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Title: Dielectric Constants And Matching Groove Parameters For Millimeter Wavelengths

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Dielectric Constants And Matching Groove Parameters For Millimeter Wavelengths

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I. Introduction

This note collects some useful numbers related to dielectrics used for millimeter wave optics, such as lenses and infrared filters. The first section gives dielectric constants and the second gives parameters for matching grooves.

II. Dielectric Constants and Refractive Indices

The dielectric constants for some materials that we commonly use at millimeter wavelengths are given in Table I.[1] At lower temperatures the dielectric constants change due to the thermal contraction in the material. Values at 4 K are taken from [2], apart from the value for PTFE which was calculated from the contraction using the *Lorentz-Lorenz* relation [3]

$$\frac{\epsilon - 1}{\epsilon + 2} = a\rho$$

where ε is the dielectric constant of the material, ρ is the material density and a is a constant of proportionality. Knowing ε at room temperature and ρ at room temperature and 4 K allows ε to be derived at 4 K. Table II gives the expansion of the materials down to 4.2 K [4].

Table I Dielectric constants and refractive indices for common millimeterwave dielectrics.

Material	At 295 K		At 4 K	
	ε	n	ε	n
PTFE (Teflon)	2.053	1.433	2.137	1.462
LDPE	2.292	1.514	2.421	1.556
HDPE	2.323	1.524	2.455	1.567
PS	2.531	1.591	2.624	1.620
TPX	2.126	1.458	2.184	1.478

Table II Expansion of some dielectrics between 4.2 K and 293 K

Material	Thermal Expansion (4.2 K to 293 K)
PTFE	1.85%
HDPE	2.0%
PS	1.50%

III. Antireflection Groove Parameters

Grooves may be cut into a dielectric surface to minimize reflections at the interface. If the dielectric has a refractive index n then perfect matching to vacuum may be made when the effective refractive index of the grooved region is given by

$$n_{eff} = \sqrt{n}$$

and the depth of the grooves is

$$d = \frac{\lambda}{4n_{eff}}$$

If the ratio of the groove width, w, to the pitch, p, is α then the effective refractive indices for parallel and perpendicular polarization are

$$n_{\parallel} = \sqrt{\alpha + (1-\alpha)n^2}$$

and

$$n_{\perp} = \sqrt{\frac{n^2}{(1-\alpha)+\alpha n^2}}$$

Values of the parameters for some dielectrics are given in Table III. When a single polarization is used and the grooves can be cut parallel (‖) or perpendicular (⊥) to the electric field the reflection coefficient may be made zero at the design wavelength, λ. If both polarizations must be matched or the grooves orientation relative to the field varies over the surface (*e.g.*, with circular grooves) both polarizations cannot be simultaneously matched. Instead, the values are chosen to give the same reflection coefficient for both polarizations (‖, ⊥). Often these values are sufficient even where a single polarization is used since the reflected power is less than 0.3% for dielectric constants up to 2.50.

For broad band applications the grooves may be designed for a center frequency λ_c given by

$$\lambda_c = \sqrt{\lambda_{max}\lambda_{min}}$$

where λ_{max} and λ_{min} are the maximum and minimum frequencies at the edges of the bands. The pitch of the grooves does not come into the above equations, but to avoid undesirable diffraction effects the pitch should be less than $\lambda/2$. At longer wavelengths we try to make them less than $\lambda/3$. Tables IV and V show the values that we use in the optics of the receivers for the 12-m Telescope. Although values are given for the 200-300 GHz band the lenses are currently not grooved.

Rectangular grooves are preferred to triangular ones since they are easier to machine. For good matching with triangular grooves they need to be deeper than the rectangular ones and the triangular cross-section becomes flimsy and deforms during the cutting operation. Rectangular grooves are readily cut with a slitting saw.

Table III Groove parameters for some common dielectrics.

Material	Temperature	α			d/λ		
		$\parallel$	$\perp$	$\parallel,\perp$	$\parallel$	$\perp$	$\parallel,\perp$
PTFE	290 K	0.589	0.411	0.500	0.209	0.209	0.209
	4 K	0.594	0.406	0.500	0.207	0.207	0.206
HDPE	290 K	0.604	0.396	0.500	0.203	0.203	0.202
	4 K	0.610	0.390	0.500	0.200	0.200	0.199
LDPE	290 K	0.602	0.398	0.500	0.203	0.203	0.203
	4 K	0.609	0.392	0.500	0.200	0.200	0.200

Table IV Groove parameters used in infrared filters. Dimensions are in inches.

Material	Frequency (GHz)	p	w	d
PTFE	60-90	0.025	0.010	0.031
	90-116	0.025	0.010	0.024
	130-170	0.025	0.010	0.016
	200-260	0.012	0.006	0.011
	260-300	0.012	0.006	0.009

Table V Groove parameters used for lenses. Dimensions are in inches.

Material	Frequency (GHz)	p	w	d
PTFE	60-90	0.020	0.010	0.031
	90-116	0.020	0.010	0.024
	130-170	0.020	0.010	0.016
	200-260	0.012	0.006	0.011
	260-300	0.012	0.006	0.009
HDPE	60-90	0.020	0.010	0.032
	90-116	0.020	0.010	0.023
	130-170	0.020	0.010	0.016
	200-260	0.012	0.006	0.010
	260-300	0.012	0.006	0.008

IV. References

[1] BIRCH, R. J.: "The far-infrared optical constants of polypropylene, PTFE and polystyrene", *Infrared. Phys*, Vol. 33, No. 1, pp. 33-38, 1992

[2] BIRCH, J. R.: "Systematic errors in dispersive Fourier transform spectroscopy in a non-vacuum environment", *Infrared. Phys.*, vol. 34, no. 1, pp 89-93, 1993.

[3] BORN, M. and WOLF, E.: *Principles of Optics*, 6th ed., (Pergamon, Oxford, 1980)

[4] SCHWARZ, G.: "Thermal expansion of polymers from 4.2 K to room temperature", *Cryogenics*, vol. 28, pp. 248-253, April, 1993.