TRANSMISSION PROPERTIES OF ZITEX IN THE INFRARED TO SUBMILLIMETER

D.J. Benford[1], M.C. Gaidis[2], J.W. Kooi

California Institute of Technology
Mail Code 320-47, Pasadena, CA 91125

Abstract

The results of measurements of the refractive index and power absorption coefficient of Zitex at 290K, 77K, and 4K in the spectral region from 1 to 1000 microns are presented. Zitex is a porous Teflon sheet with a filling factor of $\sim$ 50%, and is manufactured in several varieties as a filter paper. Zitex is found to be an effective IR block, with thin (200μm) sheets transmitting less than 1% in the 1-50μm range while absorbing $\lesssim$10% at wavelengths longer than 200μm. Some variation in the cutoff wavelength is seen, tending to be a shorter wavelength cutoff for a smaller pore size. Additionally, the thermal conductivity of Zitex at cryogenic temperatures has been measured, and is found to be roughly one-half that of bulk Teflon.

keywords: Zitex, Teflon, Fourier transform spectroscopy, far infrared, submillimeter

Introduction

To reduce the loading on cold optical elements operating in the far infrared, room temperature infrared radiation must be blocked efficiently while allowing the desired wavelengths to pass unattenuated[1, 2]. Commonly used materials include blackened polyethylene and Quartz. Unfortunately, the transmittance of blackened polyethylene is dependent on the size, concentration, and form of the carbon used to blacken it, and varies substantially in its far-infrared properties[3]. Quartz is a low-loss material

[1]Present address: NASA / Goddard Space Flight Center, Code 685, Greenbelt, MD 20771

[2]Present address: IBM, ZIP 33F, Hopewell Junction, NY 12533

when a suitable antireflection coating like Teflon is applied, but this is difficult and restricts the wavelengths over which it can be used as a highly transmissive element[4]. Teflon itself is a good IR block, but transmits power in the 5-10μm range and longward of 50μm, limiting its usefulness. Several more absorbing materials, such as Fluorogold and Fluorosint, have been used for low frequency applications, but their slow spectral cut-off characteristics are not ideal for receivers operating near 1 THz[4, 5].

Zitex[6] is a sintered Teflon material with voids of 1-60μm and a filling factor of 50%. Several different varieties are available, divided into two categories by manufacturing process. Zitex A is designed to reproduce filter paper, and so has many narrow linear paths through it and is a rough but soft sheet. It is available in 11 grades with effective pore sizes ranging from 3μm to 45μm and in thicknesses from 0.13mm (0.005") to 0.64mm (0.025"). Zitex G is made of sintered Teflon spheres of small sizes, resulting in a denser, smoother material. Available in 5 grades, the pore sizes range from 1.5μm to 5.5μm and is available in standard thicknesses of 0.10mm (0.004") to 0.38mm (0.015"), although larger thicknesses are available.

Zitex is similar in geometry to glass bead filters, in which dielectric spheres are embedded in a suspending material with a different index of refraction. A single sphere of radius a in a material of index n will scatter strongly for wavelengths $\lambda \lesssim \pi a(n-1)$[7]. Thus, for Teflon ($n = 1.44$[8]), a sphere of radius 10μm produces a shadow for wavelengths shortward of 15μm. At short wavelengths, then, a perfectly randomly scattering screen will redistribute the optical power in an incident beam equally in all directions, resulting in a large loss for well-collimated beams.

Measurements

Because of the large wavelength range involved, three Fourier Transform Spectrometer (FTS) instruments were used to characterize Zitex. For the near- to mid-infrared ($1-80$ μm; 10000-125 cm^{-1}) a commercially available Nicolet 60SX spectrometer[9] was used. The far-infrared (50 - 200 μm; 200 - 50 cm^{-1}) measurements were made on a Bruker interferometer[10] at JPL. The submillimeter data (200-1000 μm; 50-10 cm^{-1}) was obtained on an FTS at Caltech[11]. The focal ratio of the spectrometers was roughly $f/4$. A perfectly scattering surface would yield a transmission of roughly 0.4% in this case. Table 1 lists the samples we measured.

Teflon

In order that we might characterize qualitatively the difference between bulk Teflon and Zitex sheets, we measured one thin (0.25mm) and one

Table 1. Zitex samples measured.

Grade	Pore Size (μm)	Thickness (mm)	Filling Factor*	NIR data	FIR data	Submm data
G104	5-6	0.10	0.45	X		
G106	4-5	0.16	0.50	X		
G108	3-4	0.20	0.55	X	X	
G110	1-2	0.25	0.60	X	X	
G115	1-2	0.41	0.60	X		
G125	~3	3.53	~0.5	X		X
A155	2-5	0.27	0.40	X		

∗ Relative density of Teflon.

thick (0.75mm) sample of plane-parallel Teflon sheet. Figure 1 shows the results of a measurement of the far-infrared transmission of the thick sample near the cut-on region at 50-100μm. The sample was measured at room temperature and liquid nitrogen temperature, showing a slight improvement in the transmission when the sample is cold. Figure 2 shows the mid-infrared transmission of the thinner sample, which highlights the fairly narrow regions near 10-20μm where the absorption is large.

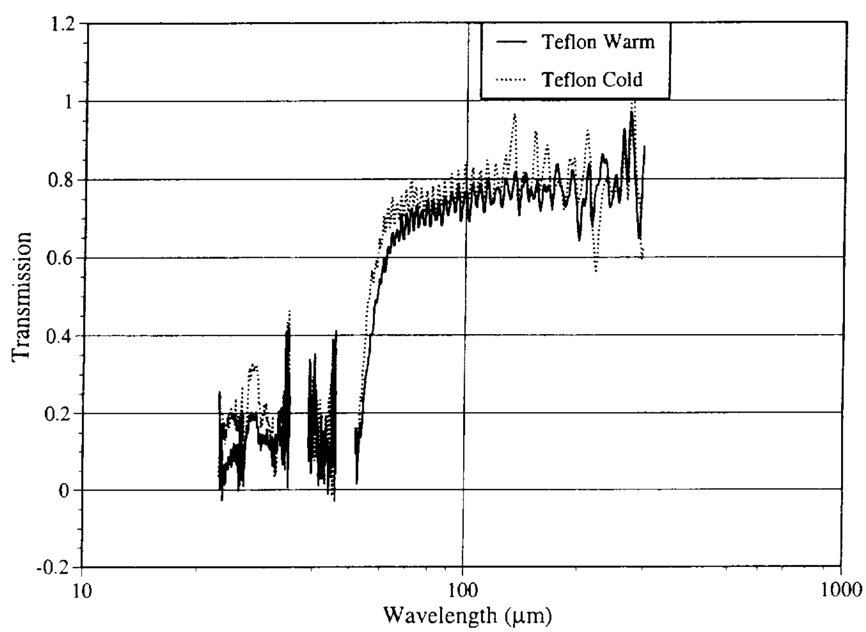

Fig. 1.— Far-Infrared transmission of a 0.75mm thick sheet of Teflon at 300K and 77K. Fabry-Perot fringes are seen in the transmissive region longward of 60μm.

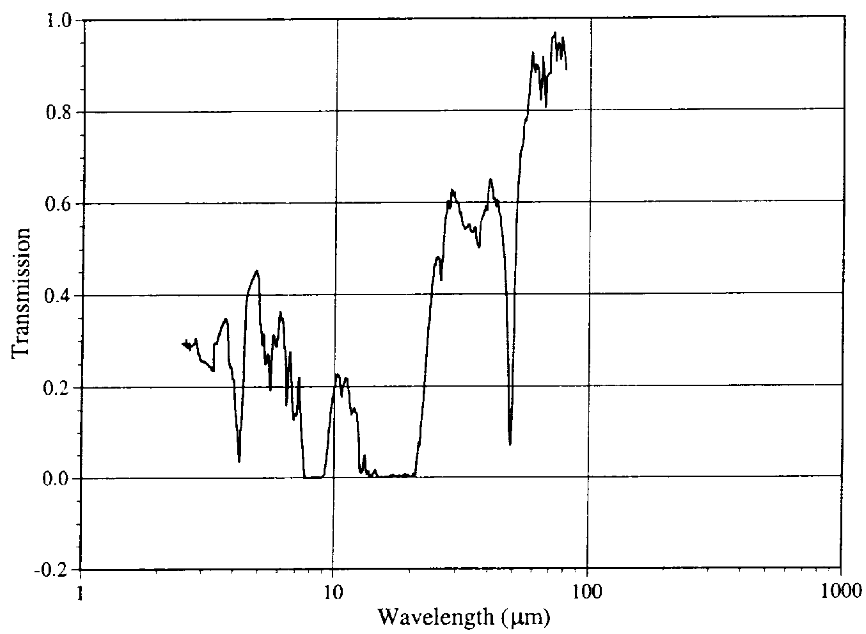

Fig. 2.— Mid-Infrared transmission of a 0.25mm thick Teflon sheet, highlighting the regions of good absorption.

Zitex G104, G106, G108, G110, G115, & A155

The samples of G104 and G106 were measured in the near- to mid-infrared to derive a transmission and an effective absorption coefficient, as shown in figure 3. The absorption coefficient α for a sheet of thickness h is calculated from the transmission T as $-\mathrm{Ln}(T)/h$. Since some wavelength-dependent fraction of the loss $(1 - T)$ is from scattering and some from absorption, the absorption coefficient cannot be used to estimate the transmission of arbitrary thicknesses. It does, however, provide a useful means of comparison with other, more purely absorptive, materials.

Combining sets of data in the near- through far-infrared for samples of G108 and G110 allows us to build a more complete picture of the profile of the cut-on of Zitex near 100μm, as shown in figure 4. Measurements of G115 and A155 are shown in figure 5. A marked shortening of the cut-on wavelength can be seen in the A155 sample, presumably as a result of its different structure.

Zitex G125

As the thickest of all the samples, the G125 sheet of Zitex was used for the longest wavelengths, covering 400 to 1600 GHz (188 to 750μm). Even with

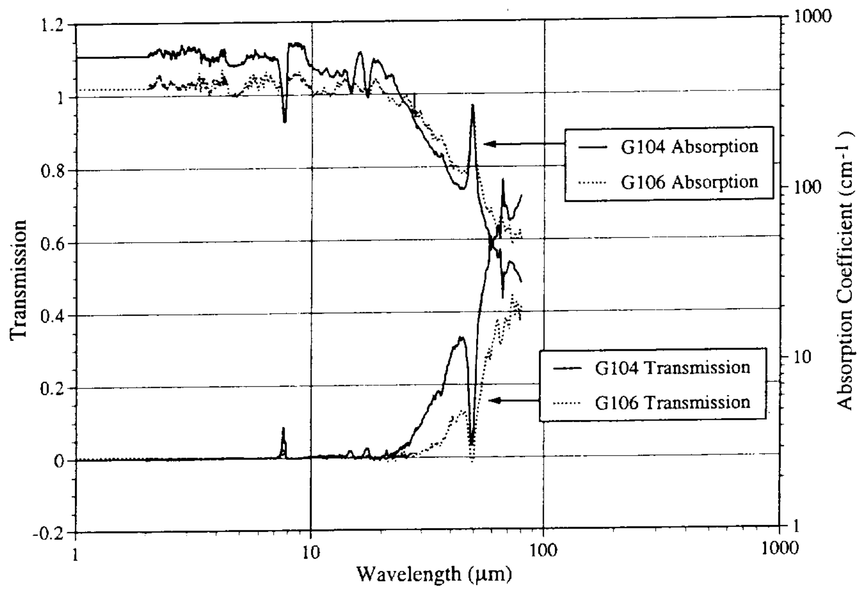

Fig. 3.— Transmission and effective absorption coefficient in nepers per cm of single sheets of Zitex G104 and G106 (pore sizes 5-6μm and 4-5μm, respectively).

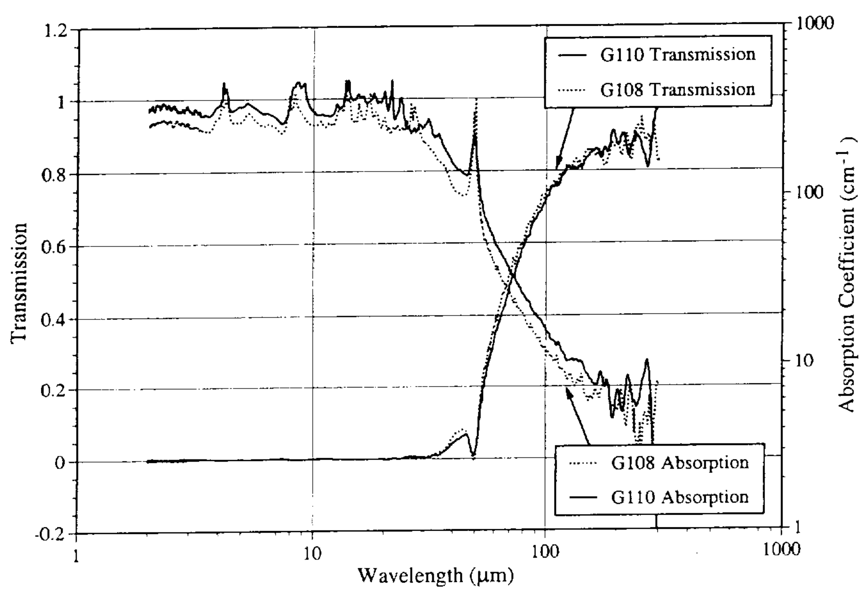

Fig. 4.— Transmission and effective absorption coefficient in nepers per cm of single sheets of Zitex G108 and G110 (pore sizes 3-4μm and 1-2μm, respectively) using near-, mid-, and far-infrared data.

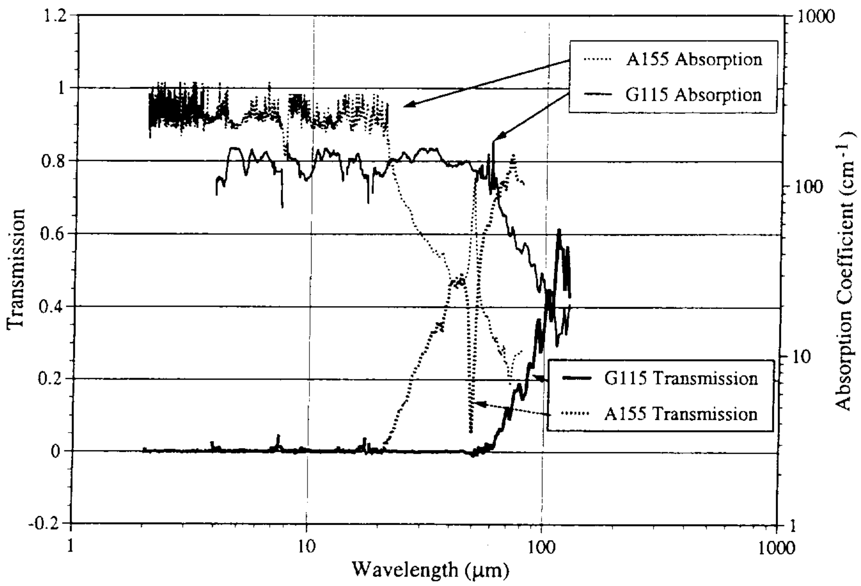

Fig. 5.— Transmission and effective absorption coefficient of Zitex G115 & A155 (pore sizes 1-2μm and 2-5μm, respectively) in the near- to mid-infrared.

a 3.5mm thick slab, the loss was small enough to be below detectability at longer wavelengths. The sample was cooled to 2K in order to determine its suitability as a mid-infrared blocking filter for helium-cooled cryostats. The transmission and effective absorption coefficient are shown in figure 6. The 1400 GHz absorption feature is known as an absorption band seen in cold Teflon[8].

Combining the data on G125 near 1 THz with data at shorter wavelengths allows us to determine the transmission over the range 20-1000μm (300 GHz-15 THz), as shown in figure 7. The effective absorption coefficient for this whole range is well fit by $\alpha = 23\exp[(\lambda_{\mu\mathrm{m}}/37)^{0.77}]$ nepers/cm. The transmission, neglecting the absorption band, follows $T = \exp(-7000\lambda_{\mu\mathrm{m}}^{-1.8})$.

Multiple Layers

A helium-cooled receiver is likely to have several layers of infrared-blocking filtration in the optical path. As a result, it is natural in the case of a scattering material like Zitex to question its efficacy in a multilayer application. Layering single-, double-, and triple-ply sheets of Zitex in close proximity (limited only by the natural wavy contours of the thin

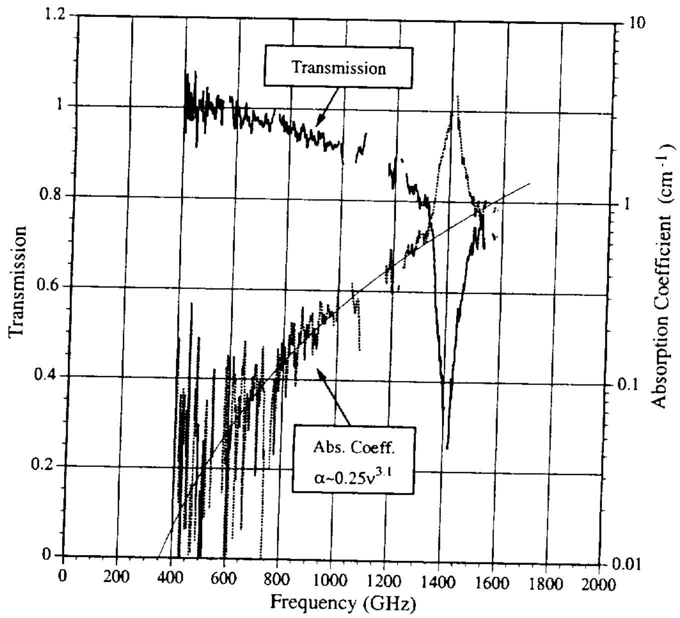

Fig. 6.— Transmission and absorption coefficient in nepers/cm of Zitex G125 between 400 and 1600 GHz (188 and 750μm).

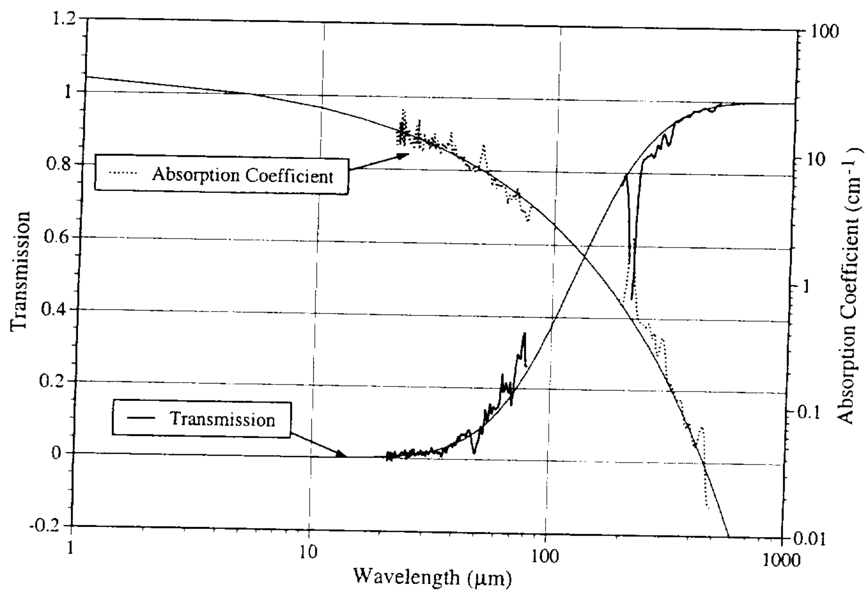

Fig. 7.— Transmission and absorption of Zitex G125 (pore size $\sim 3\mu$m).

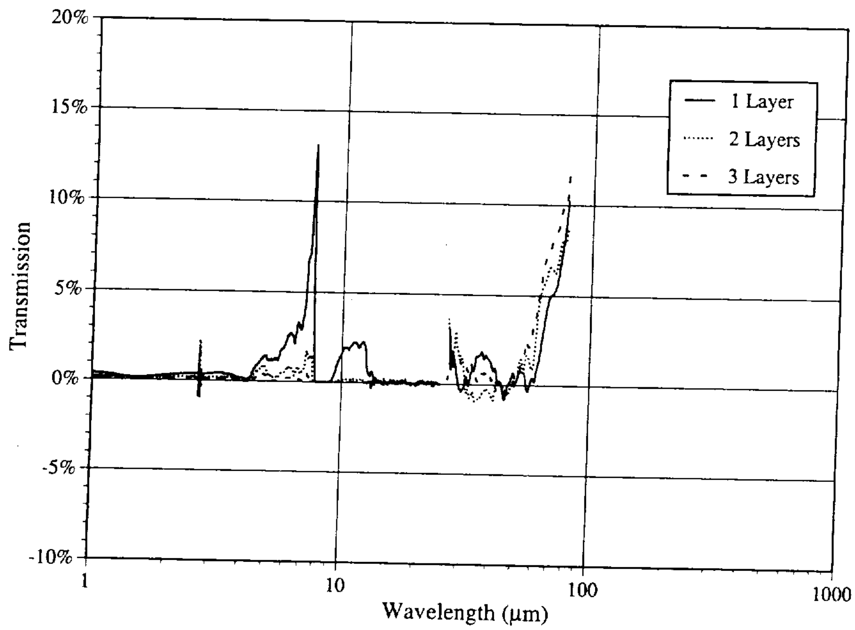

Fig. 8.— Transmission of single, double, and triple layers of Zitex in close proximity. The transmission drops more slowly than for a pure absorbing medium, implying strong scattering.

sheets) yields the transmission measurements shown in figure 8. Because the transmission drops more slowly that for a pure absorbing medium (which would have $T_3 = T_1^3$ and $T_2 = T_1^2$) in the mid-infrared, we can infer than scattering is the dominant loss mechanism and that multiple sheets are not substantially more effective than single sheets.

If, however, we separate the layers slightly and look at longer wavelengths, the picture changes. Using Zitex A155 sheets spaced by roughly 7mm, we find find the transmission shown in figure 9. At mid-infrared wavelengths, the Zitex still appears to be dominated by scattering since the effective absorption coefficient of two layers is less than that for of one layer. However, at far-infrared wavelengths, the transmission appears to be increasingly determined by absorption alone, presumably in the bulk of the Teflon; the absorption is similar to that of Birch[12].

Temperature Variation

In the case of many materials (e.g., quartz), the absorption of mid-infrared radiation is known to vary as the temperature changes[13]. To determine if there was any effect of the temperature on the transmission of Zitex, we measured the transmission of samples of G110 at 300K and 77K in the far-

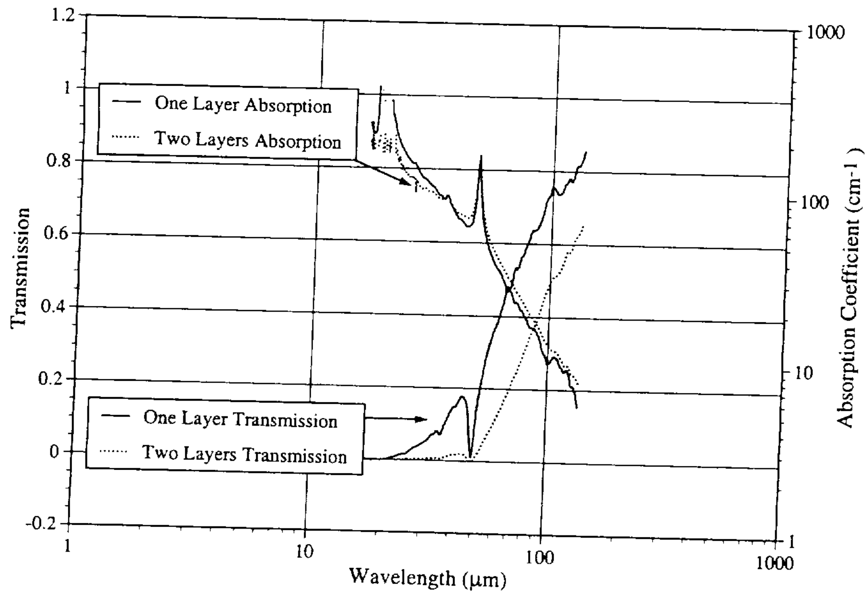

Fig. 9.— Transmission of single and double layers of Zitex in an $f/4$ beam with 7mm spacing. At mid-IR wavelengths, the Zitex acts as two scattering surfaces; at far-IR wavelengths, like an absorber.

infrared near the cut-on region. No significant variation in the transmission was seen upon cooling (figure 10), which is to be expected for dielectric scattering.

Refractive Index

Measuring the refractive index of a material of low dielectric constant is difficult near 1 THz for a nondispersive FTS. Only the thick sample of G125 could be measured, via a determination of the fringe spacing in the 3.5mm thick slab. The fringe spacing, averaged between 13 and 45 cm^{-1} (200-800 μm or 400-1350 GHz), was 1.18 cm^{-1}. This yields a refractive index for Zitex of $n = 1.20 \pm 0.07$ at a temperature of 2K. This can be compared to Teflon, which has $n = 1.44$[8]; with a filling factor of $\sim 50\%$, the expected refractive index is $n = 1.22$, exactly as measured.

Thermal Conductivity

The thermal conductance of a thick slab of Zitex was measured in the direction along the sheet using an apparatus developed for the purpose of measuring lateral thermal conductance in sheets[14]. At cryogenic temperatures ($T \leq 150$K), the conductivity of Zitex is found to be well fit by

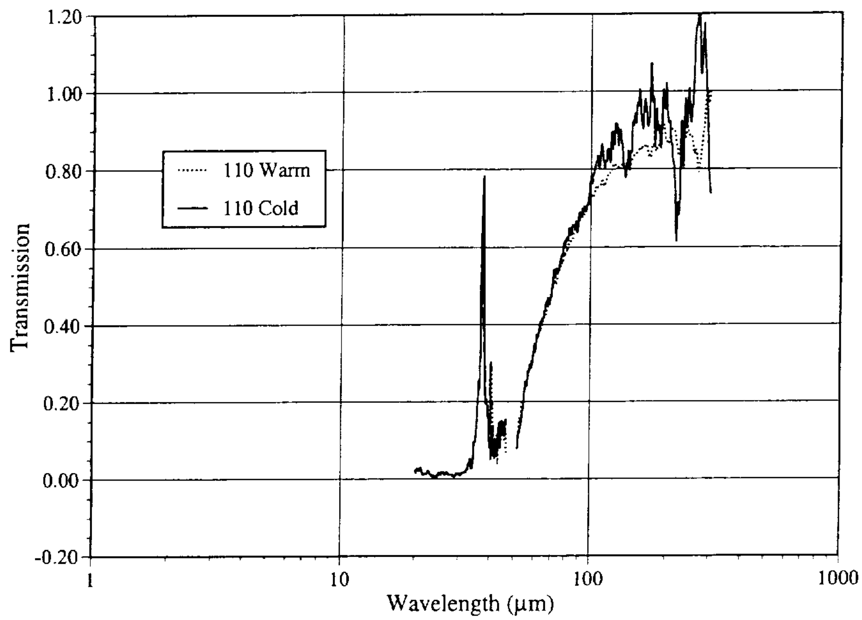

Fig. 10.— Far-Infrared transmission of Zitex G110 at 300K and 77K. No substantial variation is seen.

$K(T) = 0.01\,T^{0.58}$ W K^{-1}m^{-1}. This value is half the bulk conductivity of Teflon[15], indicating that the porous nature of Zitex does not substantially affect its thermal conductance beyond the geometric reduction. However, since Zitex sheets tend to be thin ($\sim$ 0.3mm), even the small power incident on Zitex when used as a near-infrared blocking filter will raise its temperature by a significant fraction. This suggests the use of two layers for good blocking, whereas one Teflon layer might have been sufficient to handle the optical loading. However, since the loss in Zitex at long wavelengths is so low, this solution is likely to be more efficient than the use of Teflon.

Conclusions

We have measured the refractive index and power absorption coefficient of Zitex at 290K and 77K in the spectral region from 2 to 200 microns. Its absorption at wavelengths longer than this is found to be extremely small, and with an index of refraction of $n = 1.2$, there is very little reflection loss. Zitex is an effective IR block when used to inhibit wavelengths shortward of 100μm, having lower absorption/reflection losses than black polyethylene or quartz and better IR blocking characteristics than Teflon.

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