PORTABLE FOURIER TRANSFORM MICROWAVE SPECTROMETER WITH CRYOGENIC RECEIVER FOR TRACE GAS ANALYSIS

RELATED APPLICATION

This application claims benefit of priority of U.S. Provisional Application Ser. No. 60/013,064 filed Mar. 8, 1996.

FIELD OF THE INVENTION

This invention relates to a method and apparatus for identifying gaseous particles, compounds, molecules, transient molecules, atoms, or molecular complexes and determining their concentration in a gas mixture by analysis of an emission spectrum generated by rotational transitions of molecules in gaseous substances exposed to microwave radiation. The composition of gas mixtures as well as liquids and solids converted to gas mixtures can be quantitatively determined by microwave spectroscopy. Irradiation of gases by microwaves of a given frequency excite the molecules of one of said gases within the gas mixture. The excited gas undergoes rotational transitions which are typical for that specific molecule and because of these unique rotational transitions the excited gas can be detected and identified.

The instant invention comprises a highly compact, portable, pulsed molecular-beam Fabry-Perot cavity Fourier transform microwave spectrometer which incorporates a cryogenically-cooled, low-noise amplifier in the receiving system that has been developed for trace gas analysis. A number of new improvements in the overall instrument design have been incorporated to dramatically increase the sensitivity of the instrument and at the same time simplify the electronics associated with the instrument. With these new changes, real-time analysis of trace-gas species in the parts per billion (volume) range is possible. A user-friendly software package which employs a Graphical User Interface (GUI) has been written that allows complete mouse-driven instrument control with a standard 80486 processor based personal computer.

BACKGROUND OF THE INVENTION

The Fabry-Perot cavity is an interferometer composed of 2 semireflective mirrors. When the spacing between the mirrors is an integral number of wavelengths, light is transmitted. When it is half an integer number of wavelength, destructive interference makes the transmitted intensity very low. The contrast between the maximum and minimum transmitted intensity depends on the reflectivity of the mirrors. The resolution and free spectral range (distance in angstrom between two interference orders) depends on both the spacing between the mirrors and the finesse. The phase difference can be produced in three different ways: changing the physical spacing between the mirrors, the refraction index or the incidence angle. This path difference is expressed mathematically by the basic Fabry-Perot equation:

$$\lambda\rho=2\,nt\cos\theta$$

where theta is the incidence angle of the light, lambda the wavelength, n the refraction index, and t the distance between the mirrors. It is easy to understand that given the symmetry of revolution of the Fabry-Perot etalon, a constructive interference for a given angle theta, results in a ring of light (assuming the Fabry-Perot is illuminated by an extended monochromatic source). Therefore, the multiple ring pattern typical of Fabry-Perot interferometers is present. Here the phase change is produced by the various incidence angles. A phase difference will also be produced by a change in spacing. For a given interference order (given ring) a change in spacing produces a change in angle of the ring since the product interference order by wavelength is constant. Therefore an increase in ring diameter occurs as the spacing is increased.

It is further noted that the surface finish of the mirrors and the sphericity play an important role in the overall sensitivity of the instrument.

The following articles are hereby incorporated by reference into the instant invention. Any references within these articles are also incorporated by reference into the instant application.

"A Compact Hot-Nozzle Fourier Transform Microwave Spectrometer", M. D. Harmony, K. A. Beran, D. M. Angst, and K. L. Ratzlaff, Rev. Sci. Instru., 66, 5196–5202 (1995).

"A Pulsed Molecular Beam Fourier Transform Spectrometer with Parallel Molecular Beam and Resonator Axes", J. U-Grabow and W. Stahl, Z. Naturforsch. 45a, 1043–1044 (1990).

"The Microwave Spectrum and Molecular Structure of the Ethylene-Ozone van der Waals Complex," J. Z Gillies. C. W. Gillies, R. D. Suenram, and F. J. Lovas, J. Am. Chem. Soc. 111, 3073–3074 (1989).

Two previous patents exist which concern the technique of Fourier Transform microwave spectroscopy. Both of these patents and any references within these patents are incorporated by reference into the instant application. U.S. Pat. No. 4,369,404 to Flygare et al. teaches a conventional method and apparatus for the spectroscopic observation and detection of particles. A second patent, U.S. Pat. No. 5,124,653 to Andresen et al. teaches a method and apparatus for determining the concentration of compounds in a gas mixture by microwave gas analysis. Neither of these patents contemplates or addresses the advantages of the various embodiments of the instant invention. Namely, having mirrors and vacuum chamber sufficiently small to allow the instrument to be portable, providing a vacuum chamber which incorporates several sets of fixed-tuned Fabry-Perot cavities for detecting specific chemical species of interest, providing a fixed mirror and simultaneously forming an end of the vacuum chamber, reducing the electronic components by incorporating broad-banded single-pole double-throw microwave switches, eliminating one stage of heterodyne mixing in the receiving system, fitting the microwave mirrors with at least two microwave antennas in a preferred orientation, mounting a cryogenically cooled low noise amplifier directly to the mirror, utilizing commercially available pulsed molecular beam flow valves, utilizing mirrors with ultra-fine surface finishes, and a user friendly point-and-click software system to control the overall system, are not addressed in either U.S. Pat. No. 4,369,404 or U.S. Pat. No. 5,124,653.

Certain aspects of this invention have been disclosed in the following two scientific articles, each of which was published by a respective group of authors involving some of the inventors of the present invention.

"Fourier Transform Microwave Spectroscopy: A Potential New Analytical Tool For Trace Gas Species," R. D. Suenram, F. J. Lovas, and R. L. Sams, Measurement of Toxic and Related Air Pollutants, Proceedings of the 1994 U.S. EPA/A&WMA International Symposium, 551–561 (1994).