Section 3: Polymeric Materials

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Section 3

POLYMERIC MATERIALS

Of the large number of known polymers, several exhibit useful optical properties. Various properties of optical plastics are compared with those of glasses below. The documentation of optical properties and the accuracy of data on plastics are generally not comparable to that of optical glasses. In addition, mechanical and chemical resistance properties should be checked with the material supplier because they may vary widely within a polymer group. Numerous caveats about the use and application of plastics in optical systems are noted in reference 1.

Property	Plastic	Glass
Optical		
Refractive index (n_d)	1.31–1.65	1.28–1.95
Abbe number (v_d)	92–20	91–20
Index homogeneity	$\pm 1 \times 10^{-4}$	$\pm 1 \times 10^{-6}$
Index change with temperature (10^{-6} K^{-1})	−143 to −100	−8.5 to 6.0
Birefringence (nm/cm)	60–80,000	5
Transmission range (nm)	200–2500	150–3500
Mechanical		
Density (g/cm^3)	0.83–1.46	2.3–6.3
Young modulus (10^3 N/mm^2)	1–10	46–129
Poisson's ratio		0.192–0.309
Thermal		
Expansion coefficient (10^{-6} K^{-1})	25–130	3.7–14.6
Heat capacity (J g^{-1} K^{-1})	1–2	0.31–0.89
Thermal conductivity (W m^{-1} K^{-1})	0.1–0.3	0.51–1.28
Softening temperature (°C)	360–430	750–1100

From Cook, L. M. and Stokowski, S. E., Filter materials, *Handbook of Laser Science and Technology, Volume IV: Optical Materials, Part 2* (CRC Press, Boca Raton, FL, 1995), p. 151.

Common optical plastics include:

polymethyl methacrylate (PMMA) (acrylic)
polystyrene (styrene) (PS)
methyl methacrylate styrene copolymer (NAS)
stryrene acrylonitrile (SAN), acrylic/styrene copolymer
polycarbonate (PC)
polymethylpentene (TPX)
acrylonitrile, butadienne, and styrene terpolymer (ABS)
nylon, amorphous polyamide
polyetherimide (PEI)
polysulfone
allyl diglycol carbonate (CR-39)
Telfon (Telfon AF®) (TPFE), fluorinated-(ethylenic-cyclo oxyaliphatic substituted ethylenic) copolymer

In the following tables properties of these and other optical plastics are given in order of decreasing index of refraction.

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3.1 Optical Plastics

Properties of Optical Plastics–I

Polymer	Trade name	Manufacturer	Density (g/cm^3)	Index n_D	Abbe ν_D
Polyetherimide (PEI)	Ultem	G.E. Plastics	1.27	1.658	
Polyarylsulfone	Radel	Amoco Performance	1.37	1.651	
Polyurethane	Isoplast 301	Dow	1.2	1.64–1.65	
Polysulfone	Udel P-1700	Amoco Performance	1.24	1.633	22.5
Polyarylate	Durel 400	Hoecsht Celanese	1.21	1.61	
	Ardel D-100	Amoco Performance	1.21	1.61	
Poly α-methylstyrene	Resin 18	Amoco Chemical	1.075	1.61	
Polyamide, amorphous nylon Aliphatic/aromatic	Durethan T40	Miles Inc. (Bayer AG)	1.185	1.590	
Polystyrene (PS)	Styron	Dow	1.06	1.589	31
Polyamide, amorphous nylon	Zytel 330	DuPont	1.18	1.588	
Polycarbonate (PC)	Calibre	Dow	1.20	1.586	30
	Lexan	G.E. Plastics	1.20	1.586	30.3
	Makrolon	Miles Inc.	1.2	1.586	30
Polystyrene co-maleic anhydride (SMA)	Dylark 232	Arco	1.08	1.586	31.8
Modified polyestercarbonate	Lexan SP	G.E. Plastics	1.18	1.582	
Polystyrene-butadiene copolymer	K Resin	Phillips 66	1.01	1.571	
Polystyrene-coacrylonitrile (SAN)	Lustran	Monsanto	1.07	1.57	35.3
	Lustran Sparkle	Monsanto	1.07	1.57	
	Tyril 990	Dow	1.07	1.57	
Polyester (PETG)	Kodar 6763	Eastman	1.27	1.567	
Polyamide, amorphous (nylon type 6/3)	Trogamid T	Huls-America	1.12	1.566	
Polystyrene co-methyl-methacrylate (2:1) (SMMA)	NAS 30	Novacor	1.09	1.564	35
Epoxy casting resin	OS-4000	Dexter Corp. (Hysol)	A = 1.15 B = 1.22	A = 1.563 B = 1.565	
Amorphous polyolefin from dicyclopentadiene	APO	Mitsui Petrochem.	1.05	1.54	
Acrylonitrile-butadiene-styrene terpolymer (ABS)	Cycolac CTBZ	G.E. Plastics	1.07	1.536	35
Polyamide, amorphous (nylon type 12)	Grilamid	EMS-America-Grilon	1.06	1.535	
Polystyrene co-methylmethacrylate (1:2) (SMMA)	NAS-55	Novacor	1.13	1.535	41.15
Amorphous polyolefin (APO)	ZEONEX	Zeon Chemicals	1.01	1.528	55.7

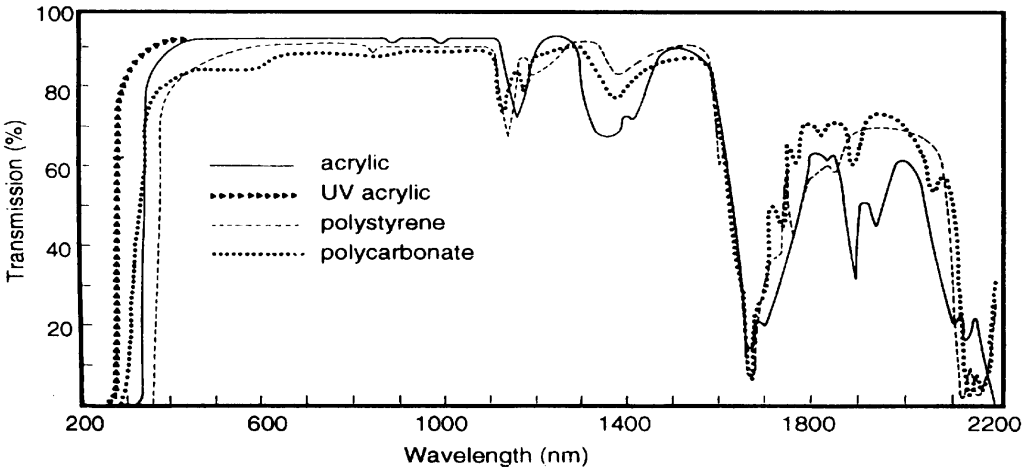
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Properties of optical plastics–I—*continued*

Polymer	Trade name	Manufacturer	Density (g/cm^3)	Index n_D	Abbe ν_D
Dicyclopolyolefin	Telene	B F Goodrich	1.0	1.528	55.3
Epoxy molding compound	MG-18	Dexter Corp. (Hysol)	1.35	1.52	
Tricyclodecyl co-methacrylate (TCDMA)	OZ-1000	Hitachi Chemical	1.16	1.500	57
Low moisture acrylic	WF-201	Mitsubishi Rayon		1.495	58
Allyl diglycol carbonate	CR-39	PPG Industries	1.32	1.498	59.3
Polymethylmethacrylate	Plexiglas	Rohm and Haas	1.19	1.491	57.4
PMMA, acrylic	Acrylite	Cyro	1.19	1.491	57.4
	CP	ICI	1.18	1.491	57.4
	Perspex	ICI	1.18	1.491	57.4
	Shinkolite P	Mitsubishi Rayon	1.19	1.491	57.4
Polymethylmethacrylate impact modified, 20%	MI-7	Rohm and Haas	1.17	1.49	
impact modified, 40%	DR-G	Rohm and Haas	1.15	1.49	
Poly(4-methylpentene-1)	TPX RT-18	Mitsui Plastics	0.833	1.463	56.3
Cellulose acetate butyrate (CAB)	Tenite	Eastman	1.15–1.2	1.46–1.49	51.9
Fluoropolymer (TPFE)	Teflon AF 1600	DuPont	1.8	1.32	92

Optical Transmission

Optical plastics transmit well in the visible and the near infrared, but absorb strongly in the ultraviolet (fluoropolymers are an exception) and throughout the infrared. Most plastics degrade somewhat both in physical and optical properties when exposed to ultraviolet radiation.



Transmission spectra of optical plastics. sample thickness: 3.2 mm.

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Properties of Optical Plastics–II

Polymer	Relative haze[a]	Hue[b]	Deflect.[c] temp. (°C)	Comments
Polyetherimide (PEI)	light	amber	200	Good thermal/chemical resistance, high color but good in near IR
Polyarylsulfone	light	yellow	204	Tough
Polyurethane	light	colorless	88	Can be custom tailored, good chemical resistance
Polysulfone	light	yellow	174	Good thermal and moisture stability, high temperature
Polyarylate	noticeable	light straw	158	High temperature, good UV resistance
Poly α-methylstyrene	slight	colorless	n/a	Brittle, can be modifier for K resin
Polyamide, amorphous nylon	slight	light straw	110	Tough, hard
Polystyrene (PS)	low	colorless	82110	Low haze grades available
Polyamide, amorphous nylon	noticeable	colorless	123	Good abrasion resistance, moisture sensitive
Polycarbonate (PC)	slight	light straw	123129	Very tough, high impact
Polystyrene co-maleic anhydride (SMA)	slight	colorless	96	Brittle
Modified polyestercarbonate	slight	light straw	107	Processes at lower temperature
Polystyrene-butadiene copolymer	noticeable	light straw	76	Tough
Polystyrene-coacrylonitrile ∂8 (SAN)	slight	light straw	93104	Tougher than polystyrene
Polyester (PETG)	slight	light straw	70	Film extruding
Polyamide, amorphous (nylon type 6/3)	noticeable	straw	124	Good abrasion resistance
Polystyrene co-methyl-methacrylate (2:1) (SMMA)	slight	colorless	98	Optical quality
Amorphous polyolefin from dicyclopentadiene	n/a	n/a	T_g = 141	Optical quality, very low moisture
Acrylonitrile-butadiene-styrene terpolymer (ABS)	noticeable	yellow	79	Tough
Polyamide, amorphous (nylon type 12)	noticeable	straw	150	Good abrasion resistance
Polystyrene co-methyl-ethacrylate (1:2) (SMMA)	slight	colorless	99	Optical quality
Amorphous polyolefin (APO)	slight	light straw	123	Optical quality
Dicyclopolyolefin	slight	light straw	107	Very low moisture (0.01%)
Epoxy molding compound	slight	colorless	120	Semiconductor embedment
Epoxy casting resin			T_g = 110	Two-part casting resin
Tricyclodecyl co-methacrylate (TCDMA)	low	colorless		Lower moisture than PMMA (1.2%)
Low moisture acrylic	sligth	light straw	103	Optical quality
Allyl diglycol carbonate	low	light straw	91	Cast thermoset, hard
			55–65	Ophthalmic use

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Properties of optical plastics–II—*continued*

Polymer	Relative haze[a]	Hue[b]	Deflect.[c] temp. (°C)	Comments
Polymethylmethacrylate PMMA, acrylic	low to slight	light straw to colorless	72–102	Optical quality, hard, widely used, scratch resistant
Impact modified, 20%	light	colorless	85	Tougher than PMMA
Impact modified, 40%	light	colorless	79	Tough, will creep with mild force
Poly(4-methylpentene-1)	slight	colorless	90 at 66 psi	Unusual properties, lowest density of all thermoplastics, infrared transmission, very tough
Cellulose acetate butyrate (CAB)	noticeable	light straw	43–88	Tough
Fluoropolymer (TPFE)	noticeable	colorless	154	Very low index of refraction, good ultraviolet transmission.

[a]Relative haze estimates: low (<0.7%); slight (to 1.5 %); light (to 3%); noticeable (>3%).

[b]Hue (yellowness) estimates: colorless, light straw, straw, yellow, amber.

[c]Heat deflection temperature at 264 psi.

The above tables are from D. Keyes, Optical plastics, *Handbook of Laser Science and Technology, Suppl. 2: Optical Materials* (CRC Press, Boca Raton, FL, 1995), pp. 85–94.

Loss Contributions (in dB/km) for PS, PMMA, and PMMA-d8 Core Fibers

Core material	PS				PMMA			PMMA-d8		
Wavelength (nm)	**552**	**580**	**624**	**672**	**518**	**567**	**650**	**680**	**780**	**850**
Total loss	162	138	129	114	57	55	128	20	25	50
Absorption	0	4	22	24	1	7	88	0	9	36
Electronic transition tail	22	11	4	2	0	0	0	0	0	0
Rayleigh scattering	95	78	58	43	28	20	12	10	6	4
Structural imperfections	45	45	45	45	28	28	28	10	10	10
Loss limit	117	93	84	69	29	27	100	10	15	40

Source: Kaino, T., Fujiki, M., and Jinguji, K., Preparation of plastic optical fibers, *Rev. Electr. Commun. Lab.* 32, 478 (1984).

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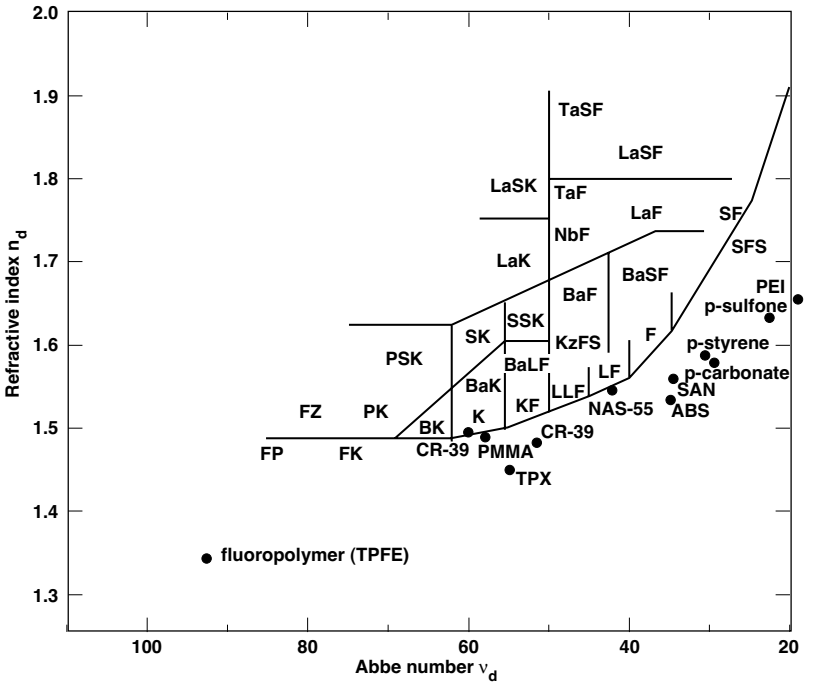
3.2 Index of Refraction

Index of Refraction of Common Optical Plastics

Wavelength (nm)	PMMA	Poly-styrene	Poly-carb.	SAN	PEI	NAS	TPFE
365.0	1.5136	1.6431	1.6432	1.6125	—	—	—
404.7	1.5066	1.6253	1.6224	1.5971	—	—	—
435.8	1.5026	1.6154	1.6115	1.5886	—	—	—
480.0	1.4983	1.6052	1.6007	1.5800	1.687	—	—
486.1	1.4978	1.6041	1.5994	1.5790	—	1.574	—
546.1	1.4938	1.5950	1.5901	1.5713	1.668	—	—
587.6	1.4918	1.5905	1.5855	1.5674	1.660	—	—
589.3	1.4917	1.5903	1.5853	1.5673		10564	1.31
643.9	1.4896	1.5858	1.5807	1.5634	1.651	—	—
656.3	1.4892	1.5849	1.5799	1.5627	—	1.558	—
706.5	1.4878	1.5820	1.5768	1.5601	—	—	—
852.1	1.4850	1.5762	1.5710	1.5551	—	—	—
1014.0	1.4831	1.5726	1.5672	1.5519	—	—	—
Abbe number	57.4	30.9	29.9	34.8	18.3	34.7	92

Adapted from a table of J. D. Lytle, *Handbook of Optics*, Vol. II (McGraw-Hill, New York, 1995), Chapter 34 (with additions).

Being carbon-based materials, the index of refraction and dispersion of polymers differ significantly from those of glasses and crystals. The locations of optical plastics relative to optical glasses are shown in the refractive index–Abbe number diagram below.



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3.3 Nonlinear Optical Properties

Abbreviations	Material
3-BCMUr	Red form of poly-3-BCMU
3-DDCTP	Poly(3-dodecylthiophene)
4-BCMUr	Red form of poly-4-BCMU
4-BCMUy	Yellow form of poly-4-BCMU
AO	Acridine orange
AY	Acridine yellow
BBB	Poly(6,9-dihydro-6,9-dioxobisbenzimidazo[2,1*b*:1',2'*j*]benzo[1*mn*][3,8]phenanthroline-3,12-diyl)
BBL	Poly{(7-oxo-7,10H-benz[de]imidazo[4',5':5,6]benzimidazo[2,1-*a*]isoquinoline 3,4:10,11-tetrayl)-10-carbonyl}
BBPEN	Bis[*n*-butyl, 2-phenyl-1,2-ethenedithiolato(2-)-*S*,*S*'] nickel
BSQ	1,3-Bis(4'-*N*,*N*-dibutylamino-2'-hydroxyphenyl)-cyclobutene-2,4-dione
DCV	4-*N*,*N*-Diethylamino-4'-*b,b*-dicyanovinyl (azobenzene)
DEANS	4-Diethylamino-4'-nitrostilbene
DNBA	4-Nitrobenzylidenyl (4'-*N*,*N*-dimethylaminoanilide)
DNTA	4-Nitrothenylidenyl (4'-*N*,*N*-dimethylaminoanilide)
DR1	Disperse red 1
ISQ	1,3-Bis(3',3'-dimethyl-2'-indoleninylidenyl)-cyclobutene-2,4-dione
LTFPG	Lead-tin fluorophosphate glass
MDCB	*m*-Dicyanobenzene
MDNB	*m*-Dinitrobenzene
Mg:OPTAP	Magnesium octaphenyl tetra-azaporphyrin
MNA	2-Methyl-4-nitroaniline
MV757	MV757 commercial epoxy resin
NFAI	5-Nitro(2-furanacroleindenyl (4'-*N*,*N*-dimethylaminoanilide)
NPCV	4-*N*,*N*-Dibutylamino-4'-(b-cyano-b-(4≤-nitrophenyl) vinyl) (azobenzene)
OMPS	Poly(*n*-octylmethylpolysilane
PBT	Poly-*p*-phenylenebenzobisthiazole
PC	Polycarbonate
PDES	Polydiethynylsilane
PDTT	Polydithieno(3,2-*b*,2',3'-*b*)thiophene
PMMA	Poly(methyl) methacrylate
PPMS	Polyphenylmethylsilane
PPV	Poly (*p*-phenylene vinylene)
PS	Polysilane
PT	Polythiophene
PTS	Bis-(*p*-toluene sulfonate) of 2,4-hexadiyne-1,6 diol (polydiacetylene)
PTS-PDA	Single crystal poly PTS polydiacetylene
PVK	Poly-*N*-ninyl carbazole
rB	Rhodamine B
SiNc	Silicon naphthalocyanine
SiPc	Silicon phthalocyanine
TCDU:	Bis-(phenylurethane) of 5,7-dodecadiyne-1,2-diol (polydiacetylene)
TCV	4-*N*,*N*-Diethylamino-4'-tricyanovinyl (azobenzene)
TNF	2,4,7-Trinitrofluorenone
TPO-N	Thiophene oligomer with N units

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Bulk Two-Photon Absorption Coefficients

Material	Excitation duration(ns)	Applied two-photon energy (eV)	Two-photon cross section (cm/GW)	Ref.	Additional information
3-BCMU	0.033	2.33	0.52	33	Benzene chloride 2.3% blue gel
4-BCMU	0.033	2.33	0.76	33	Benzene chloride 1.7% red gel
4-BCMU	0.033	2.33	<0.1	33	14% yellow form solution in DMF
4-BCMU	0.06	1.88	<0.25	34	Polymer waveguide
PPV	0.00006	4	6.8	35	PPV in silica sol-gel
PTS	0.015	2.28	28	36	Pump @1.17 eV
PTS	0.015	2.55	300	36	Pump @1.17 eV
PTS	0.015	2.78	500	36	Pump @1.17 eV
PTS	0.015	2.96	900	36	Pump @1.17 eV
TCDU	0.015	2.2	1	36	Pump @0.81 eV
TCDU	0.015	2.3	14	36	Pump @1.17 eV
TCDU	0.015	2.4	3	36	Pump @0.81 eV
TCDU	0.015	2.6	6.4	36	Pump @0.81 eV
TCDU	0.015	2.6	54	36	Pump @1.17 eV
TCDU	0.015	2.9	80	36	Pump @1.17 eV

From Garito, A. E. and Kuzyk, M. G., Two-photon absorption: organic materials, *Handbook of Laser Science and Technology, Suppl. 2: Optical Materials* (CRC Press, Boca Raton, FL, 1995), p. 329.

Techniques for Measuring Nonlinear Refraction

Abbreviation	Method	Ref.
DFWM	Degenerate four-wave mixing	1
KE	DC Kerr effect	2
MSI	Modified Sagnac interferometry	3
OKE	Optical Kerr effect	4
SA	Saturated absorption	5
TBC	Two-beam coupling	5
TRI	Time-resolved interferometry	6

All measurements in the following tables were made at room temperature.

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Nonlinear Refraction Data for Polymers

Material	Meth.	Pulse duration (ns)	Wavelength (nm)	Linear index n	$\chi^{(3)}_{1111}$ (10^{-12} cm^3/erg)	$\chi^{(3)}_{1111} - \chi^{(3)}_{1122}$ (10^{-12} cm^3/erg)	Ref.
3-DDCTP	DFWM	0.0004	620		330		7
3-DDCTP	DFWM	0.00006	620		55		7
3-DDCTP[a]	DFWM	0.00035	590	1.585	450		8
3-DDCTP[a]	DFWM	0.00035	602	1.585	330		8
3-DDCTP[a]	DFWM	0.00035	705	1.585	40		8
3-DDCTP[b]	DFWM	0.00035	590	1.61	700		8
3-DDCTP[b]	DFWM	0.00035	602	1.61	500		8
3-DDCTP[b]	DFWM	0.00035	705	1.61	40		8
4-BCMUr	DFWM	0.0005	605		400		9
4-BCMUy	DFWM	0.0005	605		25		9
4-BCMUy	DFWM	0.033	1064			$\chi^{(3)}_{1212} = 1.4$	10
4-BCMUy	DFWM	0.033	1064			$\chi^{(3)}_{1212} = 9.0$	10
4-BCMUy	DFWM	0.033	1064			$\chi^{(3)}_{1212} = 13$	10
BBB	DFWM	0.035	1064		5.5	3.7	11
BBL	DFWM	0.025	532		2000	1300	11
BBL	DFWM	0.035	1064		15	10	11
BBL[c]	DFWM	0.035	1064		20	13	11
OMPS	DFWM	10	532		2.9		12
PBT	DFWM	0.0005	585–604		9		13
PDES	DFWM	0.00009	620		3000		14
PDTT	DFWM	0.008	530	2	11,400		15
PDTT	DFWM	0.008	585	2	7,700		15
PDTT	DFWM	0.008	605	2	5,500		15
PDTT	DFWM	0.008	630	2	1,300		15
PDTT	DFWM	0.008	1060	2	30		15
Poly(4-BCMU)	TRI	0.06	1319		0.456		16
PPMS	OKE	0.003	1060,532		2.0		17
PS	OKE	0.008	1060,532		2		18
PT	DFWM	0.008	530	2	6,680		15
PT	DFWM	0.008	585	2	5,000		15
PT	DFWM	0.008	605	2	3,000		15
PT	DFWM	0.008	630	2	700		15
PT	DFWM	0.008	1060	2	30		15
PTS-PDA	DFWM	0.006	651.5	3	9,000		19
PTS-PDA	DFWM	0.006	661	3	7,275		19
PTS-PDA	DFWM	0.006	671	3	2,317		19
PTS-PDA	DFWM	0.006	681	3	1,025		19
PTS-PDA	DFWM	0.006	691	3	380		19
PTS-PDA	DFWM	0.006	701.5	3	500		19
PTS-PDA	MSI	0.06	1060	3	1250		3
PTS-PDA[a]	TRI	0.1	1060	3	6840		20
TPO-1	DFWM	0.0004	602	1.529	0.14		21
TPO-2	DFWM	0.0004	602		0.50		21
TPO-3	DFWM	0.0004	602	1.562	2.6		21
TPO-4	DFWM	0.0004	602	1.581	11		21
TPO-5	DFWM	0.0004	602	1.600	30		21
TPO-6	DFWM	0.0004	602	1.623	100		21

[a] Chemically prepared; [b] Electrochemically prepared; [c] Electrochemically doped; [d] Single crystal waveguides.

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Nonlinear Refraction Data for Solid Solutions and Copolymers

Dye	Host	Dye density (10^{22} cm^{-3})	Meth.	Pulse (ns)	Wavelength (nm)	Linear index	$\chi^{(3)}_{1111}$ (10^{-12} cm^3/erg)	Ref.
AO	LTFPG	0.00008	SA	15,000	514	1.77	3 x 10^{10}	22
AO	LTFPG	0.00008	TBC	15,000	514	1.77	4 x 10^{10}	22
AY	LTFPG	0.000077	SA	15,000	514	1.77	6 x 10^{10}	22
AY	LTFPG	0.000077	TBC	15,000	514	1.77	2 x 10^{10}	22
BBPEN	PMMA	saturation	DFWM	0.1	1064	1.49	29.9	23
BEPEN	PMMA	saturation	DFWM	0.1	1064	1.49	131	23
BSQ	PMMA	0.0028	MSI[b]	0.06	1064	1.48	2.8	24
BSQ	PMMA	0.0028	KE	8 kHz	799	1.5	0.97[a]	25
DCV	PMMA	0.0148	KE	8 kHz	632.8	1.5	1.8[a]	26
DCV	PMMA	0.0148	KE	8 kHz	676	1.5	0.53[a]	26
DCV	PMMA	0.0148	KE	8 kHz	799	1.5	0.156[a]	26
DEANS	PC	17	KE	500 Hz	597		6	27
DNBA	PMMA	0.0137	KE	8 kHz	632.8	1.5	0.093[a]	26
DNTA	PMMA	0.0276	KE	8 kHz	632.8	1.5	0.282[a]	26
DR1	PMMA	0.01	KE	8 kHz	632.8	1.5	0.23[a]	26
DR1	PMMA	0.0244	KE	8 kHz	632.8	1.5	0.51[a]	26
DR1	PMMA	0.04	KE	8 kHz	632.8	1.5	0.84[a]	26
ISQ	PMMA	0.0019	KE	8 kHz	479	1.5	0.263[a]	26
ISQ	PMMA	0.0019	KE	8 kHz	570	1.5	0.341[a]	26
ISQ	PMMA	0.0019	KE	8 kHz	632.8	1.5	0.155[a]	26
ISQ	PMMA	0.0019	KE	8 kHz	680	1.5	0.418[a]	26
ISQ	PMMA	0.0019	KE	8 kHz	799	1.5	0.387[a]	26
MDCB	PMMA	0.109	KE	8 kHz	632.8	1.5	0.0274[a]	26
MDNB	PMMA	0.124	KE	8 kHz	632.8	1.5	0.0205[a]	26
Mg:OPTAP	PMMA	5 wt%	DFWM	0.001	598	1.48	11.7	28
MNA	PMMA	0.143	OKE[b]		1064	1.5	2.08	29
NFAI	PMMA	0.0240	KE	8 kHz	632.8	1.5	0.471[a]	26
NPCV	PMMA	0.0119	KE	8 kHz	632.8	1.5	0.315[a]	26
PPV	Sol-gel silica	1:1 by weight	DFWM	0.00006	620		45	30
PPV	Sol-gel silica	1:1 by weight	DFWM	0.0004	608		91	30
PPV	Sol-gel silica	1:1 by weight	OKE	0.00006	620		38	30
rB	MV757	0.0077 M/l	DFWM	0.00035	595	1.81	10.7	31
SiNc	PMMA	30 wt%	DFWM	0.001	598	1.434	20.9	28
SiPc[c]	PMMA	10 wt%	DFWM	0.001	598	1.42	94	28
TCV	PMMA	0.0218	KE	8 kHz	632.8	1.5	3.9[a]	26
TNF	PVK	1:2 molar ratio	DFWM	0.002	602		20	32
TNF	PVK	1:4 molar ratio	DFWM	0.002	602		12	32
TNF	PVK	1:8 molar ratio	DFWM	0.002	602		7.4	32
TNF	PVK	1:16 molar ratio	DFWM	0.002	602		3.4	32
TNF	PVK	1:32 molar ratio	DFWM	0.002	602		2.0	32

[a] Assumes $\chi^{(3)}_{1111} = 3\,\chi^{(3)}_{1133}$. [b] Waveguide measurement; [c] Copolymer.

From Garito, A. E. And Kuzyk, M. G., Nonlinear refractive index: organic materials, *Handbook of Laser Science and Technology, Suppl. 2* (CRC Press, Boca Raton, FL 1995), p. 289.

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3.4 Thermal Properties

Thermal Properties of Common Plastics

Material	Thermal conductivity ($W\ m^{-1}\ K^{-1}$)	Linear thermal expansion ($10^{-5}\ K^{-1}$)	Refractive index dn/dT ($10^{-4}\ K^{-1}$)	Maximum service temp. (K)
polymethylmethacrylate	0.16–0.24	3.6–6.5	–1.05	360
polystyrene	0.10–0.13	6.0–8.0	–1.2– –1.4	350
NAS	0.18	5.6–6.5		360
styrene acrylonitrile (SAN)	0.11	6.4–6.7	–1.1	350
polycarbonate	0.19	6.6–7.0	–1.07– –1.43	390
polymethyl pentene (TPX)	0.16	11.7		385
polyamide (Nylon)	0.2–0.23	8.2		350
polyarylate	0.28	6.3		
polysulfone	0.11	2.5		430
polystyrene co-butadiene		7.8–12		
polyallyl diglycol carbonate	0.20	12.0		370
cellulose acetate butyrate	0.16–0.32			
polyethersulfone	0.13–0.17	5.5		470
polychloro-trifluoroethelyne	0.25	4.7		470
polyvinylidene fluoride		7.4–13		420
polyetherimide		5.6		440

From a table of J. D. Lytle, *Handbook of Optics,* Vol. II (McGraw-Hill, New York, 1995), Chapter 34 (with additions).

3.5 Engineering Data

Engineering Data for Transparent Polymers–I

Generic family	Trade name	Manufacturer	Tensile strength yield psi	Tensile modulus 10^5, psi	Flexural modulus 10^5, psi	Impact strength (Izod)
Transparent ABS	Magnum	Dow	7300	3.8	4.2	2
	Cycolac	GE Plastics				
Acrylic (PMMA)	Plexiglas	Rohm & Haas	9400–10800	4.5–4.7	2.5–4.5	0.4–1.2
	CP	ICI				
	Acrylite	CYRO				
	Lucite	Dupont				
Allyl diglycol carbonate	CR-39	PPG	5500	3	2.5–3.3	0.2–0.4
Cellulosics (acetate, butyrate, proponiate)	Tenite	Eastman	2000–7800	0.6–2.15	1.5–3.4	1.5–7.8
Nylon, amorphous	Zytel 330	Dupont	9800–11000	4. 05	3.86	1.8–2.8
	Grilamid	EMS				
	Trogamid T	Huls America				

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Engineering Data for Transparent Polymers–I—*continued*

Generic family	Trade name	Manufacturer	Tensile strength yield psi	Tensile modulus 10^5, psi	Flexural modulus 10^5, psi	Impact strength (Izod)
PET	Kodapak	Eastman	8500–10500	4–6	3.5–4.5	0.25–0.7
	Petlon	Miles Inc.				
	Selar	Dupont				
PETG	Kodar	Eastman	7100	2.5	2.9	1.7
Polyarylate	Durel	Hoescht Celanese	9500–10500	2.9–3.05	3.3	4.2–5.5
	Arylon	Dupont				
	Ardel	Amoco Performance				
Polycarbonate	Calibre	Dow	9000–10500	3.4	3.5	14–18
	Markrolon	Miles Inc. (Bayer)				
	Lexan	GE Plastics				
Polyetherimide	Ultem	GE Plastics	15200	4.3	4.8	0.6–1.0
Polyester (polypthalate) carbonate	Lexan PPC	GE Plastics	9500	n/a	2.94–3.38	10
Polyethersulfone	Victrex	ICI	12200	n/a	3.73	1.6
Poly-4-methylpentene-1	TPX	Mitsui Plastics	3000	2	n/a	2.0–3.0
Polyphenylsulfone	Radel	Amoco Performance	10400	3.1	0.124	12
Polystyrene	Styron	Dow	5000–12000	4–5	4–4.7	0.25–0.4
	Polystyrol	BASF				
	Hostyren	Hoescht Celanese				
	Bapolan	Bamberger				
	polystyrene	Chevron				
	polystyrene	Dart, Mobil				
	polystyrene	Amoco, Novacor				
	polystyrene	Huntsman				
Polysulfone	Udel	Amoco	10200	3.6	3.9	1.3
PVC, rigid	Geon	B.F. Goodrich	6000–7700	3.6–3.7	3.6–5	0.5–1.6
	PVC, rigid	Georgia Gulf				
	Oxyblend	Occidental				
	Unichem	Colorite				
Styrene acronylitrile)	Tyril	Dow	9000–1200	4–5.6	5–5.5	0.35–0.5
(SAN	Lustran	Monsanto				
	Luran	BASF				
	Blendex	GE Plastics				
Styrene butadiene	K Resin	Phillips	4000	1.8	2.4	0.25–0.40
Styrene maleic anhydride	Dylark	Arco	7400	4.4	4.6–4.9	0.4
Styrene methylmethacrylat	NAS	Novacorp	9000	4.5–5.0	3.5–3.9	0.2–0.3
Thermoplastic polyurethane, rigid	Isoplast 301	Dow	9000	2.6	3.4	1.5

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Engineering Data for Transparent Polymers–II

Generic family	Trade name	Chemical resistance					
		Aliph. HC	Arom. HC	Conc. base	Dilute base	Conc. inorg. acid	Dilute inorg. acid
Transparent ABS	Magnum Cycolac	F	P	G	G	P	G
Acrylic (PMMA)	Plexiglas CP Acrylite Lucite	G	P	F/P	G	P	G
Allyl diglycol carbonate	CR-39	G	G	G	G	G	G
Cellulosics (acetate, butyrate, proponiate)	Tenite	F	P	P	F	P	F
Nylon, amorphous	Zytel 330 Grilamid Trogamid T	EX	EX	G	EX	P	F
PET	Kodapak Petlon Selar	G	P/F	P	F	G/F	G
PETG	Kodar	G	P/F	P	F	G/F	G
Polyarylate	Durel Arylon Ardel	P/F	P	P	N/A	F	G
Polycarbonate	Calibre Markrolon Lexan	F	P	P	P/F	F	G
Polyetherimide	Ultem	EX	EX	N/A	N/A	EX	EX
Polyester (polypthalate) carbonate	Lexan PPC	F	F/P	P	F	F	G
Polyethersulfone	Victrex	G	F	G	G	G	G
Poly-4-methylpentene-1	TPX	F	P	EX	EX	EX	EX
Polyphenylsulfone	Radel	G	P	G	G	N/A	N/A
Polystyrene	Styron Polystyrol Hostyren Bapolan polystyrene	P	P	G	G	EX	G
Polysulfone	Udel	P/F	P	EX	EX	EX	EX
PVC, rigid	Geon Oxyblend Unichem	G	P	EX	EX	G	EX

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Engineering Data for Transparent Polymers–II—*continued*

Generic family	Trade name	Chemical resistance					
		Aliph. HC	Arom. HC	Conc. base	Dilute base	Conc. inorg. acid	Dilute inorg. acid
Polyarylate	Durel Arylon Ardel	P/F	P	P	N/A	F	G
Polycarbonate	Calibre Markrolon Lexan	F	P	P	P/F	F	G
Polyetherimide	Ultem	EX	EX	N/A	N/A	EX	EX
Polyester (polypthalate) carbonate	Lexan PPC	F	F/P	P	F	F	G
Polyethersulfone	Victrex	G	F	G	G	G	G
Poly-4-methylpentene-1	TPX	F	P	EX	EX	EX	EX
Polyphenylsulfone	Radel	G	P	G	G	N/A	N/A
Polystyrene	Styron Polystyrol Hostyren Bapolan polystyrene	P	P	G	G	EX	G
Polysulfone	Udel	P/F	P	EX	EX	EX	EX
PVC, rigid	Geon PVC, rigid Oxyblend Unichem	G	P	EX	EX	G	EX
Styrene acronylitrile (SAN)	Tyril Lustran Luran Blendex	G	P	G	G	G	G
Styrene butadiene	K Resin	P	P	P	F/G	P	F/G
Styrene maleic anhydride (SMA)	Dylark	F/G	P	G	P	F	G
Styrene methylmethacrylate (SMMA)	NAS	F/P	P	F	G	F	G
Thermoplastic polyurethane, rigid	Isoplast 301	EX	EX	EX	EX	F/G	EX

Chemical resistance codes: Aliphatic hydrocarbons; aromatic hydrocarbons; concentrated base; dilute base; concentrated inorganic acid; dilute inorganic acid. Excellent; Good; Fair; Poor.

The above tables are from Keyes, D., Optical plastics, *Handbook of Laser Science and Technology, Suppl. 2: Optical Materials* (CRC Press, Boca Raton, FL, 1995), pp. 85–94.

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