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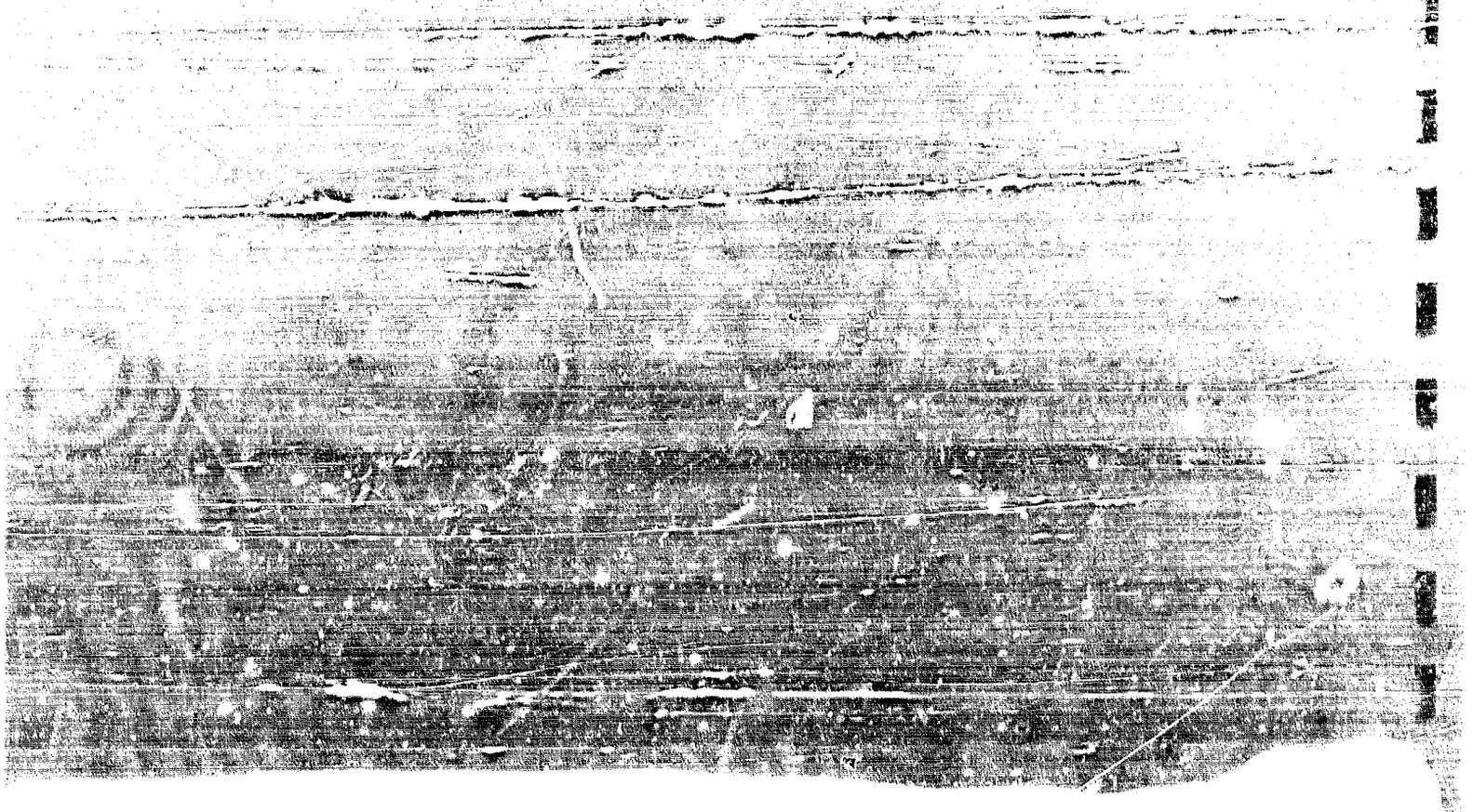
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

COMPENDIUM on High Power Infrared Laser Window Materials (LQ-10 Program)

CHARLES S. SAHAGIAN
CARL A. PITHA

AIR FORCE SYSTEMS COMMAND
United States Air Force



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SOLID STATE SCIENCES LABORATORY PROJECT 5620

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

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Abstract

This COMPENDIUM gathers together and presents in concise outline form much of the essential data on approximately 40 materials which appear to show promise for use as high power infrared laser windows in the 10.6-μm and 3- to 6-μm regions.

The data is presented in two ways: first, all candidate materials are ranked (based on available experimental values) and listed in terms of a particular key window parameter such as optical absorption, hardness, etc.; and second, pertinent data for a given candidate material are collected and presented as a single package, for example for KCl, or for CdTe, etc.

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COMPENDIUM on High Power Infrared Laser Window Materials (LQ-10 Program)

1. INTRODUCTION

1.1 Background and Objectives

Rapid progress made in recent years in the development of extremely high power lasers has uncovered serious limitations in ancillary hardware and components. In particular, the lack of materials suitable for fabrication into large, strong, stable, low absorption exit windows is delaying, and in some cases jeopardizing, the successful development of several militarily-distinctive equipments. This absence of satisfactory window material is especially acute at the 10.6-μm wavelength and is also of considerable concern in the 3- to 6-μm region.

In the early stages of their program to conduct and support selected research efforts for the purpose of identifying, preparing, characterizing, and testing prospective window materials under high power laser conditions (the LQ-10 program), AFCRL personnel attempted to collect and assess experimental results already recorded in this area. A large degree of difficulty was encountered. Required data were found to be sparse or non-existent, and much of what was assembled was judged unreliable. It became apparent that very few measurements had been made over wide enough or well-defined temperature ranges, or at the desired frequencies. For example, the reader will note that most of the photoelastic constants

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are given at visible wavelengths for lack of infrared data. Not surprisingly, many materials were found to be insufficiently characterized with regard to purity, stoichiometry, surface conditions, and so forth. In some cases – again not surprisingly – the sensitivity and accuracy of experimental equipments were too marginal, casting doubt on the results obtained.

In addition to the need for a systematic evaluation of data already in hand, it became obvious that emphasis had to be placed on the acquisition of new and more reliable data from new and improved infrared materials. Also, it was realized that a single collection point for proven and new data would be of value to R&D programs underway or planned in the overall technology of high power infrared laser windows. This document is an initial attempt in this direction.

The COMPENDIUM has three main objectives: first, to serve as a single and complete source of materials information for user scientists and engineers involved in the development and manufacture of laser windows in the 3- to 6-μm and 10.6-μm regions; second, to encourage materials and solid state scientists to conduct reliable measurements on materials so identified; and third, to encourage the search for new and/or improved window materials.

The authors solicit comments on the data contained in the following sections. New or extended information which can correct, complete, replace or otherwise improve the accuracy and thoroughness of the contents herein is earnestly sought and should be brought to the attention of the LQ-10 Program Manager at AFCRL. With the continuing availability of improved materials and measuring equipments, and with a larger number of investigators working in the field of infrared materials, it is expected that more meaningful data can be accumulated in the next few years than have been recorded to date. In this regard, it should be pointed out that a second, updated edition of the COMPENDIUM is envisioned within the year.

Apologies are made beforehand for the use of mixed systems of units. The choice for the dimensions employed in the tables fell in favor of current usage in the field, rather than for a single MKS or other system.

1.2 Glossary of Terms

MOLECULAR WEIGHT – the sum of the atomic weights of all the atoms in a molecule.

STRUCTURE – generally includes: the crystal system (a division based on the fact that all crystalline assemblages can be referred to seven sets of symmetry elements, each set containing one characteristic feature); the lattice parameter (the magnitude and direction of crystallographic axes generally chosen to correspond with the edges of the unit cell, an imaginary parallelepiped of atoms which when translated can reconstruct the pattern of all the atoms in the crystal); the space group (an array of symmetry elements in space which is self-consistent in its symmetry operations).

DENSITY – concentration of matter, measured by the mass per unit volume $\left(\frac{gm}{cm^3}\right)$.

MELTING POINT – the temperature at which the material changes from the solid to the liquid state. This property is very sensitive to the presence of impurities. The unit of measurement is ^{o}K.

BOILING POINT – the temperature at which the vapor pressure in equilibrium with the liquid is 760 mm. The unit of measurement is ^{o}K.

VAPOR PRESSURE – the pressure exerted when a solid or liquid is in equilibrium with its own vapor. The vapor pressure is a function of the substance and of the temperature. The unit of measurement is millimeter.

HARDNESS – the property of materials determined by their ability to abrade or indent one another. Two scales of hardness are used: the Moh scale, which rates materials according to their ability to scratch one another, and the Knoop scale, which is based on the extent to which a pyramidal diamond point is pressed into a material with a known force. This property varies with material orientation. Table 1 lists some representative materials which have had their hardness determined by both the Moh and Knoop methods.

Table 1. Hardness by Moh and Knoop Methods

Material	Moh	Knoop	Material	Moh	Knoop
Gypsum	2	32	Quartz	7	820
Calcite	3	135	Topaz	8	1340
Fluorite	4	163	Titanium Nitride	9	1800
Apatite	5	430	Diamond	10	7000
Orthoclase	6	560			

HEAT CAPACITY – the quantity of heat required to produce a $1^{o}K$ temperature change in a material. The heat capacity at constant pressure, C_p, is greater than that at constant volume, C_v, by the work of expansion in the constant pressure process and the increase in internal energy accompanying the expansion. The units of measurement are cal/mole, ^{o}K.

REFRACTIVE INDEX – the refractive index, n, of a material is the ratio of the velocity of electromagnetic radiation in vacuum, c, to the velocity of the radiation in the material, v, that is, $n = \frac{c}{v}$. As a practical matter, the refractive index is almost universally measured with respect to the velocity of radiation in air.

In effect, what is usually reported is the relative refractive index – the ratio of the refractive index of the material to that of air, hopefully dry. The refractive index of dry air varies with wavelength; it is reported to be 1.00029 at 6.7μm and 1.00039 at 8.7μm.

Cubic crystals are optically isotropic. Single crystals of the tetragonal, hexagonal, or trigonal systems have two principal refractive indices which are designated as the ordinary, n_o, and the extraordinary, n_e.

TEMPERATURE COEFFICIENT OF THE REFRACTIVE INDEX – this property is a measure of the change in refractive index with temperature and will generally have a different value at each wavelength and temperature. In actual practice, the coefficient is ordinarily measured over a range of temperatures for a given wavelength, so that the experimental value is an average over that range. Another limitation of accuracy is that as the temperature is changed during the measurement, the specimen expands or contracts, causing a change in refractive index. Unfortunately, many investigators neglect to mention whether compensation has been made. The unit of measurement is $^{o}K^{-1}$.

ABSORPTION COEFFICIENT – the absorption coefficient, β, of a material is the reciprocal of the length over which the intensity of an incident beam, I_o, falls to 1/e, or 36.8%, of its original value. This term is derived from the Bouguer-Lambert law of absorption

$$\frac{I_x}{I_o} = e^{-\beta x},$$

in which I_x is the intensity of the beam after traversing a specimen of the thickness x. This is an idealized relation which assumes no reflection at the air-crystal interfaces. The unit of measurement is cm^{-1}.

DIELECTRIC CONSTANT – the ratio of the strength of an electric field in a vacuum to that in a specimen for the same distribution of charge. It is a function of both frequency and temperature.

ENERGY GAP – the difference in energy level between the top of the valence band and the bottom of the conduction band. The unit of measurement is eV

DEBYE TEMPERATURE – defined by the equation

$$\theta_D = \frac{h\nu_m}{k},$$

where h = Planck's constant, k = Boltzmann's constant, and ν_m = maximum frequency of the lattice vibrations. The unit of measurement is ^oK.

THERMAL CONDUCTIVITY – the amount of heat conducted per sec across 1 square cm of the specimen when the temperature gradient along the specimen is 1^oK per cm. The units of measurement are cal/sec, ^oK.

LINEAR COEFFICIENT OF THERMAL EXPANSION – a measure of the fractional change in length per degree Kelvin change in temperature:

$$\alpha = \frac{1}{l_T}\frac{dl}{dT},$$

where l_T = length of specimen at temperature T. What is most commonly reported as α is the mean coefficient of expansion,

$$\bar{\alpha} = \frac{1}{l_o}\frac{\Delta l}{\Delta T},$$

since a significant temperature change is necessary in most measuring methods. The unit of measurement is $^oK^{-1}$.

ELASTIC MODULI - the elastic moduli, s_{ij}, sometimes called elastic compliance constants, are the proportionality constants in the generalized Hooke's Law equations relating the stress components (X_x, Y_y, ... X_y) to the strain components (x_x, y_y, ... x_y).

$$\begin{bmatrix} x_x \\ y_y \\ y_z \\ y_z \\ z_x \\ x_y \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} & s_{13} & s_{14} & s_{15} & s_{16} \\ s_{21} & s_{22} & s_{23} & s_{24} & s_{25} & s_{26} \\ s_{31} & s_{32} & s_{33} & s_{34} & s_{35} & s_{36} \\ s_{41} & s_{42} & s_{43} & s_{44} & s_{45} & s_{46} \\ s_{51} & s_{52} & s_{53} & s_{54} & s_{55} & s_{56} \\ s_{61} & s_{62} & s_{63} & s_{64} & s_{65} & s_{66} \end{bmatrix} \begin{bmatrix} X_x \\ Y_y \\ Z_z \\ Y_z \\ Z_x \\ X_y \end{bmatrix}.$$

The units of measurement are cm^2/dyne.

For cubic materials, these moduli are related to other well-known constants as follows:

Young's Modulus, $E = 1/s_{11}$

Poisson's Ratio, $\sigma = -s_{12}/s_{11}$

Rigidity or Shear Modulus, $\mu = 1/s_{44}$

Compressibility $= -3(s_{11} + 2s_{12})$

Elastic Constants, $c_{ij} =$

$c_{11} = (s_{11} + s_{12})/(s_{11} - s_{12})(s_{11} + 2s_{12})$

$c_{12} = -s_{12}/(s_{11} - s_{12})(s_{11} + 2s_{12})$

$c_{44} = 1/s_{44}$.

ELASTIC CONSTANTS – the elastic constants, c_{ij} (also called elastic coefficients and elastic stiffness constants) are proportionality constants in the generalized Hooke's Law equations relating strain components (x_x, y_y, --- x_y) to stress components (X_x, Y_y, ---- X_y).

$$\begin{bmatrix} X_x \\ Y_y \\ Z_z \\ Y_y \\ Z_z \\ X_y \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} & c_{15} & c_{16} \\ c_{21} & c_{22} & c_{23} & c_{24} & c_{25} & c_{26} \\ c_{31} & c_{32} & c_{33} & c_{34} & c_{35} & c_{36} \\ c_{41} & c_{42} & c_{43} & c_{44} & c_{45} & c_{46} \\ c_{51} & c_{52} & c_{53} & c_{54} & c_{55} & c_{56} \\ c_{61} & c_{62} & c_{63} & c_{64} & c_{65} & c_{66} \end{bmatrix} \begin{bmatrix} x_x \\ y_y \\ z_z \\ y_z \\ z_x \\ x_y \end{bmatrix} .$$

The units of measurement are dyne/cm^2.

For cubic materials, these constants are related to other well-known constants as follows:

Young's Modulus, $E = (c_{11} + 2c_{12})(c_{11} - c_{12})/(c_{11} + c_{12})$

Poisson's Ratio, $\sigma = c_{12}/(c_{11} + c_{12})$

Rigidity or Shear Modulus, $\mu = c_{44}$

Bulk Modulus = $(c_{11} + 2c_{12})/3$.

APPARENT ELASTIC LIMIT – an arbitrarily chosen limit taken from the stress-strain curve of a material. A commonly accepted limit occurs when the slope of the stress-strain curve is half the slope at the origin. The units of measurement are dyne/cm^2.

MODULUS OF RUPTURE – nominal stress at fracture in a bend or torsion test. In bending, the modulus of rupture is the bending moment at fracture divided by the section modulus. In torsion, modulus of rupture is the torque of fracture divided by the polar section modulus. The units of measurement are dyne/cm^2.

STRESS-OPTIC CONSTANTS – the stress-optic constants, p_{ij} are coefficients relating strain components (x_x, y_y --- x_y) to changes in refractive index according to the following relationships:

$$\frac{2}{n_{ij}^3}\begin{bmatrix} n_{11} - v_{11} \\ n_{22} - v_{22} \\ n_{33} - v_{33} \\ n_{23} - v_{23} \\ n_{31} - v_{31} \\ n_{12} - v_{12} \end{bmatrix} \cong \begin{bmatrix} 1/v_{11}^2 - 1/n_{11}^2 \\ 1/v_{22}^2 - 1/n_{22}^2 \\ 1/v_{33}^2 - 1/n_{33}^2 \\ 1/v_{23}^2 - 1/n_{23}^2 \\ 1/v_{31}^2 - 1/n_{31}^2 \\ 1/v_{12}^2 - 1/n_{12}^2 \end{bmatrix} = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} & p_{15} & p_{16} \\ p_{21} & p_{22} & p_{23} & p_{24} & p_{25} & p_{26} \\ p_{31} & p_{32} & p_{33} & p_{34} & p_{35} & p_{36} \\ p_{41} & p_{42} & p_{43} & p_{44} & p_{45} & p_{46} \\ p_{51} & p_{52} & p_{53} & p_{54} & p_{55} & p_{56} \\ p_{61} & p_{62} & p_{63} & p_{64} & p_{65} & p_{66} \end{bmatrix} \begin{bmatrix} x_x \\ y_y \\ z_z \\ y_z \\ z_x \\ x_y \end{bmatrix}.$$

In these equations, n_{ij}, is the refractive index of the unstrained crystal, while v_{ij} is that of the strained crystal.

PIEZO-OPTIC CONSTANTS – piezo-optic constants, q_{ij}, are coefficients relating stress components (X_x, Y_y --- X_y) to changes in refractive index:

$$\frac{2}{n_{ij}^3}\begin{bmatrix} n_{11}-v_{11} \\ n_{22}-v_{22} \\ n_{33}-v_{33} \\ n_{23}-v_{23} \\ n_{31}-v_{31} \\ n_{12}-v_{12} \end{bmatrix} \cong \begin{bmatrix} 1/v_{11}^2 - 1/n_{11}^2 \\ 1/v_{22}^2 - 1/n_{22}^2 \\ 1/v_{33}^2 - 1/n_{33}^2 \\ 1/v_{23}^2 - 1/n_{23}^2 \\ 1/v_{31}^2 - 1/n_{31}^2 \\ 1/v_{12}^2 - 1/n_{12}^2 \end{bmatrix} = \begin{bmatrix} q_{11} & q_{12} & q_{13} & q_{14} & q_{15} & q_{16} \\ q_{21} & q_{22} & q_{23} & q_{24} & q_{25} & q_{26} \\ q_{31} & q_{32} & q_{33} & q_{34} & q_{35} & q_{36} \\ q_{41} & q_{42} & q_{43} & q_{44} & q_{45} & q_{46} \\ q_{51} & q_{52} & q_{53} & q_{54} & q_{55} & q_{56} \\ q_{61} & q_{62} & q_{63} & q_{64} & q_{65} & q_{66} \end{bmatrix} \begin{bmatrix} X_x \\ Y_y \\ Z_z \\ Y_z \\ Z_x \\ X_y \end{bmatrix}.$$

The elasto-optic and piezo-optic constants are related as follows:

$$p_{ij} = \sum_{k=1}^{6} q_{ik}\, c_{kj}$$

$$q_{ij} = \sum_{k=1}^{6} p_{ik}\, s_{kj}.$$

2. DATA BY MATERIAL PARAMETERS

This section presents data as a function of several material parameters expected to be of use to developmental scientists and engineers. For additional information about a particular material, reference should be made to the more detailed sections which follow. Also, prime references for the data listed are generally given in the following sections.

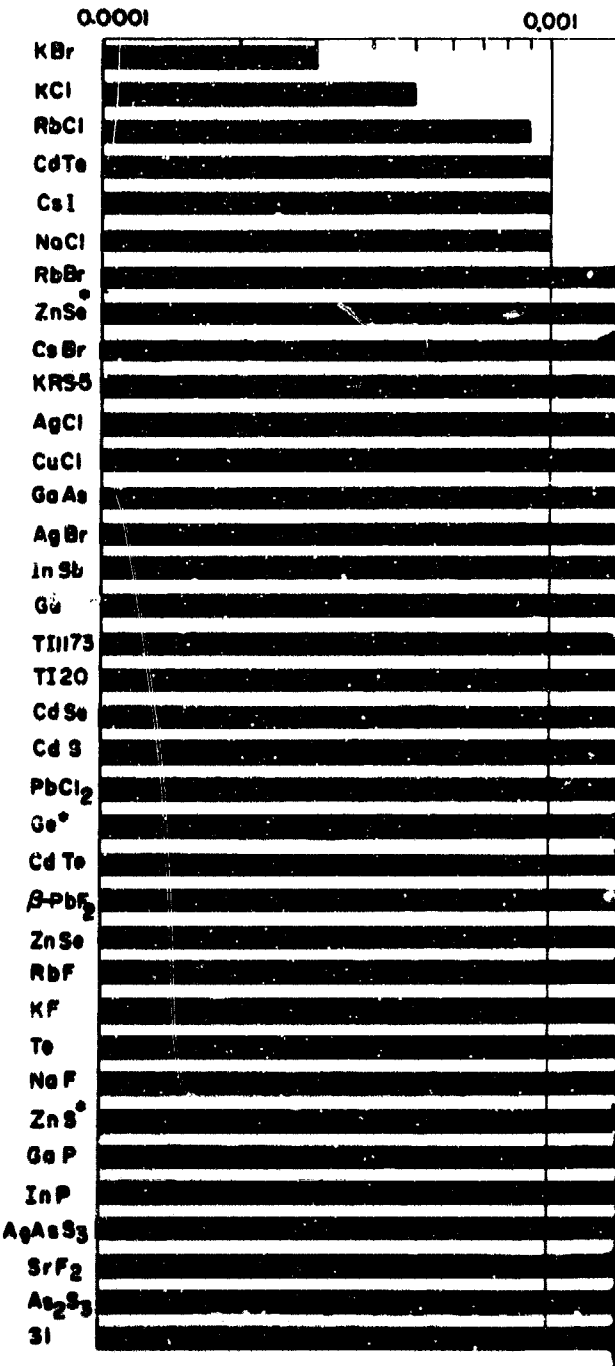
While data on over 200 different materials were collected and evaluated over the past months, only about 40 materials were finally selected as prospective high power infrared laser window materials and are the ones listed in the following tables, figures, and charts. One major criterion was used in this selection, namely, the requirement that the material display, through laboratory tests, an optical absorption coefficient of 1 cm^{-1} or less at the particular wavelength. Materials whose coefficients are in excess of this arbitrary (but rather high) level are not expected to become candidate window materials – even with eventual material quality improvement – and are not included in the COMPENDIUM.

2.1 Optical Absorption Coefficient

Table 2. Optical Absorption Coefficients, β at $\sim 10\mu m$

Material	$\beta(cm^{-1})$	Material	$\beta(cm^{-1})$
KBr	0.0003	CdSe	0.03
KCl	0.0005	CdS	0.03
RbCl	0.0009	$PbCl_2$	0.04
CdTe	0.001	Ge*	0.06
CsI	0.001	CdTe*	0.08
NaCl	0.001	β -PbF_2	0.1
RbBr	0.002	ZnSe	0.1
ZnSe*	0.004	RbF	0.1
CsBr	0.004	KF	0.2
KRS-5	0.005	Te	0.3
AgCl	0.005	NaF	0.4
CuCl	0.006	ZnS*	0.4
GaAs	0.006	GaP	0.4
AgBr	0.007	InP	0.5
InSb	0.009	Ag_3AsS_3	0.5
Ge	0.02	SrF_2	0.6
TI # 1173	0.02	Ag_2S_3	0.7
TI # 20	0.03	Si	1.0

*Polycrystal


0.0001
0.001
KBr
KCl
RbCl
CdTe
CsI
NaCl
RbBr
ZnSe*
CsBr
KRS-5
AgCl
CuCl
GaAs
AgBr
InSb
Ge
TlI175
TI2O
CdSe
CdS
PbCl2
Ge*
CdTe
β-PbF2
ZnSe
RbF
KF
Te
NaF
ZnS*
GaP
InP
AgAsS3
SrF2
As2S3
SI

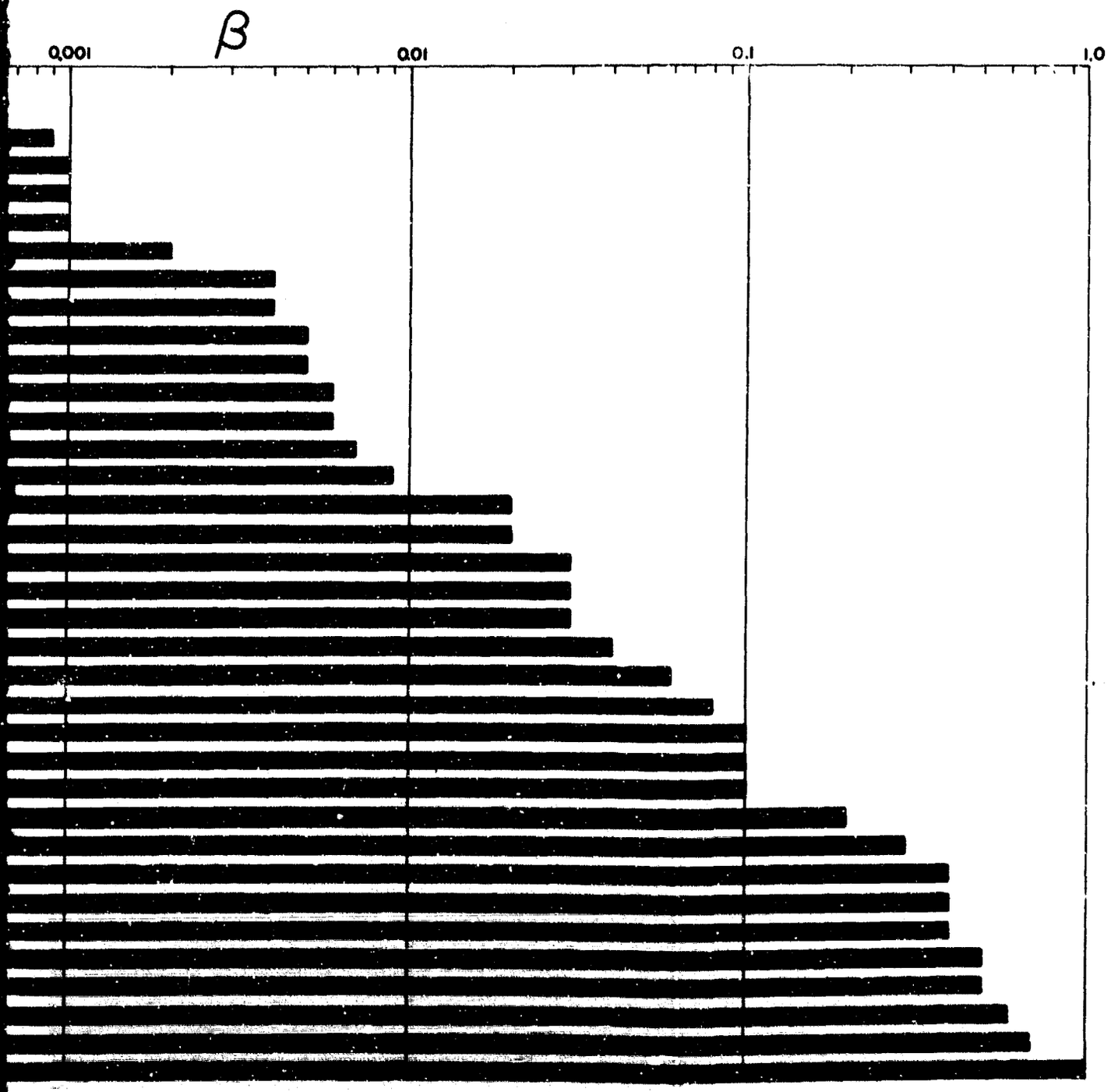
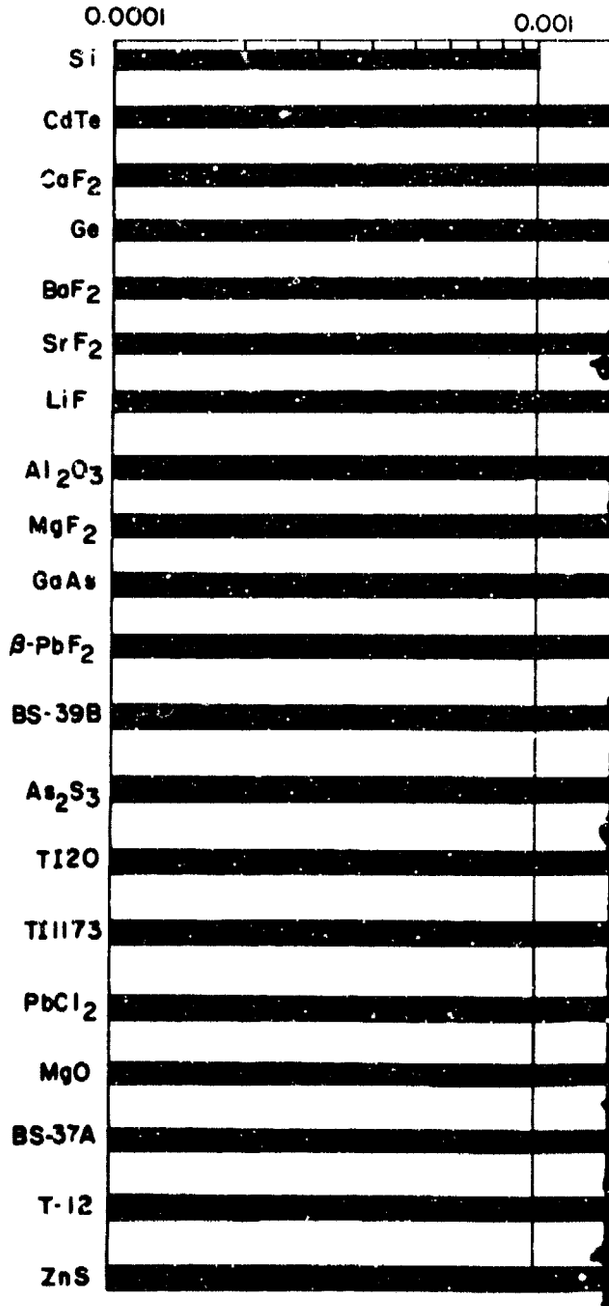


Figure 1. Optical Absorption Coefficient, β at 10 μm

Table 3. Optical Absorption Coefficients, β at $\sim 3\mu$m

Material	β (cm^{-1})	Material	β (cm^{-1})
Si	0.001	β-PbF_2	0.02
CdTe	0.002	BS-39B	0.02
CaF_2	0.003	As_2S_3	0.03
Ge	0.003	TI # 20	0.03
BaF_2	0.003	TI # 1173	0.03
SrF_2	0.003	$PbCl_2$	0.03
LiF	0.003	MgO	0.05
Al_2O_3	0.003	BS-37A	0.05
MgF_2	0.005	T-12	0.1
GaAs	0.009	β-ZnS	0.4


0.0001
0.001
Si
CdTe
CaF_2
Ge
BaF_2
SrF_2
LiF
Al_2O_3
MgF_2
GaAs
β-PbF_2
BS-39B
As_2S_3
TI20
TI1173
$PbCl_2$
MgO
BS-37A
T-12
ZnS

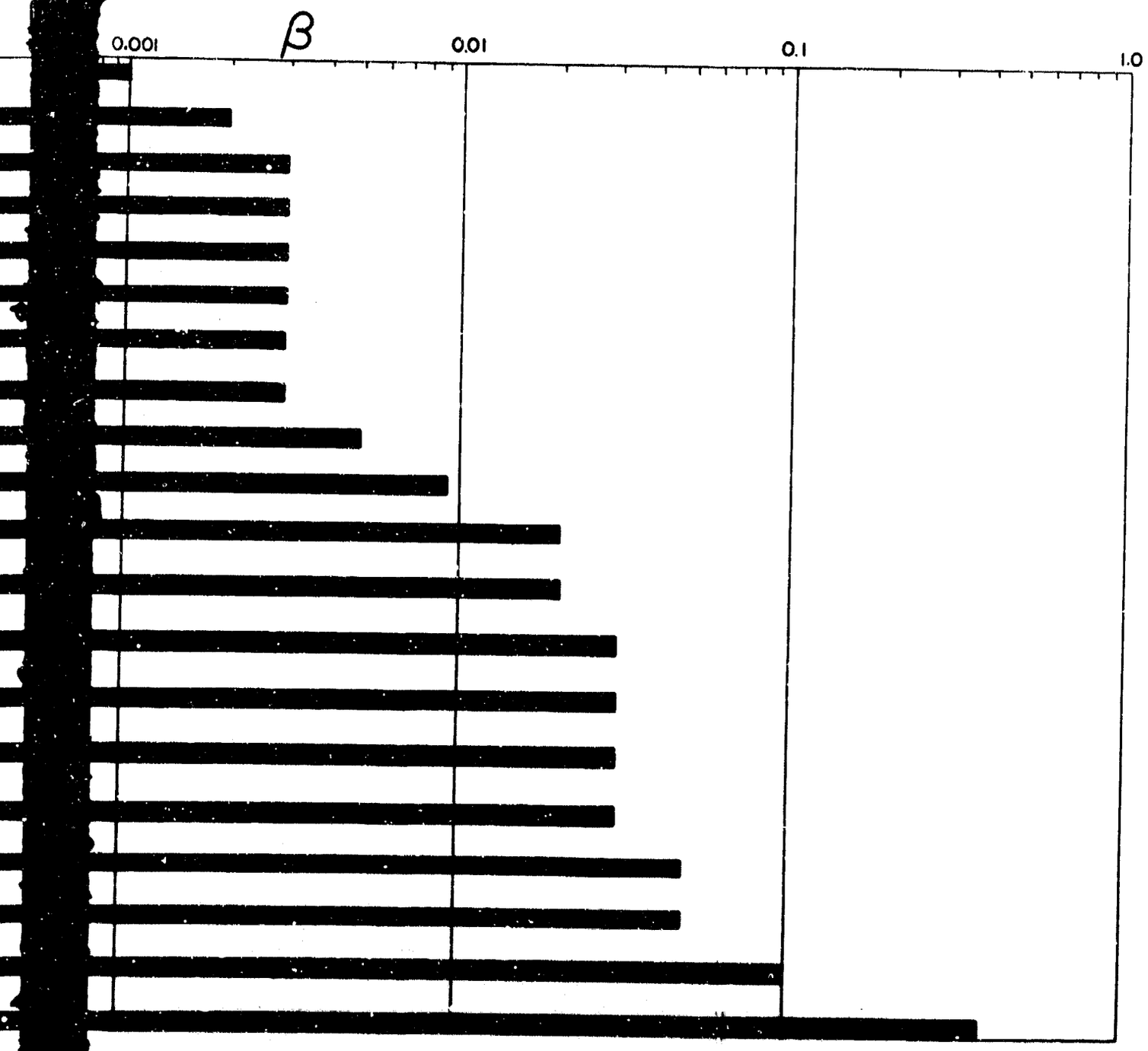


Figure 2. Optical Absorption Coefficient, β at 3 μm

2.2 Temperature Coefficient of Refractive Index

Table 4. Temperature Coefficient of Refractive Index $\frac{dn}{dT}$ at $\sim 10\mu m$

Material	$\frac{dn}{dT} \times 10^{-5}/^{o}K$	Material	$\frac{dn}{dT} \times 10^{-5}/^{o}K$
CsI	-9.17	InP	+ 8.2
CsBr	-6.3	GaP	+10.0
CaF_2	-5.6	CdTe	+11.75
KCl	-2.75	Si	+16.2
KBr	-2.6	GaAs	+18.7
NaCl	-2.52	Ge	+26.8
NaF	-0.7	InSb	+63.2
TI # 1173	+7.9		

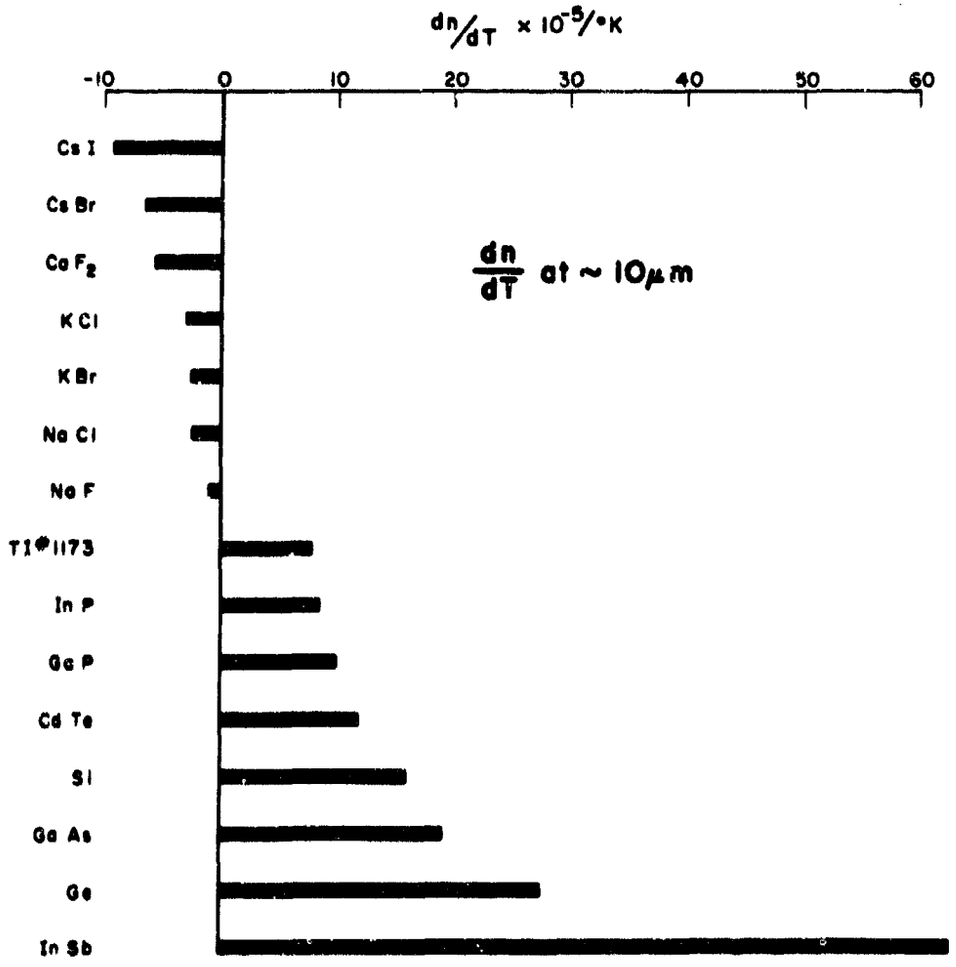


Figure 3. Temperature Coefficient of Refractive Index $\frac{dn}{dT}$ at ~ 10μ m

Table 5. Temperature Coefficient of Refractive Index, $\frac{dn}{dT}$, at $\sim 3\mu m$

Material	$\frac{dn}{dT} \times 10^{-5}/^{o}K$	Material	$\frac{dn}{dT} \times 10^{-5}/^{o}K$
CsI	-9.54	Al_2O_3	1.0
CsBr	-6.3		
KBr	-4.0	MgO	1.89
KCl	-3.2	As_2S_3	2.0
NaCl	-2.5 to -3.3	Si	3.9
BaF_2	-1.7	ZnSe	4.8
LiF	-1.6	CdTe	10.7
NaF	-1.6	GaAs	14.9
SrF_2	-1.2	Ge	27.7
CaF_2	-0.6 to 1.15		

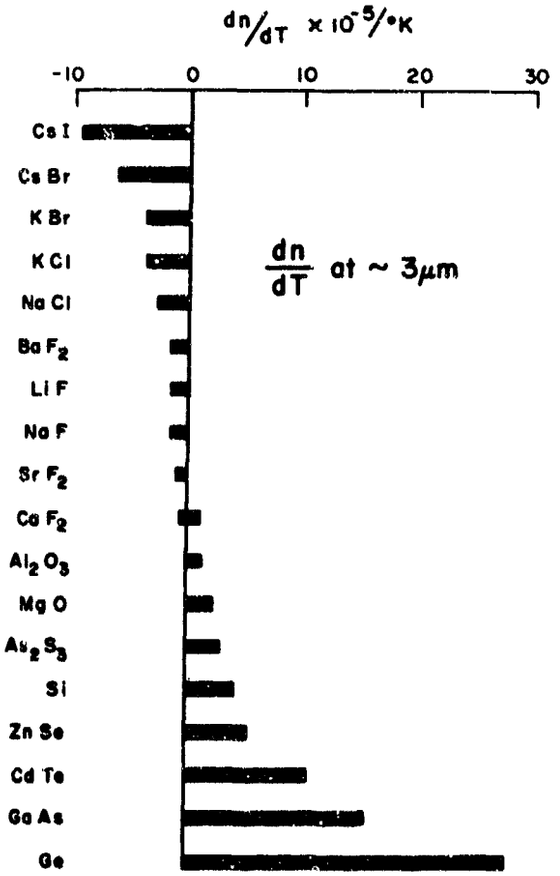


Figure 4. Temperature Coefficient of Refractive Index $\frac{dn}{dT}$ at $\sim 3\mu m$

2.3 Thermal Conductivity

Table 6. Thermal Conductivity of IR Materials, κ

Material	$\kappa \times 10^{-4}$ cal/cm, sec, ^{o}K	Material	$\kappa \times 10^{-4}$ cal/cm, sec, ^{o}K
Si	2590	NaCl	220
InP	1673	CaF_2*	190
MgO	1435	KF	170
Ge	1400	CdTe	167
GaAs	1147	Te	150
MgO*	1040	KBr	115
InSb	850	CdTe*	98
β-ZnS	633	KI	74
Al_2O_3	550 $\perp$c, 600 $\parallel$c	RbCl	50
CdS	478	RbBr	50
ZnS*	370	AgBr	29
MgF_2	360	AgCl	28
MgF_2*	350	CsI	27
ZnSe	335	CsBr	23
ZnSe*	310	KRS-5	13
BaF_2	287	As_2S_3	9
LiF	270	TI # 1173	7
GaP	263	TI # 20	6
SrF_2	239	As_2Se_3	1
CaF_2	237	BS-37A	0.1
NaF	220	BS-39B	0.1
KCl	220		

*Polycrystal

2.4 Linear Thermal Expansion Coefficient

Table 7. Linear Thermal Expansion Coefficient, α, for IR Materials

Material	$\alpha \times 10^{-6}/^{o}K$	Material	$\alpha \times 10^{-6}/^{o}K$
GaP	3.5 - 5.8	SrF_2	15.8 - 23.5
CdS	4$\perp$, 2.1$\parallel$	Te	16.7
Si	4.2	BaF_2	18.4 - 20.3
CdTe	4.5 - 6.2	MgF_2	18.8$\parallel$, 13.1$\perp$
InSb	4.8	CaF_2	19.7 - 24
CdTe*	5.5 - 5.9	CaF_2*	19.7 - 24
Ge	5.5 - 6.1	T - 12	21
GaAs	5.7	As_2Se_3	22
Ge*	6.1	As_2S_3	22.4 - 24.6
β-ZnS	6.1	AgCl	30 - 31
β-ZnS	6.2$\parallel$, 6$\perp$	β-PbF_2	30.5
ZnS*	6.6 - 7.5	LiF	32.3 - 37
Al_2O_3	6.7$\parallel$, 5.0$\perp$	AgBr	34.9
ZnSe	7-8.2	KCl	36
ZnSe*	7.5 - 8.2	NaF	32 - 36
ZnTe	8	NaBr	37 - 42
BS-37A	9.3	KI	30 - 43
BS-39B	9.7	KBr	36 - 43
MgO	9.8 - 13.8	NaCl	36 - 44
MgF_2*	10.6 - 12.0	NaI	41 - 47
MgO*	11.5 - 12.8	CsBr	47.9
TI # 20	13.3	CsI	48 - 50
TI # 1173	15	KRS-5	58

*Polycrystal

2.5 Specific Heat

Table 8. Specific Heat of IR Materials, $J/cm^3, {}^oK$

InSb	10.2	AgBr	1.9
KI	9.83	NaCl	1.84
LiF	4.1	Ge	1.65
CdS	3.83	Si	1.6
GaP	3.49	As_2S_3	1.46
MgO	3.13	GaAs	1.42
MgO*	3.13	KCl	1.35
NaF	3.04	TI # 1173	1.32
Al_2O_3	3.0	CdTe	1.3
MgF_2*	2.93	TI # 20	1.29
CaF_2*	2.71	KBr	1.20
CaF_2	2.7	MgF_2	1.19
BS-39B	2.68	CsBr	1.17
SrF_2	2.54	As_2Se_3	1.17
BS-37B	2.46	CsI	0.91
T-12	2.37	BaF_2	0.40
ZnS*	1.99	ZnSe	0.38
AgCl	1.98	β-ZnS	0.2

*Polycrystal

2.6 Hardness

Table 9. Hardness of IR Materials (Knoop)

Al_2O_3	1370	ZnSe	135-150
Si	1150	SrF_2	130
GaP	780-945	CaF_2	120-163
GaAs	750	CdS	122
Ge	700-880	CdSe	117$\parallel$, 53$\perp$
Ge*	692	As_2S_3	109
MgO	692	LiF	102-113
MgO*	640	BaF_2	65-82
MgF_2*	576	NaF	60
InP	535	CdTe	45
MgF_2	415	CdTe*	45
ZnS*	325-354	KRS-5	40
InSb	223	CsBr	20
CaF_2*	200	NaCl	18
β -PbF_2	200	AgCl	9.5
α -ZnS	178	KCl	9.3
TI # 20	171	AgBr	7
TI # 1173	150	KBr	7
ZnSe*	150		

*Polycrystal

2.7 Young's Modulus

Table 10. Young's Modulus, E, for IR Materials

Material	E($\times 10^6$ psi)	Material	E($\times 10^6$ psi)
MgO	51 <111>	InSb	10.77 <111>
Al_2O_3	50	ZnSe	10.3
MgO*	47.8 - 48.2	ZnSe*	10.0
BS-39B	20.1	β-ZnS	9.6
Si	19	LiF	9.3
MgF_2	16.6 - 24.5	KCl	7.2 (110)
MgF_2*	16.0 - 16.6	CdS	6.5
BS-37A	15.5	NaCl	5.8
Ge	15	CdTe	5.3
SrF_2	14.5	CdTe*	5.3
CaF_2*	14.2 - 21.0	KBr	3.9
ZnS*	14	AgBr	3.2 - 4.6
α-ZnS	14	TI # 1173	0.64 - 13.1
TI # 20	13	AgCl	2.9
GaAs	12	KRS-5	2.3
T-12	11.5	As_2S_3	2.3
CaF_2	10.9 - 17.5	CsBr	2.3
β-PbF_2	11	CsI	0.8

*Polycrystal

2.8 Melting or Softening Point of IR Materials

Table 11. Melting or Softening Point of IR Materials

Material	°K	Material	°K
MgO	2800	RbF	775
Al_2O_3	2030	KBr	730
α-ZnS	1850	RbCl	715
CdS	1550	BS-39B	700
ZnSe	1525	RbBr	682
Si	1420	NaI	651
CaF_2	1360	CsBr	636
GaP	1350	CsI	621
GaAs	1280	InSb	525
BaF_2	1280	$PbCl_2$	501
MgF_2	1260	Ag_3AsS_3	480
β-ZnS	1188	AgCl	455
CdTe	1098	SrF_2	450
T-12	1060	Te	450
InP	1055	CuCl	430
NaF	990	AgBr	430
Ge	936	KRS-5	415
KF	880	TI # 1173	370
LiF	870	TI # 20	340
β-PbF_2	855	As_2S_3	210
NaCl	800	As_2Se_3	200
KCl	776		

3. DATA BY MATERIAL

This section presents data by material, arbitrarily organized into one of 4 categories, namely the halides, pnictides, chalcogenides, and glasses, elements, other compounds.

A materials locator has been devised on the next page which will facilitate the location of each particular material

3.1 Halides (I-VII's, II-VII's, etc.)

- Lithium Fluoride
- Sodium Fluoride
- Sodium Chloride
- Potassium Fluoride
- Potassium Chloride
- Potassium Bromide
- Rubidium Fluoride
- Rubidium Chloride
- Rubidium Bromide
- Cesium Bromide
- Cesium Iodide
- Silver Chloride
- Silver Bromide
- Cuprous Chloride
- Calcium Fluoride
- Strontium Fluoride
- Barium Fluoride
- Magnesium Fluoride
- β-Lead Fluoride

3.2 Pnictides (III-V's, etc.)

- Indium Phosphide
- Indium Antimonide
- Gallium Phosphide
- Gallium Arsenide

3.3 Chalcogenides (II-VI's, etc.)

- Zinc Sulfide
- Zinc Selenide
- Cadmium Sulfide
- Cadmium Selenide
- Cadmium Telluride
- Arsenic Trisulfide
- Silver Thioarsenate

3.4 Glasses, Elements, and Other Compounds

- Germanium
- Silicon
- Tellurium
- Aluminum Oxide
- Magnesium Oxide
- TI # 1173
- TI #20
- KRS-5
- BS-37A
- BS-39B
- T-12

Lithium Fluoride

LiF 26

MOLECULAR WEIGHT: 25.94

STRUCTURE: Cubic, NaCl type, space group Fm3m, a_o = 4.0270 Å

DENSITY: 2.638 gm/cm.^{3} at 293°K (x-ray)

MELTING POINT: 1143°K

BOILING POINT: 1950°K

VAPOR PRESSURE: 1mm at 1320°K

HARDNESS: 102 (Knoop)

DIELECTRIC CONSTANT: ϵ_o = 9.23, ϵ_∞ = 1.90 at 420°K

ENERGY GAP: 12.9 eV

OPTICAL PROPERTIES

Refractive Index: $T = 296.6^{\circ}K$

λ (μm)	n	$\frac{dn}{dT}$ ($^{\circ}K^{-1}$)	λ (μm)	n
3.00	1.36660		4.60	1.33645
3.20	1.36359		4.80	1.33165
3.40	1.36037		5.00	1.32661
3.60	1.35693	16×10^{-6}	5.20	1.32131
3.80	1.35329		5.40	1.31575
4.00	1.34942		5.60	1.30993
4.20	1.34535		5.80	1.30384
4.40	1.34100		6.00	1.29745

Absorption Coefficient: 0.003/cm at 2.8 μm; 0.006/cm at 4.4 μm; 0.09/cm at 5.1 μm

HEAT CAPACITY:

$T(^{o}K)$	=	89.1	112.1	132.9	149.1	169.6	188.9	210.9	232.0	248.5	271.7
C_p (cal/mole, ^{o}K)	=	2.394	3.816	5.024	5.852	6.762	7.534	8.158	8.716	9.074	9.538

DEBYE TEMPERATURE: $737 \pm 9^{o}K$

THERMAL CONDUCTIVITY: 190 to 350 $\times 10^{-4}$ cal/cm, sec, ^{o}K at $314^{o}K$

LINEAR THERMAL EXPANSION COEFFICIENT:

$\Delta T(^{o}K)$	=	90 - 78	113 - 90	133 - 113	153 - 133	173 - 153	193 - 173	213 - 193	233 - 213
$\alpha(\times 10^{-6}/^{o}K)$	=	5.98	10.44	14.90	18.51	21.45	24.15	26.42	28.34

ΔT	=	253 - 233	273 - 253	303	345	423	460
α	=	29.93	31.40	34.1	35.9	39.1	41.0

ELASTICITY

Apparent Elastic Limit: 10.9 to 25.1 $\times 10^{7}$ dynes/cm^{2}

Modulus of Rupture: 14.1 to 36.1 $\times 10^{7}$ dynes/cm^{2}

Elastic Moduli: ($\times 10^{-13}$ cm^{2}/dyne)

T(°K)	s_{11}	$-s_{12}$	s_{44}
292	11.8	3.5	15.7
373	12.9	3.8	16.2
423	13.5	3.9	16.4
473	14.4	4.2	16.8

PHOTOELASTICITY

Stress-Optic Constants: ($\times 10^{13}$ cgs)

T(°K)	$q_{11}-q_{12}$	q_{44}
293	-1.42	-0.76
373	-1.47	-0.81
423	-1.51	-0.84
473	-1.60	-0.86

Strain-Optic Constants:

p_{11} = 0.02 to 0.016

p_{12} = 0.108 to 0.130 at 5893 Å

p_{44} = -0.045 to -0.064

Sodium Fluoride

MOLECULAR WEIGHT: 41.99

STRUCTURE: Cubic, NaCl type, space group Fm3m, a_o = 4.64 Å

DENSITY: 2.809 gm/cm^3 at 293°K

MELTING POINT: 1264°K

BOILING POINT: 1963°K

VAPOR PRESSURE: 1mm at 1350°K

HARDNESS: 6 (Knoop)

DIELECTRIC CONSTANT: $\epsilon_{\omega 0}$ = 1.7 ϵ_{ω} = 5.1

ENERGY GAP: 10.5 eV

OPTICAL PROPERTIES

Refractive Index: $T = 291^{\circ}K$

$\lambda(\mu m)$	n	$\frac{dn}{dT}(^{\circ}K^{-1})$	$\lambda(\mu m)$	n	$\frac{dn}{dT}(^{\circ}K^{-1})$
3.10	1.3135		8.50		-0.7×10^{-5}
3.30	1.3123		9.10	1.2552	
3.50	1.3115	-1.6×10^{-5}	9.30	1.2520	
3.70	1.3099		9.50	1.2486	
3.90	1.3091		9.70	1.2453	
4.10	1.3080		9.90	1.2418	
4.50	1.3055		10.10	1.2382	
4.70	1.3039		10.30	1.2346	
4.90	1.3025		10.50	1.2309	
5.10	1.3010		10.70	1.2273	
5.30	1.2994		10.90	1.2231	
5.50	1.2978		11.26	1.211	
5.70	1.2957		11.74	1.200	
5.90	1.2940				

Absorption Coefficient: 0.77/cm at $10.50\mu m$

HEAT CAPACITY:

$T(^{\circ}K)$ =	80	100	120	140	160	180	200	220	240	260	280	300
C_p (cal/mole, $^{\circ}K$) =	3.868	5.455	6.785	7.840	8.675	9.295	9.755	10.14	10.47	10.75	10.99	11.22

DEBYE TEMPERATURE: $438 \pm 12^{\circ}K$

THERMAL CONDUCTIVITY: ($\times 10^{-3}$ cal/cm, sec, $^{\circ}K$,

22.0 at $298^{\circ}K$; 25.1 at $273^{\circ}K$

LINEAR THERMAL EXPANSION COEFFICIENT:

$T(^{\circ}K)$ =	100	140	180	209	240	260	270	303	345	389	468
α ($\times 10^{-6}/^{\circ}K$) =	14.32	21.30	25.80	27.44	29.78	30.81	31.35	32.2	33.1	34.2	35.9

ELASTICITY

Elastic Moduli (Adiabatic): ($\times 10^{-10}$ cm^2/dyne)

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Moduli (Adiabatic): ($\times 10^{-13}$ cm^2/dyne)

T(°K)	s_{11}	$-s_{12}$	s_{44}
293	11.45	2.0	35.35
323	11.67	2.1	35.62
373	12.04	2.1	36.08
423	12.42	2.2	36.56
473	12.84	2.3	37.02

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T(°K)	c_{11}	c_{12}	c_{44}
80	0.71	2.312	2.897
260	9.862	2.428	2.819
270	9.807	2.436	2.813
280	9.749	2.444	2.807
290	9.690	2.452	2.801
300	9.630	2.459	2.794

PHOTOELASTICITY:

Sodium Chloride

NaCl

MOLECULAR WEIGHT: 58.44

STRUCTURE: Cubic, NaCl type, space group Fm3m, a_o = 5.6402 Å

DENSITY:

$T(^oK)$ =	273	298	323	343
$d(gm/cm^3)$ =	2.1605	2.1615	2.1559	2.1521

MELTING POINT: 1076°K

BOILING POINT: 1686°K

VAPOR PRESSURE: 1mm at 1138°K

HARDNESS: 18 (Knoop)

DIELECTRIC CONSTANT: 5.6 to 6.3 at 1.6×10^6 Hz
6.12 at 10^4 Hz
5.62 at 2.5×10^5 Hz

ENERGY GAP: 8.6 eV

OPTICAL PROPERTIES

Refractive Index: $T = 293^{\circ}K$

$\lambda(\mu m)$	n	$\frac{dn}{dT}(^{\circ}K^{-1})$	$\lambda(\mu m)$	n	$\frac{dn}{dT}(^{\circ}K^{-1})$
2.9466	1.52466		5.0032	1.51883	
3.2736	1.52371		5.3009	1.51790	
3.5359	1.52312		5.8932	1.51593	
3.6288	1.52286		6.4		-32.41×10^{-6}
3.8192	1.52238		8.85		-25.23×10^{-6}
4.1230	1.52156		9.00	1.50100	
4.7120	1.51979		9.50	1.49980	
4.96		-32.81×10^{-6}	10.0184	1.49462	
			11.7864	1.48171	

Absorption Coefficient: 0.00134/cm at 10.6 μm

HEAT CAPACITY:

$T(^{o}K)$ =	70	90	140	160	200	250	300	350	400	450	500
C_p(cal/mole, ^{o}K) =	5.975	7.720	9.998	10.558	11.210	11.766	12.00	12.26	12.50	12.69	12.88

DEBYE TEMPERATURE: $292.6 \pm 0.5^{o}K$ at $T = 0^{o}K$, $321^{o}K$

THERMAL CONDUCTIVITY:

$T(^{o}K)$ =	273	289	303	308	343
$\kappa(\times 10^{-3}$ cal/cm, sec, $^{o}K)$ =	16.7	15.5	15.0	14.7	13.0

LINEAR THERMAL EXPANSION COEFFICIENT:

$T(^{o}K)$ =	223	253	273-423
$\alpha(\times 10^{-6}/^{o}K)$ =	43	45	44

ELASTICITY

Apparent Elastic Limit: 24×10^7 dynes/cm^2

Modulus of Rupture: 3.9×10^7 dynes/cm^2

Elastic Moduli (Adiabatic): ($\times 10^{-13}$ cm^2/dyne)

T(°K)	s_{11}	$-s_{12}$	s_{44}	T(°K)	s_{11}	$-s_{12}$	s_{44}
90	18.77	3.21	75.18	250	21.65	4.33	77.84
150	19.72	3.61	76.03	270	22.08	4.49	78.26
170	20.06	3.75	76.36	350	23.95	4.98	79.08
190	20.43	3.89	76.70	400	25.23	5.46	80.14
210	20.82	4.03	77.07	450	26.63	5.96	81.22
230	21.21	4.18	77.47	500	28.18	6.49	82.37

PHOTOELASTICITY

Stress-Optic Constants: ($\times 10^{13}$ cgs)

T(°K)	$q_{11} - q_{12}$	q_{44}
293	-1.12	-0.94
373	-0.99	-0.90
423	-0.91	-0.87
473	-0.84	-0.84

Potassium Fluoride

KF 38

MOLECULAR WEIGHT: 58.10

STRUCTURE: Cubic, NaCl type, space group Fm3m, a_o = 5.347 Å

DENSITY: 2.534 gm/cm^3 at 293°K

MELTING POINT: 1139°K

BOILING POINT: 1773°K

VAPOR PRESSURE: 1mm at 1158°K

HARDNESS:

DIELECTRIC CONSTANT: 5.46

ENERGY GAP: 10.9 eV

OPTICAL PROPERTIES

Refractive Index: 1.361 at 0.57 μm

Absorption Coefficient: 0.21/cm at 10.6 μm

K.F.

HEAT CAPACITY: C_p = 11.73 cal/mole, ^{o}K at 298^{o}K

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY: 170×10^{-4} cal/cm, sec, ^{o}K

LINEAR THERMAL EXPANSION COEFFICIENT:

$T(^{o}K)$	=	173	223	273	423
$\alpha (\times 10^{-6}/^{o}K)$	=	23.4	24.8	26.9	34.8

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T(°K)	c_{11}	c_{12}	c_{44}	T(°K)	c_{11}	c_{12}	c_{44}
140	7.105	1.580	1.284	240	6.706	1.578	1.265
160	7.024	1.576	1.281	260	6.622	1.628	1.260
180	6.943	1.567	1.277	280	6.547	1.591	1.256
200	6.863	1.575	1.273	300	6.480	1.600	1.252
220	6.776	1.590	1.269				

PHOTOELASTICITY:

Potassium Chloride

KCl 42

MOLECULAR WEIGHT: 74.56

STRUCTURE: Cubic, NaCl type, space group Fm3m, a_o = 6.2931 Å

DENSITY:

T(°K)	50	100	150	200	250	303
d (gm/cm^3)	2.031	2.026	2.018	2.008	1.997	1.983-1.992 (volumetric) 1.987 (x-ray)

MELTING POINT: 1049°K

BOILING POINT: 1870°K

VAPOR PRESSURE: 1mm at 1094°K

HARDNESS: 7.2 (Knoop) on (110) plane; 9.3 on (100) plane with 200 gram indenter load

DIELECTRIC CONSTANT: 4.64 at 10^6 Hz and 303°K; 5.03 at 10^4 Hz and 293°K

ENERGY GAP: 8.5 eV

OPTICAL PROPERTIES

Refractive Index: $T = 293^{\circ}K$

λ (μm)	n	$\frac{dn}{dT}$ ($\times 10^{-5}/^{\circ}K$)	λ (μm)	n	$\frac{dn}{dT}$ ($\times 10^{-5}/^{\circ}K$)
3.945		-3.31	8.2505	1.46264	-2.92
3.5359	1.373027	13.28	8.6398	1.46078	-2.87
4.125	1.47215		9.500	1.45857	
4.7146	1.47104	-3.20	10.0184	1.45672	-2.75
5.3038	1.469925	-3.15	10.108	1.45658	
5.50	1.46962		10.500	1.45473	
5.8932	1.46872	-3.10	11.00	1.45263	
8.00	1.46350		11.756		-2.48

Absorption Coefficient: 4.8×10^{-4}/cm at 10.6 μm

HEAT CAPACITY:

$T(^{\circ}K)$ =	60	80	100	125	150	175	[illegible]
C_p (cal/mole, $^{\circ}K$) =	6.330	8.195	9.380	10.305	10.965	11.369	[illegible]
C_v (cal/mole, $^{\circ}K$) =	6.312	8.157	9.324	10.183	10.709	11.030	[illegible]

DEBYE TEMPERATURE: 246°K (from adiabatic elastic constants)

THERMAL CONDUCTIVITY:

$T(^{\circ}K)$ =	83	195	273	299	315	373
κ ($\times 10^{-3}$ cal/cm, sec, $^{\circ}K$) =	50.2	24.85	16.65	15.9	15.6	13.70

LINEAR THERMAL EXPANSION COEFFICIENT:

$T(^{\circ}K)$ =	173	223	273	423
α ($\times 10^{-6}/^{\circ}K$) =	30.7	31.4	35.5	39.8

ELASTICITY

Apparent Elastic Limit: 2.3×10^7 dynes/cm^2

Modulus of Rupture: 4.4×10^7 dynes/cm^2

Elastic Moduli: ($\times 10^{-11}$ cm^2/dyne)

T(°K)	s_{11}	s_{12}	s_{44}	T(°K)	s_{11}	s_{12}	s_{44}
80	0.2136	-0.023	1.507	240	0.2454	-0.031	1.560
90	0.2150	-0.024	1.509	260	0.2500	-0.032	1.569
130	0.2218	-0.026	1.518	280	0.2546	-0.033	1.578
150	0.2257	-0.027	1.524	293	0.253	-0.037	1.595
170	0.2299	-0.028	1.531	323	0.2594	-0.042	1.608
190	0.2342	-0.028	1.539	373	0.2717	-0.047	1.629
200	0.2364	-0.029	1.543	423	0.2849	-0.053	1.650
220	0.2409	-0.030	1.551	473	0.2994	-0.061	1.672

PHOTOELASTICITY

Stress-Optic Constants: ($\times 10^{13}$ cgs)

T(°K) =	293	373	423	473
$q_{11} - q_{12}$ =	+1.57	+1.66	+1.73	+1.81
q_{44} =	0.474	0.499	0.515	0.529

Strain-Optic Constants:

λ(Å)	p_{11}	p_{12}	p_{44}
5893	0.210	0.158	-0.027
5461	0.211	0.156	-0.024
4358	0.182	0.134	

Potassium Bromide

MOLECULAR WEIGHT: 119.01

STRUCTURE: Cubic, NaCl type, space group Fm3m, a_o = 6.5961 Å

DENSITY:

$T(^oK)$ =	100	150	200	250	273	298	323
$d(gm/cm^3)$ =	2.8061	2.792	2.777	2.763	2.756	2.7485	2.7399

MELTING POINT: 1003°K

BOILING POINT: 1653°K

VAPOR PRESSURE: 1mm at 1068°K

HARDNESS: 5.3 (110), 7.0 (100) (Knoop)

DIELECTRIC CONSTANT:

4.90 at 10^2 to 10^{10} Hz and 297°K

4.97 at 10^2 to 10^{10} Hz and 360°K

4.75 at 250 KHz and 297°K

ENERGY GAP: 7.8 eV

OPTICAL PROPERTIES

Refractive Index:

λ (μm)	n	$\frac{dn}{dT}$ ($^{\circ}K^{-1}$)
3.419	1.53612	
4.256	1.53523	-4.0×10^{-5}
6.238	1.53208	
8.662	1.52903	
9.724	1.52695	-2.6×10^{-5}
11.035	1.52404	

Absorption Coefficient: 5×10^{-5}/cm at 10.6 μm

KBr

HEAT CAPACITY:

$T(^{o}K)$	= 80	100	125	150	175	200	225
C_p(cal/mole, ^{o}K)	= 9.421	10.305	10.975	11.410	11.716	11.915	12.085

T	= 250	270	300	350	400	450	500
C_p	= 12.245	12.370	12.40	12.60	12.80	12.97	13.15

DEBYE TEMPERATURE: 174^{o}K

THERMAL CONDUCTIVITY:

$T(^{o}K)$	= 223	273	323	373
$\lambda(\times 10^{4}$cal/cm, sec, $^{o}K)$	= 60	50	48	48

LINEAR THERMAL EXPANSION COEFFICIENT:

$T(^{o}K)$	= 223	253	273	293	313	333	353	373	393	413	433	453	473
$\alpha(\times 10^{-6}/^{o}K)$	= 42	41	40	41	45	44	39	36	38	41	42	43	44

ELASTICITY

Apparent Elastic Limit: 24×10^7 dynes/cm^2

Modulus of Rupture: 3.9×10^7 dynes/cm^2

Elastic Coefficients: $c_{ij} \times 10^{11}$ (dynes/cm^2) $= A_0 + A_1 T \times 10^{-3} + A_2 T^2 \times 10^{-6} + A_3 T^3 \times 10^{-9} + A_4 T^4 \times 10^{-12}$ ($T = {}^\circ K$)

	polynomial order	A_0	A_1	A_2	A_3	A_4
c_{11}	4	3.540	-2.567	-1.620	+4.349	-2.986
	2	3.553	-2.872	+0.373		
c_{44}	4	0.511	-0.098	-0.116	+0.132	-0.119
	2	0.511	-0.100	-0.077		
$1/2(c_{11} - c_{12})$	4	1.485	-1.487	-0.332	+1.161	-0.544
	2	1.495	-1.653	+0.417		

PHOTOELASTICITY

Stress-Optic Constants: ($\times 10^{13}$ cgs)

$T({}^\circ K)$	$q_{11} - q_{12}$	q_{44}
298	+1.73	-4.48
398	1.82	-4.63
423	1.91	-4.72
473	2.03	-4.78

Strain-Optic Constants:

$p_{11} = 0.241$ $p_{12} = 0.191$ $p_{44} = -0.023$ at 5890 Å

Rubidium Fluoride

MOLECULAR WEIGHT: 104.47

STRUCTURE: Cubic, NaCl type, space group Fm3m

DENSITY: 3.504 gm/cm^3 at 293°K

MELTING POINT: 1048°K

BOILING POINT: 1683°K

VAPOR PRESSURE: 1mm at 1194°K

HARDNESS:

DIELECTRIC CONSTANT: $\epsilon_o = 6.48$

ENERGY GAP: 10.4 eV

OPTICAL PROPERTIES

Refractive Index: 1.396 at 0.59 μm, 293°K

Absorption Coefficient: 0.2 at 10 μm

HEAT CAPACITY: C_p = 12.2 cal/mole, °K at 298°K

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY:

LINEAR THERMAL EXPANSION COEFFICIENT:

T(°K) =	80	100	150	200	250	300	350	400	450	500
α ($\times 10^{-6}$/°K) =	21	24	29	31	33	34	35	36	37	38

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T(°K)	c_{11}	c_{12}	c_{44}
300	5.525	1.395	0.925
80	6.55	1.35	0.965

PHOTOELASTICITY:

Rubidium Chloride

RbCl

54

MOLECULAR WEIGHT: 120.92

STRUCTURE: Cubic, NaCl type, space group Fm3m, a_o = 6.5810 Å

DENSITY:

T(°K) =	90	120	150	180	210	240	273	291	298	323
d(gm/cm^3) =	2.8572	2.8507	2.8430	2.8345	2.8256	2.8163	2.8057	2.818 (x-ray)	2.7979	2.7922

MELTING POINT: 988°K

BOILING POINT: 1663°K

VAPOR PRESSURE: 1mm at 1065°K

HARDNESS:

DIELECTRIC CONSTANT: 4.68 to 5.20

ENERGY GAP: 8.2 eV

OPTICAL PROPERTIES

Refractive Index: 1.48 in the 1 to 8 μm range

Absorption Coefficient: 0.00092/cm at 10.6 μm

HEAT CAPACITY: C_p = 12.3 cal/mole, °K at 298°K

DEBYE TEMPERATURE: 166, 168, 171°K

THERMAL CONDUCTIVITY: 50×10^{-4} cal/cm, sec, °K

LINEAR THERMAL EXPANSION COEFFICIENT:

T(°K) =	70	90	110	130	150	170	190	210	230	250	270	290	300
$\alpha(\times 10^{-6}/°K)$ =	21.9	25.4	27.5	28.9	30.1	31.1	32.0	32.8	33.6	34.4	35.1	35.8	36.1

ELASTICITY

Apparent Elastic Limit:

Modulus of Eupture:

Elastic Coefficients: ($\times 10^{11}$ dyne/cm^2)

T(°K)	c_{11}	c_{12}	c_{44}
298	3.6053	0.62621	0.46711
273	3.6899	0.61940	0.47009
251	3.7497	0.59948	0.47232
230	3.8134	0.59222	0.47454
210	3.8830	0.57849	0.47659
190	3.9432	0.56634	0.47877
170	4.0092	0.55689	0.48078
150	4.0708	0.54716	0.48295

PHOTOELASTIC PROPERTIES

Stress-Optic Constants:

$q_{11} - q_{12} = +3.83 \times 10^{13}$ cgs

$q_{44} = -9.40$

Rubidium Bromide

RbBr

MOLECULAR WEIGHT: 165.38

STRUCTURE: Cubic, NaCl type, space group Fm3m, a_o = 6.889 Å

DENSITY:

T(°K)	=	273	298	323
d(gm/cm^3)	=	3.3581	3.3486	3.3402

MELTING POINT: 955°K

BOILING POINT: 1613°K

VAPOR PRESSURE: 1mm at 1054°K

HARDNESS:

DIELECTRIC CONSTANT: 5.26

ENERGY GAP: 7.7 eV

OPTICAL PROPERTIES

Refractive Index: 1.5528

Absorption Coefficient: 0.0016/cm at 10.6 μm

HEAT CAPACITY:

$T(^{o}K)$ =	86.8	110.6	132.2	148.4	170.5	187.5	212.2	229.6	249.2	272.7
C_p(cal/mole, ^{o}K) =	10.712	11.434	11.790	11.976	12.148	12.259	12.396	12.454	12.504	12.494

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY:

LINEAR THERMAL EXPANSION COEFFICIENT:

$T(^{o}K)$ =	80	100	120	140	160	180	200	220	240	260	270
$\alpha(\times 10^{-6}/^{o}K)$ =	27.20	29.67	31.23	32.33	33.23	33.99	34.72	35.42	36.10	36.70	36.98

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T(°K)	c_{11}	c_{12}	c_{44}
140	3.597	0.444	0.393
160	3.542	0.431	0.391
180	3.488	0.459	0.390
200	3.430	0.465	0.388
220	3.373	0.473	0.387
240	3.317	0.480	0.385
260	3.262	0.486	0.383
280	3.204	0.494	0.382
300	3.152	0.500	0.380

PHOTOELASTICITY

Stress-Optic Constants: ($\times 10^{13}$ cgs)

$q_{11} - c_{12} = +3.84$ at 5890 Å

$q_{44} = -8.08$

$q_{11} = q_{12}$ at 2020 Å

$q_{44} = 0$ at 2140 Å

Cesium Bromide

MOLECULAR WEIGHT: 212.81

STRUCTURE: Cubic, CsCl type, space group $Pm\bar{3}m$, $a_o = 4.296$ Å

DENSITY:

(T^oK)	= 273	298	323
$d(gm/cm^3)$	= 4.449	4.433	4.418

MELTING POINT: 909°K

BOILING POINT: 1573°K

VAPOR PRESSURE: 1mm at 748°K

HARDNESS: 19.5 (Knoop)

DIELECTRIC CONSTANT: 6.51 at 10^6 Hz at 298°K

ENERGY GAP: 7.8 eV

OPTICAL PROPERTIES

Refractive Index: $T = 298^{\circ}K$

$\lambda(\mu m)$	n(expt'l)	n(calc'd)
3.0		1.66901
3.3610	1.66866	
4.0		1.66813
4.258	1.66794	
5.0		1.66737
6.0		1.66659
6.465	1.66587	
9.0		1.66370
9.724	1.66283	
10.0		1.66251
11.035	1.66118	

$\frac{dn}{dT}(^{\circ}K^{-1})$: avg 7.9×10^{-5} at 297 to $304^{\circ}K$

Absorption Coefficient: 0.0044/cm at 10.6 μm

HEAT CAPACITY:

$T(^{o}K)$ =	80	100	120	140	160	180	200	220	240	260	280	300
C_p(cal/mole, ^{o}K) =	10.73	11.22	11.53	11.77	11.94	12.07	12.16	12.24	12.31	12.37	12.42	12.46

DEBYE TEMPERATURE: 148.8°K, calc'd at 4.2°K

THERMAL CONDUCTIVITY: 23.0×10^{-4} cal/cm, sec, °K

LINEAR THERMAL EXPANSION COEFFICIENT: $47.9 \times 10^{-6}/^{o}K$ between 293 and 323°K

$T(^{o}K)$ =	80	100	120	140	160	180	200	220	240	260	280
$\alpha(\times 10^{-6}/^{o}K)$ =	36.8	38.8	40.3	41.5	42.5	43.4	44.3	45.0	45.8	46.4	46.7

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Moduli: ($\times 10^{-11}$ cm^2/dyne)

T(°K)	s_{11}	$-s_{12}$	s_{44}
293	0.38	0.09	1.32
323	0.38	0.09	1.37
373	0.39	0.09	1.46
423	0.40	0.09	1.57
473	0.40	0.10	1.70

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T(°K)	c_{11}	c_{12}	c_{44}
50	3.311	1.014	0.976
110			0.913
220	3.137	0.866	0.809
240	3.111	0.852	0.792
260	3.091	0.845	0.775
280	3.071	0.818	0.759
300	3.056	0.776	0.743

PHOTOELASTICITY:

Cesium Iodide

CsI 88

MOLECULAR WEIGHT: 259.81

STRUCTURE: Cubic, CsCl type, space group Pm3m, a_o = 4.5675 Å

DENSITY: 4.523 gm/cm^3 at 293°K

MELTING POINT: 894°K

BOILING POINT: 1553°K

VAPOR PRESSURE: 1mm at 1011°K

HARDNESS:

DIELECTRIC CONSTANT: 5.66 at 10^6Hz and 298°K

ENERGY GAP: 6.3 eV

OPTICAL PROPERTIES

Refractive Index:

$\lambda(\mu m)$	n	$\frac{dn}{dT}(^{o}K^{-1})$
5.00	1.74400	-9.54×10^{-5}
3.419	1.74353	
4.00	1.74305	
4.258	1.74278	
5.00	1.74239	-9.38×10^{-5}
6.00	1.74181	
9.00	1.73991	
9.724	1.73937	
10.00	1.73916	-9.17×10^{-5}
11.00	1.73835	

Absorption Coefficient: 0.0013/cm at 10.6 μm

HEAT CAPACITY: 12.4 cal/mole, ^{o}K at 298^{o}K

DEBYE TEMPERATURE: 93.6^{o}K

THERMAL CONDUCTIVITY: 27×10^{-4} cal/cm, sec, ^{o}K

LINEAR THERMAL EXPANSION COEFFICIENT:

T(oK)	=	80	100	120	140	160	180	200	220	240	260	270
$\alpha(\times 10^{-6}/^{o}K)$	=	38.9	40.7	42.0	43.0	43.9	44.6	45.4	46.2	47.0	47.7	48.1

ELASTICITY

Apparent Elastic Limit: 24×10^7 dynes/cm^2

Modulus of Rupture: 3.9×10^7 dynes/cm^2

Elastic Coefficients: ($\times 10^{11}$ cm^2/dyne)

T(°K)	c_{11}	c_{12}	c_{44}
80	2.660	0.751	0.808
120	2.619	0.728	0.775
160	2.576	0.707	0.742
200	2.535	0.685	0.709
240	2.492	0.665	0.676
260	2.470	0.654	0.660
280	2.450	0.644	0.643
295	2.434	0.636	0.632

PHOTOELASTICITY

Stress-Optic Constants: ($\times 10^{-13}$ cgs)

$q_{11} - q_{12} = -2.48$ $\qquad$ $q_{44} = +3.80$ at 5890 Å

$q_{11} = q_{12}$ at 2590 Å $\qquad$ $q_{44} = 0$ at 2150 Å

Silver Chloride

AgCl 70

MOLECULAR WEIGHT: 143.32

STRUCTURE: Cubic, NaCl type, space group Fm3m, $a_o = 5.549$ Å

DENSITY: 5.57 gm/cm^3 (x-ray)

MELTING POINT: 728°K

BOILING POINT:

VAPOR PRESSURE: 1mm at 1185°K

HARDNESS: 9.5 (Knoop)

DIELECTRIC CONSTANT: 11.2 at 10^6 Hz

ENERGY GAP: 3.0 eV

OPTICAL PROPERTIES

Refractive Index: T = 296.9°K

λ(μm)	n	λ(μm)	n
3.00	2.00230	6.00	1.99483
3.50	2.00102	9.00	1.98464
4.00	1.99983	9.50	1.98255
4.50	1.99866	10.00	1.98034
5.00	1.99745	10.50	1.97801
5.50	1.99618	11.00	1.97558

Absorption Coefficients: 0.005/cm at 10.6 μm

HEAT CAPACITY:

$T(^{\circ}K)$ =	75	88	105	130	149	174	191	210	230	250	270	292
C_p(cal/mole, $^{\circ}K$) =	8.779	9.501	10.230	10.834	11.203	11.582	11.760	12.030	12.083	12.182	12.050	12.080

DEBYE TEMPERATURE: 183°K

THERMAL CONDUCTIVITY: 27.1×10^{-4} cal/cm, sec, $^{\circ}K$ at 325°K

LINEAR THERMAL EXPANSION COEFFICIENT:

$T(^{\circ}K)$ =	100	200	300	400	500
$\alpha(\times 10^{-6}/^{\circ}K)$ =	22	26	30	32	40

ELASTICITY

Apparent Elastic Limit: 5.1×10^7 dynes/cm^2

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T(°K)	c_{11}	c_{12}	c_{44}
80	7.168	3.850	0.681
120	6.923	3.809	0.670
160	6.682	3.766	0.660
200	6.446	3.723	0.649
240	6.200	3.662	0.638
260	6.082	3.629	0.633
280	5.963	3.605	0.627
295	5.860	3.582	0.622

PHOTOELASTICITY:

Silver Bromide

AgBr

MOLECULAR WEIGHT: 187.78

STRUCTURE: Cubic, NaCl type, space group $Fm3m$, $a_o = 5.7745$ Å

DENSITY: 6.473 gm/cm^3

MELTING POINT: 703°K

DECOMPOSITION POINT: >1500°K

VAPOR PRESSURE:

HARDNESS: 7 (Knoop)

DIELECTRIC CONSTANT: 12.2 at 10^6 Hz

ENERGY GAP: 2.9 eV

OPTICAL PROPERTIES

Refractive Index: 2.2318 at 0.671 μm at 299^{o}K

Absorption Coefficient: 0.0073/cm at 10.6 μm

HEAT CAPACITY:

$T(^{o}K)$ =	83	101	115	135	150	166	183	200	222	246	270	298
C_p(cal/mole, ^{o}K) =	10.305	10.932	11.293	11.497	11.749	11.945	12.088	12.155	12.297	12.326	12.406	12.375

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY: 29×10^{-4} cal/cm, sec, ^{o}K at $273^{o}K$

LINEAR THERMAL EXPANSION COEFFICIENT:

$T(^{o}K)$ =	77	273	322	373	473
$\alpha(\times 10^{-6}/^{o}K)$ =	27	30	31	32	43

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T(°K)	c_{11}	c_{12}	c_{44}
299	5.63	3.23-3.37	0.720
373	5.21	3.08-3.27	0.691
423	4.88	2.97-3.17	0.672
473	4.53	2.84-3.05	0.653

PHOTOELASTICITY:

Ag Br

Cuprous Chloride

CuCl 78

MOLECULAR WEIGHT: 98.99

STRUCTURE: Cubic, Space Group F43m $a_o = 5.416$ Å

DENSITY: 4.14 gm/cm^3

MELTING POINT: 695°K

BOILING POINT: 1765°K

VAPOR PRESSURE:

HARDNESS: 2 to 2 1/2 (Moh)

DIELECTRIC CONSTANT: 8

ENERGY GAP: ~ 3 eV

OPTICAL PROPERTIES

Refractive Index:

1.90 at 3.3 μm

1.88, 1.93 at ~ 10 μm

Absorption Coefficient: 0.006/cm at 10.6 μm

HEAT CAPACITY: C_p = 3.40 cal/molc, $^{\circ}$K at 298°K

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY:

LINEAR THERMAL EXPANSION COEFFICIENT:

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

$c_{11} = 4.25$

$c_{12} = 3.9$

$c_{44} = 2.1$

PHOTOELASTICITY:

Calcium Fluoride

CaF_2 28

MOLECULAR WEIGHT: 78.06

STRUCTURE: Cubic, Fluorite type, space group Fm3m, a_o = 5.4626 Å at 298°K

DENSITY: 3.181 gm/cm^3 (x-ray)

MELTING POINT: 1681°K

BOILING POINT: ~2750°K

VAPOR PRESSURE:

HARDNESS: 120 to 163 (Knoop)

DIELECTRIC CONSTANT: ϵ_o = 6.90, ϵ_∞ = 2.04 at 350°K; ϵ_o = 6.81, ϵ_∞ = 2.04 at 300°K

ENERGY GAP:

OPTICAL PROPERTIES

Refractive Index:

λ (μm)	n	$-\frac{dn}{dT}$ ($\times 10^{-6}$/°K)	λ (μm)	n	$-\frac{dn}{dT}$ ($\times 10^{-6}$/°K)
3.00	1.41785		5.01882	1.39873	7.3
3.20	1.41639		5.3034	1.39520	7.2
3.3026	1.41561	8.2	5.40	1.39394	
3.422	1.41467	8.1	5.60	1.39127	
3.5970	1.41393	6.0	5.80	1.38849	
3.7067	1.41229	7.8	6.140	1.38539	7.0
4.00	1.40963		9.00	1.32677	
4.258	1.40713	7.5	9.200	1.32168	
4.40	1.40567		9.40	1.31643	
4.60	1.40354		9.60	1.31101	
4.80	1.40130		9.724	1.30756	5.6

Absorption Coefficient: $< 10^{-4}$/cm at 4 μm, 0.006/cm at 6.1 μm

CaF2

HEAT CAPACITY:

$T(^{o}K)$ =	85	104	125	146	166	186	206	226	246	266	298
C_p (cal/mole, ^{o}K) =	5.295	7.313	9.146	10.80	12.03	13.04	13.82	14.49	15.04	15.50	16.02

DEBYE TEMPERATURE: $513.6 \pm 2.5^{o}K$

THERMAL CONDUCTIVITY:

$T(^{o}K)$ =	83	200	273	298	373
$\kappa(\times 10^{-4}$ cal/cm, sec, $^{o}K)$ =	932	360	246.8	232	191

LINEAR THERMAL EXPANSION COEFFICIENT:

$T(^{o}K)$ =	80	100	120	140	157.3	186.9	209.8	231.4	255.6	278.6
$\alpha(\times 10^{-6}/^{o}K)$ =	5.1	7.6	9.9	11.7	13.02	14.65	13.05	16.78	17.58	18.53

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Moduli: ($\times 10^{-13}$ cm^2/dyne)

s_{11} = 6.91 to 6.94; s_{12} = -1.49 to -1.53; s_{44} = 27.7 to 29.6

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T(°K)	c_{11}	c_{12}	c_{44}
298	1.64	0.44 to 0.53	3.37
195	1.67	0.45 to 0.57	3.48

PHOTOELASTICITY

Stress-Optic Constants:

q_{11} = -0.413; q_{12} = +1.04; q_{44} = 0.39 at 5893 Å

Strontium Fluoride SrF_2

MOLECULAR WEIGHT: 125.62

STRUCTURE: Cubic, Fluorite type, space group Fm3m, a_o = 5.800 Å

DENSITY: 4.20 gm/cm^3 (by x-ray);

T(°K) =	80	100	120	140	160	180	200	220	240	260	280	300
d(gm/cm^3) =	4.319	4.316	4.314	4.311	4.308	4.304	4.300	4.295	4.290	4.286	4.281	4.277

MELTING POINT: 1725°K

BOILING POINT: 2730°K

VAPOR PRESSURE: 8.5mm at 2095°K

HARDNESS: 130 (Knoop)

DIELECTRIC CONSTANT:

ϵ_o = 6.62, ϵ_∞ = 2.07 at 350°K

ϵ_o = 6.50, ϵ_∞ = 2.07 at 300°K.

ENERGY GAP:

OPTICAL PROPERTIES

Refractive Index: $n = 1.44$ at $4\ \mu m$, and $\frac{dn}{dT} = -1.19 \times 10^{-5}\ ^{o}K^{-1}$

Absorption Coefficient: $< 10^{-4}$/cm at $4\ \mu m$; 0.006/cm at $7.5\ \mu m$ 0.6/cm at $10.6\ \mu m$

HEAT CAPACITY:

DEBYE TEMPERATURE: 380°K

THERMAL CONDUCTIVITY: 239×10^{-4} cal/cm, sec, °K

LINEAR THERMAL EXPANSION COEFFICIENT:

T(°K) =	80	100	120	140	160	180	200	220	240	260	270
α ($\times 10^{-6}$/°K) =	6.0	8.6	10.7	12.3	13.7	14.8	15.6	16.3	16.8	17.3	17.5

ELASTICITY

Apparent Elastic Limit;

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dyne/cm^2)

T(^{C}K)	c_{11}	c_{12}	c_{44}
300	12.35	4.305	3.128
280	12.39	4.342	3.144
260	12.44	4.376	3.161
240	12.48	4.510	3.176
220	12.53	4.446	3.191
200	12.58	4.485	3.205
180	12.62	4.521	3.219
160	12.66	4.554	3.235
140	12.71	4.592	3.250
120	12.75	4.626	3.264
100	12.79	4.664	3.280
80	12.82	4.695	3.291

PHOTOELASTICITY:

Barium Fluoride

BaF_2

MOLECULAR WEIGHT: 175.34

STRUCTURE: Cubic, Fluorite type, space group Fm3m, a_o = 6.2001 Å

DENSITY: 4.8860 (x-ray) at 293°K

MELTING POINT: 1593°K

BOILING POINT: 2533°K

VAPOR PRESSURE: 12.7mm at 1960°K

HARDNESS: 65 (Knoop)

DIELECTRIC CONSTANT: ϵ_o = 7.40, ϵ_∞ = 2.17 at 350°K; ϵ_o = 7.32, ϵ_∞ = 2.17 at 300°K

ENERGY GAP:

OPTICAL PROPERTIES

Refractive Index: at T = 298°K

λ (μm)	n	$\frac{dn}{dT}$ (×10^{-6}/°K)	λ (μm)	n	$\frac{dn}{dT}$ (×10^{-6}/°K)
3.00	1.46115	~-17	5.343	1.44878	
3.2434	1.46016		5.40	1.44839	
3.422	1.45940		5.549	1.44732	
3.50	1.45862		5.60	1.44699	
3.80	1.45768		6.00	1.44404	
4.00	1.45670		9.00	1.41441	
4.20	1.45566		9.20	1.41193	
4.40	1.45458		9.40	1.40938	
4.60	1.45345		9.60	1.40677	
4.80	1.45226		9.80	1.40408	
5.00	1.45102		10.00	1.40133	
5.138	1.45012		10.20	1.39850	
5.20	1.44973		10.40	1.39560	~-9

Absorption Coefficient: 0.003/cm at 2.8 μm; 0.09/cm at 10.6 μm

HEAT CAPACITY:

$T(^{o}K)$ =	80	100	120	140	160	180	200	220	240	260	280	300
C_p(cal/mole, ^{o}K) =	8.41	10.53	12.21	13.48	14.41	15.13	15.74	16.20	16.54	16.77	16.90	16.98

DEBYE TEMPERATURE: $282^{o}K$

THERMAL CONDUCTIVITY: 280×10^{-4} cal/cm, sec, ^{o}K

LINEAR THERMAL EXPANSION COEFFICIENT:

$T(^{o}K)$ =	80	100	125	150	200	225	250	275	300	325	350
$\alpha(\times 10^{-6}/^{o}K)$ =	7.4	9.9	12.2	14.0	16.1	15.5	17.4	18.1	18.8	19.4	20.0

ELASTICITY

Apparent Elastic Limit: 2.7×10^{12} dynes/cm^2

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{12}$ dynes/cm^2)

T(°K)	c_{11}	c_{12}	c_{44}
298	0.89 - 0.92	0.40 - 0.42	0.255
195	0.94	0.426	0.264

PHOTCELASTICITY

Stress-Optic Constants:

$q_{11} \cdot q_{12} = -2.93$, $q_{11} = -0.617$

$q_{12} = 2.31$, $q_{44} = 1.06$

at $\lambda = 5893$ Å

Strain-Optic Constants:

$p_{11} - p_{12} = -14.61 \times 10^{-2}$(cgs)

$p_{44} = 2.639 \times 10^{-2}$(cgs)

Magnesium Fluoride

MgF_2

MOLECULAR WEIGHT: 62.31

STRUCTURE: Tetragonal, SnO_2 type, space group $P4_2/mnm$, $a_o = 4.623$ Å, $c_o = 3.052$ Å

DENSITY: 3.1766 gm/cm^3 at 291°K

MELTING POINT: 1585°K

BOILING POINT: 2510°K

VAPOR PRESSURE:

HARDNESS: 415 to 576 (Knoop)

DIELECTRIC CONSTANT: 4.87 along c-axis, 5.45 perpendicular to the c-axis between 95 KHz and 42 MHz

ENERGY GAP:

OPTICAL PROPERTIES

Refractive Index:

$n_o = 1.3770$, $n_e = 1.38950$ at $0.58937\ \mu m$

$\frac{dn_o}{dT} = 0.19 \times 10^{-5}\ ^oK^{-1}$ at $0.7065\ \mu m$

$\frac{dn_e}{dT} = 0.10 \times 10^{-5}\ ^oK^{-1}$ at $0.7065\ \mu m$

Absorption Coefficient: 0.0055/cm at 2.8 μm, 0.006/cm at 5.1 μm, 0.1/cm at 6.1 μm

HEAT CAPACITY:

C_p = 17.04 cal/mole, ^{o}K at 298^{o}K

$C_p = 16.93 + 2.52 \times 10^{-3}T - 2.55 \times 10^{-5}T^2$ where T = ^{o}C, between 25 and 100^{o}C

T(^{o}K) =	80	95	114	135	155	176	196	216	236	256	276
C_p (cal/mole, ^{o}K) =	3.552	4.754	6.330	8.007	9.339	10.51	11.49	12.37	13.06	13.73	14.23

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY: 277×10^{-4} cal/cm, sec, ^{o}K at room temperature

$\lambda = \frac{3.17}{T} + 0.85$, λ = thermal conductivity in watts/meter, ^{o}K

T = ^{o}K, between 298^{o}K and 1173^{o}K

LINEAR THERMAL EXPANSION COEFFICIENT: T = ^{o}K, between 323 and 883^{o}K

$\alpha_{\perp} = 9.213 \times 10^{-6} + 6.805 \times 10^{-9}T + 1.097 \times 10^{-11}T^2/^{o}K$

$\alpha_{\parallel} = 13.39 \times 10^{-6} + 7.416 \times 10^{-9}T + 1.072 \times 10^{-11}T^2/^{o}K$

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture: 5.00×10^8 to 1.044×10^9 dynes/cm^2

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T(°K)	c_{11}	c_{33}	c_{44}	c_{66}	c_{12}	c_{13}
293	12.37 - 13.95	17.70 - 20.41	5.52 - 5.64	9.51 - 9.78	7.32 - 8.97	5.36 - 6.25
173	14.23	20.78	5.7[illegible]	9.88	9.19	6.31

PHOTOELASTICITY:

β-Lead Fluoride

MOLECULAR WEIGHT: 245.19

STRUCTURE: Cubic, Fluorite type, space group $Fm3m$, $a_o = 5.940$ Å

DENSITY: 7.659gm/cm.^{3} (x-ray, 588°K); 8.24gm/cm^3 at 293°K

MELTING POINT: 1128°K

BOILING POINT: 1563°K

VAPOR PRESSURE: 10mm at 1177°K

HARDNESS: 200 (Knoop)

DIELECTRIC CONSTANT: 28

ENERCY GAP:

OPTICAL PROPERTIES

Refractive Index: 1.65 at 4 μm; 1.58 at 8 μm

Absorption Coefficient: 0.013/cm at 4 μm; 0.1/cm at 9.5 μm

HEAT CAPACITY:

DEBYE TEMPERATURE: 219 ± 2°K

THERMAL CONDUCTIVITY:

LINEAR THERMAL EXPANSION COEFFICIENT:

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Moduli: ($\times 10^{-13}$ cm^2/dyne)

$s_{11} = 15.34$

$-s_{12} = 4.9$

$s_{44} = 4.756$

PHOTOELASTICITY:

Indium Phosphide

InP

MOLECULAR WEIGHT: 145.79

STRUCTURE: Cubic, zinc-blende type, space group $F\bar{4}3m$, $a_o = 5.869$ Å

DENSITY: 4.81 gm/cm^3

MELTING POINT: 1343°K under an equilibrium pressure of phosphorous of 60 atmospheres

BOILING POINT:

VAPOR PRESSURE: 10.5 atm at 1343°K

HARDNESS: 530 (Knoop)

DIELECTRIC CONSTANT: $\epsilon_o = 12.35$, $\epsilon_\infty = 9.52$

ENERGY GAP: 1.27 eV

OPTICAL PROPERTIES

Refractive Index:

λ (μm)	n
2.00	3.134
5.00	3.08
6.00	3.07
9.00	3.06
10.00	3.05
12.00	3.05

Absorption Coefficient: 0.5/cm at 10.6 μm

HEAT CAPACITY:

$T(^{\circ}K)$	= 70	90	110	130	150	170	190	210	230	250	273
C_p (cal/mole, $^{\circ}K$)	= 4.636	5.744	6.740	7.620	8.360	8.948	9.422	9.634	10.140	10.386	10.640

DEBYE TEMPERATURE: 321°K

THERMAL CONDUCTIVITY: 0.162 cal/cm, sec, °K

LINEAR THERMAL EXPANSION COEFFICIENT: $4.5 \times 10^{-6}/^{\circ}K$

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

$c_{11} = 10.22$ $c_{12} = 5.76$ $c_{44} = 4.50$

PHOTOELASTICITY:

Indium Antimonide

InSb

MOLECULAR WEIGHT: 236.52

STRUCTURE: Cubic, zinc-blende type, space group $F\bar{4}3m$, $a_o = 6.4782$ Å

DENSITY: 5.775 gm/cm^3 at 298°K

MELTING POINT: 809°K

BOILING POINT:

VAPOR PRESSURE: 10mm at 809°K

HARDNESS: 223 (Knoop)

DIELECTRIC CONSTANT: $\epsilon_\infty = 15.6$, $\epsilon_o = 17$

ENERGY GAP: 0.17 eV at 293°K

OPTICAL PROPERTIES

Refractive Index:

λ(μm)	n
2.07	4.03
8.00	3.995
9.01	3.967
10.06	3.953
11.01	3.937

Absorption Coefficient: 0.009/cm at 10.6 μm

HEAT CAPACITY:

$T(^{\circ}K)$	=	70	90	110	130	150	170	190	210	230	250	273
C_p (cal/gm, atom, $^{\circ}K$)	=	7.262	8.614	9.496	10.114	10.580	10.900	11.126	11.330	11.494	11.620	11.734

DEBYE TEMPERATURE: 181°K

THERMAL CONDUCTIVITY: 0.0478 cal/cm, sec, °K at 300°K

LINEAR THERMAL EXPANSION COEFFICIENT:

$T(^{\circ}K)$	=	80	100	120	140	160	180	200	220	240	260	280	300	320	340
$\alpha (\times 10^{-6}/^{\circ}K)$	=	1.7	2.7	3.4	3.8	4.2	4.6	4.9	5.0	5.0	5.0	5.1	5.2	5.3	5.4

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T(°K)	c_{11}	c_{12}	c_{44}
0	6.66	3.35	3.14
100	6.649	3.351	3.137
200	6.607	3.345	3.107
300	6.472	3.265	3.071
400	6.312	3.166	3.034
500	6.131	3.039	2.998

PHOTOELASTICITY:

Gallium Phosphide

GaP

MOLECULAR WEIGHT: 100.70

STRUCTURE: Cubic, zinc-blende type, space group $F\bar{4}3m$, $a_o = 5.448$ Å

DENSITY:

MELTING POINT: 1623°K

BOILING POINT:

VAPOR PRESSURE: 13.5 atm at 1623°K

HARDNESS: 945 (Knoop)

DIELECTRIC CONSTANT: $\epsilon_\infty = 8.5$ $\epsilon_o = 10$

ENERGY GAP: 2.261 eV at 300°K

OPTICAL PROPERTIES

Refractive Index:

λ (μm)	n
3.50	2.95
4.00	2.95
4.50	2.95
5.00	2.94
6.00	2.92
9.00	2.91
10.00	2.90

Absorption Coefficient: 0.39/cm at 10.6 μm

GaP

HEAT CAPACITY:

DEBYE TEMPERATURE: 500°K at 298°K

THERMAL CONDUCTIVITY: 0.263 cal/cm, sec, °K

LINEAR EXPANSION COEFFICIENT: $5.81 \times 10^{-6}/^{\circ}K$

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2) (T = 300°K)

c_{11} = 14.120 c_{12} = 6.253 c_{44} = 7.047

PHOTOELASTICITY:

Strain-Optic Constants:

p_{11} = -0.151 p_{12} = -0.082 p_{44} = -0.074 λ = 0.63 μm

Gallium Arsenide

MOLECULAR WEIGHT: 144.63

STRUCTURE: Cubic, zinc-blende type, space group $F\bar{4}3m$, $a_o = 5.6534$ Å

DENSITY: 5.37 gm/cm^3 (x-ray); 5.3161 gm/cm^2 (unannealed)

MELTING POINT: 1511°K

BOILING POINT:

VAPOR PRESSURE: 0.9mm at 1511°K

HARDNESS: 750 (Knoop)

DIELECTRIC CONSTANT: $\epsilon_\infty = 10.9$, $\epsilon_o = 12.5$

ENERGY GAP: 1.435 eV at 294°K

OPTICAL PROPERTIES

Refractive Index:

λ (μm)	n	$\frac{1}{r}\frac{dn}{dT}$ ($^{o}K^{-1}$)
3.0	3.303	
4.0	3.289	
5.0	3.269	
6.0	3.246	
9.0	3.143	
10.0	3.095	
10.6		$5.64 \pm 0.28 \times 10^{-5}$
11.0	3.047	

Absorption Coefficient: 0.005/cm at 10.6 μm

HEAT CAPACITY:

$T(^{o}K)$ =	70	90	110	130	150	170	190	210	230	250	273
C_p(cal/gm atom, ^{o}K) =	4.760	6.244	7.460	8.390	9.116	9.630	10.040	10.386	10.654	10.840	10.962

DEBYE TEMPERATURE: 312 to 355^{o}K

THERMAL CONDUCTIVITY: 0.1147 cal/cm, sec, ^{o}K

LINEAR THERMAL EXPANSION COEFFICIENTS:

$T(^{o}K)$ =	80	120	160	200	240	280	320	360
$\alpha(\times 10^{-6}/^{o}K)$ =	1.3	3.0	4.3	5.2	5.7	5.9	6.1	6.0

ELASTICITY:

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T = 300°K	c_{11} = 11.810	c_{12} = 5.320	c_{44} = 5.940
T = 77°K	= 12.210	= 5.660	= 5.990

PHOTOELASTICITY

Strain-Optic Constants:

p_{11} = -0.165 p_{12} = -0.140 p_{44} = -0.072 λ = 1.15 μm

Zinc Sulfide (Zinc Blende)

ZnS

MOLECULAR WEIGHT: 97.43

STRUCTURE: Cubic, zinc-blende type, space group $F\bar{4}3m$, $a_o = 5.4060$ Å at 299°K

DENSITY: 4.098 gm/cm^3 (x-ray)

DECOMPOSITION POINT: 1923°K to 2123°K

VAPOR PRESSURE:

HARDNESS: 200 (Knoop)

DIELECTRIC CONSTANT: $\epsilon_o = 8.9$, $\epsilon_\infty = 5.7$

ENERGY GAP: 3.54 eV at 293°K

OPTICAL PROPERTIES

Refractive Index:

λ (μm)	n	$\frac{dn}{dT}$ ($^{o}K^{-1}$)
3	2.253	
4	2.251	
13.3	2.2	
10.6		7.5×10^{-5}

Absorption Coefficient: 0.15/cm at 10.6 μm

HEAT CAPACITY: C_p = 10.8 cal/mole, ^{O}K at 298^{O}K

DEBYE TEMPERATURE: 299^{O}K

THERMAL CONDUCTIVITY: 0.0633 cal/cm, sec, ^{O}K at 273^{O}K

LINEAR THERMAL EXPANSION COEFFICIENT:

T(^{O}K) =	96	133	173	213	253
α($\times 10^{-6}$/^{O}K) =	1.38	3.25	4.50	5.40	6.05

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T(°K)	c_{11}	c_{12}	c_{44}
93	10.550	6.540	4.680
113	10.540	6.535	4.675
133	10.520	6.530	4.670
153	10.500	6.520	4.670
173	10.480	6.515	4.660
193	10.460	6.510	4.660
213	10.435	6.505	4.650
233	10.410	6.500	4.650
253	10.380	6.490	4.640
273	10.350	6.485	4.630
293	10.320	6.475	4.620

PHOTOELASTICITY

Strain-Optic Constants:

$p_{11} = 0.091$ $p_{12} = \sim -0.01$ $p_{44} = 0.075$ at 6328 Å

Zinc Selenide

ZnSe

MOLECULAR WEIGHT: 144.34

STRUCTURE: Cubic, zinc-blende type, space group $F\bar{4}3m$

DENSITY: 5.267 gm/cm^3 (x-ray)

MELTING POINT: 1798°K

BOILING POINT:

VAPOR PRESSURE: 0.7mm at 1798°K

HARDNESS: 121 to 150 (Knoop)

DIELECTRIC CONSTANT: $\epsilon_o = 9.2$, $\epsilon_\infty = 6.10$

ENERGY GAP: 2.58 eV at 293°K

OPTICAL PROPERTIES

Refractive Index:

λ (μm)	n	$\frac{dn}{dT}$ ($^{o}K^{-1}$)
3	2.440	
4		4.8×10^{-5}
10	2.405	

Absorption Coefficient: 0.03/cm at 10.6 μm

HEAT CAPACITY: C_p = 4.4 cal/mole, °K at 80°K

DEBYE TEMPERATURE: 246°K

THERMAL CONDUCTIVITY:

0.0335 cal/cm, sec, °K at 300°K
0.0311 cal/cm, sec, °K at 327°K

LINEAR THERMAL EXPANSION COEFFICIENT:

T(°K) =	80	100	120	140	160	180	200	220	240	260	280	300	320	340
α ($\times 10^{-6}$/°K) =	1.2	2.5	3.5	4.2	4.8	5.4	6.0	6.3	6.6	6.3	7.0	7.2	7.3	7.4

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2) (T = 298°K)

$c_{11} = 8.10$ $c_{12} = 4.88$ $c_{44} = 4.41$

PHOTOELASTICITY:

Cadmium Sulfide

CdS

MOLECULAR WEIGHT: 144.46

STRUCTURE: Hexagonal, wurtzite type, space group $P6_3mc$, $a_o = 4.136$ Å

DENSITY: 4.820 gm/cm^3 (x-ray)

SUBLIMATION POINT: 1253°K under one atmosphere

VAPOR PRESSURE:

HARDNESS: 122 (Knoop) parallel to the c-axis; 73 (Knoop) perpendicular to the c-axis

DIELECTRIC CONSTANT: $\epsilon_\infty = 5.4(\parallel C)$, $5.3(\perp c)$ at 300°K

ENERGY GAP: 2.425 eV ($\parallel c$) at 300°K; 2.410 eV($\perp c$) at 300°K

OPTICAL PROPERTIES

Refractive Index:

λ (μm)	n	λ (μm)	n
4	2.271	8	2.240
5	2.262	9	2.235
6	2.255	10	2.228
7	2.248	11	2.215

Absorption Coefficient: 0.032/cm at 10.6 μm; 0.01/cm at 3 μm

HEAT CAPACITY: C_p = 13 cal/mole, ^{o}K

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY: 0.0380 cal/cm, sec, ^{o}K at 293^{o}K

LINEAR THERMAL EXPANSION COEFFICIENT:

$\bar{a}_{\parallel c}$ = 2.1×10^{-6}/^{o}K over the range 77^{o} to 298^{o}K

$\bar{a}_{\perp c}$ = 4×10^{-6}/^{o}K over the range 77^{o} to 298^{o}K

$\bar{a}_{\parallel c}$ = 3.5×10^{-6}/^{o}K over the range 323^{o} to 773^{o}K

$\bar{a}_{\perp c}$ = 5×10^{-6}/^{o}K over the range 323^{o} to 773^{o}K

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dyne/cm^2) (T = 298^{o}K)

$c_{11}^E = 9.07$	$c_{11}^D = 9.13$
$c_{33}^E = 9.38$	$c_{33}^D = 9.623$
$c_{12}^E = 5.81$	$c_{12}^D = 5.88$
$c_{13}^E = 5.10$	$c_{13}^D = 4.97$
$c_{44}^E = 1.504$	$c_{44}^D = 1.560$
$c_{66} = 1.630$	

PHOTOELASTICITY

Strain-Optic Constants:

$p_{11} = 0.142$ $p_{12} = 0.066$ $p_{31} = 0.041$ $p_{44} = 0.054$ at 6328 Å

Cadmium Selenide

CdSe

MOLECULAR WEIGHT: 191.36

STRUCTURE: Hexagonal, space group $P6_3mc$, $a_o = 4.299$ Å, $c_o = 7.010$ Å

DENSITY: 5.663 gm/cm^3 (x-ray)

MELTING POINT: 1623°K

BOILING POINT:

VAPOR PRESSURE: 0.4mm at 1623°K

HARDNESS: 117 (Knoop) ($\parallel$c); 53 (Knoop) ($\perp$c)

DIELECTRIC CONSTANT: $\epsilon_\infty(\perp c) = 6.2$, $\epsilon_\infty(\parallel c) = 6.3$ at 298°K, $\epsilon_o(\perp c) = 9.33$, $\epsilon_o(\parallel c) = 10.22$

ENERGY GAP: 1.74 eV at 300°K

OPTICAL PROPERTIES

Refractive Index:

$\lambda(\mu m)$	n_o	n_e	$\lambda(\mu m)$	n_o	n_e
1.5	2.484	2.504	3.80	2.4498	2.4694
3.00	2.4522	2.4741	4.00	2.4491	2.4685
3.20	2.4532	2.4726	5.0	2.445	2.464
3.40	2.4518	2.4714	10.6	2.442	2.461
3.60	2.4509	2.4702			

Absorption Coefficient: 0.032/cm at 10.6 μm

HEAT CAPACITY: C_p = 8.0 cal/mole, °K at 80°K

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY: 0.0143 cal/cm, sec, °K at 300°K

LINEAR THERMAL EXPANSION COEFFICIENT:

T(°K)	= 80	100	120	140	160	180	200	220	240	260	280	320
$\alpha(\times 10^{-6}/°K)$	= 1.4	2.7	3.5	4.2	4.9	5.4	5.9	6.2	6.5	6.8	7.0	7.3

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

$c_{11}^E = 7.41$	$c_{11}^D = 7.42$
$c_{33}^E = 8.36$	$c_{33}^D = 8.477$
$c_{12}^E = 4.54$	$c_{12}^D = 4.53$
$c_{13}^E = 3.93$	$c_{13}^D = 3.86$
$c_{44}^E = 1.317$	$c_{44}^D = 1.340$
$c_{66} = 1.445$	

PHOTOELASTICITY:

Cadmium Telluride

CdTe

MOLECULAR WEIGHT: 240.02

STRUCTURE: Cubic, zinc-blende type, space group $F\bar{4}3m$, $a_o = 6.4815$ Å

DENSITY: 5.8541 gm/cm^3 (x-ray)

MELTING POINT: 1371°K

VAPOR PRESSURE: 0.3mm at 1371°K

HARDNESS: 41 to 60 (Knoop)

DIELECTRIC CONSTANT: $\epsilon_o = 10.2$, $\epsilon_\infty = 7.1$

ENERGY GAP: 1.44 eV

OPTICAL PROPERTIES

Refractive Index: (for hot-pressed CdTe) T = 298°K

λ (μm)	n	λ (μm)	n
3.0	2.695	7.0	2.679
3.5	2.691	8.0	2.677
4.0	2.688	9.0	2.674
5.0	2.684	10.0	2.672
6.0	2.681		

Absorption Coefficient: 0.001/cm at 10.6 μm; 0.002 at 4 μm

HEAT CAPACITY: C_p = 9.0 cal/mole. ^{o}K at 80^{o}K

DEBYE TEMPERATURE: 145^{o}K

THERMAL CONDUCTIVITY: (for hot pressed CdTe)

T(^{o}K) =	413	393	373	353	333	313	293	273	253	233
κ (cal/sec, cm, ^{o}K) =	0.0085	0.0086	0.0088	0.0090	0.0092	0.0095	0.0098	0.010	0.012	0.013

LINEAR THERMAL EXPANSION COEFFICIENT:

$\bar{\alpha}$ = 5.5 × 10^{-6}/^{o}K in the temperature range 293 to 373^{o}K
$\bar{\alpha}$ = 5.9 × 10^{-6}/^{o}K in the temperature range 293 to 473^{o}K
$\bar{\alpha}$ = 6.2 × 10^{-6}/^{o}K in the temperature range 293 to 523^{o}K

T(^{o}K) =	80	100	120	140	160	180	200	220	240	260	280	300	320	340
α (×10^{-6}/^{o}K) =	0.6	1.4	2.2	3.0	3.4	3.8	4.1	4.4	4.6	4.8	5.0	5.0	5.1	5.0

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

3.13×10^8 dynes/cm^2 at 298°K

4.06×10^8 dynes/cm^2 at 373°K

3.17×10^8 dynes/cm^2 at 77°K

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2) (T = 298°K)

$c_{11} = 5.351$ $c_{12} = 3.681$ $c_{44} = 1.994$

PHOTOELASTICITY:

Arsenic Trisulfide

As_2S_3

MOLECULAR WEIGHT: 246.04

STRUCTURE: Class or crystal-Monoclinic space group, $P2_1/n$, $a_o = 11.47$ Å, $b_o = 9.59$ Å, $c_o = 4.25$ Å, $\beta = 90^o27'$

DENSITY:

3.20 gm/cm^3 at 293°K for the glass

3.489 gm/cm^3 at 293°K for the crystal (x-ray)

SOFTENING POINT: 473° to 573°K

BOILING POINT: 838°K

VAPOR PRESSURE:

HARDNESS: 109 (Knoop)

DIELECTRIC CONSTANT: 8.1

ENERGY GAP:

OPTICAL PROPERTIES

Refractive Index: $T = 298^{\circ}K$

$\lambda(\mu m)$	n	$\frac{dn}{dT}(\times 10^{-6}/^{\circ}K)$	$\lambda(\mu m)$	n	$\frac{dn}{dT}(\times 10^{-6}/^{\circ}K)$
4.200	2.41035	2	9.400	2.38570	0
4.400	2.40956		9.600	2.38436	0
4.600	2.40876		9.800	2.38298	0
4.800	2.40802		10.000	2.38155	
5.000	2.40725	1	10.200	2.38007	
5.200	2.40649	1	10.400	2.37855	
5.400	2.40571		10.600	2.37698	
5.600	2.40493		10.800	2.37536	0
6.0	2.40333		11.000	2.37369	

Absorption Coefficient: 0.029/cm at 4 μm; 0.7/cm at 10.6 μm

HEAT CAPACITY: C_p = 29 cal/mole, ^{o}K

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY: 4×10^{-4} cal/cm, sec, ^{o}K at $313^{o}K$

LINEAR THERMAL EXPANSION COEFFICIENT: $\tilde{a}$ = 24.62 $\times 10^{-6}$ in the range 306 to $438^{o}K$

ELASTICITY

Apparent Elastic Limit:

Young's Modulus: 1.8×10^{10} dynes/cm^2

Modulus of Rupture: 1.7×10^{8} dynes/cm^2

PHOTOELASTICITY

Strain-Optic Constants:

$p_{11} = +0.277$ $\quad p_{12} = +0.272$ at $\lambda = 0.63\ \mu m$

$= +0.308$ $\quad = +0.299$ at $\lambda = 1.15\ \mu m$

Silver Thioarsenate

Ag_3AsS_3

MOLECULAR WEIGHT: 494.72

STRUCTURE: Trigonal, $a_o = 10.74$ Å, $c_o = 8.658$ Å

DENSITY: 5.69 gm/cm^3 (x-ray)

MELTING POINT: 753°K

BOILING POINT:

VAPOR PRESSURE:

HARDNESS: 2 to 2.5 (Mon)

DIELECTRIC CONSTANT: $\epsilon_{11} = 14.5$; $\epsilon_{32} = 18$ at 20×10^6 Hz under constant strain conditions

ENERGY GAP:

OPTICAL PROPERTIES

Refractive Index:

$n_o = 2.7318$, $n_e = 2.5178$ at 4.62 μm

Absorption Coefficient: 0.5/cm for o-ray at 10.6 μm

HEAT CAPACITY:

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY:

LINEAR THERMAL EXPANSION COEFFICIENT:

ELASTICITY:

PHOTOELASTICITY:

Ag_3AsS_3

Germanium

MOLECULAR WEIGHT: 72.59

STRUCTURE: Cubic, diamond type, space group Fd3m, a_o = 5.6576 Å

DENSITY: 5.325 gm/cm^3 at 298°K

MELTING POINT: 1209°K

BOILING POINT:

VAPOR PRESSURE: 10^{-6} mm at 1220°K

HARDNESS: 850 (Knoop)

DIELECTRIC CONSTANT: 16.6 at 10^{10} Hz

ENERGY GAP: 0.67 eV at 293°K

OPTICAL PROPERTIES

Refractive Index: T = 300°K

λ (μm)	n
2.998	4.0453
3.3033	4.0370
3.4188	4.0336
4.258	4.0217
4.866	4.0170
8.66	4.0036
9.72	4.0026
11.04	4.0018

Absorption Coefficient: 0.003/cm at 4 μm; 0.017/cm at 10.6 μm

HEAT CAPACITY:

$T(^{\circ}K)$ =	80	100	120	140	160	180	200	220	240	260	280	300
C_p(cal/gm atom,$^{\circ}K$) =	2.989	3.302	3.838	4.261	4.587	4.837	5.033	5.190	5.318	5.423	5.511	5.590

DEBYE TEMPERATURE: 295°K

THERMAL CONDUCTIVITY:

$T(^{\circ}K)$ =	80	90	100	125	150	175	200	250	300	400	500
κ(cal/cm, sec, $^{\circ}K$) =	0.740	0.607	0.537	0.394	0.310	0.263	0.227	0.174	0.143	0.105	0.0807

LINEAR THERMAL EXPANSION COEFFICIENT:

$T(^{\circ}K)$ =	80	100	120	140	160	180	200	220	240	260	280	300
α ($\times 10^{-6}/^{\circ}K$) =	1.05	2.20	3.25	3.91	4.29	4.58	4.80	5.03	5.23	5.42	5.59	5.75

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T($^\circ$K)	c_{11}	c_{12}	c_{44}
293	12.891	4.832	6.712
273	12.900	4.844	6.724
233	12.975	4.868	6.749
193	13.028	4.888	6.773
153	13.077	4.907	6.798
113	13.122	4.926	6.822
93	13.140	4.936	6.831
73	13.158	4.946	6.840

PHOTOELASTICITY

Stress-Optic Constants: (deg, cm/Kg)

	$\lambda(\mu m)$	90°K	300°K	350°K
q_{44}	2.0	6.01	6.12	6.05
	2.2	5.52	5.68	
	2.4	5.06	5.27	5.26
	2.5	4.86	5.06	5.08
$q_{11} - q_{12}$	1.8	0.62	-1.12	
	2.0	1.07		
	2.2	1.20	+0.63	
	2.4	1.27		
	2.5	1.27		

Silicon

MOLECULAR WEIGHT: 28.086

STRUCTURE: Cubic, diamond type, space group Fd3m, a_o = 5.4301 Å

DENSITY: 2.328 gm/cm^3 at 298°K (x-ray)

MELTING POINT: 1693°K

BOILING POINT:

VAPOR PRESSURE: 10^{-3} mm at 1680°K

HARDNESS 1150 (Knoop)

DIELECTRIC CONSTANT: 13 at 10^{10} Hz

ENERGY GAP: 1.107 eV at 293°K

OPTICAL PROFERTIES

Refractive Index: $T = 299^{\circ}K$

λ (μm)	n	λ(μm)	n
3.00	3.4320	5.50	3.4213
3.3033	3.4297	6.00	3.4202
3.4188	3.4286	8.00	3.4184
3.50	3.4284	8.50	3.4182
4.00	3.4255	10.00	3.4179
4.258	3.4242	10.50	3.4178
4.50	3.4236	11.04	3.4176
5.00	3.4223		

Absorption Coefficient: 0.001/cm at 4 μm; 1/cm at 10.6 μm

HEAT CAPACITY:

$T(^{\circ}K)$	=	80	100	120	140	160	180	200	220	240	260	280	300
C_p(cal/gm atom, $^{\circ}K$)	=	1.261	1.739	2.205	2.650	3.057	3.420	3.755	4.009	4.248	4.455	4.638	4.796

DEBYE TEMPERATURE: $674 \pm 4^{\circ}K$

THERMAL CONDUCTIVITY:

$T(^{\circ}K)$	=	80	90	100	125	150	175	200	250	300	400	500
κ(cal/cm, sec, $^{\circ}K$)	=	3.32	2.72	2.27	1.43	1.00	0.776	0.635	0.597	0.372	0.251	0.191

LINEAR THERMAL EXPANSION COEFFICIENT:

$T(^{\circ}K)$	=	80	100	120	140	160	180	200	220	240	260	280	300	320
$\alpha(\times 10^{-6}/^{\circ}K)$	=	-0.58	-0.18	+0.07	0.33	0.62	0.93	1.25	1.61	1.98	2.29	2.51	2.64	+2.71

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T(°K)	c_{11}	c_{12}	c_{44}
293	16.572	6.392	7.957
273	16.595	6.405	7.964
233	16.638	6.428	7.977
193	16.679	6.452	7.989
153	16.710	6.472	7.998
113	16.735	6.487	8.005
93	16.742	6.493	8.006
73	16.748	6.499	8.007

PHOTOELASTICITY

Strain-Optic Constants:

$p_{11} + 2p_{12} = -0.10$

$p_{11} - p_{12} = -0.167$

$p_{44} = -0.074$

Tellurium

MOLECULAR WEIGHT: 127.60

STRUCTURE: Trigonal, space group $P3_121$ or $P3_221$, $a_o = 4.4572$ Å, $c_o = 5.9290$ Å

DENSITY: 6.2259 gm/cm^3 (x-ray)

MELTING POINT: 723°K

BOILING POINT: 1263°K

VAPOR PRESSURE: 1mm at 793°K

HARDNESS: 2.3 (Moh)

DIELECTRIC CONSTANT: $_c$ = 22.7, $_c$ = 38.6 between 4 and 14 m

ENERGY GAP: 0.29 eV

OPTICAL PROPERTIES

Refractive Index:

λ (μm)	$n_{\perp c}$	$n_{\parallel c}$
4	4.929	6.372
5	4.864	6.316
6	4.838	6.286
7	4.821	6.257
8	4.809	6.253
10	4.796	6.246
12	4.783	6.237

Absorption Coefficient: 0.3/cm at 10.6 μm

HEAT CAPACITY: C_p = 4.986 cal/gm atom, °K at 296°K

DEBYE TEMPERATURE: 145°K

THERMAL CONDUCTIVITY: 0.0150 cal/cm, sec, °K

LINEAR THERMAL EXPANSION COEFFICIENT:

$\alpha_\perp = 27.5 \times 10^{-6}/°K$, $\alpha_\parallel = -1.52 \times 10^{-6}/°K$ at 303°K

T(°K)	80	100	140	180	220	260
$\alpha_\perp$ ($\times 10^{-6}$/°K)	+25.2	+26.0	+26.2	+27.0	+28.0	+28.4

T(°K)	60	100	140	180	220	260
$\alpha_\parallel$ ($\times 10^{-6}$/°K)	-5.8	-4.8	-3.4	-2.6	-2.2	-2.6

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture.

Elastic Coefficient: ($\times 10^{11}$ cgs)

$c_{11} = 3.28$ $c_{12} = 0.86$ $c_{13} = 2.50$ $c_{33} = 7.22$ $c_{44} = 3.14$ $c_{14} = \pm 1.23$

Elastic Moduli: ($\times 10^{-11}$ cgs)

$s_{11} = 56.1$ $s_{12} = -13.6$ $s_{13} = -14.4$ $s_{33} = 23.8$ $s_{44} = 52.9$ $s_{14} = \pm 26.9$

PHOTOELASTICITY

Strain-Optic Constants:

$p_{11} = 0.155$ $p_{12} = 0.130$ at 10.6 μm

Aluminum Oxide

Al_2O_3

MOLECULAR WEIGHT: 101.96

STRUCTURE: Trigonal, space group $R\bar{3}_c$ $a_o = 4.758$ Å, $c_o = 12.991$ Å

DENSITY: 3.987 gm/cm^3 (x-ray)

MELTING POINT: 2323°K

BOILING POINT: 3353°K

VAPOR PRESSURE: .1mm at 2421°K

HARDNESS: 2100 (Knoop)

DIELECTRIC CONSTANT: 10.55 at 298°K over the range 10^2 to 10^8 Hz

ENERGY GAP: 7 eV at 298°K

OPTICAL PROPERTIES

Refractive Index: $T = 297^{\circ}K$

$\lambda(\mu m)$	n	$\frac{dn}{dT}(\times 10^{-6}/^{\circ}C)$	$\lambda(\mu m)$	n
3.2439	1.70457		4.40	1.65662
3.422	1.69818		4.60	1.64840
3.5070	1.69504		4.80	1.63553
3.7087	1.68746		4.954	1.62665
3.80	1.68368	+10	5.1456	1.61514
4.00	1.67524		5.349	1.60202
4.2553	1.66371		5.577	1.58638

Absorption Coefficient: 0.01/cm at 3 μm; 0.04/cm at 4 μm; 0.28 at 4.5 μm

HEAT CAPACITY: C_p = 18.88 cal/mole, °K at 298°K

DEBYE TEMPERATURE: 1027°K

THERMAL CONDUCTIVITY:

$\kappa_{\parallel c}$ = 0.055 cal/cm, sec, °K at 296°K

$\kappa_{\perp c}$ = 0.060 cal/cm, sec, °K at 299°K

LINEAR THERMAL EXPANSION COEFFICIENT:

$\alpha_{\parallel c} = 6.7 \times 10^{-6}$/°K at 323°K

$\alpha_{\perp c} = 5.0 \times 10^{-6}$/°K at 323°K

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2)

T(°K)	c_{11}	c_{12}	c_{13}	c_{14}	c_{33}	c_{44}
100	50.007	16.167	11.137	-2.326	50.239	15.102
150	50.011	16.259	11.199	-2.337	50.210	15.025
200	49.960	16.330	11.212	-2.345	50.132	14.945
250	49.853	16.366	11.205	-2.348	50.024	14.845
300	49.735	16.397	11.220	-2.358	49.911	14.739
350	49.565	16.404	11.187	-2.369	49.750	14.624
400	49.413	16.438	11.161	-2.377	49.592	14.505
450	49.264	16.481	11.102	-2.388	49.391	14.381
500	49.061	16.476	11.052	-2.401	49.182	14.256

PHOTOELASTICITY

Strain-Optic Constants:

$p_{11} = \sim 0.20$

$p_{12} = \sim 0.08$

$p_{44} = 0.085$

$p_{31} = \sim 0$

$p_{13} = \sim 0$

$p_{33} = 0.252$

Magnesium Oxide

MgO

MOLECULAR WEIGHT: 40.31

STRUCTURE: Cubic, space group Fm3m, $a_o = 4.213$ Å

DENSITY: 3.581 gm/cm^3 (x-ray)

MELTING POINT: 3073°K

BOILING POINT: 3873°K

VAPOR PRESSURE:

HARDNESS: 692 (Knoop)

DIELECTRIC CONSTANT: $\epsilon_o = 9.8$, $\epsilon_\infty = 2.95$

ENERGY GAP: 7.77 eV at 295°K

OPTICAL PROPERTIES

Refractive Index: T = 296°K

λ (μm)	n	$\frac{dn}{dT}$ (×10^{-6}/°K)
3.3033	1.68526	
3.5078	1.68055	
4.258	1.66039	19.2
5.138	1.63138	
5.35	1.62404	

Absorption Coefficient: 0.05/cm at 5.5 μm

HEAT CAPACITY: C_p = 8.94 cal/mole, °K at 298°K

DEBYE TEMPERATURE: 943°K at 80°K

THERMAL CONDUCTIVITY: 0.06 cal/cm, sec, °K at 233°K

LINEAR THERMAL EXPANSION COEFFICIENT:

T(°K) =	80	100	120	140	160	180	200	220	240	260	273	280	300
$\alpha(\times 10^{-6}/°K)$ =	1.2	2.3	3.4	4.6	5.6	6.6	7.4	8.1	8.8	9.4	9.7	9.9	10.3

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients (Adiabatic): ($\times 10^{11}$ dynes/cm^2)

T(°K)	c_{11}	c_{12}	c_{44}	T(°K)	c_{11}	c_{12}	c_{44}
80	29.77	8.58	15.673	310	28.88	8.78	15.464
150	29.72	8.64	15.643	330	28.78	8.80	15.438
170	29.63	8.66	15.627	350	28.64	8.81	15.410
190	29.53	8.68	15.609	370	28.52	8.83	15.382
210	29.42	8.69	15.589	390	28.40	8.85	15.354
230	29.32	8.71	15.568	410	28.27	8.86	15.324
250	29.21	8.73	15.542	430	28.14	8.88	15.294
270	29.10	8.74	15.516	450	28.01	8.89	15.264
290	28.99	8.76	15.490	470	27.88	8.91	15.234

PHOTOELASTICITY

Stress-Optic Constants: ($\times 10^{13}$ cgs)

T(°K)	$q_{11} - q_{12}$	q_{44}
293	1.24	0.68
373	1.25	0.72
423	1.28	0.74
473	1.33	0.76

Strain-Optic Constants:

$p_{11} = -0.31$

$p_{12} = -0.07$ at $\lambda = 5890$ Å

$p_{44} = -0.107$

TI 1173

$Ge_{28}Sb_{12}Se_{60}$

FORMULA WEIGHT: 8231.12

STRUCTURE: Glass

DENSITY: 4.67 gm/cm^3 at 298°K

SOFTENING POINT: 600°K

BOILING POINT:

VAPOR PRESSURE:

HARDNESS: 150 (Knoop)

DIELECTRIC CONSTANT:

ENERGY GAP:

OPTICAL PROPERTIES

Refractive Index:

λ(μm)	n	λ(μm)	n	$\frac{dn}{dT}(^{o}K^{-1})$
3.0	2.6263	6.0	2.6135	3.1×10^{-5}
3.5	2.6228	9.0	2.6040	
4.0	2.6200	9.5	2.6024	
4.5	2.6182	10.0	2.6002	2.8×10^{-5}
5.0	2.6165	10.5	2.5984	
5.5	2.6145	11.0	2.5962	

Absorption Coefficient: 0.002/cm at 10.6 μm

HEAT CAPACITY: $C = 0.066\ cal/gm^{\circ}K$

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY: $7.2 \times 10^{-4}\ cal/cm, sec, ^{\circ}K$

LINEAR THERMAL EXPANSION COEFFICIENT:

$\bar{\alpha} = 15.7 \times 10^{-6}/^{\circ}K$ in the range 273 to 293°K

$\bar{\alpha} = 15.8 \times 10^{-6}/^{\circ}K$ in the range 293 to 333°K

ELASTICITY

Apparent Elastic Limit:

Modulus of Elasticity: 3.1×10^{6} dynes/cm^{2} at 298°K

Modulus of Rupture:

Annealed 17.3×10^{7} dynes/cm^{2}

Tempered 6.9×10^{8} dynes/cm^{2}

Poisson's Ratio: 0.25

PHOTOELASTICITY:

TI 20

$Ge_{33}As_{12}Se_{55}$

170

FORMULA WEIGHT: 7187.85

STRUCTURE: Glass

DENSITY: 4.40 gm/cm^3

SOFTENING POINT: > 610°K

BOILING POINT:

VAPOR PRESSURE:

HARDNESS: 171 (Knoop)

DIELECTRIC CONSTANT·

ENERGY GAP:

OPTICAL PROPERTIES

Refractive Index: T = 298°K

λ (μm)	n	λ (μm)	n
3.0	2.513	6.0	2.503
3.5	2.510	9.0	2.[illegible]
4.0	2.508	9.5	2.493
4.5	2.506	10.0	2.492
5.0	2.505	10.5	2.490
5.5	2.504	11.0	2.488

Absorption Coefficient: < 1.10/cm at 10 μm; ≤0.03/cm. at 3 μm

HEAT CAPACITY: C = 0.070 cal/gm, ^{o}K

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY: 6.1×10^{-4} cal/cm, sec, ^{o}K

LINFAR THERMAL EXPANSION COEFFICIENT: $13.3 \times 10^{-6}/^{o}$K

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Modulus of Elasticity: 3.2×10^6 dynes/cm^2 at 298°K

Shear Modulus: 1.3×10^6 dynes/cm^2 at 298°K

Poisson's Ratio: 0.19

PHOTOELASTICITY:

KRS-5

FORMULA WEIGHT: 307.78

STRUCTURE: Cubic

DENSITY: 7.54 gm/cm^3

SOFTENING POINT: >470°K

BOILING POINT:

VAPOR PRESSURE:

HARDNESS: 40 (Knoop)

DIELECTRIC CONSTANT: 32.5 in the range 10^2 to 10^7 Hz

ENERGY GAP: 0.66 eV

OPTICAL PROPERTIES

Refractive Index:

λ (μm)	n	$\frac{1}{n}\frac{dn}{dt}$ ($^{o}K^{-1}$)
3.3	2.36	
6.0		9.96×10^{-5}
10.0		9.91×10^{-5}
10.6	2.37	

Absorption Coefficient: 0.005/cm at 10.6 μm

HEAT CAPACITY:

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY: 13×10^{-4} cal/cm, sec, ^{o}K at 293^{o}K

LINEAR THERMAL EXPANSION COEFFICIENT: $58 \times 10^{-6}/^{o}$K between 293 and 373^{o}K

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture:

Elastic Coefficients: ($\times 10^{11}$ dynes/cm^2) (Room Temperature)

$c_{11} = 3.31$ $c_{12} = 1.320$ $c_{44} = 0.579$

Young's Modulus: 1.1157×10^{11} dynes/cm^2

PHOTOELASTICITY

Strain-Optic Constants:

$p_{11} - p_{12} = 0.08$

$p_{44} = 0.157$ at 0.61 μm

BS-37A

$CaO-MgO-Al_2O_3-SiO_2$

FORMULA WEIGHT:

STRUCTURE: Glass

DENSITY: 2.9 gm/cm^3

SOFTENING POINT: 973°K

BOILING POINT:

VAPOR PRESSURE:

HARDNESS: 6 (Moh)

DIELECTRIC CONSTANT:

ENERGY GAP:

OPTICAL PROPERTIES

Refractive Index:

λ (μm)	n
3.000	1.6236
3.500	1.6180
4.00	1.6074
4.5	1.595

Absorption Coefficient: 0.05/cm at 3 μm; 1.75/cm at 5 μm

HEAT CAPACITY: C = 0.203 cal/gm, ^{o}K

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY: 0.119×10^{-4} cal/cm, sec, ^{o}K at 323^{o}K

LINEAR THERMAL EXPANSION COEFFICIENT:

$\bar{\alpha} = 9.15 \times 10^{-6}/^{o}$K in the range 293 to 773^{o}K

$\bar{\alpha} = 8.75 \times 10^{-6}/^{o}$K in the range 293 to 673^{o}K

$\bar{\alpha} = 8.35 \times 10^{-6}/^{o}$K in the range 293 to 573^{o}K

$\bar{\alpha} = 7.9 \times 10^{-6}/^{o}$K in the range 293 to 473^{o}K

$\bar{\alpha} = 7.4 \times 10^{-6}/^{o}$K in the range 293 to 373^{o}K

$\bar{\alpha} = 7.9 \times 10^{-6}/^{o}$K at 373^{o}K

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture: 8.3×10^{8} dynes/cm^2 at 298°K

Young's Modulus: 10.7×10^{11} dynes/cm^2 at 298°K

PHOTOELASTICITY:

BS-39B

$CaO\text{-}BaO\text{-}MgO\text{-}Al_2O_3$

FORMULA WEIGHT:

STRUCTURE: Glass

DENSITY: 3.1 gm/cm^3

SOFTENING POINT:

BOILING POINT:

VAPOR PRESSURE:

HARDNESS: 6 (Moh)

DIELECTRIC CONSTANT:

ENERGY GAP:

OPTICAL PROPERTIES

Refractive Index:

λ (μm)	n
3.000	1.6364
3.500	1.6282
4.00	1.6181
4.5	1.607

Absorption Coefficient: 0.02/cm at 3 μm; 0.43/cm at 5 μm

HEAT CAPACITY: $C = 0.206$ cal/gm, $^{\circ}K$

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY: 0.106×10^{-4} cal/cm, sec, $^{\circ}K$ at $323^{\circ}K$

LINEAR THERMAL EXPANSION COEFFICIENT: $\bar{\alpha} = 9.7 \times 10^{-6}/^{\circ}K$ between 293 and $770^{\circ}K$

ELASTICITY

Apparent Elastic Limit:

Modulus of Rupture: 6.9×10^{8} dynes/cm^2 at 298°K

Young's Modulus: 13.9×10^{11} dynes/cm^2 at 298°K

PHOTOELASTICITY:

T-12

$(Ba,Ca)F_2$ (Hot Pressed)

MOLECULAR WEIGHT:

STRUCTURE:

DENSITY: 4.35 gm/cm^3

SOFTENING POINT: 1333°K

BOILING POINT:

VAPOR PRESSURE:

HARDNESS: 4.5 (Moh)

DIELECTRIC CONSTANT: 8.5 at 10^4 Hz

ENERGY GAP:

OPTICAL PROPERTIES

Refractive Index: n = 1.41 at 3.3 μm

Absorption Coefficient: 0.12/cm at 4 μm

HEAT CAPACITY: $C = 0.13\ cal/gm, {}^{o}K$

DEBYE TEMPERATURE:

THERMAL CONDUCTIVITY:

LINEAR THERMAL EXPANSION COEFFICIENT:

$20.2 \times 10^{-6}/{}^{o}K$ in the range 273 to $298{}^{o}K$

$21.0 \times 10^{-6}/{}^{o}K$ in the range 298 to $333{}^{o}K$

ELASTICITY:

PHOTOELASTICITY:

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13. ABSTRACT

This COMPENDIUM gathers together and presents in concise outline form much of the essential data on materials which appear to show promise for use as high power infrared laser windows in the 10.6-μm and 3- to 6-μm regions.

The data is presented in two ways: first, all candidate materials are ranked (based on their best measured values) and listed in terms of a particular key window parameter such as optical absorption, hardness, etc.; and second, pertinent data for a given candidate material are collected and presented as a single package, for example for KCl, or for CdTe, etc.

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