Barium Fluoride (BaF_2)

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Barium fluoride is a general-purpose optical window material that offers a wide range of transparency, from the ultraviolet to the long-wave infrared (0.15 to 12 μm), with low reflectance loss and low dispersion. This combination of broad transparency and low dispersion is rare in optical window materials used in infrared systems. It allows experimenters to conveniently perform initial system alignment in the visible and then switch to the IR with only minor correction of the optical components. Furthermore, barium fluoride has good surface hardness (Knoop scale: 78 kg/mm^2), and it is not attacked by water vapor, though humidities in excess causes surface damage. It has moderate flexure strength (27 MPa) and is very brittle, requiring careful handling. Thus, barium fluoride is better suited for laboratory than for field work. It is also a relatively inexpensive single-crystal material that is readily available from a number of vendors.

Barium fluoride is a cubic crystal with the fluorite structure, space group Fm3m (O_h^5), with four formula units per unit cell. The lattice constant is 6.2001 Å, giving a theoretical density of 4.886 g/cm^3. The atomic arrangement is barium atoms occupy the 4(a) sites (m3m or O_h symmetry), and the fluorine atoms occupy the 8(c) sites ($\bar{4}3m$ or T_d symmetry). Melting point is 1641 K.

Ultraviolet reflectance of both BaF_2 was measured by Gatos et al. [1] up to 20 eV at room temperature and liquid-helium temperature. Rubloff [2] has measured the room-temperature reflectance up to 36 eV. Unfortunately, these measurements are on reduced to optical constants. However, similar measurements from 10 to 33 eV by Nisar and Robin [3] have been reduced to optical constants utilizing the Kramers–Kronig relation. Thin-film optical constant data is available from transmittance and reflectance measurements by Zukic et al. [4], but only between 0.21 and 0.3 μm. These results extend the Nisar and Robin data out down to 6.3 eV. These data are fitted in Table I and plotted in Fig. 1.

The Urbach tail represents absorption below the band gap, defining the

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edd of transparency. The room-temperature absorption coefficient was determined from transmission measurements by Tomiki and Miyata [5] in the spectral range from 9.1 to 9.35 eV and fitted to the functional form

$$\beta_{abs}(E,T) = \beta_{00}\exp[\sigma_s(T)(E - E_g)/k_BT], \tag{1}$$

where β_{abs} is the absorption coefficient (typically in units of cm^{-1}); β_{00} is a scaling coefficient (in units of cm^{-1}), E_g is the band-gap energy at absolute zero temperature, typically given in electron volts; k_B is Boltzmann's constant; and T is temperature in Kelvins. The exponential factor $\sigma_s(T)$ is given by the equation

$$\sigma_s(T) = \sigma_0\frac{2k_BT}{E_p}\tanh\frac{E_p}{2k_BT}, \tag{2}$$

where E_p is an effective acoustic-phonon energy of the material. The Urbach tail parameters for BaF_2 are: $\beta_{00} = 4.17 \times 10^8\ cm^{-1}$, $E_g = 10.162$ eV, $\sigma_0 = 0.58$, and $E_p = 0.04$ eV. The room-temperature values for k in Table I and Fig. 1 for this spectral region are generated using Eqs. (1) and (2).

The room-temperature (25° C) index of refraction from the ultraviolet to the infrared (0.27 to 10.3 μm) has been measured by Malitson [6] using a prism and the minimum-deviation technique. A Sellmeier model of the form

$$n^2(\lambda,T) = 1 + \sum_i \frac{\lambda^2\Delta s_i(T)}{\lambda^2 - \lambda_i^2(T)} \tag{3}$$

is used to accurately represent the data (±0.00002). Model parameters are listed in Table II. A comprehensive analysis on a variety of data sets was performed by Li [7]. A Sellmeier formula was also generated covering the range from 0.13 to 13 μm at $T = 20°$ C. The Li model parameters are also listed in Table II. Because the Sellmeier model has a physical basis, the extrapolation to higher frequencies beyond the experimental limit is justified. The values for n in Table I and Fig. 1 for the spectral region from 650 to 67,000 cm^{-1} are generated by the preceding formula. A temperature-dependent Sellmeier model covering the range from 100 to 450 K has been developed by Tropf [8]. Room-temperature thermo-optic coefficients, measured at different wavelengths, are listed in Table III [6, 9–13]. Notice that the thermo-optic coefficients are negative. This gives BaF_2 some ethereal performance as an optical element. An ethereal material has the property that

$$\frac{d(n(T)L(T))}{dT} = 0.$$

The value of the optical-path derivative as given above for BaF_2 is 7.5×10^{-6} mL per Kelvin at visible and near-infrared wavelengths. Thus, BaF_2 is useful for optical designs that require insensitivity to temperature.

Laser-calorimetry data [14] at DF (3.8 μm) and HF (2.7 μm) laser wavelengths indicate low-level absorption in roughly the middle of the transparency range of BaF_2 material obtained from Adolf Meller had absorption-coefficient values of 2.0×10^{-4} cm^{-1} at the DF laser wavelength and 1.4×10^{-4} cm^{-1} at the HF laser wavelength. Material obtained from Optovac had absorption-coefficient values of 2.0×10^{-3} cm^{-1} at the DF laser wavelength and 1.8×10^{-3} cm^{-1} at the HF laser wavelength. The lowest values are listed in Table I and plotted in Fig. 1. The low-level absorption and the near-ethereal performance of BaF_2 make it a candidate window material for high-power laser applications.

The multiphonon absorption (multiple-quanta lattice vibrations) edge marks the end of infrared transparency. Absorption-coefficient measurements by Deutsch [15] are represented by the simple formula

$$\beta_{mp}(\nu) = \beta_0 \exp\left(-\gamma \frac{\nu}{\nu_0}\right), \tag{4}$$

where for BaF_2, $\beta_0 = 49.641$ cm^{-1} and $\nu_0/\gamma = 75.9$ cm^{-1} at room temperature. The values of β in the spectral range from 800 to 1250 cm^{-1} in Table I and Fig. 1 are obtained from this formula. The data cover the three-phonon to four-phonon regions. Temperature-dependent experimental data on the absorption coefficient are described in Upton *et al.* [16]. A temperature-dependent multiphonon model has been developed by Thomas *et al.* [17] and applied to BaF_2. Measurements in the two-phonon region are reported by Kaiser *et al.* [18]. The experimental results are listed in Table I and plotted in Fig. 1.

The *one-phonon* (one-quantum fundamental lattice vibrations) region is opaque and therefore characterized by reflectance measurements. A room-temperature reflectance measurement is reported by Kaiser *et al.* [18]. Temperature-dependent data are available from Hoffmann [19]. The classical-oscillator model is often used to fit the reflectance data and then to derive the optical constants. The classical-oscillator model is expressed in terms of the relative permittivity, $\kappa(\nu,T)$, as given by[1]

$$\kappa_r(\nu,T) = \kappa_\infty(T) + \sum_i \frac{\Delta\kappa_i(T)\nu_i^2(T)}{\nu_i^2(T) - \nu^2 + j\Gamma_i(\nu,T)\nu}, \tag{5}$$

where $\Delta\kappa_i$, Γ_i, and ν_i are the ith-mode strength, line width, and long-wavelength transverse optical frequency, ν_{TO_i}, respectively. The sum on i is over all transverse optical modes. For BaF_2, there is only one allowed

[1] The expression uses the engineering convention for a time harmonic field of $\exp(-j\omega t)$. To convert to the convention commonly used in the physics texts, use $j = -j$.

infrared-active vibrational mode based on group theory of a perfect lattice. This is formally stated as

$$\Gamma = F_{1u}(\mathrm{IR}) + F_{2g}(\mathrm{R}).$$

The first mode is infrared active (mode 1 in Table IV), and the second mode is Raman active (241 cm^{-1} [20]). Table IV lists the classical-oscillator-model parameters used to fit the experimental data. More than one mode is needed to account for impurities and defects in real materials. Also, the high-frequency edge of the reflectance spectrum must include two-phonon contributions (see mode 4, Hoffmann [19], in Table IV). The n and k values in Table I and Fig. 1 are generated by Eq. (5) and the parameters from Hoffmann [19].

Below ν_{TO}, the index of refraction, n, is determined by extrapolation of the classical-oscillator model with reasonable accuracy. The absorption coefficient has been measured by Bosomworth [21]. Table I and Fig. 1 list and display the resulting values.

The static-dielectric constant data is the sum of all the strengths of higher frequency oscillators, including vibrational and electronic. Using Eq. (5), the static dielectric constant, $\epsilon_0(T) = \epsilon'(0,T)$, becomes

$$\epsilon_0(T) = \epsilon_\infty(T) + \sum_j \Delta\epsilon_j(T). \tag{6}$$

Based on the parameters listed in Table IV, we expect the value of ϵ_0 to be between 6.73 and 7.63. Experimental results, obtained from capacitance bridges operating from 1 kHz to 1 MHz, produce values from 7.28 to 7.36, with most results closer to the higher value [13, 22–24]. The corresponding refractive index value is $n_0 = 2.71$. Because the static dielectric constant predicted by the Hoffmann [19] parameters is close to the experimental result, his model parameters are used in the calculations of n in Table I and Fig. 1 below ν_{TO}. The static-index values are located incorrectly at 1×10^4 μm; however, there is little difference in the value of n_0 at the measured wavelength and the plotted wavelength.

Whenever possible, physically based models are used to represent experimental measurements in Table I and Fig. 1. The models tend to reduce noise and allow interpolation and extrapolation to obtain meaningful results where no experimental data exist. In some cases, the models discussed in this section also allow temperature-dependent data to be obtained.

REFERENCES

1. V. A. Chanin, M. G. Karin, V. K. Sidorin, K. K. Sidorin, M. V. Shevelev, G. P. Starinov, and M. B. Zhegalina, Optical constants and energy-band structure of fluorite-type crystals. Sov. Phys. Solid State 16, 2313–2316 (1975).
2. G. W. Rubloff, Far-infrared reflectance spectra and the electronic structure of ionic crystals. Phys. Rev. B 5, 662–684 (1972).

3. M. Nisar and S. Robin, Far ultraviolet absorption spectra of SrF_2 and BaF_2, *Pak. J. Sci. Ind. Res.* 17, 49–54 (1974).
4. M. Zukic, D. G. Torr, J. F. Spann, and M. R. Torr, Vacuum ultraviolet thin films. 1: Optical constants of BaF_2, CaF_2, LaF_3, MgF_2, Al_2O_3, HfO_2 and SiO_2 thin films, *Appl. Opt.* 29, 4284–4292 (1990).
5. T. Tomiki and T. Miyata, Optical studies of alkali fluorides and alkaline earth fluorides in VUV region, *J. Phys. Soc. Jpn.* 27, 658–678 (1969).
6. I. H. Malitson, Refractive properties of barium fluoride, *J. Opt. Soc. Am.* 54, 628–632 (1964).
7. H. H. Li, Refractive index of alkaline earth halides and its wavelength and temperature derivatives, *J. Phys. Chem. Ref. Data* 9, 161–289 (1980).
8. M. J. Tropf, Temperature-dependent refractive index models for BaF_2, CaF_2, MgF_2, SrF_2, LiF, NaF, KCl, ZnS and ZnSe, *Opt. Eng.* 34, 1369–1373 (1995).
9. A. Feldman, D. Horowitz, R. M. Waxler, and M. J. Dodge, "Optical Materials Characterization Final Technical Report, February 1, 1978–September 30, 1978," NBS Technical Note 993, February 1979.
10. H. G. Lipson, Y. F. Tsay, B. Bendow, and P. A. Ligor, Temperature dependence of the refractive index of alkaline earth fluorides, *Appl. Opt.* 15, 2352–2354 (1976).
11. Y. F. Tsay, H. G. Lipson, and P. A. Ligor, The temperature variation of the thermo-optic coefficient of CaF_2, *J. Appl. Phys.* 48, 1953–1955 (1977).
12. R. J. Harris, G. T. Johnston, G. A. Kepple, P. C. Krok, and H. Mukai, Infrared thermooptic coefficient measurement of polycrystalline ZnSe, ZnS, CdTe, CaF_2 and BaF_2, single crystal KCl and TI-20 glass, *Appl. Opt.* 16, 436–438 (1977).
13. M. Wintersgill, J. Fontanella, C. Andeen, and D. Schuele, The temperature variation of the dielectric constant of "pure" CaF_2, SrF_2, BaF_2, and MgO, *J. Appl. Phys.* 50, 8259–8261 (1979).
14. J. A. Harrington, D. A. Gregory, and W. F. Otto, Jr., Infrared absorption in chemical laser window materials, *Appl. Opt.* 15, 1953–1959 (1976).
15. T. F. Deutsch, Absorption coefficient of infrared laser window materials, *J. Phys. Chem. Solids* 34, 2091–2104 (1973).
16. H. G. Lipson, B. Bendow, N. E. Massa, and S. S. Mitra, Multiphonon infrared absorption in the transparent regime of alkaline-earth fluorides, *Phys. Rev. B* 13, 2614–2619 (1976).
17. M. E. Thomas, R. I. Joseph, and W. J. Tropf, Infrared transmission properties of sapphire, spinel, yttria and ALON as a function of temperature and frequency, *Appl. Opt.* 27, 239 (1988); M. E. Thomas, Temperature dependence of the complex index of refraction, in "Handbook of Optical Constants of Solids II" (E. D. Palik, ed.), pp. 177–201, Academic Press, Orlando, Florida, 1991; M. E. Thomas, A computer code for modeling optical properties of window materials, in Window and Dome Technologies and Materials, *Proc. of SPIE* 1112, 260–267 (1989).
18. W. Kaiser, W. G. Spitzer, R. H. Kaiser, and L. E. Howarth, Infrared properties of CaF_2, SrF_2, and BaF_2, *Phys. Rev.* 127, 1950–1954 (1962).
19. C. H. Raffensparger, Optical constants of infrared active phonons as a function of frequency and temperature, M.S. Thesis, Johns Hopkins University, Baltimore, Maryland (1986).
20. I. Richman, Longitudinal optical phonons in CaF_2, SrF_2 and BaF_2, *J. Chem. Phys.* 41, 2836–2837 (1964).
21. D. R. Bosomworth, Far-infrared optical properties of CaF_2, SrF_2, BaF_2, and CdF_2, *Phys. Rev.* 157, 709–715 (1967).
22. K. V. Rao and A. Smakula, Dielectric properties of alkaline earth fluoride single crystals, *J. Appl. Phys.* 37, 319–323 (1966).
23. C. Andeen, J. Fontanella, and D. Schuele, Low-frequency dielectric constants of the alkaline earth fluorides by the method of substitution, *J. Appl. Phys.* 42, 2216–2219 (1971).
24. G. A. Samara, Temperature and pressure dependences of the dielectric properties of PbF_2 and the alkaline-earth fluorides, *Phys. Rev. B* 13, 4529–4544 (1976).

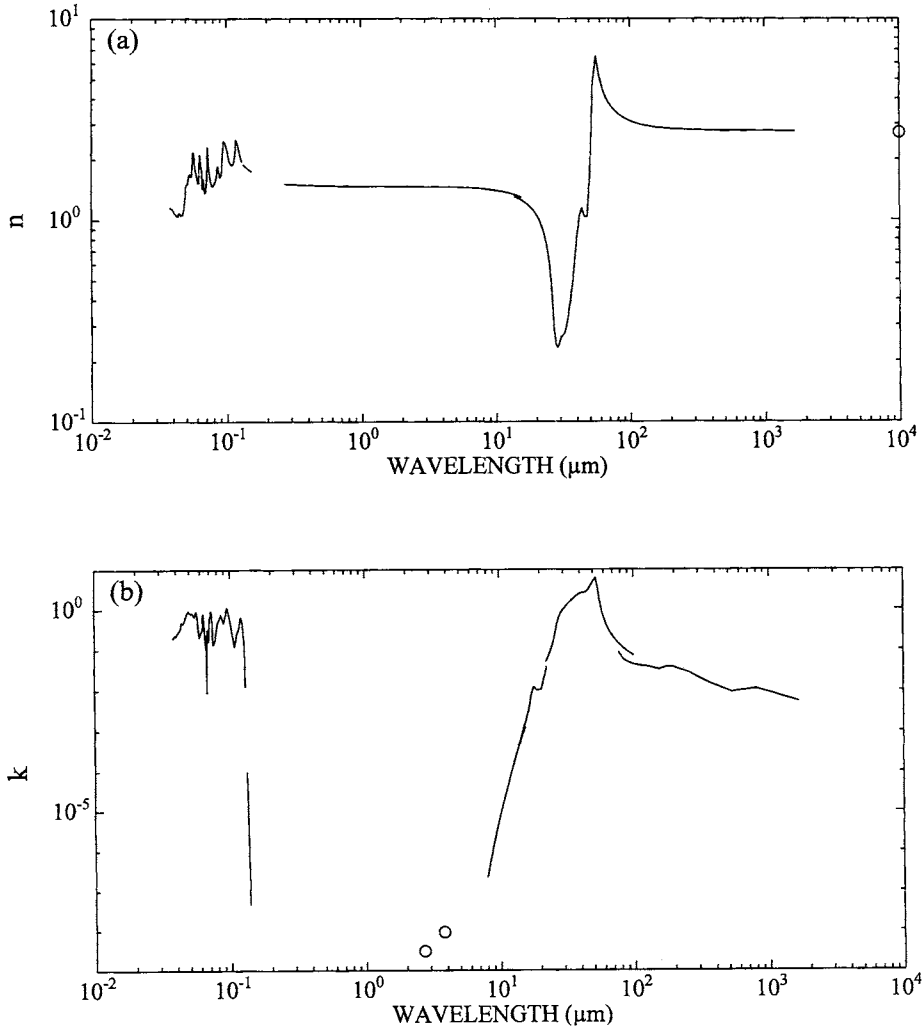

Fig. 1. (a) Log–log plot of the room-temperature index of refraction, n, for BaF_2 versus wavelength in microns. (b) Log–log plot of the room-temperature extinction coefficient, k, for BaF_2 versus wavelength in microns. Isolated data points are indicated with a symbol.

TABLE I

Values of n and k for BaF_2 from Various References[a]

eV	cm^{-1}	nm	n	k
32.91	265400	0.03767	1.149 [3]	0.1598 [3]
31.71	255400	0.03910	1.134	0.2200
31.42	253500	0.03946	1.139	0.2268
31.20	251600	0.03974	1.118	0.2154
30.39	244800	0.04086	1.084	0.2436
29.97	241700	0.04137	1.077	0.2614
28.91	233100	0.04289	1.049	0.3217
28.71	231600	0.04318	1.043	0.3344
28.00	226700	0.04535	1.084	0.3707
28.02	226600	0.04348	1.046	0.4149
28.05	225100	0.04565	1.037	0.4400
28.22	220400	0.04393	1.051	0.4727
27.47	221400	0.04514	1.074	0.4452
27.22	219950	0.04547	1.054	0.4598
27.07	218350	0.04589	1.054	0.4865
26.81	216200	0.04625	1.043	0.5383
26.46	213450	0.04686	1.037	0.6116
25.75	207700	0.04916	1.133	0.7583
25.65	206300	0.04853	1.106	0.8265
25.34	204500	0.04891	1.271	0.8810
25.22	203400	0.04916	1.303	0.9061
25.03	204906	0.04994	1.449	0.9075
24.72	199400	0.03916	1.429	0.8574
24.91	197700	0.03039	1.507	0.8341
24.18	195400	0.05128	1.517	0.8032
23.02	109100	0.05167	1.381	0.7774
23.09	197400	0.05149	1.604	0.8149
23.28	191400	0.03205	1.649	0.8408
23.57	189700	0.05271	1.640	0.8149
23.39	180300	0.03313	1.686	0.7773
23.91	194700	0.03413	1.654	0.7004
23.04	187400	0.03471	1.639	0.8632
22.46	181300	0.05315	1.202	0.7544
22.14	179400	0.05464	2.116	0.8573
22.05	177700	0.05620	2.163	0.8887
21.38	176800	0.05671	2.163	0.8035
21.35	175900	0.05694	2.133	0.7863
21.26	174900	0.05725	2.072	0.7729
21.38	174100	0.05745	2.041	0.6609
21.49	173400	0.05758	1.972	0.5527
21.49	172400	0.05786	1.926	0.4565
21.39	172100	0.05811	1.870	0.4154
21.20	171406	0.05833	1.828	0.3044
21.13	170800	0.05861	1.791	0.2075
20.96	169900	0.05903	1.685	0.2049
20.23	163100	0.06430	1.527	0.2286

(continued)

[a] References given in brackets.

TABLE I (Continued)

Lithium Fluoride

eV	cm^{-1}	μm	n	k
19.97	161100	0.06208	1.929	0.3889
19.79	159700	0.06264	2.096	0.3454
19.73	159100	0.06283	2.102	0.3940
19.71	159000	0.06290	2.096	0.4407
19.65	158500	0.06309	2.073	0.3899
19.60	158100	0.06330	2.073	[illegible]
19.54	157600	0.06314	2.050	0.7018
19.48	157100	0.06340	2.004	0.7259
19.44	156800	0.06377	1.953	0.7319
19.37	156200	[illegible]	1.907	[illegible]
19.28	155500	0.06449	1.803	0.4693
19.14	154300	0.06479	1.873	0.3408
19.08	153900	0.06409	1.812	0.2290
18.96	152900	0.06538	1.739	0.2107
18.88	152100	0.06575	1.504	0.1016
18.78	151500	0.06608	1.433	0.1349
18.62	150200	0.06603	1.507	0.0961
18.48	149200	0.06704	1.589	0.0540
18.40	148400	0.06739	1.529	[illegible]
18.33	147900	0.06761	1.573	0.0611
18.32	147732	0.06769	1.402	0.1209
18.31	147764	0.06779	1.487	0.1665
18.26	147400	0.06779	1.459	0.3106
18.20	147300	0.06779	1.406	0.2694
18.16	147100	0.06809	1.417	0.3101
18.00	145200	0.06885	1.367	0.2612
18.05	145600	0.06868	1.368	0.2027
17.98	145300	0.06810	1.372	0.1651
17.90	145000	0.06896	1.334	0.2058
17.73	142900	0.06959	1.472	0.3497
17.61	142500	0.07018	1.457	0.3106
17.63	142200	0.07034	1.474	0.5254
17.57	142900	0.07044	1.488	0.4928
17.58	141500	0.07036	1.498	0.5128
17.58	141487	0.07020	1.908	0.5679
17.43	140600	0.07114	1.627	0.6296
17.29	139300	0.07173	2.208	0.6744
17.22	138900	0.07140	2.346	0.7031
17.21	138800	0.07200	2.241	0.7717
17.21	138800	0.07200	2.241	0.5364
17.20	138800	0.07208	2.776	0.8964
17.14	138200	0.07230	2.105	0.9364
16.98	137000	0.07301	1.859	0.7947
16.96	136800	0.07318	1.863	0.8829
16.88	136200	0.07354	1.880	0.7537
16.72	134800	0.07416	1.739	0.4680
16.63	134100	0.07454	1.689	0.2587

TABLE 3 (Continued)

Barium Fluoride

eV	cm^{-1}	μm	n	k
16.61	134000	0.074464	1.676	0.1981
16.48	132900	0.07523	1.619	0.1369
16.32	131600	0.07599	1.550	0.1405
16.04	129400	0.07729	1.481	0.1046
15.86	127900	0.07820	1.457	0.2023
15.73	126800	0.07884	1.472	0.2521
15.61	125900	0.07940	1.485	0.3047
15.49	124900	0.08003	1.507	0.3531
15.20	122600	0.08157	1.586	0.4248
15.07	121600	0.08225	1.581	0.5121
14.90	120200	0.08317	1.586	0.5955
14.81	119400	0.08376	1.620	0.5974
14.59	117700	0.08498	1.814	0.6452
14.50	116900	0.08550	1.845	0.7004
14.42	116300	0.08600	1.845	0.7457
14.32	115500	0.08721	1.705	0.6855
14.40	116100	0.08656	1.845	0.5621
14.30	115300	0.08725	1.933	0.5057
13.76	111000	0.09013	1.835	0.4075
13.43	108300	0.09298	1.675	0.3273
13.37	107800	0.09314	1.684	0.2959
13.20	107200	0.09329	2.210	0.7253
13.23	106800	0.09358	2.366	0.7724
13.21	106500	0.09398	2.215	0.8299
13.18	106300	0.09410	2.426	0.8461
13.11	105700	0.09490	2.527	1.000
13.09	105500	0.09552	2.443	1.115
12.84	103500	0.09658	2.827	1.057
12.81	103300	0.09678	2.816	0.9259
12.79	103100	0.09699	2.579	0.9291
12.71	102500	0.09755	2.367	0.8061
12.65	102100	0.09799	2.337	0.7929
12.57	101300	0.09867	2.367	0.7258
12.51	100900	0.09908	2.299	0.6593
12.41	100100	0.09987	2.299	0.6061
12.34	99500	0.1005	2.209	0.509
12.23	98700	0.1013	2.166	0.4437
12.15	97900	0.1021	2.096	0.3770
12.05	97210	0.1029	2.033	0.3087
11.99	96720	0.1034	1.982	0.2576
11.96	96510	0.1035	1.926	0.2154
11.88	95800	0.1043	1.982	0.321
11.81	91300	0.1047	1.973	0.1592
11.09	89410	0.1123	1.909	0.2278
10.96	88230	0.1133	1.832	0.2623
10.80	87140	0.1148	1.158	0.2957
10.60	85500	0.1169	2.491	0.4761

(continued)

TABLE I *(Continued)*

Barium Fluoride

eV	cm^{-1}	μm	n	k
10.54	85040	0.1176	2.465	0.3917
10.46	84400	0.1185	2.447	0.4592
10.41	83960	0.1191	2.417	0.5208
10.38	83720	0.1195	2.398	0.5806
10.27	82800	0.1208	2.328	0.6321
10.12	81650	0.1225	2.236	0.5717
10.07	81190	0.1232	2.199	0.5121
10.01	80700	0.1239	2.163	0.4417
9.953	80260	0.1246	2.132	0.3712
9.891	79750	0.1254	2.094	0.3053
9.850	79440	0.1259	2.075	0.2423
9.771	78810	0.1269	2.038	0.1713
9.716	78370	0.1276	2.013	0.1095
9.646	77800	0.1285	1.980	0.06145
9.590	77350	0.1293	1.954	0.01223
9.321	75180	0.1330	1.882 [4]	
9.357	75470	0.1325		9.759E-5 [5]
9.287	74910	0.1335		2.589E-5
9.218	74350	0.1345		7.004E-6
9.214	74320	0.1346	1.873	
9.150	73800	0.1355		1.932E-6
9.137	73690	0.1357	1.857	
9.083	73260	0.1365		5.431E-7
9.017	72730	0.1375		1.555E-7
8.975	72390	0.1381	1.834	
8.952	72200	0.1385		4.535E-8
8.808	71040	0.1408	1.815	
8.697	70150	0.1426	1.800	
8.538	68860	0.1452	1.782	
8.396	67710	0.1477	1.767	
8.099	65320	0.1531	1.741	
8.266	66670	0.15	1.678 [7]	
6.199	50000	0.20	1.557	
4.959	40000	0.25	1.519	
4.133	33330	0.30	1.501	
4.592	37037	0.27	1.51031 [6]	
3.874	31250	0.32	1.49636	
3.350	27027	0.37	1.48821	
2.952	23809	0.42	1.48301	
2.637	21276	0.47	1.47946	
2.384	19230	0.52	1.47691	
2.175	17543	0.57	1.47503	
1.999	16129	0.62	1.47358	
1.850	14925	0.67	1.47245	
1.722	13888	0.72	1.47153	
1.610	12987	0.77	1.47078	
1.512	12195	0.82	1.47016	

TABLE I *(Continued)*

Barium Fluoride

eV	cm^{-1}	μm	n	k
1.425	11494	0.87	1.46963	
1.347	10869	0.92	1.46917	
1.278	10309	0.97	1.46877	
1.215	9803	1.02	1.46842	
1.158	9345	1.07	1.46811	
1.107	8928	1.12	1.46783	
1.059	8547	1.17	1.46757	
1.016	8196	1.22	1.46733	
0.976	7874	1.27	1.46710	
0.939	7575	1.32	1.46689	
0.904	7299	1.37	1.46669	
0.873	7042	1.42	1.46651	
0.843	6802	1.47	1.46632	
0.815	6578	1.52	1.46615	
0.789	6369	1.57	1.46598	
0.765	6172	1.62	1.46581	
0.742	5988	1.67	1.46565	
0.720	5813	1.72	1.46549	
0.700	5649	1.77	1.46533	
0.681	5494	1.82	1.46517	
0.663	5347	1.87	1.46501	
0.645	5208	1.92	1.46485	
0.629	5076	1.97	1.46470	
0.613	4950	2.02	1.46454	
0.598	4830	2.07	1.46438	
0.584	4716	2.12	1.46422	
0.571	4608	2.17	1.46406	
0.558	4504	2.22	1.46390	
0.546	4405	2.27	1.46374	
0.534	4310	2.32	1.46358	
0.523	4219	2.37	1.46341	
0.512	4132	2.42	1.46325	
0.501	4048	2.47	1.46308	
0.492	3968	2.52	1.46291	
0.482	3891	2.57	1.46273	
0.473	3816	2.62	1.46256	
0.464	3745	2.67	1.46238	
0.459	3704	2.70		3.03E-9 [14]
0.455	3676	2.72	1.46220	
0.447	3610	2.77	1.46202	
0.439	3541	2.82	1.46184	
0.432	3484	2.87	1.46165	
0.424	3424	2.92	1.46146	
0.417	3367	2.97	1.46127	
0.410	3311	3.02	1.46107	
0.403	3257	3.07	1.46088	
0.397	3205	3.12	1.46068	

(continued)

TABLE I *(Continued)*

Barium Fluoride

eV	cm^{-1}	μm	n	k
0.391	3154	3.17	1.46047	
0.385	3105	3.22	1.46027	
0.379	3058	3.27	1.46006	
0.373	3012	3.32	1.45985	
0.367	2967	3.37	1.45964	
0.362	2923	3.42	1.45942	
0.357	2881	3.47	1.45920	
0.352	2840	3.52	1.45898	
0.347	2801	3.57	1.45876	
0.342	2762	3.62	1.45853	
0.337	2724	3.67	1.45830	
0.333	2688	3.72	1.45806	
0.328	2652	3.77	1.45783	
0.326	2632	3.80		9.07E-9 [14]
0.324	2617	3.82	1.45759	
0.320	2583	3.87	1.45734	
0.316	2551	3.92	1.45710	
0.312	2518	3.97	1.45685	
0.308	2487	4.02	1.45660	
0.304	2457	4.07	1.45634	
0.300	2427	4.12	1.45608	
0.297	2398	4.17	1.45582	
0.293	2369	4.22	1.45556	
0.290	2341	4.27	1.45529	
0.287	2314	4.32	1.45502	
0.283	2288	4.37	1.45475	
0.280	2262	4.42	1.45447	
0.277	2237	4.47	1.45419	
0.274	2212	4.52	1.45391	
0.271	2188	4.57	1.45362	
0.268	2164	4.62	1.45333	
0.265	2141	4.67	1.45304	
0.262	2118	4.72	1.45274	
0.259	2096	4.77	1.45244	
0.257	2074	4.82	1.45214	
0.254	2053	4.87	1.45183	
0.252	2032	4.92	1.45153	
0.249	2012	4.97	1.45121	
0.246	1992	5.02	1.45090	
0.244	1972	5.07	1.45058	
0.242	1953	5.12	1.45026	
0.239	1934	5.17	1.44993	
0.237	1915	5.22	1.44960	
0.235	1897	5.27	1.44927	
0.233	1879	5.32	1.44893	
0.230	1862	5.37	1.44860	
0.228	1845	5.42	1.44825	

TABLE I *(Continued)*

Barium Fluoride

eV	cm^{-1}	μm	n	k
0.226	1828	5.47	1.44791	
0.224	1811	5.52	1.44756	
0.222	1795	5.57	1.44721	
0.220	1779	5.62	1.44685	
0.218	1763	5.67	1.44649	
0.216	1748	5.72	1.44613	
0.214	1733	5.77	1.44576	
0.213	1718	5.82	1.44540	
0.211	1703	5.87	1.44502	
0.209	1689	5.92	1.44465	
0.207	1675	5.97	1.44427	
0.205	1661	6.02	1.44388	
0.204	1647	6.07	1.44350	
0.202	1633	6.12	1.44311	
0.200	1620	6.17	1.44271	
0.199	1607	6.22	1.44232	
0.197	1594	6.27	1.44192	
0.196	1582	6.32	1.44151	
0.194	1569	6.37	1.44110	
0.193	1557	6.42	1.44069	
0.191	1545	6.47	1.44028	
0.190	1533	6.52	1.43986	
0.188	1522	6.57	1.43944	
0.187	1510	6.62	1.43901	
0.185	1499	6.67	1.43858	
0.184	1488	6.72	1.43815	
0.183	1477	6.77	1.43772	
0.181	1466	6.82	1.43728	
0.180	1455	6.87	1.43683	
0.179	1445	6.92	1.43638	
0.177	1434	6.97	1.43593	
0.176	1424	7.02	1.43548	
0.175	1414	7.07	1.43502	
0.174	1404	7.12	1.43456	
0.172	1394	7.17	1.43409	
0.171	1385	7.22	1.43363	
0.170	1375	7.27	1.43315	
0.169	1366	7.32	1.43268	
0.168	1356	7.37	1.43220	
0.167	1347	7.42	1.43171	
0.165	1338	7.47	1.43122	
0.164	1329	7.52	1.43073	
0.163	1321	7.57	1.43024	
0.162	1312	7.62	1.42974	
0.161	1303	7.67	1.42923	
0.160	1295	7.72	1.42873	
0.159	1287	7.77	1.42822	

(continued)

TABLE I (*Continued*)

Barium Fluoride

eV	cm^{-1}	μm	n	k
0.158	1274	7.85	1.42770	
0.157	1270	7.87	1.42719	
0.156	1263	7.92	1.42660	
0.156	1254	7.97	1.42543	
0.155	1250.0	8.0	1.4259 [7]	1.225E-7 [19]
0.146	1176.5	8.5	1.4204	6.224E-7
0.138	1111.1	9.0	1.4145	1.560E-6
0.131	1052.6	9.5	1.4083	[illegible]
0.124	1000.0	10.0	1.4014	7.404E-6
0.118	952.4	10.5	1.3943	1.430E-5
0.113	909.1	11.0	1.3866	2.731E-5
0.108	869.6	11.5	1.3783	4.305E-5
0.103	833.3	12.0	1.3697	[illegible]
0.100	800.0	12.5	1.3604	0.000151
0.0954	769.2	13.0	1.3506	0.000206
[illegible]	748.7	13.0	1.3402	0.000308
[illegible]	714.3	13.0	1.3292	0.000453
[illegible]	727.2	13.75	1.3040 [19]	0.000400 [19]
[illegible]	704.9	14.19	1.2923	[illegible]
[illegible]	690.0	14.49	1.2821	[illegible]
[illegible]	674.5	14.83	1.2733	[illegible]
[illegible]	663.1	15.08	1.2600	0.00123
[illegible]	[illegible]	15.71	1.2453	0.00177
[illegible]	[illegible]	15.94	1.2377	0.00225
[illegible]	617.8	16.52	1.2328	[illegible]
[illegible]	611.1	16.36	1.2228	0.00380
[illegible]	596.5	16.76	1.2077	0.00441
[illegible]	[illegible]	16.94	1.2028	0.00048
[illegible]	584.1	17.12	1.1938	0.00048
[illegible]	578.1	17.29	1.1847	[illegible]
[illegible]	[illegible]	17.36	1.1767	0.00938
[illegible]	[illegible]	17.73	1.1685	[illegible]
[illegible]	557.2	17.84	1.1580	0.01159
[illegible]	[illegible]	18.09	1.1468	0.01196
[illegible]	546.0	18.34	1.1395	0.01145
[illegible]	531.6	18.81	1.1190	0.01049
[illegible]	526.3	18.99	1.1699	0.01500
[illegible]	518.5	19.40	1.0880	[illegible]
[illegible]	505.7	19.77	1.0582	[illegible]
[illegible]	491.5	20.34	1.0858	[illegible]
[illegible]	[illegible]	20.67	1.0465	0.01131
[illegible]	479.3	20.86	1.0019	0.01275
[illegible]	472.5	21.18	0.9406	0.01300
[illegible]	465.9	21.40	0.8501	[illegible]
[illegible]	457.6	21.85	0.8511	0.02537
[illegible]	451.6	22.14	0.9010	[illegible]
[illegible]	[illegible]	22.38	0.8967	[illegible]

TABLE I (Continued)

Barium Fluoride

eV	cm^{-1}	μm	n	k
0.05543	447.1	22.36	0.8995	0.03795
0.05455	440	22.73	0.8529	0.05806 [19]
0.05331	430	23.26	0.8074	0.0898
0.05207	420	23.81	0.7493	0.0934
0.05083	410	24.39	0.6778	0.1062
0.04959	400	25.00	0.5922	0.1330
0.04835	390	25.64	0.4873	0.1645
0.04711	380	26.32	0.3491	0.2867
0.04587	370	27.03	0.2900	0.4904
0.04463	360	27.78	0.2491	0.5991
0.04339	350	28.57	0.2325	0.7475
0.04215	340	29.41	0.2454	0.8911
0.04091	330	30.30	0.8895	1.020
0.03967	320	31.25	0.2832	1.145
0.03843	310	32.26	0.2225	1.290
0.03719	300	33.33	0.2840	1.266
0.03595	290	34.48	0.3597	1.094
0.03471	280	35.71	0.4044	1.835
0.03347	270	37.04	0.5907	2.049
0.03223	260	38.46	0.6339	2.300
0.03099	250	40.00	0.8233	2.592
0.02975	240	41.67	1.0400	2.568
0.02851	230	43.48	1.139	2.804
0.02727	220	45.45	1.036	2.868
0.02603	210	47.62	1.038	3.504
0.02479	200	50.00	1.536	4.911
0.02355	190	52.63	4.894	6.135
0.02231	180	55.56	0.644	2.025
0.02107	170	58.82	5.158	0.797
0.01983	160	62.50	4.451	0.6051
0.01859	150	66.67	3.587	0.2938
0.01736	140	71.43	2.698	0.1950
0.01611	130	76.92	3.477	0.1449
0.01599	128.94	77.55	3.036 [19]	0.0875 [20]
0.01590	128.23	77.98	2.454	0.0846
0.01576	127.13	78.66	3.477	0.0800
0.01561	125.90	79.43	3.498	0.0731
0.01538	124.07	80.60	3.377	0.0709
0.01519	122.51	81.63	3.356	0.0607
0.01506	121.40	82.37	3.350	0.0546
0.01489	120.13	83.25	3.320	0.0600
0.01446	116.60	85.72	3.273	0.0569
0.01392	112.28	89.06	3.226	0.0512
0.01332	107.46	93.06	3.172	0.0480
0.01269	102.38	97.68	3.123	0.0448
0.01208	97.45	102.6	3.079	0.0426
0.01137	91.80	108.9	3.031	0.0409

(continued)

TABLE I *(Continued)*

Barium Fluoride

eV	cm^{-1}	μm	n	k
0.01063	85.77	116.6	2.991	0.0395
0.01003	80.87	123.6	2.961	0.0385
0.00949	76.53	130.7	2.937	0.0390
0.00877	70.71	141.4	2.909	0.0347
0.00799	64.46	155.1	2.881	0.0326
0.00712	57.45	174.1	2.855	0.0373
0.00643	51.89	192.7	2.837	0.0374
0.00484	39.00	256.4	2.803	0.0272
0.00414	33.40	299.4	2.792	0.0203
0.00330	26.59	376.2	2.781	0.0141
0.00234	18.90	529	2.772	0.0090
0.00155	12.50	800	2.766	0.0108
0.00074	6.00	1666.7	2.763	0.0053
0.0	0	∞	2.713 [13]	0.0

TABLE II

Room-temperature Sellmeier Model Parameters

ith mode		$\Delta\epsilon_i$	λ_i
Malitson model [6]			
	1	0.643356	0.057789
	2	0.506762	0.10968
	3	3.8261	46.3864
Li model [7]			
	1	0.33973	0.0
	2	0.81070	0.10065
	3	0.19652	29.87
	4	4.52469	63.82

TABLE III

Thermo-optical Coefficients of Barium Fluoride

Wavelength (μm)	dn/dT (10^{-6}/K)	Measurement temperature (°C)	Reference
0.3250	−15.6	37	[11]
0.4047	−15.0	15–55	[6]
0.4416	−16.3	37	[11]
0.4579	−15.6	20	[9]
0.5461	−15.2	15–55	[6]
0.6328	−16.0	20	[9]
	−16.7	37	[10, 11]
	−16.4	25–65	[12]
0.6563	−15.2	15–55	[6]
0.7679	−15.5	15–55	[6]
1.15	−16.2	20	[9]
	−17.1	37	[10, 11]
	−16.8	25–65	[12]
3.39	−15.9	20	[9]
	−16.8	37	[10, 11]
	−16.3	25–65	[12]
10.6	−14.5	20	[9]
∞	290	7–47	[13]

TABLE IV

Room-Temperature Classical Oscillator Model Parameters

Mode number i	ν_i (cm^{-1})	$\Delta\epsilon_i$	Γ_i/ν_i	Reference
1	184	4.5	0.020	[18]
2	278	0.07	0.30	
$\epsilon_\infty = 2.16$				
1	188	4.5	0.069	[19]
2	236	0.96	0.21	
3	278	0.015	0.15	
4	328	0.014	0.125	
$\epsilon_\infty = 2.141$				