

# Refractive Index at THz Frequencies of Various Plastics

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**Abstract:** We measure the refractive index via a minimum deviation prism technique of various plastics from 70-290 $\mu\text{m}$  (1-4THz) using a tunable terahertz gas laser. We find these plastics have indices varying from 1.43-1.61 over this range.

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## 1. Introduction and Experimental Method

In the minimum deviation technique, a prism situated on a rotational stage deviates an incoming beam of monochromatic light which is then focused on to a detector. A rotary sample stage varies the incident angle of the source while the detector, mounted on a rotational arm, locates the final deviated beam. From simple geometry and Snell's Law the deviation angle may be shown to be given by [1],

$$D = \theta + \sin^{-1} \left[ n \cdot \sin \left\{ A - \sin^{-1} \left( \frac{\sin \theta}{n} \right) \right\} \right] - A \quad (1)$$

Where  $D$  is the deviation angle,  $\theta$  sample stage angle,  $A$  apex angle of the prism, and  $n$ , the refractive index. At the minimum, the ray passes symmetrically through the prism such that  $\theta = (A + D_{\min})/2$  and the second term in Eq. (1) goes to zero. Consequently,

$$n = \frac{\sin[(A + D_{\min})/2]}{\sin(A/2)} \quad (2)$$

The advantage of this method is that we need only locate the minimum of  $D$ . Any initial offset in  $\theta$  merely shifts the plot of  $\theta$  vs.  $D$  along the  $\theta$ -axis, and does not affect the location of  $D_{\min}$  on the curve. We measure  $D$  for many values of sample stage angle. The resulting fit is more precise than a single measurement. By fitting the data to  $N$  points to determine the minimum, the uncertainty in  $D_{\min}$  is reduced by a factor of  $1/\sqrt{N}$ . We fit  $D(\theta)$  in the vicinity of the minimum to determine  $D_{\min}$  and hence  $n$ .

### 1.1 Setup

The terahertz laser consists of a cavity which can be filled with gases such as  $\text{CH}_3\text{OH}$ ,  $\text{CD}_3\text{OH}$ ,  $\text{CH}_2\text{F}_2$ , or  $\text{CH}_3\text{Cl}$  [2]. A  $\text{CO}_2$  pump laser supplies energy to the cavity which is optimized by tuning a piezoelectric-controlled etalon. In our setup, two orthogonal He-Ne lasers on fine-adjustment mounts are used to position the sample and align the source, detector, and goniometer stages. The detector is a thermoelectric camera array retrofitted with a polyethylene window and a short focal length polyethylene lens to focus radiation onto the detector.

### 1.2 Error Analysis

The error in refractive index,  $\Delta n$ , is due to several factors: dispersion, spectral width of the source, error in measurement of apex angle, and least count of the goniometer stage [3].

$$(\Delta n)^2 = \left( \frac{\partial n}{\partial \lambda} \cdot \Delta \lambda \right)^2 + \left( \frac{\partial n}{\partial A} \cdot \Delta A \right)^2 + \left( \frac{\partial n}{\partial D} \cdot \Delta D \right)^2 \quad (3)$$

$\partial n/\partial \lambda$  may be estimated from dispersion data and is nominally  $0.005 \mu\text{m}^{-1}$ .  $A = 30^\circ$  for all our prisms. For our source,  $\Delta \lambda \approx 0.5 \text{ nm}$ . Therefore,  $(\partial n/\partial \lambda \Delta \lambda)$  is much smaller than the other terms and can be neglected. Of the remaining two terms, the  $\partial n/\partial A \cdot \Delta A$  term has the largest effect since  $\Delta A = 2.5$  and  $\Delta D = 0.5$  minutes of arc. The result is that  $\Delta n = \pm 0.0015$ .

## 2. Results

Figure 1 compares the spectral dispersion of low density and high density polyethylene [4]. As expected, the two curves track each other quite well, the only difference being density. In addition, HDPE is known to have a higher degree of crystallinity than LDPE, which appears less opaque to the naked eye [5]. Our values of  $n$  are slightly higher than ref. [5], but in excellent agreement with refs. [6, 7] with a characteristic absorption peak near 120  $\mu\text{m}$ . This peak has been observed before by other authors [7, 8] and is identified as the  $B_{1u}$  lattice mode. These values will also depend on manufacturer.

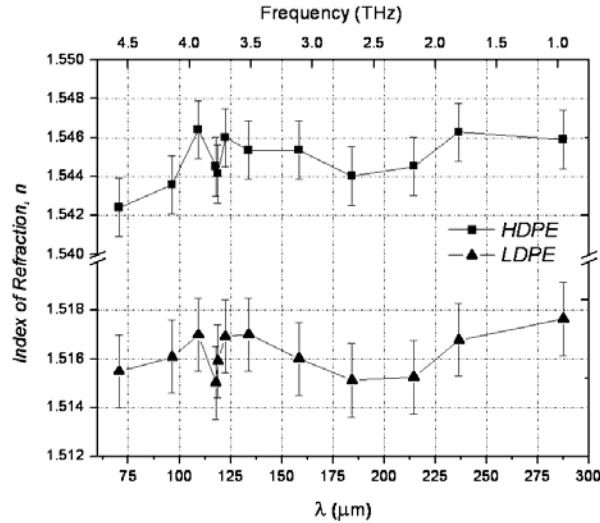


Fig. 1. Spectral dispersion for low and high density polyethylene.

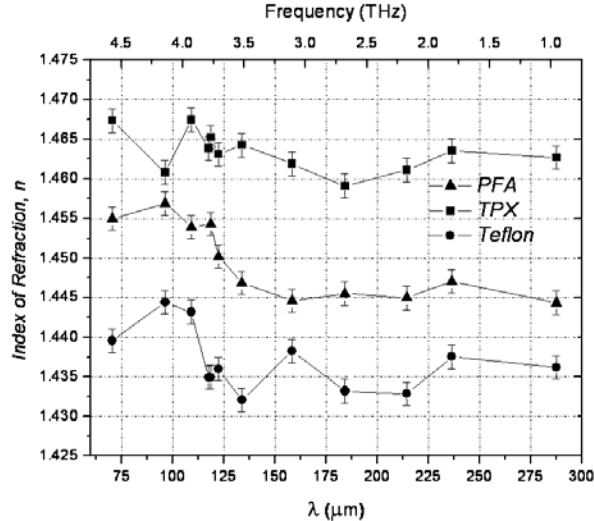


Fig. 2. Spectral dispersion for PFA, TPX, and teflon.

Figure 2 shows three materials of lower index exhibiting normal dispersion, with TPX [4, 9] showing a resonance near 120  $\mu\text{m}$ , and resonances for teflon near 100  $\mu\text{m}$  and 160  $\mu\text{m}$ . PFA (perfluoroalkoxyethylene) and teflon are similar in behavior. Figure 3 shows rexolite [10], a high index commercial material used for radar applications, with a resonance near 120  $\mu\text{m}$ . CTFE is relatively flat over the entire spectrum showing normal dispersion with no significant absorption peaks within the error bars. Polystyrene shows peaks around 120  $\mu\text{m}$  and 180  $\mu\text{m}$ . All measurements correspond well with results obtained by other authors [11]. For these three materials resonances tend to occur at shorter wavelengths below 160  $\mu\text{m}$ .

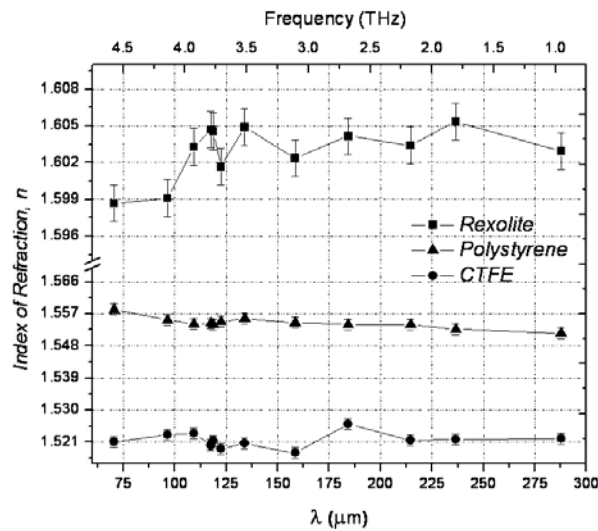


Fig. 3. Spectral dispersion for Rexolite, polystyrene, and CTFE.

LDPE and HDPE, TPX, Teflon, PFA, and polystyrene transmit well over the entire spectrum, whereas CTFE and rexolite more strongly absorb, making detection of the signal at the detector more difficult. We also observed a small degree of birefringence for teflon.

### 3. Conclusion

We have demonstrated a simple technique for this application and found a range of values for  $n$  from 1.43 to 1.61 for a variety of materials which will aid the optical designer in designing lenses and other optical elements. Our measurement show good agreement with previous authors, and have extended the spectrum of data in the literature with high precision.

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