The Performance of an Amplitude Fourier Spectrometer for Far-Infrared Solid-State Spectroscopy

J. GAST, L. GENZEL, AND U. ZWICK

Abstract—**A far-infrared Fourier interferometer for amplitude-phase reflection spectroscopy on solids is described. It can be used with small samples at low temperatures and with fairly high resolution (<0.1 cm^{-1}). The spectral range presently is 10–1000 cm^{-1}.**

I. INTRODUCTION

CONVENTIONAL Fourier spectroscopy yields the power spectrum of either reflectance or transmittance because the sample is placed outside the interferometer. However, by putting the sample in one arm of a Michelson interferometer, one has the unique possibility of amplitude-phase Fourier spectroscopy. The asymmetric sample interferogram can be transformed into the spectral functions of phase and amplitude of reflectance or transmittance. From this, the complex refractive index (n,k) or the dielectric function (ϵ',ϵ'') are computed by standard expressions. Several papers during the last years [1]–[3] have reported on the theory and applications of this type of spectroscopy for the infrared.

Since this technique appears to be especially advantageous for solid-state reflection spectroscopy, an interferometer has been developed which allows small samples to be measured in the middle and far infrared, at low temperatures and with high resolution. A preliminary description of this instrument has been published recently [4].

II. THE INTERFEROMETER

The optical layout of the Michelson-type interferometer is shown in Fig. 1. The novel feature is that the sample and reference mirror are located inside the interferometer at focal points which are independent of the path difference between the two arms of the interferometer. The interferograms are produced by moving one of the cube-corner mirrors which are placed in parallel beams.

In the sample chamber, which is a cryostat for low-temperature measurements, Fig. 2, the radiation is reflected upwards onto the horizontally placed sample and reference mirror lying on a highly plane-parallel fused silica plate which has three holes for the passage of the radiation. One hole is for the sample, two holes for two reference mirrors. By rotating the fused silica plate in its plane, one can achieve three combinations for the ends

Manuscript received May 6, 1974.

J. Gast is with Bruker-Physik A.G., Karlsruhe-Forchheim, Germany.

L. Genzel and U. Zwick are with the Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany.

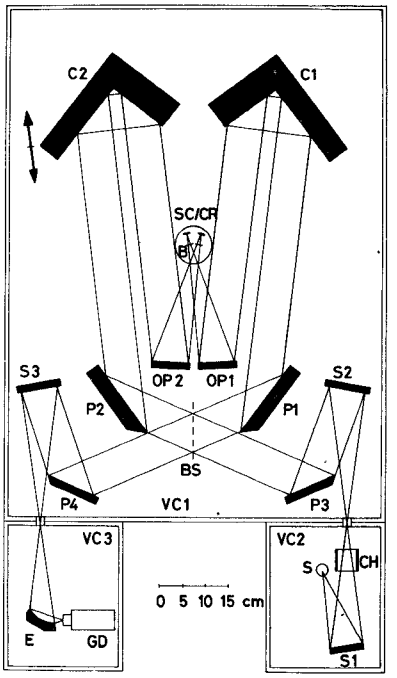

Fig. 1. Optical plan of the asymmetric vacuum Michelson interferometer; S1–S3: spherical mirrors; P1–P4: plane mirrors; OP1,OP2: off-axis paraboloids; C1,C2: cube-corner mirrors; BS: beamsplitter; E: off-axis ellipsoid; S: source; CH: chopper; GD: Golay detector; SC: sample chamber; CR: cryostat; B: beam reflected upwards; VC1–VC3: vacuum chambers.

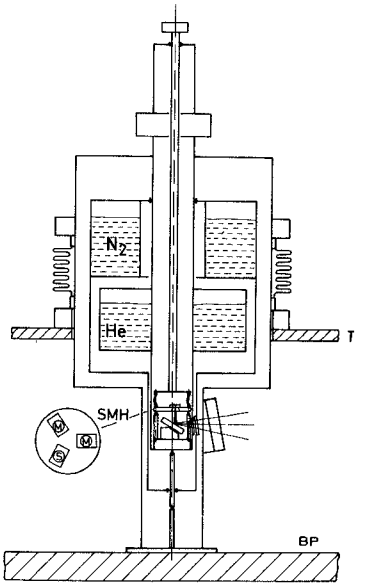

Fig. 2. Cryostat for the amplitude-phase Fourier spectrometer; T: cover of the vacuum tank; BP: optical base plate; SMH: sample–mirror holder.

of the two interferometer arms, namely, sample–mirror, mirror–mirror, and mirror–sample. In this way, one can take sample and background interferograms without removing the sample or the mirrors from their base plate.

Vacuum chambers for the whole instrument provide pressure down to 10^{-5} torr. This allows the use of a He cryostat with only one window for the exchange gas sample chamber. The window is inclined to the vertical by a small angle to avoid deranging reflections. It has to be plane parallel and optically homogeneous.

With a Golay detector and a Moirée-controlled drive of the cube-corner mirror, the spectral range of the instrument is from 10 to 1000 cm^{-1}. A laser-controlled drive and low temperature detectors extend this range on both ends. A maximum path difference of ± 30 cm determines the highest resolution. Samples as small as 4×4 mm^2 can be measured. It is important to minimize the unevenness of the reflection surface of the sample to prevent pseudocoherence effects [2]. Backside reflection from the sample must be avoided by using wedge-shaped crystals.

III. MEASUREMENTS

As a performance test and as a demonstration of the range of applicability, a series of reflection measurements were made for several crystals whose infrared spectra are fairly well known. The spectra of InSb and InAs have been shown already in the earlier paper [4]. We present here a measurement on a single crystal of $SrTiO_3$.

The sample had a highly polished area (unevenness $<$ 0.5 μm) of about 0.5 cm^2 and a spherelike back face. Fig. 3 shows the results for the power reflectance r^2 and the phase ϕ in the spectral range from 20 to 700 cm^{-1}. These quantities are defined by the complex amplitude reflectance $r = r \exp(i\phi_r)$ of the sample and reference-mirror reflectance $r_m = \exp(i\pi)$ so that the phase of Fig. 3 is given by $\phi = \phi_r - \pi$.

The determination of the dielectric function $\epsilon = \epsilon' + i\epsilon''$ from r and ϕ_r is done with the help of standard expressions. In the range from 300 to 700 cm^{-1} our results of ϵ' and ϵ'' confirm those obtained by several authors [5], [6] who

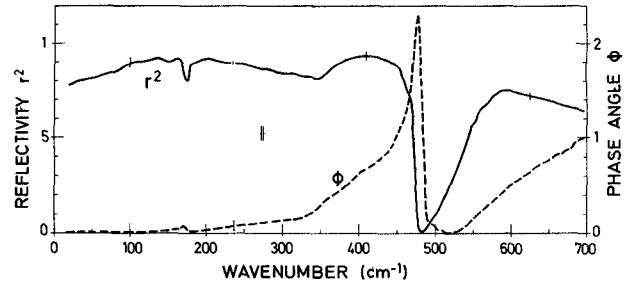

Fig. 3. Power reflectivity r^2 and phase angle ϕ of $SrTiO_3$ at room temperature.

measured the power reflectance and used the Kramers–Krönig analysis to obtain the dielectric functions.

The measurements in the low-frequency region, however, show that the evaluation of the dielectric function is very sensitive to the accuracy at which the phase ϕ can be measured. The necessary signal-to-noise ratio is difficult to achieve in the far infrared, and also phase errors from sampling the interferogram are very critical. This example demonstrates that amplitude-phase Fourier spectroscopy is only superior to conventional methods in cases of strongly structural spectra for which the amplitude and phase change rapidly, and also in cases for which information has to be gained from regions of low reflectance.

REFERENCES

[1] J. E. Chamberlain, J. E. Gibbs, and H. A. Gebbie, "Refractometry in the far infrared using a two beam interferometer," *Nature*, vol. 198, pp. 874–875, June 1963.

[2] E. E. Bell, "Measurement of the far-infrared optical properties of solids with a Michelson interferometer used in the asymmetric mode: Part I: Mathematical formulation," *Infrared Phys.*, vol. 6, pp. 57–74, July 1966; also, "The use of asymmetric interferograms in transmittance measurements," *J. Phys.*, vol. 28, suppl. colloq. C2, pp. C2-18–C2-25, Mar.–Apr. 1967.

[3] E. E. Russell and E. E. Bell, "Measurement of the far-infrared optical properties of solids with a Michelson interferometer used in the asymmetric mode: Part II: The vacuum interferometer," *Infrared Phys.*, vol. 6, pp. 75–84, July 1966.

[4] J. Gast and L. Genzel, "An amplitude Fourier spectrometer for infrared solid state spectroscopy," *Opt. Commun.*, vol. 8, pp. 26–30, May 1973.

[5] C. H. Perry, B. N. Khanna, and G. Rupprecht, "Infrared studies of Perovskite titanates," *Phys. Rev.*, vol. 135, pp. 408–412, July 1964.

[6] A. S. Barker, Jr., "Temperature dependence of the transverse and longitudinal optic mode frequencies and charges in $SrTiO_3$ and $BaTiO_3$," *Phys. Rev.*, vol. 145, pp. 391–399, May 1966.