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A New Technique for Dispersive-Reflection Spectroscopy in the Far Infrared

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Abstract—**A new technique is described for measuring the amplitude- and phase-reflection spectra of solids in the far infrared. The field of view in the fixed arm of a Michelson interferometer is divided by screens to allow the specimen and reference mirror to be placed side by side. Interferograms are then recorded by reflection from each in turn so that phase errors arising from the physical replacement of the reference mirror by the specimen are eliminated. The method is demonstrated with room-temperature and low-temperature measurements on a crystal of KBr.**

INTRODUCTION

During the past few years important advances have been made in the use of dispersive (or asymmetric) Fourier-transform spectroscopy for the determination of refractive-index spectra (n,k) in the far infrared from transmission measurements [1]–[3], and for obtaining the optical constants directly from measurements of amplitude- and phase-reflection spectra (r,ϕ) [4]–[6].

To make dispersive reflection measurements on solids the fixed (reference) mirror of a Michelson interferometer is replaced by the specimen and an asymmetric interferogram is obtained which can be Fourier analyzed to give a complex transform. The complex reflectivity

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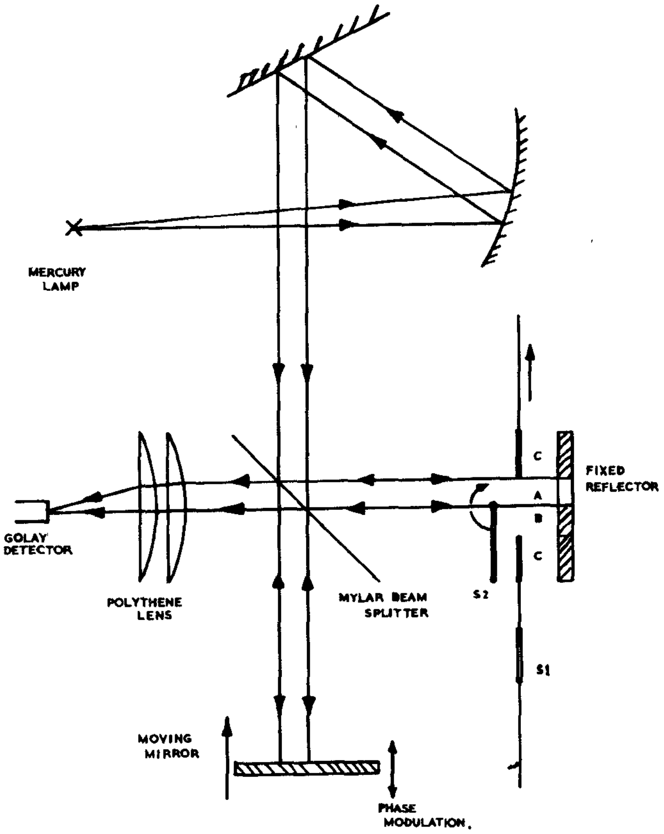

Fig. 1. Schematic diagram of the Michelson interferometer showing the two movable screens $S1$ and $S2$ in front of the fixed reflector, and the paths of the coherent beams of radiation using part A.

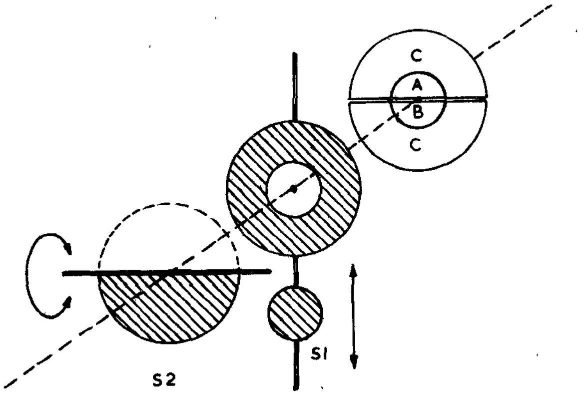

Fig. 2. The geometry of the two screens and the division of the field of view at the fixed reflector.

$r \exp(i\phi)$ is found by dividing this transform by the transform of the symmetric interferogram obtained with the reference mirror, and the advantages of this technique over the Kramers–Krönig analysis have been described elsewhere [6]–[8].

There is, however, one major difficulty in dispersive-reflection spectroscopy. The accuracy of the phase measurement is limited by the error, Δx, in the determination of the relative positions of the specimen and reference-mirror surfaces when the two interferograms are recorded. Accurate values for the optical constants can only be obtained if the phase error is a few degrees at most, which corresponds at 300 cm^{-1} to $\Delta x \lesssim 0.2$ μm. This precision is difficult to achieve experimentally and is the main obstacle to widespread use of the technique.

In previously published techniques Δx has usually consisted mainly of the positional error in the mechanical replacement of the reflecting surfaces together with the backlash error in the micrometer screw, but we have recently reported room-temperature measurements on a KBr crystal using a new technique which circumvents the need for precise mechanical replacement of reflecting surfaces [8]. The method can be extended to eliminate the backlash error and is suitable for use at low temperatures and on samples of area $\gtrsim 1$ cm^2.

The performance of the instrument has recently been improved by changing from amplitude modulation to phase modulation [9], [10], and in this paper we report our first phase-modulated measurements with this technique. Room-temperature and low-temperature amplitude- and phase-reflection measurements on a crystal of KBr are presented.

EXPERIMENTAL METHOD

The basic idea of the instrument, illustrated in Figs. 1 and 2, is that the fixed mirror in a Michelson interferometer is replaced by an optically flat reflector whose surface is divided up as follows. There is an outer ring C which is metallized. The circle inside this ring is divided into two equal D-shaped parts. Part A is the surface of the specimen and part B is metallized. By an arrangement of opaque screens which have been designed to prevent crosstalk between the three areas, each of these parts may in turn be used as the reflector. First, the outer ring is used to align the whole reflector so that the incident beam is perpendicular to the surface. Having a large radius, it provides a very reproducible alignment. Then a specimen interferogram S is recorded with part A exposed and a reference interferogram B' is recorded with part B exposed. The interferograms are Fourier transformed and the ensuing complex spectra are ratioed to give the complex-reflection spectrum. The procedure for obtaining the optical constants from the interferograms is illustrated in Fig. 3. To reduce systematic errors caused by asymmetry between the two sides (A and B) of the instrument, this output spectrum is reratioed against a ratioed calibration spectrum obtained from two further interferograms, A and B, recorded in a separate experiment with the fixed reflector replaced by a reference mirror. The optical constants (n,k) can then be computed from the calibrated amplitude and phase-reflection spectra (r,ϕ).

A Grubb Parsons/NPL modular Michelson interferometer has been modified for this work as described in our previous article [8], and a 50-mm-diam optically flat crystal of KBr has been used to demonstrate the technique. The polished surface was first aluminized leaving exposed only the area $A \sim 2.5$ cm^2 (Fig. 2). By using a microscope with an interference objective the thickness of the aluminium deposit was found to be $\sim$0.08 μm which is too thin to cause significant errors in the infrared-phase spectrum.

For the low-temperature measurements, the cold-finger arrangement illustrated in Fig. 4 was used. The specimen was mounted on a copper block attached at three points by nylon bolts and steel springs to a sensitive alignment mechanism, and the back of the block was attached by thick flexible copper braid to a cold finger containing liquid nitrogen. The nylon bolts provide fairly effective thermal isolation between the specimen mount and the alignment mechanism, and the arrangement permits precise alignment of the crystal after it has been cooled. Provision has not yet been made for adequate heat shields to be placed between the specimen and its surroundings or for optical filtering to prevent short-wave radiation from the mercury lamp reaching the specimen, so it has so far only been possible to reduce the crystal temperature to about 200 K. However, the results demonstrate that after allowing sufficient time for the temperature of the specimen to stabilize, the technique is suitable for low-temperature measurements, and that the phase measurement can be made with the same precision as at room temperature.

The technique of dividing the field of view has the disadvantage that, using amplitude modulation at the source, a large additional dc load is carried on the interferograms because of the difference in size between areas A and B and the area of the moving mirror. This, together with the need for four interferograms for each specimen spectrum, increases the likelihood of excessive noise. To obtain a satisfactory signal-to-noise ratio, phase modulation [9], [10] has been added by mounting the moving mirror on a plastic ring cemented to the cone of a small loudspeaker bolted to the micrometer spindle. After some initial difficulties a loudspeaker arrangement was found with mechanical stability within the requirements of the phase measurements. A photometric accuracy of about 2 percent is achieved on the final-amplitude spectra at a resolution of 2 cm^{-1} using a Golay detector with 1-s integration time per sampling point.

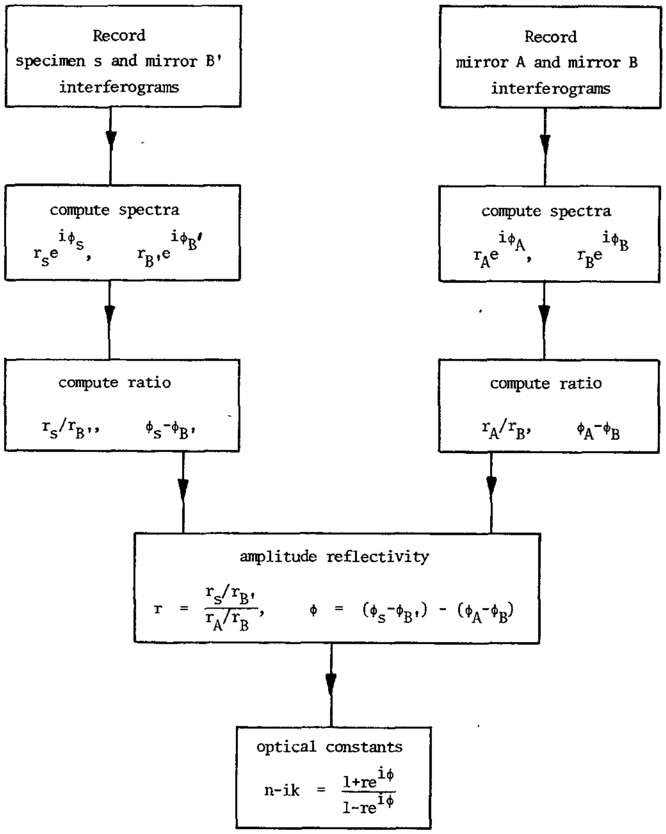

Fig. 3. Block diagram of the data-processing sequence.

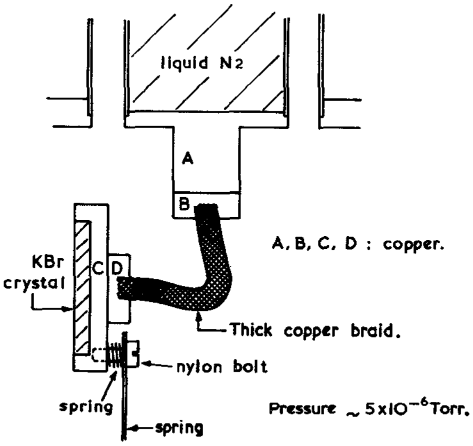

Fig. 4. Schematic diagram of the specimen mount and cold finger.

In the Grubb Parsons/NPL cube interferometer the moving mirror scans the interferogram in 2.5 μm steps and the sampling interval is used to monitor the accuracy of the phase measurements as follows. The specimen is installed and cooled as shown in Fig. 4 and, after allowing several hours for the instrument to become thermally stable, the interferometer is aligned using area C by maximizing the detector signal at the grand maximum near the zero path position with the moving mirror at a sampling point. Interferograms S and B' (Fig. 5) are then recorded by reflecting from areas A and B in turn. Backlash errors are minimized by scanning each interferogram in the same direction, and the first point on each interferogram is used as the phase reference. The specimen is then replaced by a reference mirror and two calibration interferograms, A and B, Fig. 6, are recorded after following a similar alignment procedure.

After this, reproducibility of the sampling positions on the interferograms provides a good indication of the final accuracy of the phase measurements. In particular, for satisfactory performance of the instrument the following should be true.

1) Repeated interferograms from either area A or area B, even after realignment, should be indistinguishable; i.e., the sampling points should lie at the same positions on the interferograms.

2) The sampling points should be nearly, but not necessarily exactly, at the same positions on interferograms A, B, and B'.

This is illustrated in Figs. 5 and 6 where a typical set of four interferograms is shown with the sampling points near the zero path positions marked on interferograms A, B, and B'. The amplitude- and phase-reflection coefficients (r,ϕ) and the optical constants (n,k) can then be computed from the interferograms by following the procedure set out in Fig. 3.

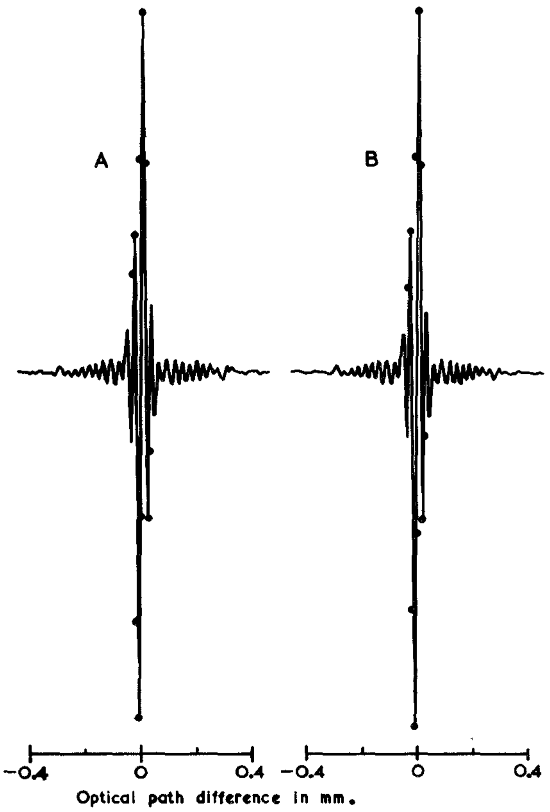

Fig. 6. Phase-modulated calibration interferograms A and B obtained by reflection from a reference mirror.

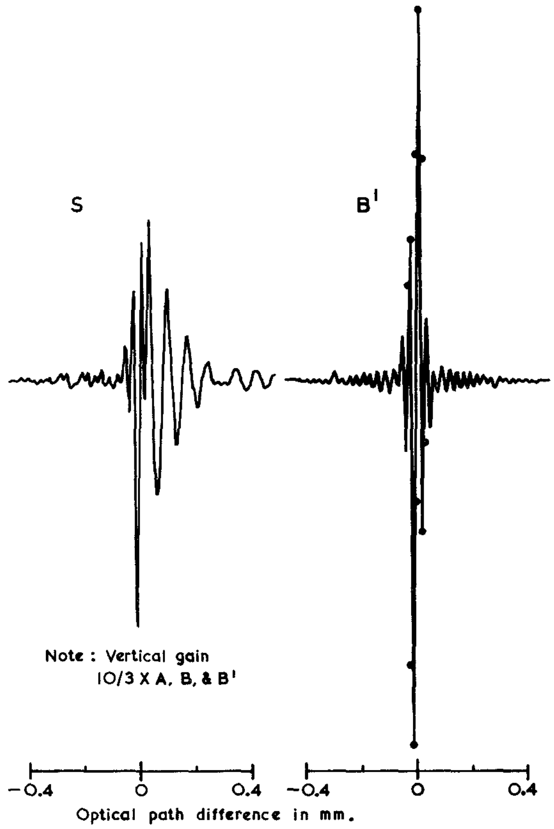

Fig. 5. Phase-modulated interferograms obtained by reflection from the cooled specimen and the reference mirror B'.

Fig. 7 shows the amplitude- and phase-reflection spectra

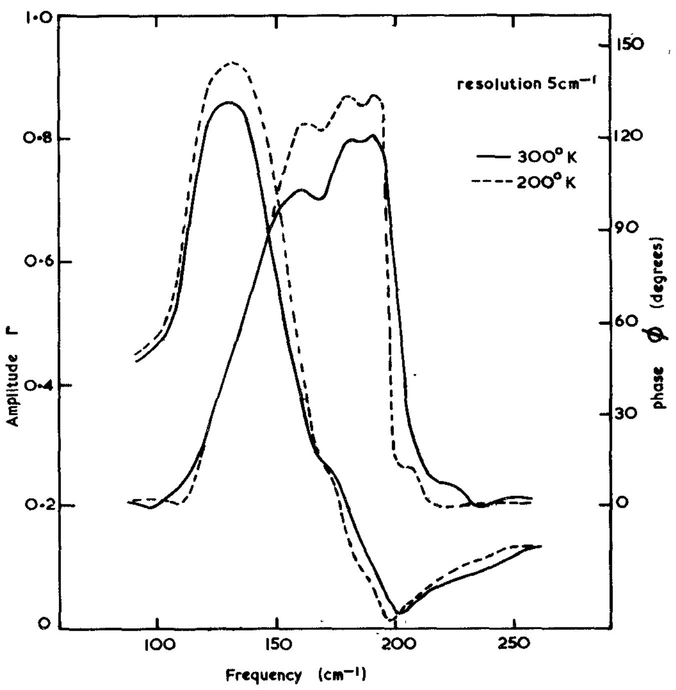

Fig. 7. The amplitude- and phase-reflection spectra of KBr measured at 200 and 300 K.

of KBr measured with this technique at 300 and about 200 K. In each case, one set of four interferograms has been used with an integration time of 1 s/sampling point.

CONCLUSION

A technique is described for measuring the amplitude- and phase-reflection spectra of solids in the far infrared without precise mechanical replacement of reflecting surfaces. The technique is illustrated with measurements at 5-cm^{-1} resolution on a KBr crystal at 300 and 200 K. Using this technique, amplitude- and phase-reflection spectra can be measured at low temperatures with the same precision as at room temperature. More careful cryogenic engineering will enable the measurements to be extended to lower temperatures.

The technique has the disadvantage that four interferograms are required for each spectrum, but it is found that by using phase modulation on the moving mirror a satisfactory signal-to-noise ratio can be obtained with a Golay detector on samples of area greater than about 1 cm^2.

The accuracy of the phase measurement is limited by the backlash error in the moving-mirror micrometer screw which amounts to $\sim\pm 0.15$ μm. However, because of the ease with which one can switch from the specimen to the reference mirror, backlash errors can be eliminated by reflecting from each surface in turn on a single scan of the moving mirror.

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Atmospheric Noise in the Far Infrared (300–3000 μm)

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***Abstract*—Noise measurements in the frequency regions 5–200 Hz and 5.2×10^{-4}–8.3×10^{-3} Hz have been performed in the wavelength region between 300 and 3000 μm from the high altitude observatory of Testa Grigia, Italy (3.500 m).**

In the high frequency region a specially designed Ge bolometer operating in background-limited-infrared-photoconductor conditions matched to a 1.5-m telescope has been used, while at low frequency a radiometer designed for atmospheric transmittance measurements was employed.

In both regions no excess noise with respect to the photon noise relative to 300-K blackbody has been detected.

I. INTRODUCTION

ANY further development in ground based far infrared (FIR) astronomy requires a better knowledge of low frequency noise which may be introduced by atmospheric fluctuations.

While measurements in the near infrared (NIR) (8–14

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