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Transmission Measurements of Selected Liquids in the Far Infrared

M. A. Walker
R. K. Richards
D. P. Hutchinson

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TRANSMISSION MEASUREMENTS OF SELECTED LIQUIDS IN THE FAR INFRARED

M. A. Walker,* R. K. Richards, and D. P. Hutchinson

*Summer undergraduate research intern from Morehouse College, Atlanta, GA. 30314.

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ABSTRACT

Measurements were taken of the transmission of 0.119 mm radiation through 22 liquids using a variable length absorption cell for the preparation of the design of an acousto-optic modulator. Seven of these liquids were then selected to be tested at wavelengths of 0.185 mm, 0.307 mm, and 0.447 mm. It was found that a light grade of mineral oil proved to have excellent transmission in the far-infrared (FIR) spectrum. We were able, from the data collected, to estimate the index of refraction of these liquids at wavelengths longer than 0.3 mm.

INTRODUCTION

The need for new plasma diagnostics has generated an interest in the development of an acousto-optic modulator which will frequency shift an FIR laser. For this investigation, liquids were tested for their application as transmitting materials. Transmission measurements of the liquids at selected wavelengths between 0.1 mm and 0.5 mm, therefore, were taken in an absorption cell with the desire to find some with an absorption length of about 2.5 cm. This was considered to be a convenient length for construction of such a cell.

A similar experiment by Vogel and Dodel[1] has been performed in which they investigated the absorption properties of cyclohexane and carbon tetrachloride. In our study, we compared these liquids to others

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*Summer undergraduate research intern from Morehouse College, Atlanta, GA 30314.

which would be easier to use. In choosing the liquids to be tested in our study, it was desirable to use liquids that were readily available, consistent in quality, and relatively safe to handle.

EXPERIMENTAL SETUP

The experimental setup is shown in Fig. 1. The laser beam was split before entering the absorption cell to provide a reference of laser power. The various wavelengths were selected by changing the lasing medium in an FIR laser which was pumped by a CO_2 laser. For all of these wavelengths the FIR power was typically 10 mW which was sufficient for measurements by the pyroelectic detectors used in this experiment. The windows in the cell were made of crystal quartz to allow for maximum transmission and to be non-reactive with the liquids. One window was fixed and the other was mounted to a motorized assembly which could translate the window, giving a cell length variation from 0

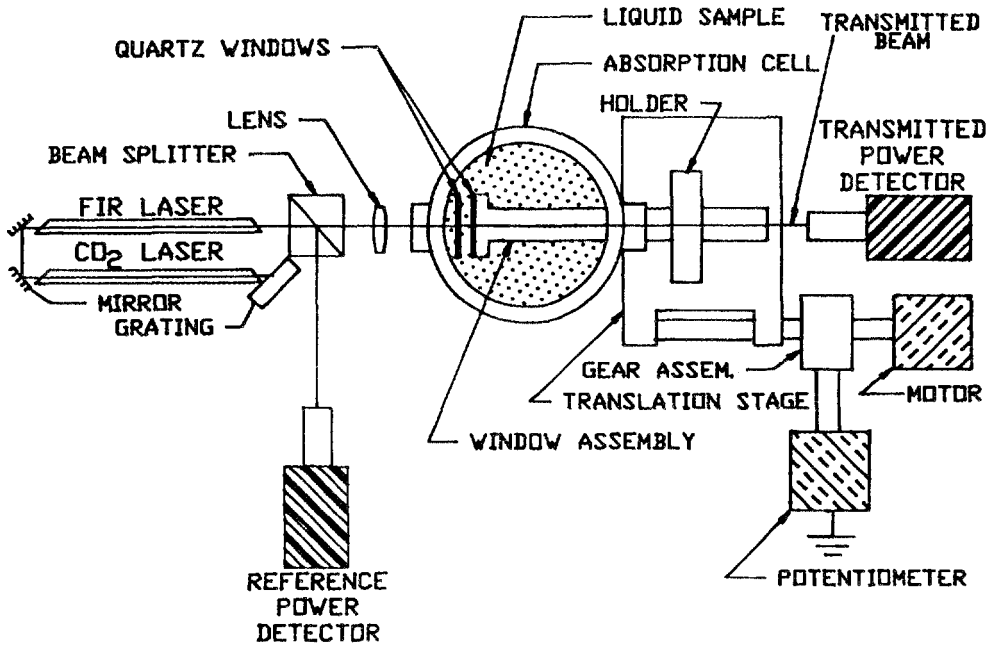

Fig. 1. A schematic of the FIR transmission experiment for measurements of transmission of selected liquids at wavelengths between 0.1 mm and 0.5 mm.

to 2.5 cm. A potentiometer was connected to the translation stage in such a way as to give rise to a linear proportionality of the voltage across the potentiometer to the window displacement. The reference and transmitted power signals were then recorded by an X-Y plotter as a function of window displacement.

There were several practical considerations which arose in this investigation. One was that the absorption cell had to be cleaned out before the next liquid sample could be tested. This was accomplished through the use of a dishwashing detergent followed by a thorough rinsing with water and ethyl alcohol. The alcohol had to be thoroughly evaporated from the cell due to the extreme absorbency of alcohol in the far infrared as tested in this investigation. Because liquids such as cyclohexane and carbon tetrachloride are solvents, the problem of maintenance of the absorption cell was compounded due to the dissolving of the silicone-based lubricant on the O-ring. This resulted in the necessity of its relubrication after each test.

DATA AND ANALYSIS

The data collected were analyzed with the aid of CURVEFIT CRT,* a computer software package designed to do a least-squares curve fit to a given set of data points. It gives the coefficients of specified curve parameters and the correlation coefficient. Because we are considering absorption, an exponential curve

$$A\exp(-kx)$$

which represents transmitted laser power was fitted to the data. The fitting routine generated values for A, the transmitted laser power with no absorption, and k, the absorption coefficient. The data were then normalized to represent a transmission curve, for example mineral oil at 0.119 mm in Fig. 2. The inverse of k represents the absorption length (L) of the sample liquid and these are given in Table 1 and Table 2 for all liquids tested.

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*CURVEFIT CRT is a registered trademark of West Coast Consultants.

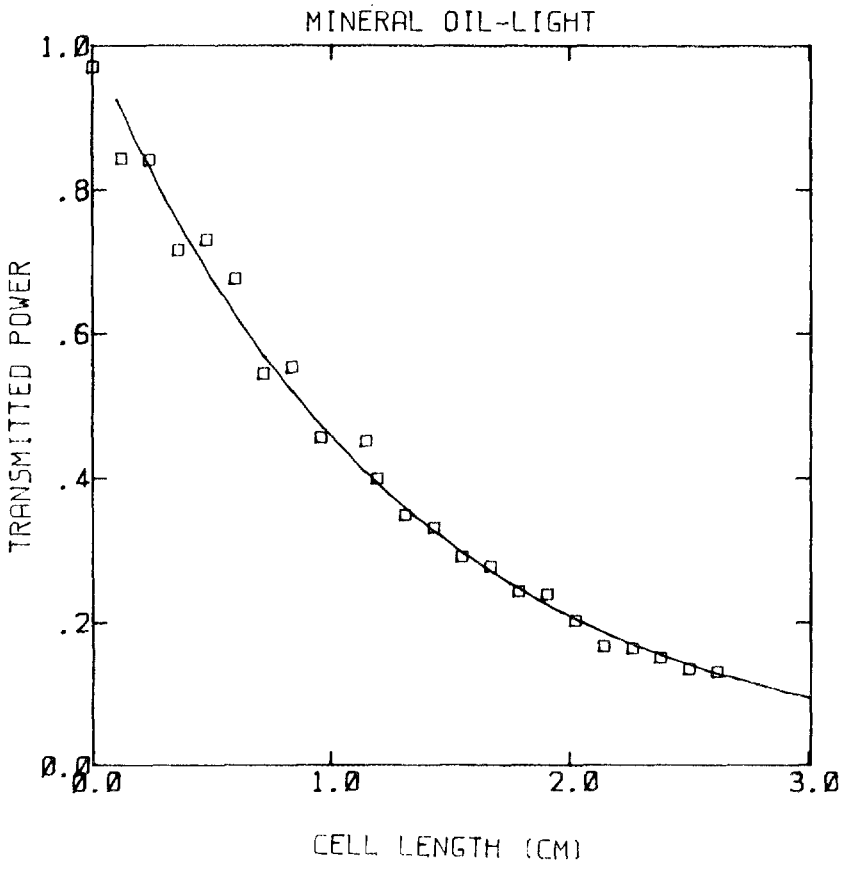

Fig. 2. The transmission curve of a light grade of mineral oil scanned at 0.119 mm.

The scatter in data about the best fit curve is generated by laser power fluctuations. This is apparent with the data sets generated with the largest laser power fluctuations having the smallest correlation coefficients. Corrections for the power variations with respect to the reference signal reduced the data scatter to less than 10%.

A modulation of the transmitted power with respect to the window displacement became readily apparent in the data at wavelengths longer than 0.3 mm with the period of oscillation being approximately half the laser wavelength; in air, the period of oscillation became equal to half the laser wavelength. We were then able to estimate the index of refraction of the liquids, within 5% accuracy, from the ratio of the

Table 1. Absorption lengths at 0.119 mm

Liquids	L (cm)	Liquids	L (cm)
Mineral oil-light	1.225	Narcoil 10 oil	0.176
Mineral oil-extra h.	1.126	Dow-Corning 705 oil	0.168
Hexanes	1.100	Santovac 5 oil	0.129
Inland 19 oil	1.087	Glycerin	0.118
Exxon Univolt 60 oil	0.993	Cottonseed oil	0.058
Cyclohexane	0.931	Wesson Sunlight oil	0.051
Carbon tetrachloride	0.468	Castor oil	0.041
Fomblin Y/25 oil	0.447	HE-500 Leybold-Heraeus turbo oil	0.049
Freon TF	0.404	Octoil	0.036
Freon 113	0.304	Isopropyl alcohol	0.025
Oleic acid	0.185	Butyric acid	0.022

Table 2. Absorption lengths at other wavelengths tested (cm)

Liquids	0.185 mm	0.307 mm	0.447 mm
Mineral oil-light	2.96	5.01	9.58
Mineral oil-ex. heavy	2.24	3.57	8.44
Hexanes	1.75	1.87	2.05
Inland 19	1.76	3.11	7.10
Exxon Univolt 60 oil	1.11	2.11	3.22
Cyclohexane	1.69	2.74	1.02
Carbon tetrachloride	0.53	0.59	0.72

number of oscillations per unit length in the sample to the number of oscillations per unit length in air. These indices of refraction are presented in Table 3.

Table 3. Index of refraction

Liquids	0.307 mm	0.447 mm
Mineral oil - light	1.44	1.46
Mineral oil - extra heavy	1.44	1.46
Inland 19 oil	1.41	1.42
Exxon Univolt 60 oil	1.41	1.49
Cyclohexane	1.36	1.39
Carbon tetrachloride	1.33	1.36

DISCUSSION

We have determined the absorption length at 0.119 mm for 22 liquids; the hydrocarbons tested in this study had the overall longest absorption lengths. The seven liquids with the longest absorption lengths at 0.119 mm were selected for study at 0.185 mm, 0.307 mm, and 0.447 mm. All of these liquids except for cyclohexane showed an increase in their absorption lengths for an increase in wavelength. For the wavelengths longer than 0.3 mm, the index of refraction was estimated and found to be in the general range of 1.3 to 1.5.

For an acousto-optic modulator in the FIR, mineral oil has excellent transmission. The results of this study show it has a convenient absorption length (the ideal cell length), is readily available, and is neither toxic nor reactive. The type of mineral oil selected does not appear to be critical since the light and extra heavy grades had similar absorption lengths at all wavelengths tested.

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