing said gas and guiding electromagnetic waves of said radiation,
- receiving a radiation signal from said gas sample cell via said radiation outlet,
- mixing the received radiation signal with a delayed transmitted radiation signal to obtain an output signal, and
- outputting said output signal for performing a spectral analysis.

[0013] According to still another aspect a gas analysis system is provided comprising:
- a gas analysis apparatus as disclosed herein, and
- an analyzer that applies a spectral analysis of the output signal, said analyzer comprising a communication interface for communication with said gas analysis apparatus.

[0014] Still further, according to still another aspect a replaceable gas sample cell for use in a gas analysis apparatus is provided, said gas sample cell comprising:
- a gas inlet allowing the input of gas to be analyzed
- a gas outlet allowing the output of gas,
- a radiation inlet allowing the input of electromagnetic radiation,
- a radiation outlet allowing the output of electromagnetic radiation, and
- a hollow waveguide containing said gas and guiding electromagnetic waves of said radiation,
wherein said gas sample cell employing rotational spectroscopy.

[0015] Preferred embodiments are defined in the dependent claims. It shall be understood that the claimed gas analysis method has similar and/or identical preferred embodiments as the claimed gas analysis apparatus and as defined in the dependent claims.

[0016] Human breath is a complex gas with over 200 different volatile organic compounds (VOC). VOCs in breath are divided to two groups. One group is composed of exogenous compounds which are halogenated organic compounds that indicate recent exposure to drugs or environmental pollutants. The other group comprises endogenous compounds which give valuable information concerning a disease state. These compounds are derived from the blood by passive diffusion across the pulmonary alveolar membrane. Several of VOCs are associated with particular disease states. For instance, alkanes are associated with lung cancer, formaldehyde is associated with breast cancer, acetone is associated with diabetes, and nitric oxide is associated with asthma. In general, a certain combination of different VOCs is associated with particular diseases.

[0017] Breath analysis is a non-invasive method, which can be easily repeated. No discomfort is associated unlike blood and urine tests. No work up of breath samples is required in contrast to analyzes performed on serum or urine samples.

[0018] One of the aspects of the disclosure is to employ rotational spectroscopy. Sub-mm-wave and THz radiation are absorbed if electromagnetic radiation is applied to molecules due to the rotational modes of the molecules. The gas phase of the molecule which has a dipole moment is relevant for this phenomenon. This dipole moment enables the electric field to exert a torque on the molecule causing it to rotate more quickly or slowly. The energy is absorbed at frequencies corresponding to the molecules rotational
state transition frequency. Rotational state transitions are unique for each species of molecule. This enables to identify and detect molecules in the gas phase. Rotational spectroscopy is generally known in the art and is e.g. described in Gerecht E. et al. "Chirped-pulse terahertz spectroscopy for broadband trace gas sensing", Optics Express, April 2011, Vol. 19, No. 9, pages 8973-8984.

[0019] It is to be understood that both the foregoing general description of the invention and the following detailed description are exemplary, but are not restrictive of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] A more complete appreciation of the disclosure and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

Fig. 1 shows a block diagram of a first embodiment of the proposed gas analysis apparatus,

Fig. 2 shows a block diagram of a second embodiment of the proposed gas analysis apparatus for breath analysis,

Fig. 3 shows an embodiment of a gas sample cell in the form of a bent waveguide,

Fig. 4 shows another embodiment of a waveguide for use as a gas sample cell comprising a dielectric layer,

Fig. 5 shows an embodiment of a replaceable gas sample cell,

Fig. 6 shows a block diagram of an embodiment of the radiation transmitter,

Fig. 7 shows block diagrams of embodiments of the radiation receiver,

Fig. 8 shows block diagrams of embodiments of the radiation generator,
Fig. 9 shows a block diagram of a propose gas analysis system comprising a third embodiment of the proposed gas analysis apparatus and

Fig. 10 shows a flow chart of an embodiment of the proposed gas analysis method.

DESCRIPTION OF THE EMBODIMENTS

[0021] Referring now to the drawings, wherein like reference numerals designate identical or corresponding parts throughout the several views, Fig. 1 shows a block diagram of the general layout of the proposed gas analysis apparatus 1. It comprises as central element a gas sample cell 10 having a gas inlet 11 and a gas outlet 12 allowing the input and output of gas to be analyzed and a radiation inlet 13 and a radiation outlet 14 allowing the input and output of electromagnetic radiation, said gas sample cell employing rotational spectroscopy and comprising a hollow waveguide 15 containing said gas and guiding electromagnetic waves of said radiation. A radiation generator 20 generates frequency modulated radiation in a millimeter and/or submillimeter wavelength range. A radiation transmitter 30 transmits a radiation signal generated by said radiation generator 20 into said gas sample cell 10 via said radiation inlet 13, i.e. a transmitted radiation signals that represents the radiation generated by said radiation generator. A radiation receiver 40 receives a radiation signal from said gas sample cell 10 via said radiation outlet 14, said receive radiation signal representing the radiation output from said gas sample cell 10, and mixes the received radiation with a delayed transmitted radiation signal to obtain an output signal for performing a spectral analysis. Finally, in this embodiment an analyzer 50 is provided that applies a spectral analysis of the output signal, i.e. to spectrally analyze the output signal that is output by said radiation receiver 40.

[0022] Such a gas analysis apparatus 1 can generally be used for analysis of many kind of gases which have dipole moments. For instance, probes of gas taken at a particular location can be checked to determine which molecules are contained in the gas or if a particular molecule (e.g. a poisonous molecule) is contained in the gas. Further, such
a gas analysis apparatus 1 can be used for medical purposes, for instance to check exhaled
breath of a person (or animal) to find indications for a particular disease that the person (or
animal) already has or will have in the near future.

[0023] The phenomenon of 'rotational spectroscopy' actually happens in the gas
sample cell; subsequently, the variation of the radiated field (caused by the interaction of
the radiation with the molecules) is observed by the radiation receiver. The characteristic
measurement results (as a signal corresponding to variation/difference of the transmitted
and received radiation) analyzed at the analyzer measure the absorption or transmission
characteristics across the frequency band (spectrum) of observation. The phenomenon is
caused by the 'rotational excitement' (caused by the electromagnetic wave/field) of the
molecules in the gas sample cell.

[0024] Fig. 2 shows a more detailed block diagram of a preferred embodiment of
the proposed gas analysis apparatus 2 that is particularly configured for breath analysis, i.e.
analysis of exhaled breath of a person. This embodiment comprises a few additional
components in addition to the components comprised in the general embodiment of the gas
analysis apparatus 1 shown in Fig. 1.

[0025] In particular, a breath acquisition and gas handling module 60 is provided
that ensures gas evacuation, injection of the gas (e.g. the exhaled breath) and, preferably,
stabilizes the gases in the sample cell 10 at a certain pressure. Such a module 60 may, of
course, also be provided in gas analysis apparatus 1, as needed, and may be use for other
gases than exhaled breath.

[0026] Further, a transition 70 is arranged between the radiation transmitter 30
and the gas sample cell 10 to couple the emitted electromagnetic energy to the gas sample
cell 10. Alternatively or in addition a transition 71 is arranged between the gas sample cell
10 and the radiation receiver 40 to couple the received electromagnetic energy to the
radiation receiver 40.
[0027] A display 80, e.g. a monitor, is provided to show the result of the analysis. For instance, the content and concentration of specific VOCs in the exhaled breath are shown on the display 80. Further, information on a related (already existing) disease or disease which may possibly develop in the future may be shown.

[0028] The gas sample cell 10 is the place where the gas (e.g. the exhaled breath) is analyzed, preferably at a known pressure and temperature. Preferably, the cell 10 should have a lower pressure than atmospheric pressure in order to cope with pressure related broadening of spectral lines of molecules. The breath acquisition and gas handling module 60 may be used to ensure the pressure level of the gas sample cell 10.

[0029] The gas sample cell preferably comprises (or is built as) a hollow waveguide. In this case the TE (Transversal Electric) mode can be excited in the waveguide. In comparison to free space propagation, loss of the electromagnetic energy decreases dramatically. The waveguide can have different forms, e.g. straight, curved, meander-like, bent, etc. This constructional freedom enables to have enough length, but at the same time consume only a relatively small volume by the gas sample cell.

[0030] A preferred embodiment of a gas sample cell 10a in the form of a bent waveguide 15a is shown in Fig. 3. In this embodiment the waveguide 15a has a rectangular cross-section, but other cross sections (e.g. circular, elliptical, quadratic, ...) are also usable in general. Further, a common gas inlet and outlet 16 is provided at one side of the waveguide 15a.

[0031] To keep the gas inside the waveguide 15a but allow the radiation to enter and leave, respectively, the waveguide 15a, a dielectric layer 17 may be provided as depicted in Fig. 4. The dielectric layer 17 may be arranged directly in front of or close to the radiation input 13 and the radiation output 14 of the waveguide 15a.
[0032] To evacuate the gas sample cell 10 from measured gas samples and fill the cell with a new sample at a certain (lower) pressure takes certain time. In order to eliminate this time replaceable (e.g. disposable or recyclable) sample cells can be used. These are cells which have already very low pressure. Exhaled breath is measured once, and then the used cell is replaced with a new cell. This will also ensure that no molecules from the previous measurement are available and potentially contaminate a measurement. An embodiment of such a replaceable, disposable gas sample cell 10b is depicted in Fig. 5.

[0033] The replaceable, disposable gas sample cell 10b, in particular the side walls 18 and the bottom 19 may be made of glass or other suitable material with non-contact radiation coupler(s) (i.e. radiation input / output) 13, 14 to convey the (broadband) electromagnetic (EM) field into the gas sample cell 10b (in reflection mode) or through the gas sample cell 10b (in transmission mode measurement). The gas sample cell 10b might also be made of heterogeneous material, i.e. as a hollow waveguide equipped with EM-transparent 'windows' (not shown) on each side, such as lenses made of PTFE (Polytetrafluorethylene), silicon or other EM-transparent material, which may be also be part of the transitions 70, 71 shown in Fig. 2.

[0034] As one alternative, the gas sample cell is, in its original state before use, empty (for 'almost vacuum' type of measurements). This is e.g. prepared in the production process of the gas sample cell, particular of the disposable type.

[0035] As another alternative, the gas sample cell is loaded with a specific marker gas (preferably at a lower pressure than normal air pressure). The marker gas may be selected such that molecules of the marker gas react with the specific molecules (or family of molecules) to be detected. This simplifies the detection process by providing the required specificity and sensitivity. In addition this avoids the need for a high quality vacuum in the gas sample cell. Different gas sample cells (with different marker gas/gasses content) can also be provided to detect different sicknesses (based on the specific target
molecules detected by the marker gas molecules). Thus, the gas sample cell is preferably removable in the general layout of the gas analysis apparatus.

[0036] In an advantageous embodiment the gas sample cell contains specific (e.g. hygroscopic or hydrophilic) absorbent to control or reduce the amount of humidity which can influence the measurement quality (typically the air humidity might have a negative impact on the measurement quality).

[0037] Preferably, the gas input 13 and/or the gas output 14 (e.g. via an inlet/outlet such as a valve) of the gas sample cell are controlled (open, close). Preferably, a non-contact mechanism (e.g. a magnetic valve which is controlled by a near-DC coil to generate the field) is used for this purpose. In another embodiment the valve might operate automatically once triggered (e.g. to suck in a specific volume of gas).

[0038] A block diagram of an embodiment of the radiation transmitter 40 is shown in Fig. 6. It comprises as one or more frequency multiplier(s) 41, one or more (band pass) filter(s) (BPF) 42 and one or more amplifier(s) 43. Multipliers and amplifiers are preferably monolithically integrated circuits. They consume very little space and consume low power. In comparison to bulky breath analysis devices, integrated circuits at sub-mm-wave and THz frequency range provide that the complete gas analysis apparatus gets smaller and portable.

[0039] Block diagrams of two embodiments of the radiation receiver 50 are shown in Fig. 7. The first embodiment of the radiation receiver 50a shown in Fig. 7A comprises one or more low noise amplifier(s) 51, a sub-harmonic mixer 52a, one or more multiplier(s) 53, an intermediate frequency (IF) amplifier 54 and a band pass filter 55. The second embodiment of the radiation receiver 50b shown in Fig. 7B comprises one or more low noise amplifier(s) 51, an IQ mixer 52b, one or more multiplier(s) 53, and - in each of the I and Q paths - an intermediate frequency (IF) amplifier 54 and a band pass filter 55. In
the radiation generator the multipliers and amplifiers are preferably monolithically inte-
grated circuits as well.

[0040] Fig. 8 shows block diagrams of several embodiments of the radiation gen erator 20. Preferably, a frequency modulated continuous wave (FMCW) signal is generated in the radiation generator 50. In other embodiments a continuous or stepped frequency modulated signal is generated.

[0041] Generally, the radiation generator 20 has two RF outputs. One output is shifted in frequency compared with the other output. However, they are synchronous signals which are generated from the same reference signal. The signals can be generated in different ways. In a first embodiment of the radiation generator 20a depicted in Fig. 8A a frequency generator 21 (e.g. an oscillator) and two direct digital synthesizers (DDS) 22-1, 22-2 are used. In a second embodiment of the radiation generator 20b depicted in Fig. 8B a frequency generator 21 and two digital-to-analogue converters (DAC) 23-1, 23-2 are used. Furthermore, hybrid (PLL-DDS) synthesizers (not shown) can also be used in other embodiments. Using these techniques, a high frequency resolution can be achieved, fast scanning can be realized and selective frequency bands can be analyzed.

[0042] In alternative embodiments the radiation signals are generated from the same source. Two embodiments of such radiation generators 20c, 20d having a single chirp frequency generator 24 with two outputs are depicted in Figs. 8c and 8d. In the radiation generator 20c a delay line 25 is coupled to one of the outputs of the chirp generator 24 to delay the output signal compared to the output signal at the other output of the chirp generator 24 and thus to provide the desired frequency shift by an offset frequency \( f_A \). In the radiation generator 20d a mixer 26 and a band pass filter 27 are coupled to one of the outputs of the chirp generator 24 to mix the signal with the desired offset frequency \( f_A \) and filter it and thus to provide the desired frequency shift.
[0043] As mentioned above the analyzer 50 is configured to analyze the received signal. For this purpose, chemo metric methods or related methods may be used as e.g. described in the book: Chemometrics (Data analysis for the laboratory and chemical plant, Richard G. Brereton, ISBN: ISBNs: 0-471-48977-8. For instance, the spectral lines obtained from the spectral analysis are compared to spectral lines recorded in a database for various chemical molecules or compounds. Thus, the content of the analyzed gas, e.g. the exhaled breath, is found. Methods to identify and correlate spectral lines to diseases are generally known in the art (e.g. from the above cited paper of Cao W. et al. "Breath Analysis: Potential for Clinical Diagnosis and Exposure Assessment" and may additionally be used. In any case, the detection method shall be flexible and shall be able to be modified, for instance by software updates (e.g. downloads, for which additional components (not shown) for update, download or other communication with external devices are provided) or reconfiguration options within the gas analysis apparatus.

[0044] In general, the analysis may even be performed outside the gas analysis apparatus. A gas analysis system 3 comprising another embodiment of a gas analysis apparatus 4 is shown in Fig. 9. The gas analysis system 3 comprises, besides the gas analysis apparatus 4, an analyzer 5 that applies a spectral analysis of the output signal of said gas analysis apparatus. Said analyzer 5 comprises a communication interface 6 for communication with said gas analysis apparatus 4. Similarly, the gas analysis apparatus comprises a communication interface 90 for communication with the external analyzer 5. The external analyzer may be configured as a processing unit (e.g. a computer, server, etc. plus software) or may be (part of) a cloud 7 (plus software) as shown in Fig. 9.

[0045] Thus, by communicating (wired or wireless) the spectroscopic measurement results (e.g. attenuation characteristic over frequency scan) to a remote analyzer a decoupling of the measurement process and the analysis process is achieved. Thereby the analysis software and processing performance (computation power) can be modified independently from the gas analysis apparatus, in particular to keep the gas analysis apparatus simple and cheap.
In this context, it shall be noted that, in general, the concept of "cloud computing" includes the utilization of a set of shared computing resources (e.g. servers) which are typically consolidated in one or more data center locations. For example, cloud computing systems may be implemented as a web service that enables a user to launch and manage computing resources (e.g. virtual server instances) in third party data centers. In a cloud environment, computer resources may be available in different sizes and configurations so that different resource types can be specified to meet specific needs of different users. For example, one user may desire to use a small instance as a web server and another larger instance as a database server, or an even larger instance for processor intensive applications. Cloud computing offers this type of outsourced flexibility without having to manage the purchase and operation of additional hardware resources within an organization. A cloud-based computing resource is thought to execute or reside somewhere in the "cloud", which may be an internal corporate network or the public Internet. From the perspective of an application developer or information technology administrator, cloud computing enables the development and deployment of applications that exhibit scalability (e.g., increase or decrease resource utilization as needed), performance (e.g., execute efficiently and fast), and reliability (e.g., never, or at least rarely, fail), all without any regard for the nature or location of the underlying infrastructure.

A flow chart of an exemplary embodiment of the proposed gas analysis method is depicted Fig. 10. In a first step S1 the gas (e.g. the exhaled breath is acquired and injected to the evacuated gas sample cell. In a second step S2 a FMCW or SFCW (stepped frequency modulated) transmit signal is generated. In a third step S3 the generated transmit signal is transmitted to the gas sample cell. In a fourth step S4 the received signal is amplified and mixed with the delayed transmit signal. In a fifth step S5 a fixed IF signal is generated, amplified and filtered, wherein, preferably, a marker from the radiation generator indicates the frequency position of the transmit signal (e.g. chirp signal) to the analyzer. In a sixth step S6 the IF signal is analyzed and processed and the contents and/or concentrations of elements or compounds contained in the analyzed gas are identified. Further, eventually, related disease(s) and/or health conditions are determined. Finally, in a
seventh step S7 the obtained information (contents and/or concentrations of elements, related disease(s) and/or health conditions) is displayed (or otherwise output, e.g. transmitted to another device for further processing, evaluation, storage or display).

[0048] In summary, the present disclosure provides a gas analysis apparatus and method that can separate also nearby spectral lines due to a high frequency resolution, enables fast scanning due to a short measurement time and is easy to use. The apparatus is small and inexpensive, in particular due to the preferably used MMIC technology. Further, absolute concentrations and specificity can be obtained in preferred embodiments. The apparatus and method can advantageously be used for the analysis of exhaled breath of a person (e.g. a patient) or an animal.

[0049] An optionally usable replaceable (in particular disposable) gas sample cell provides the additional advantages that such a hygienic/aseptic and one-time use gas sample cell avoids contamination between different measurements. Further, if a quasi-vacuum is already prepared in the gas sample cell during the manufacturing process the spectrometer might be simpler to realize (e.g. does not require the use of a vacuum pump) and the measurement time can be further reduced (e.g. by avoiding the time for creating the vacuum). Still further, if the disposable gas sample cell contains a hydrophilic material to take care of the humidity the measurement accuracy can be improved or better controlled (as unknown humidity is taken care of).

[0050] Still further, trace gases or marker gases can be used in the disposable gas sample cell to improve the specificity of the apparatus even further. The measurement is then done in an indirect fashion as the 'marker gas' reacts with the molecules to be detected and then the apparatus either measures the specific response of the combination of marker gas and selected molecules or 'the amount of remaining/non-reacted marker gas'. Finally, a diversification can be achieved as the apparatus can be equipped with different gas cells (e.g. for detecting different diseases by their specific mix of characteristic molecules in the sample).
[0051] Obviously, numerous modifications and variations of the present disclosure are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

[0052] In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single element or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

[0053] Any reference signs in the claims should not be construed as limiting the scope.
CLAIMS

1. A gas analysis apparatus comprising:
   - a gas sample cell having a gas inlet and a gas outlet allowing the input and output of gas to be analyzed and a radiation inlet and a radiation outlet allowing the input and output of electromagnetic radiation, said gas sample cell employing rotational spectroscopy and comprising a hollow waveguide containing said gas and guiding electromagnetic waves of said radiation,
   - a radiation generator that generates frequency modulated radiation in a millimeter and/or submillimeter wavelength range,
   - a radiation transmitter that transmits a radiation signal generated by said radiation generator into said gas sample cell via said radiation inlet,
   - a radiation receiver that receives a radiation signal from said gas sample cell via said radiation outlet and mixes the received radiation signal with a delayed transmitted radiation signal to obtain an output signal for performing a spectral analysis.

2. The gas analysis apparatus as claimed in claim 1, wherein said gas sample cell is configured to load exhaled breath as gas to be analyzed and wherein said radiation inlet is configured to allow the input of exhaled breath into said gas sample cell.

3. The gas analysis apparatus as claimed in claim 1, wherein said gas sample cell is configured to load said gas to be analyzed at a predetermined pressure and temperature.

4. The gas analysis apparatus as claimed in claim 1, wherein said gas sample cell is configured as replaceable, in particular disposable, gas sample cell.
5. The gas analysis apparatus as claimed in claim 1, wherein said waveguide is bent, curved, meander-like or angled and has a rectangular or round cross-section.

6. The gas analysis apparatus as claimed in claim 1, further comprising a radiation transition that couples said transmitted radiation signal into said gas sample cell.

7. The gas analysis apparatus as claimed in claim 1, further comprising a radiation transition that couples the radiation signal out of said gas sample cell into said radiation receiver.

8. The gas analysis apparatus as claimed in claim 6 or 7, wherein said radiation transition comprises a dielectric layer, a radiation antenna, a radiation lens and/or a matching structure.

9. The gas analysis apparatus as claimed in claim 1, wherein said gas sample cell is loaded with a predetermined marker gas and/or an absorbent.

10. The gas analysis apparatus as claimed in claim 1, wherein said radiation generator comprises a digital, solid state, tunable signal generator.

11. The gas analysis apparatus as claimed in claim 10, wherein said signal generator comprises two radiation signal generator modules and a reference signal generator module coupled to both radiation signal generator modules, said radiation signal generator modules being configured to generate identical, but time-shifted frequency modulated radiation signals.

12. The gas analysis apparatus as claimed in claim 11.
wherein said radiation signal generator modules each comprises a direct digital synthesizer, a digital-to-analog converter or a PLL direct digital synthesizer.

13. The gas analysis apparatus as claimed in claim 10, wherein said signal generator comprises a signal generator module outputting the generated radiation signals at two outputs, wherein at one output a delay module for delaying the output radiation or a series coupling of a mixer and a filter for mixing the output radiation signals with a predetermined offset frequency and filtering the mixed signal is coupled.

14. The gas analysis apparatus as claimed in claim 1, wherein said radiation generator is configured for FMCW signal generation for generating continuous or stepped frequency modulated radiation signals.

15. The gas analysis apparatus as claimed in claim 1, wherein circuits of said radiation transmitter and/or said radiation receiver are monolithically integrated circuits.

16. The gas analysis apparatus as claimed in claim 1, further comprising an analyzer that applies a spectral analysis of the output signal.

17. The gas analysis apparatus as claimed in claim 16, wherein said analyzer is configured to identify pronounced spectral lines and/or to search for the presence of predetermined spectral lines in the spectrum of the analyzed output signal.

18. The gas analysis apparatus as claimed in claim 1, further comprising a communication interface for communication with an external analyzer that applies a spectral analysis of the output signal.

19. A gas analysis method comprising:
generating frequency modulated radiation in a millimeter and/or submillimeter wavelength range,
- transmitting a radiation signal generated by said radiation generator into a gas sample cell via a radiation inlet, said gas sample cell having a gas inlet and a gas outlet allowing the input and output of gas to be analyzed and said radiation inlet and a radiation outlet allowing the input and output of electromagnetic radiation, said gas sample cell employing rotational spectroscopy and comprising a hollow waveguide containing said gas and guiding electromagnetic waves of said radiation,
- receiving a radiation signal from said gas sample cell via said radiation outlet,
- mixing the received radiation signal with a delayed transmitted radiation signal to obtain an output signal, and
- outputting said output signal for performing a spectral analysis.

20. A gas analysis system comprising:
- a gas analysis apparatus as claimed in claim 18, and
- a radiation analyzer that applies a spectral analysis of the output signal, said analyzer comprising a communication interface for communication with said gas analysis apparatus.

21. The gas analysis system as claimed in claim 20, further comprising a cloud that includes said analyzer.

22. A replaceable gas sample cell for use in a gas analysis apparatus as claimed in claim 1, said gas sample cell comprising:
- a gas inlet allowing the input of gas to be analyzed
- a gas outlet allowing the output of gas,
- a radiation inlet allowing the input of electromagnetic radiation,
- a radiation outlet allowing the output of electromagnetic radiation, and
- a hollow waveguide containing said gas and guiding electromagnetic waves of said radiation,
wherein said gas sample cell employing rotational spectroscopy.

23. The replaceable gas sample cell as claimed in claim 22, wherein said hollow waveguide comprises a predetermined vacuum.

24. The replaceable gas sample cell as claimed in claim 22, wherein said gas inlet and/or said gas outlet comprise at least one automatic contactless valve.

25. The replaceable gas sample cell as claimed in claim 22, wherein said hollow waveguide is loaded with a predetermined marker gas and/or an absorbent.
Fig. 2

Analyzer

Receiver

Sample Cell

Breath Acquisition & Gas Handling

Transmitter

Exhaled Breath

DISPLAY

Generator

Transmitter

Sample Cell

Transition

10

11

12

13

14

15

1

2

40

50

80

60

70

71

30

20
gas acquisition and injection

signal generation

signal transmission

signal reception

signal processing

analysis

display/output

Fig. 10
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

INV. A61B5/05  G01N21/35  G01N33/497  G01N22/00

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
A61B  G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal , WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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<td>EYAL GERECHT ET AL: &quot;Chi ped-pul se terahertz spectroscopy for broadband trace gas sensi ng&quot;, OPTICS EXPRESS, vol. 19, no. 9, 25 Apri l 2011 (2011-04-25), page 8973, XP055086009, ISSN: 1094-4087, DOI: 10.1364/OE.19.008973 abstract; sect on &quot;2. Experimental setup&quot; ; f i g u r e 2</td>
<td>1-3 , 6-7, 9-21</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) on which the invention is considered to be obvious over the cited prior art

"O" document containing technical passages which may be relevant to the patentability of the claimed invention

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"A" document member of the same patent family

Date of the actual completion of the international search: 31 October 2013

Date of mailing of the international search report: 08/11/2013

Authorized officer: Wei nberger, Thorsten
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<td>US 6 527 398 B1 (FETZER GREGORY J [US]) 4 March 2003 (2003-03-04) abstract; ; column 14, line 52 - line 60; figure 1</td>
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