Application of Fabry-Perot Interferometry to Detection of Raman Scattering from Atmospheric Pollutants

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Theme

THE use of the Fabry-Perot interferometer as a filter with transmission windows occurring at regular intervals in frequency (cm^{-1}) provides a highly sensitive method for detection of atmospheric gases using their Raman spectra excited by a suitable laser. Some of the operating advantages include signal gains of several orders of magnitude, a simple direct interpretation of the results in terms of the density and types of the gaseous constituents, size and weight reductions from conventional apparatus, ease of operation, and relative freedom from interference from other molecules in the scattering volume. This method is compared with the techniques that have been discussed in the literature by other workers in the field.

Contents

Previous attempts have been made to apply the Raman effect to the detection of impurity gases in the atmosphere.[1-4] These have all applied the vibrational Raman effect. Here, we propose the use of the filtering properties of the Fabry-Perot interferometer and the rotational Raman effect to greatly improve the sensitivity of the detection of molecules through the Raman effect.

The transmission of the Fabry-Perot interferometer consists of a series of fringes equally spaced in frequency (cm^{-1}). A pure rotational spectrum of a linear molecule consists of a set of nearly equally spaced lines that may be very efficiently sampled with the Fabry-Perot interferometer. The sampling property is the basic principle that renders this scheme effective. Since the spacing of the rotational lines of a molecular spectrum is a specific property of a given molecule, then the simultaneous transmission of nearly all the incident light from Raman scattered photons signals that the plates are separated from each other by a distance directly related to the molecular constants.[5] Since other types of molecular rotors differ in the form of their term value formulas, the transmission varies, but the principle is similar and is being discussed in detail elsewhere.[6]

The Fabry-Perot interferometer possesses additional advantages, such as a large etendue', which is related to its effective light transmitting ability, and very high resolving power.

Because of the gain of the rotational Raman cross-section over that of the vibrational Raman effect (about 10^2 or more) and the increased throughput for the Fabry-Perot interferometer compared with the conventional monochromator (usually more than 100), one can expect to gain several factors of ten in sensitivity for gases which occur as pollutants in our atmosphere compared with those sensitivities quoted by earlier methods.[1-4] This indicates that pollutants can be detected at ranges exceeding several hundred meters at concentrations down to at least one hundred ppm.

In a practical sense, there may be considerable advantages to this method other than the gain in sensitivity. For example, the imaging requirements of the Fabry-Perot are not as high as for conventional monochromators reducing the requirements on the other optical components so that, using a readily obtainable finesse of 30, allows the detection of pollutants down to below 100 ppm.

Improvements in the sensitivity of the method are readily available through the use of shorter-wavelength laser light or resonance Raman effects, for example. Detailed studies of this method are in progress.

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References

[1] Kobayasi, T. and Inaba, H., "Laser Raman for Air Pollution Probe," *Proceedings of the IEEE*, Vol. 58, 1970, pp. 1568–1572.

[2] Inaba, H. and Kobayasi, T., "Laser Raman Radar for Chemical Analysis of Polluted Air," *Nature*, Vol. 224, pp. 170–172, 1969.

[3] Cooney, J. A., "Measurements on the Raman Component of Laser Atmospheric Backscatter," *Applied Physics Letters*, Vol. 12, 1968, pp. 40–41.

[4] Leonard, D. A., "Feasibility Study of Remote Monitoring of Gas Pollutant Emissions by Raman Spectroscopy," Final Report on Contract CPA 22-69-62, Nov. 1970, AVCO Everett Research Lab., Everett, Mass.

[5] Barrett, J. J. and Myers, S. A., "A New Interferometric Method for Studying Periodic Spectra using a Fabry-Perot Interferometer," *Journal of the Optical Society of America*, Vol. 61, 1971, pp. 1246–1251.

[6] Smith, W. H. and King, R., "Calculated Profiles for Rotational Raman Scattering from Molecules Multiplexed by a Fabry-Perot Interferometer," *Applied Optics*, to be submitted; also available from the author.