A Monolithic Interferometer for FT-IR Spectroscopy

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When two separate bundles of parallel light beams having the same characteristic wavelength and propagation are combined, the combination of the bundles causes a phenomenon called light interference. To create such an interference, Michelson used two mirrors at 90° and a beamsplitter to separate the beams and recombine them. Figure 1 is a schematic of the classical Michelson interferometer.

The manifestation of light interference, as seen on a piece of ground glass, is a series of dark and light lines called fringes. Analysis of the fringe pattern yields the properties of the wavefront, and, thus, the optical and mechanical properties of all of the optical elements that transmit or reflect the light waves through the interferometer.

In many applications, one of the interferometer mirrors is accurately moved, causing movement of the fringes. In addition, focusing the fringes on a photodetector enables measurement of their intensity. This combination of controlling the linear movement of the fringes, and thus the optical path, and measuring their intensity yields the spectral information that enables the performance of the Fourier transformation. This type of analysis produces an absorption curve for a given transparent sample through which the light waves are passing. These are the basic fundamentals for the creation of an FT-IR interferometer system. This discussion is about the heart of the FT-IR system, which is the optical interferometer assembly.

Interferometers are very sensitive to environmental conditions. In FT-IR applications, where the Michelson configuration is widely used, the common method of assembly is to mount the mirrors and the beamsplitter kinematically, using some kind of screw arrangement, on an aluminum chassis. A significant part of the assembly process is the alignment procedure involved in each assembly, where element positions must be maintained within millionths of an inch and angular orientations within fractions of a second. To enable this alignment, each mirror mount is provided with an *X,Y* tilting mechanism. This mechanism must be able to lock the optical elements in place without distorting the exiting wavefront of the system.

A common problem with this configuration is that the mirror alignment is very sensitive to vibration, shock, and slight metal fatigue conditions. It is also sensitive to changes in ambient temperature because the optical elements are usually made of glass, and the chassis is made of aluminum. These materials have very different coefficients of thermal expansion (CTEs) and conductivities. The assembly of optical elements and a chassis with different CTEs and conductivities would normally require a flexible member between the mirrors and the aluminum chassis. However, this requirement contradicts a more important one, that is, that the interface between the different components in the assembly be totally stiff. Various technologies have been developed to overcome this problem; nonetheless, maintaining constant alignment is a routine and costly process. Hence the need for a more accurate and stable interferometer. To address this need, an interferometer encompassing a monolithic body assembly of two mirrors and a beamsplitter (PLX, Deer Park, NY) was developed with an assembly that is used with a PLX hollow retroreflector to separate and recombine the beams.

The monolithic body of the interferometer is made of fused quartz plates assembled into a sandwichlike structure. The mirrors and beamsplitter, also made from quartz, are mounted onto the main structure using proprietary technology. The use of all-

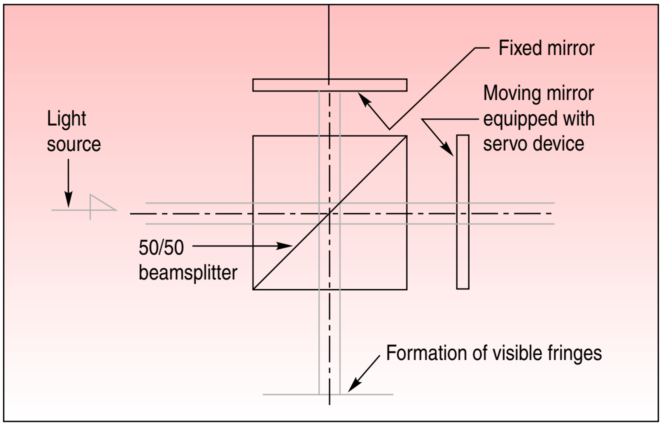

Figure 1. Schematic of the Michelson interferometer.

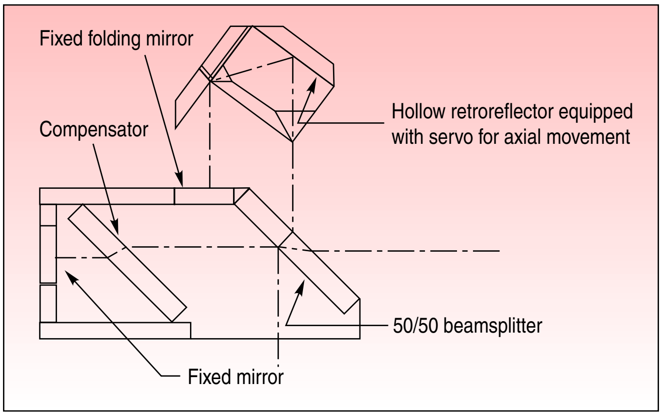

Figure 2. Schematic representation of the PLX interferometer.

Figure 3. Representational view of the monolithic interferometer.

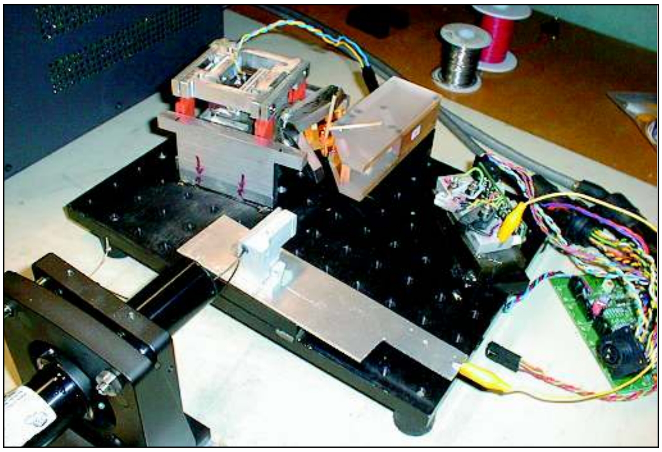

Figure 4. Monolithic interferometer on a breadboard as tested.

quartz elements eliminates the problem of materials with different CTEs and conductivities.

The unit is designed for double-pass applications in order to accommodate NIR, broadband interferometry. Typically, quartz transmits efficiently from 0.2 to 3.6 µm. The beamsplitter was designed for 50/50 transmission/reflection, and the mirror coatings were designed for high reflectance at this range. A hollow retroreflector is used for folding the beams to create and move fringes. Tested at 0.6328 µm parallel light output, the interferometer exhibits wavefront distortion of $<\lambda/10$ waves output at a double pass through the hollow retroreflector. Figures 2 and 3 show schematic and representational views of the unit.

The process for creating these monolithic optical structures is a mature technology. It has been used in military, aerospace, deep space, and laboratory applications to build many systems that exhibit critical accuracy and long-term stability, even under adverse environmental conditions. The interferometer has been designed primarily for OEM applications. It can be adapted to accommodate

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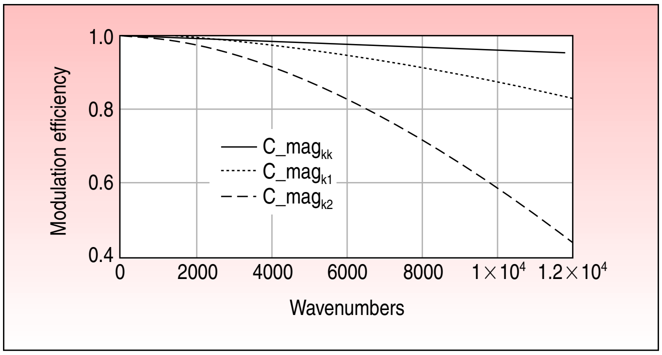

Figure 5. Graph showing the effects of 0.25, 0.5, and 1 waves tilt on modulation efficiency.

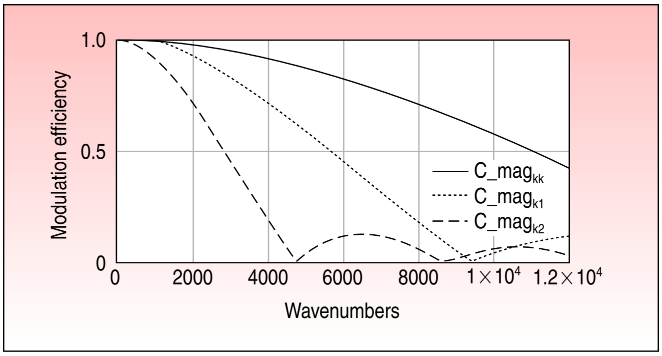

Figure 6. Graph showing the effects of 1, 2, and 4 waves HeNe tilt on modulation efficiency.

a wide range of sizes, accuracies, and wavelengths.

Of the many challenges facing the designers of Michelson interferometer–based instruments, thermal and mechanical alignment stability are probably the most formidable. For an instrument to exhibit good thermal stability the optical components used in the interferometer must maintain wavefront accuracy of ¼ wave HeNe or better over the operating temperature range. In addition, the components making up the interferometer must remain aligned to within ¼ wave HeNe, or better, over temperature, time, and the shock and vibration encountered during shipping.

To understand how wavefront accuracy and alignment affect stability we need to look at modulation efficiency, which is defined as the ratio of modulated light to total light. It is a measure of how completely the wavefronts interfere. If we consider wavefront accuracy and alignment to be affected by a simple tilt and we ignore parasitic reflections from surfaces not in the interferometer cavity, we can express modulation efficiency as follows:

$$C_{mag} = \frac{\left| \iint I_k(y,z)\, dz\ dy\ yz \right|}{A^2 \iint dz\ dy\ yz} \qquad [1]$$

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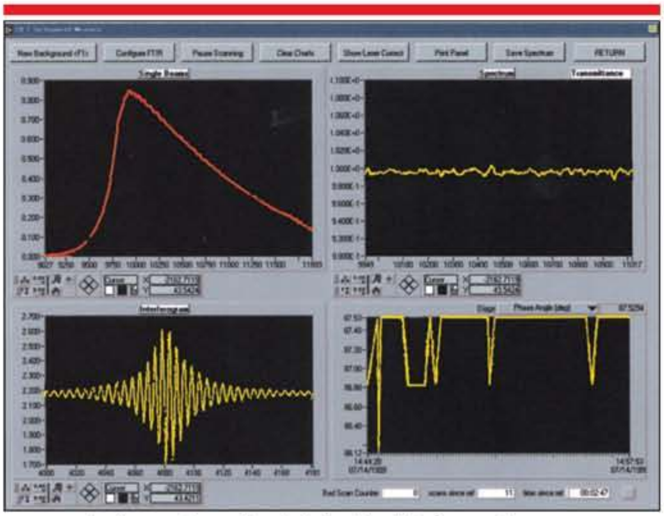

Figure 7. Instrument monitor data for the interferometer.

Figure 8. Stability test data from the interferometer.

where $I_k = A_\upsilon^2 e^{i2\pi\upsilon[x_k + \Delta x(y,z)]}$ and C_{mag} is modulation efficiency, A_υ is amplitude at frequency υ, x_k is pathlength difference in the interferometer cavity, Δx is the distribution of path difference due to tilt, y,z is the coordinates in a circular beam, and k is the integer value (index variable).

We can perform this integration and plot the value of C_{mag} as a function of wave numbers for a given tilt; for the sake of simplicity $xk = 0$ (no path difference, ZPD), $\Delta x(y,z) = y \times 0$ (tilt in y direction only), and $A = 1$. Figures 5 and 6 show that the modulation efficiency for a given tilt is a function of wavelength and that for a greater tilt the modulation efficiency at shorter wavelengths drops off more rapidly. Because the modulation efficiency determines the signal amplitude, we can see how misalignments can affect the stability of the instrument, especially at shorter wavelengths, which are of interest in near-IR instruments.

On-Line Technologies (East Hartford, CT) and PLX have combined efforts to develop a near-IR and mid-IR system based on the monolithic interferometer. The company tested a prototype of the interferometer on a breadboard using its data acquisition system and servo mirror controller (Figure 4). The system tested was designed for the near-IR region. An incandescent light was used as the source and a silicon photodiode as the detector. The breadboard was covered with a Plexiglas box during the test to protect the interferometer from drafts.

The system scanned continuously for 24 h and data were collected every 5 min. The interferograms were then fast-Fourier transformed (FFT), and the region containing the highest S/N was averaged and plotted. Figure 7 shows the sampled interferogram and the result of the FFT (single beam), transmittance, and reference laser data. Figure 8 shows the energy in the region between 10,000 and 11,000 wavenumbers (1–0.91 µm) plotted as a function of time. Also plotted is the ambient temperature measured in proximity to the breadboard.

CONCLUSION

The data show that the system as tested has a temperature dependence of approximately 0.15% per degree Fahrenheit, which is very good for a near-IR system on a prototyping breadboard. In addition the monolithic interferometer appeared to be rugged and mechanically stable.

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