

DIELECTRIC MEASUREMENTS OF COMMON POLYMERS AT MILLIMETER WAVELENGTH RANGE^{*}

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ABSTRACT

Complex refractive index and Complex dielectric permittivity and loss tangent data for polyethylene, polypropylene, poly-4 methyl pentene-1 (TPX) and polytetrafluoroethylene (Teflon) are presented over the frequency range 40-300 GHz. All of these non-polar polymers are extremely low loss material. Like the micro-wave region, polyethylene demonstrates exceptionally low loss characteristic in the entire millimeter wave region. Polar polymers such as Nylon and plexiglass exhibit much higher absorption (nearly an order of magnitude higher) loss compared to non-polar polymers.

Polymers are excellent candidates as low loss dielectric materials for millimeter wave applications such as lenses, windows and dielectric waveguides. These materials are very easy to fabricate to any shape and size. The most commonly used high molecular weight organic polymers are polyethylene terephthalate (known as Mylar), polystyrene, polymethylmethacrylate (plexiglass), polyethylene, polypropylene, poly-4-methylpentene-1 (known as TPX) and polytetrafluoroethylene. The absorption coefficient or the loss tangent of mylar, polystyrene and plexiglass are very high in the submillimeter [1-3] region which forbids their use as window or lens material. However, thin films of these are in extensive use as beam splitters in the far and mid-infrared spectral region.

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Non-polar polymers are relatively low loss and become potential candidate for use as lenses, window and waveguide materials.

The commonest non-polar polymers are the last four in the list above. The T.P.X. is transparent in the visible wavelength region and is superior to the others in its hardness and resistance to deformation by heat[4]. Its refractive index in the submillimeter wave (~ 1.46) also matches closely with its refractive index in the visible region (~ 1.43). This avoids the realignment of an instrument equipped with TPX lens or windows, once it is aligned using the visible radiation.

PTFE (Teflon) is relatively softer but it is inert to all known organic liquids [5,6]. It is very low loss in the radio frequency region but the absorption increases with frequency. A very strong absorption band [5,7] appears in the submillimeter wave range at 6 THz which precludes its routine use beyond 4.50 THz. The microwave loss of unsintered PTFE exhibited extremely low value (40 μ radians).

Polyethylene and polypropylene have been familiar to radio and microwave frequency workers for a long time. [8] Polyethylene is relatively low loss up to midinfrared frequency (18 THz) [9]. It has an intense sharp absorption band at the center of the submillimeter wave band (2.1 THz) and the use of an alternative material as the window or lens is desirable in the region 1.65 - 2.65 THz. Polypropylene was first used in the submillimeter wave region [9,10] as a substitute for polyethylene. It is more easy to fabricate and its mechanical properties are more attractive. Around 1 GHz region dielectric application it has been used in a rather parallel fashion as a substitute for polyethylene [8]. The loss angle $\tan \delta$ at 1 GHz of both polyethylene and polypropylene is of the order of one part in ten thousand.

In the strict sense there is no pure polymer and they all show wide ranges of molecular weight. These semicrystalline materials are made of crystalline regions spread throughout an amorphous matrix are quite inhomogeneous. The optical

properties of all polymers (particularly the absorption coefficient) can vary markedly with the composition, history and the temperature of the specimen [11]. Absorptions by polymers in the millimeter and submillimeter wave region arise from low frequency intramolecular modes, intermolecular or lattice modes, amorphous region processes, relaxation or non-resonant processes and from impurities accidentally or deliberately present in the material [7,8]. The mid and near infrared absorptions arise from vibrations of highly localized groups of atoms.[7] For a long chain molecule chain twisting motions give rise to absorptions in the far-infrared (submillimeter wave region).

We have employed dispersive Fourier transform spectroscopic technique [12-15] applied to a polarizing two beam modular interferometer [16-20] for our measurements on polymers. It uses mercury vapor lamp as broad band radiation source, free standing wire grid polarizers as beam splitter and cryogenically operated fast InSb hot electron bolometer as detector.

The complex Fourier transform of the recorded interferograms with and without the specimen generates phase and amplitude from which absorption coefficient and refractive index spectra are evaluated via an iterative procedure. [12] The real and imaginary parts of the dielectric permittivity and loss tangent are simply translated via derivations of Maxwell's celebrated relation $\hat{\epsilon} = \hat{n}^2$ where $\hat{\epsilon}$ and \hat{n} represent respectively the complex dielectric permittivity and complex refractive index. The specially constructed highly stable interferometer utilizes throughout of 60 mm radiation in order to avoid diffraction effects. The final data are highly reproducible reflecting five figures accuracy in the real part of the dielectric permittivity and to about 1% accuracy in the loss tangent.

The new millimeter wave continuous data over the frequency range 60-300 GHz for absorption coefficient, real part of the dielectric permittivity and loss tangent for high density polyethylene, polypropylene (isotactic), teflon and TPX (poly-4 methylpentent-1 are shown in figures 1-4. The absorption coefficient increases with increase in frequency. All of these non-polar polymers show much lower loss compared to our recently found low loss materials. [17] Polyethylene exhibits lowest loss of all, which is consistent with the previous microwave finding. Unlike the three other non-polar polymers, the loss tangent value of Teflon decreases with increase in frequency reflecting a possible low frequency band (mode) arising around low GHz region. Results on polar polymers will also be presented at the meeting. In a preliminary test, it is observed that their absorptions are much higher, nearly an order of magnitude higher over the entire millimeter and

submillimeter wavelength range. Moreover the structures are more complicated. They cannot be considered as low loss material.

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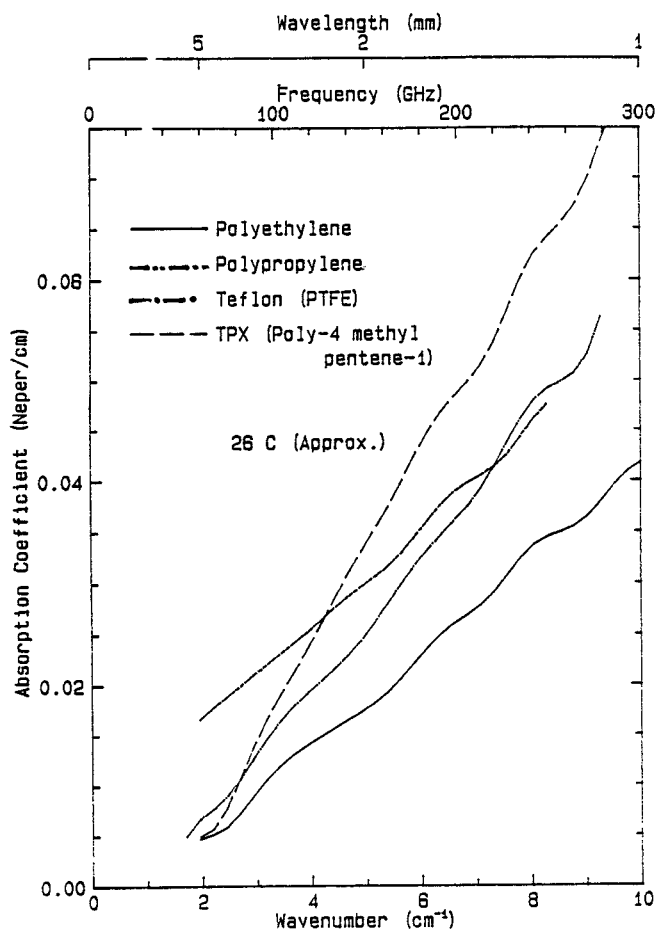


Figure 1. Comparison of absorption coefficient spectra for polyethylene, polypropylene, Teflon and TPX, at millimeter wavelength range. The absorption is very low but shows a tendency of increase with increase in frequency.

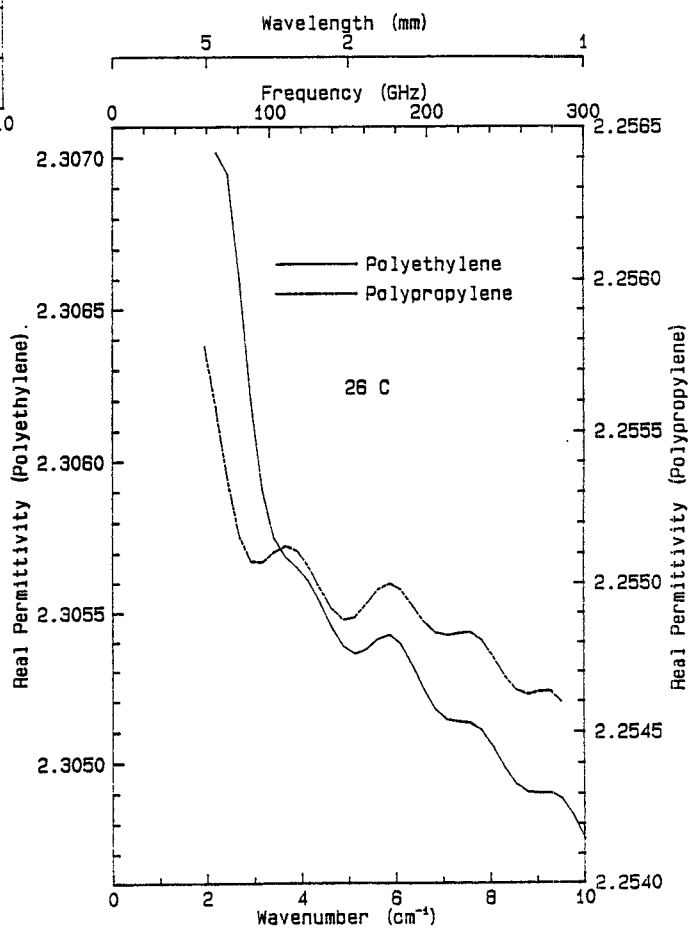


Figure 2. Spectra for real part of dielectric permittivity of polyethylene and polypropylene at millimeter wavelength range.

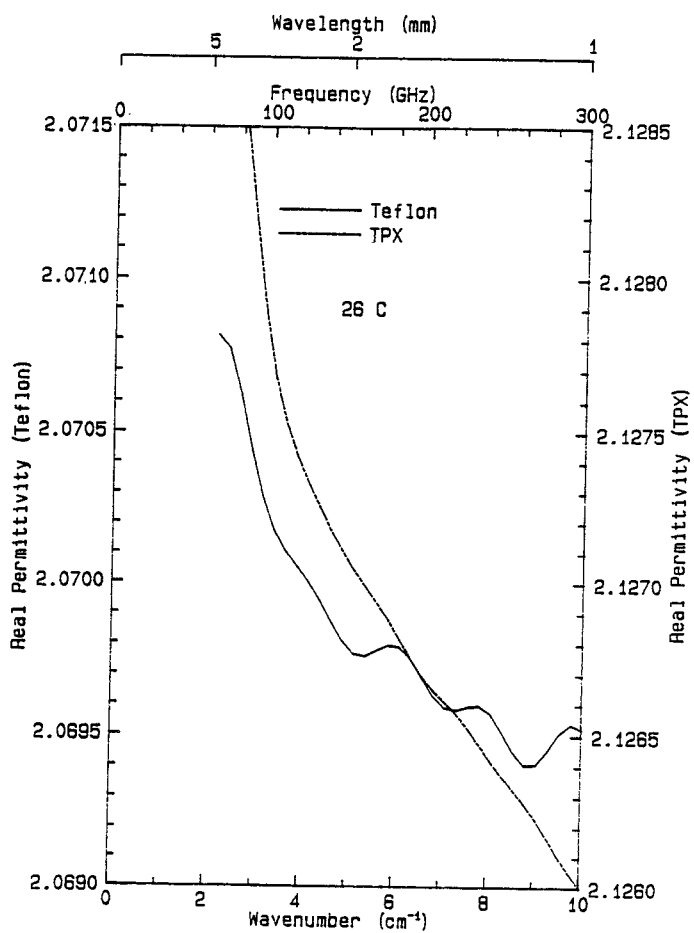


Figure 3. Spectra for real part of dielectric permittivity of Teflon and TPX at millimeter wavelength range.

Figure 4. Comparison of loss tangent spectra of polyethylene, polypropylene, Teflon (PTFE) and TPX (Poly-4 methyl pentene-1) at millimeter wavelengths

