



## Instrumentation for Sensitive Gas Measurements

Measurements are based on cavity-enhanced absorption.

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An improved instrument for optical absorption spectroscopy utilizes off-axis paths in an optical cavity in order to increase detection sensitivity while suppressing resonance effects. The instrument is well suited for use in either cavity ring-down spectroscopy (CRDS) [in which one pulses an incident light beam and measures the rate of decay of light in the cavity] or integrated cavity output spectroscopy (ICOS) [in which one uses a continuous-wave incident light beam and measures the power of light in the cavity as a function of wavelength].

Typically, in optical absorption spectroscopy, one seeks to measure absorption of a beam of light in a substance (usually a gas or liquid) in a sample cell. In CRDS or ICOS, the sample cell is placed in (or consists of) an optical cavity, so that one can utilize multiple reflections of the beam to increase the effective optical path length through the absorbing substance and thereby in-

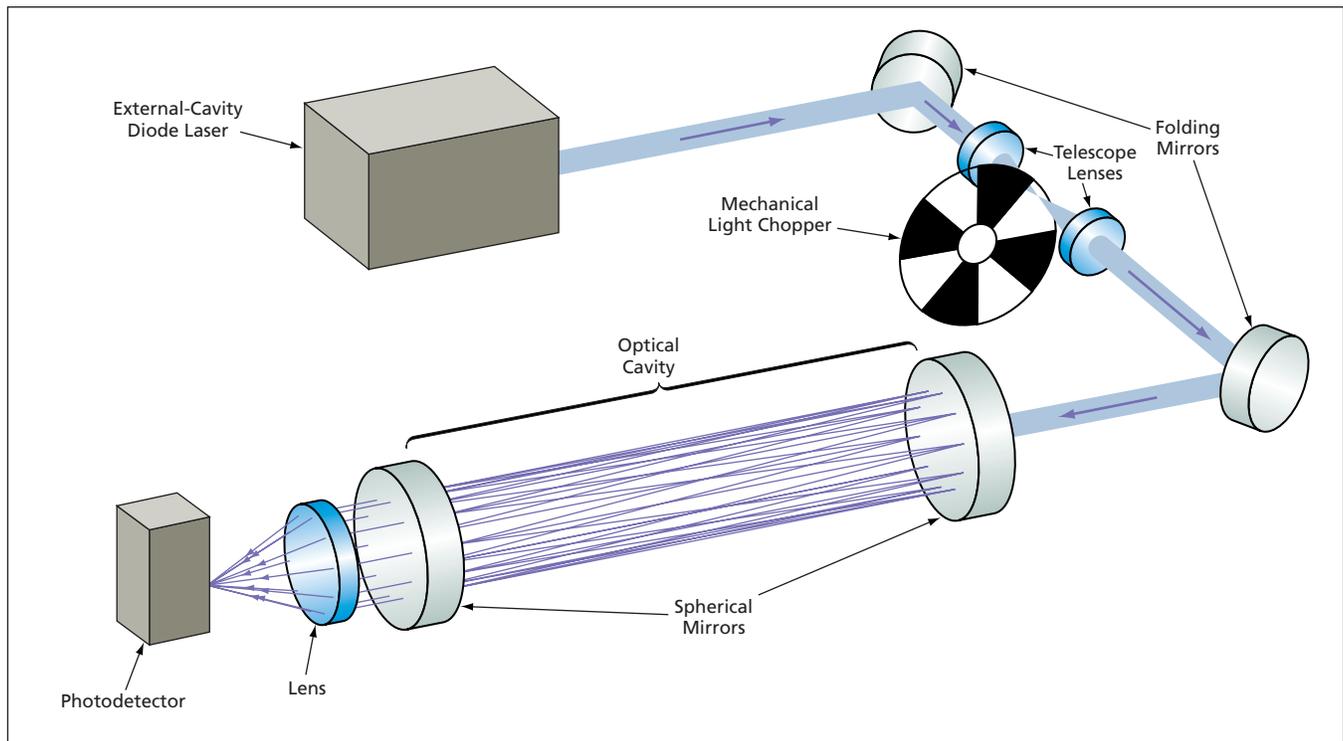
crease the sensitivity for measuring absorption. If an absorbing substance is not present in the optical cavity, one can utilize the multiple passes of the light beam to increase the sensitivity for measuring absorption and scattering by components of the optical cavity itself.

It is desirable to suppress the effects of resonances in the cavity in order to make the spectral response of the cavity itself as nearly constant as possible over the entire wavelength range of interest. In the present instrument, the desired flattening of the spectral response is accomplished by utilizing an off-axis beam geometry to effectively decrease the frequency interval between longitudinal electromagnetic modes of the cavity, such that the resulting transmission spectrum of the cavity is nearly continuous: in other words, the cavity becomes a broad-band optical device.

The instrument (see figure) includes an external-cavity diode laser, the output of which is directed by folding mir-

rors into an optical cavity. Optionally, the electromagnetic modes of the laser and the cavity can be matched by use of two telescope lenses. Also, optionally, the laser beam can be chopped for (CRDS) or not chopped (for ICOS). The optical cavity is bounded by two identical mirrors, typically having a diameter of 25 mm and a radius of curvature of 6 m (and, hence, a focal length of 3 m). Typically, the mirrors are longitudinally separated by a distance of 67 cm. Preferably, the mirrors both have reflectivities  $>0.99$ , though reflectivities as low as 0.5 could be acceptable in some applications.

The aforementioned choice of typical parameters — and in particular, the choice of a mirror focal length greater than the cavity length — was made on the basis of numerical simulations of a variety of cavity designs that yield dense mode spectra. The simulations showed that the long-focal-length condition minimizes the sensitivity of perfor-



The **Optical Path Through the Cavity** comprises multiple off-axis segments. With a suitable choice of design parameters, this arrangement yields a dense longitudinal-mode spectrum that offers several advantages.

mance to changes in the alignment and spacing of the mirrors. In addition, as a result of this choice of parameters, the light emerges from the cavity in a pattern that facilitates focusing of the light onto a possibly small photodetector.

The greatest advantage afforded by this design, relative to an on-axis design, is that one can use a narrow-band laser (bandwidth < 100 MHz), without need for complex, expensive equipment for precisely controlling the cavity length to manipulate or suppress resonances. Another advantage is reduction of optical feedback from the cavity to the laser and consequent elim-

ination of need for optical components to suppress such feedback.

Yet another advantage is removal of a major constraint on the alignment of the overall optical system: Instead of only one possible alignment geometry (the laser beam aligned with the optical axis of the cavity), one can choose any alignment for which there is a stable optical path through the cavity. As a result, alignment routine can be simplified and the instrument is less sensitive to vibration.

Currently, a product line of instruments is being developed based on the technology described above for high-

sensitivity, precision, and accurate gas measurements. Some applications that will benefit from this technology include atmospheric monitoring, chemical and biological agent detection, industrial process control, and medical diagnostics.

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*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center, (650) 604-5104. Refer to ARC-14690-1.*

## Apparatus for Testing Flat Specimens of Thermal Insulation

An improved design affords flexibility for testing under diverse conditions.

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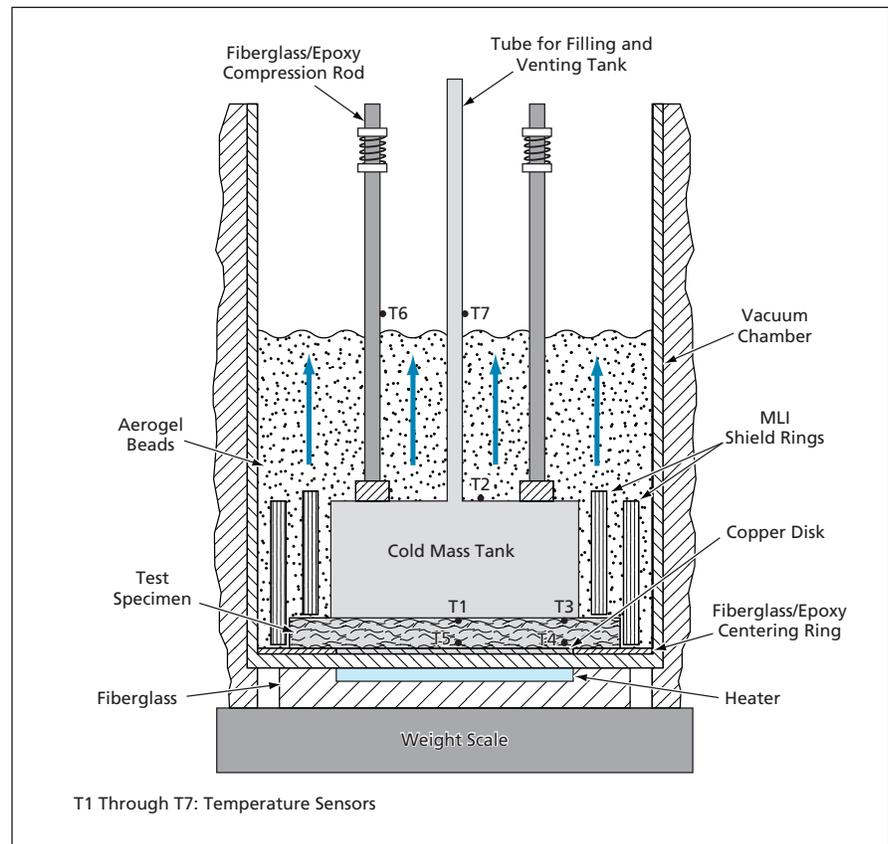
An apparatus has been developed to implement an improved method of testing flat-plate specimens of thermal-insulation materials for cryogenic application. The method includes testing under realistic use conditions that could include vacuum and mechanical loading at a pressure up to 70 psi ( $\approx 0.48$  MPa). The apparatus can accommodate a rigid or flexible specimen having thickness up to 1.25 in. ( $\approx 3.2$  cm) and diameters between 6 and 10 in. (about 15.2 and 25.4 cm, respectively). Typical test conditions include boundary temperatures between 77 K and 373 K and vacuum/interstitial gas filling at a pressure between  $10^{-6}$  torr ( $\approx 1.3 \times 10^{-4}$  Pa) and 760 torr (atmospheric pressure  $\approx 0.1$  MPa). The interstitial gas could be  $N_2$ , He,  $CO_2$ , or any other suitable gas to which the insulation is expected to be exposed in use. Relative to prior apparatuses and testing methods, this apparatus and the testing method that it implements offer advantages of relative simplicity and ease of use.

The basic principle of operation of the apparatus is that of boil-off calorimetry, using liquid nitrogen or any other suitable liquid that boils at a desired temperature below ambient temperature. Comparative rates of flow of heat through the thicknesses of the specimens (heat-leak rates) and apparent-thermal-conductivity values are obtained from tests of specimens. Absolute values of heat-leak rates and apparent thermal conductivities are computed from a combination of (1) the aforementioned comparative values and (2) calibra-

tion factors obtained by testing reference specimens of materials that have known thermal-insulation properties.

The apparatus includes a full complement of temperature sensors, a vacuum pump and chamber, a monitoring and

control system, and tools and fixtures that enable rapid and reliable installation and removal of specimens. A specimen is installed at the bottom of the vacuum chamber, and a cold-mass assembly that includes a tank is lowered into posi-



**A Specimen Is Sandwiched** between a cold mass tank containing liquid nitrogen and a heated copper plate. The apparent thermal conductivity of the specimen is determined from the liquid-nitrogen boil-off rate and the temperatures of the top and bottom specimen surfaces.