

THE FAR INFRARED OPTICAL PROPERTIES OF InP AT 6 AND 300 K

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Received August 16, 1983

The amplitude and phase reflection spectra of InP have been determined in the far infrared at 6 and 300 K by dispersive Fourier transform spectroscopy and used to calculate values of the optical constants and dielectric functions in the region of the fundamental lattice resonance.

Key Words: far infrared, optical constants, dielectric parameters, InP.

Introduction

Although it is nearly thirty years since the first reported measurements of the optical constants of the II-VI and III-V semiconductors (1), there are still comparatively few reliable values available for the far infrared region, particularly at frequencies near or below the reststrahlen band where the crystals are opaque due to the combined effects of the fundamental lattice resonance and free carrier absorption. In the most recently reported work, the technique of dispersive Fourier transform spectroscopy (DFTS) has been used to determine the optical properties of CdTe(2) and InAs(3) in this region, and in this paper we report the first measurements by DFTS of the far infrared optical constants and dielectric parameters of InP at 6 and 300 K.

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Experimental Method

The amplitude and phase reflection spectra of an undoped single crystal of InP obtained from MCP Electronic Materials Ltd. (4) were determined at a resolution of 2 cm^{-1} between about 150 and 450 cm^{-1} at 6 and 300 K by amplitude reflection spectroscopy. The dimensions of the sample were approximately 23 mm diameter and 2.85 mm thickness. The experimental technique and method of sample preparation, and the analytical techniques used to determine the amplitude and phase reflection spectra, the optical constants and the dielectric functions from the measured interferograms have been described in detail elsewhere (5,6).

Results and Discussion

The measured values of the amplitude and phase reflection spectra, the optical constants (n, k) and the dielectric parameters (ϵ', ϵ'') at 300 K are shown in Figure 1, and the results of similar measurements at 6 K are shown in Figure 2.

It should be noted from Figures 1(a) and 2(a) that at frequencies below about 300 cm^{-1} and above about 380 cm^{-1} the absolute value of the phase cannot be determined satisfactorily by this technique as it is very close to the phase of the reference mirror. However, the random noise level in the amplitude and phase are less than 0.005 and 30 m rad , respectively, over most of the measured range, so the signal-to-noise ratio is good enough to reveal many weak features in the spectra for the first time. Away from the reststrahlen band the absolute value of the phase is dominated by systematic errors arising from small errors in the location of the interferograms on the micrometer scale. The sources of these errors have been discussed in detail elsewhere (6), and in the present measurements they result in a residual positional error (Δx) of less than $0.1\mu\text{m}$, which corresponds to a systematic phase error of $\Delta\phi = 4\pi\bar{\nu}\Delta x$ at wavenumber $\bar{\nu}$. It follows from the Fresnel relations (7) that the ensuing values of k and ϵ'' are only well-determined in the range $300 - 380\text{ cm}^{-1}$ although the observed structure outside this region (see Figures 1(b) and 2(b)) is reproducible. Reliable values of these parameters away from the reststrahlen band can be obtained either by supplementing these measurements by absorption measurements to determine the phase (8), or by transmission DFTS (9).

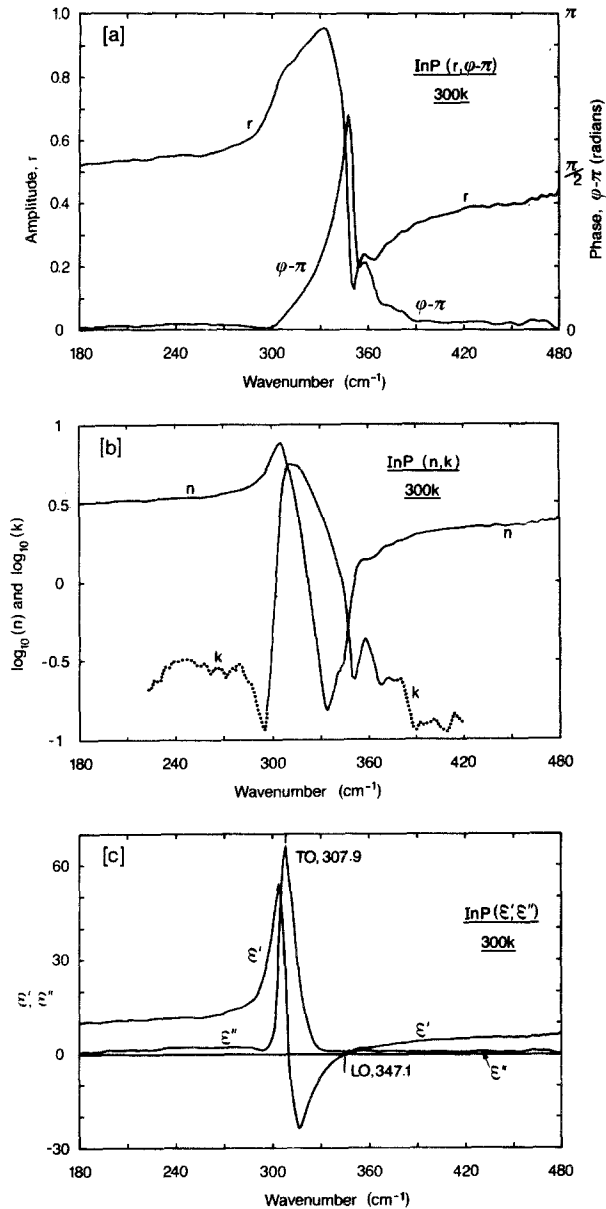


Figure 1. Measured values of (a) the amplitude and phase reflection spectra, (b) the optical constants, and (c) the dielectric parameters of InP at 300K. In (b) dotted lines indicate regions in which reproducible structure is observed in k (and hence ϵ'') but where there is a large uncertainty in the absolute value due to systematic errors in the phase.

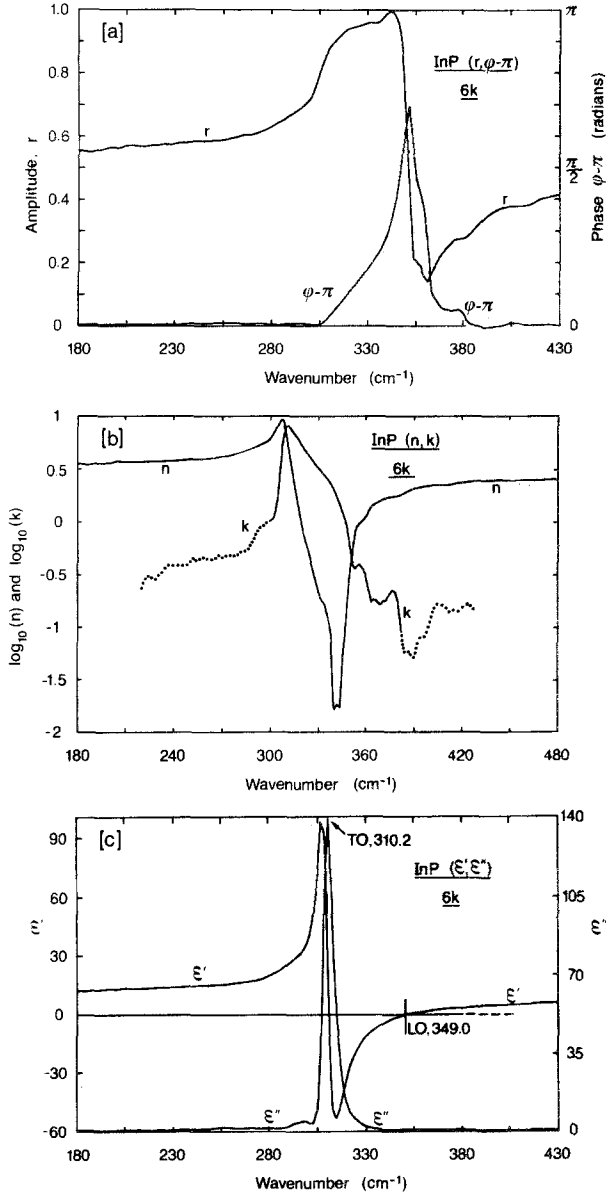


Figure 2. Measured values of (a) the amplitude and phase reflection spectra, (b) the optical constants, and (c) the dielectric parameters of InP at 6K. In (b) dotted lines indicate regions in which reproducible structure is observed in k (and hence ϵ'') but where there is a large uncertainty in the absolute value due to systematic errors in the phase.

Most of the new spectral features revealed by these measurements can be explained as two-phonon combination bands, and careful interpretation of this structure by critical point analysis can provide improved values for phonon frequencies at the major symmetry points in the Brillouin zone. However, this is more conveniently done by considering the anharmonic self-energy of the zone-centre transverse optic phonon, which can be calculated from the dielectric functions using an expression derived by Cowley (10). This procedure has been demonstrated previously for CdTe (11) and InAs (3), and will form the basis of a separate article on phonon frequencies in InP (12), in which the present data will be correlated with previous observations of two-phonon structure by infrared emission spectroscopy (13), Raman spectroscopy (14) and infrared transmission spectroscopy (15-19).

The frequencies of the transverse and longitudinal optic modes at the zone centre, ω_{TO} and ω_{LO} , respectively, determined from the poles in the dielectric response at both temperatures, are indicated in Figures 1(c) and 2(c), and compared with previously reported values in Table 1. It can be seen that the present values are reasonably consistent with those determined by Raman scattering. However, Raman scattering is the most accurate method for determining these frequencies. The reason for this, apart from any differences in resolution between the various determinations, is that in infrared reflection spectroscopy the frequencies of these optical modes are determined from the limits of the reststrahlen band (where $\epsilon' < 0$), which are ill-defined at finite temperatures because of the effects of anharmonicity. Determination of the two frequencies by this method thus requires accurate measurements of the slopes of the amplitude and phase reflection spectra, whereas in Raman spectroscopy, scattering from these phonons results in sharp symmetrical spectral lines. This can be seen by comparing the form of our measured amplitude and phase spectra near ω_{TO} and ω_{LO} with the Raman spectra presented in References (20) and (21). The uncertainties in the location of the poles in the computed dielectric functions are about $\pm 0.5 \text{ cm}^{-1}$ for both ω_{TO} and ω_{LO} in the present work, but this takes no account of the uncertainties in the measured slopes. In the case of crystals of the NaCl and CsCl structure, in which first order Raman scattering does not occur (24), these difficulties are usually avoided by making infrared transmission measurements on thin films deposited on suitable substrates (25). However, although this method has

been used by Iwasa et al (26) in the case of GaAs, it is not usually employed for measurements on zincblende structure crystals because of the difficulty of producing suitable specimens.

Method	Room Temperature		Helium Temperature		Ref
	ω_{TO}	ω_{LO}	ω_{TO}	ω_{LO}	
Raman	303.7±0.3	345.0±0.3	308.2±0.3	349.5±0.3	20
Raman	303.3	345.4	-	-	21
Raman	304.5±0.3	346.4±0.3	-	-	14
Infrared Emission	314	342	-	-	13
Infrared Reflection	307±8	351±5	-	-	22
Infrared Reflection (DFTS)	307.9	347.1	310.2	349.0	This Work
Neutron Scattering	306.6±6.7	343.3±10	-	-	23

TABLE 1. Comparison of the zone centre optical mode frequencies for InP determined from the present measurements with previously reported values. See text for a discussion of experimental errors.

Acknowledgement

We gratefully acknowledge financial support for this work from SERC and we wish to thank Dr. J.R. Birch of the National Physical Laboratory, Teddington, for the loan of the InP crystal.

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