

AD-A146 657

= (2)

TACTICAL WEAPON
GACIAC

GUIDANCE & CONTROL
INFORMATION ANALYSIS CENTER

HANDBOOK OF THE PROPERTIES OF OPTICAL MATERIALS

L.N. DURVASULA
N.P. MURARKA

GACIAC HB 84-01
JANUARY 1984

DTIC FILE COPY

Published by GACIAC
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

DoD Technical Sponsor
Joint Service Guidance and Control Committee
Members from OUSDR&E, Army, Navy,
Air Force, and DARPA

Approved for public release:
Distribution unlimited

DTIC
ELECTE
OCT 15 1984
B

84 10 10 012

NOTICES

Handbook. This Handbook has been published by the Tactical Weapon Guidance and Control Information Analysis Center (GACIAC) as part of its services to the guidance and control community. GACIAC is a DoD Information Analysis Center, administered by the Defense Technical Information Center, operated by IIT Research Institute under Contract No. DLA900-80-C-2853. GACIAC is funded by DTIC, DARPA, and U. S. Army, U. S. Navy, U. S. Air Force Laboratories/Controlling Activities having an interest in tactical weapon guidance and control. The Contracting Officer is Mrs. S. Williams, DESC, Dayton, Ohio. The Contracting Officers Technical Representative is Mr. H. C. Race, DRSMI-RN, U. S. Army Missile Command, Redstone Arsenal, Alabama 35898.

Reproduction. Permission to reproduce any material contained in this document must be requested and approved in writing by the U. S. Army Missile Command, ATTN: DRSMI-RN, Redstone Arsenal, Alabama 35898. This document is only available from GACIAC, IIT Research Institute, 10 West 35th Street, Chicago, Illinois 60616.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release: Distribution unlimited	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE			4. PERFORMING ORGANIZATION REPORT NUMBER(S) GACIAC HB-84-01	
5. MONITORING ORGANIZATION REPORT NUMBER(S)			6a. NAME OF PERFORMING ORGANIZATION IIT Research Institute	
6b. OFFICE SYMBOL (if applicable)			7a. NAME OF MONITORING ORGANIZATION U.S. Army Missile Command	
6c. ADDRESS (City, State, and ZIP Code) 10 West 35th Street Chicago, IL 60616			7b. ADDRESS (City, State, and ZIP Code) Attn: DRSMI-RN Redstone Arsenal, AL 35898	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Night Vision & Electro-Optics			8b. OFFICE SYMBOL (if applicable)	
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DLA900-80-C-2853			10. SOURCE OF FUNDING NUMBERS	
8c. ADDRESS (City, State, and ZIP Code) Attn: DELNV-R Fort Belvoir, VA 22060			PROGRAM ELEMENT NO. 65802 S	PROJECT NO. 1.0
			TASK NO.	WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) Handbook of The Properties of Optical Materials				
12. PERSONAL AUTHOR(S) L.N. Durvasula / N.P. Murarka				
13a. TYPE OF REPORT Handbook		13b. TIME COVERED FROM TO		14. DATE OF REPORT (Year, Month, Day) January 1984
				15. PAGE COUNT 253
16. SUPPLEMENTARY NOTATION This document available only from GACIAC, IIT Research Institute, 10 West 35th Street, Chicago, Illinois 60616. (410948) Cost \$35.00				
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	Electro-optic materials Detector materials Handbook	
11	2 & 3		Acousto-optic materials Optical materials	
20	6 & 12		Passive materials Materials	
19. ABSTRACT (Continue on reverse if necessary and identify by block number) This report summarizes a literature review of infrared, electro-optical, acousto-optic, passive and detector materials. In particular the physical, thermal, mechanical, electrical and optical properties of these classes of materials have been presented. The data presented here is based on the available unclassified published literature which has also been referenced in the report.				
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Howard C. Race			22b. TELEPHONE (Include Area Code) (205)876-5449	22c. OFFICE SYMBOL DRSMI-RN

DD FORM 1473, 84 MAR

03 APR edition may be used until exhausted
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

HANDBOOK OF THE PROPERTIES OF OPTICAL MATERIALS

L.N. DURVASULA

N.P. MURARKA

IIT RESEARCH INSTITUTE

Published by GACIAC
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By <i>\$35.00</i>	
Distribution <i>GACIAC</i>	
Availability Codes	
Dist	Avail and/or Special
<i>A-121</i>	

Copies available only from GACIAC.
Reproduction not authorized except
by specific permission.

Approved for public release.
Distribution unlimited.

GACIAC - A DoD Information Analysis Center
Operated by IIT Research Institute, 10 W. 35th St., Chicago, IL 60616
DoD Technical Sponsor - Joint Service Guidance and Control Committee
Members from OUSDR&E, Army, Navy, Air Force, and DARPA

FOREWORD

This report was prepared for the Night Vision and Electro-Optics Laboratory, Fort Belvoir as part of a special task entitled "Handbook of Properties of Optical Materials". This special task was conducted by IIT Research Institute, Chicago under the Guidance and Control Information Analysis Center (GACIAC), Contract DLA900-80-C-2853.

This report summarizes the literature review of optical materials including electro-optical, acousto-optic, passive and detector materials. In particular the structural, chemical, electrical and optical properties of these materials have been presented. The data presented are based on the available unclassified published literature. Although appropriate care has been taken to synopsise the referenced materials, any suggestions for improvements will be welcome.

This program was administered under the direction of NV&EOL with Dr. T. Cox as Project Engineer. Dr. N.P. Murarka was the IITRI Program Manager.

TABLE OF CONTENTS

	Page
1. INTRODUCTION.....	1
2. DEFINITIONS.....	3
2.1 Basic Properties Definitions.....	3
2.1.1 Physical Properties.....	3
2.1.2 Thermal Properties.....	3
2.1.3 Mechanical Properties.....	5
2.1.4 Electrical Properties.....	5
2.1.5 Optical Properties.....	6
2.2 Electro-Optical Materials.....	10
2.3 Acousto-Optic Materials.....	12
2.4 Passive Materials.....	14
2.5 Detector Materials.....	14
References.....	16
APPENDIX A PROPERTIES OF MATERIALS.....	A-1
As ₂ Se ₃ Arsenic Selenide.....	A-2
As ₂ S ₃ Arsenic Trisulfide.....	A-5
BaF ₂ Barium Fluoride.....	A-8
CdSe Cadmium Selenide.....	A-15
CdS Cadmium Sulfide (Greenockite).....	A-19
CdTe Cadmium Telluride.....	A-25
CdGeAs ₂	A-30
CdGeP ₂	A-34
CaCO ₃ Calcium Carbonate (Aragonite, Calcite).....	A-37
CsBr Cesium Bromide.....	A-43
CsI Cesium Iodide.....	A-48
CuCl Copper Chloride (Nantokite).....	A-52
GaSb Gallium Antimonide.....	A-55
GaAs Gallium Arsenide.....	A-60
Ge Germanium.....	A-66
InSb Indium Antimonide.....	A-78

TABLE OF CONTENTS CONT.

	Page
InAs Indium Arsenide.....	A-82
InP Indium Phosphide.....	A-88
PbSe Lead Selenide.....	A-93
PbS Lead Sulfide (Galena).....	A-99
Pb _{1-x} Sn _x Te Lead-Tin-Telluride.....	A-105
LiF Lithium Fluoride.....	A-110
LiNbO ₃ Lithium Niobate.....	A-116
LiTaO ₃ Lithium Tantalate.....	A-123
Hg _{1-x} Cd _x Te Mercury Cadmium Telluride.....	A-130
HgS Mercury Sulfide (Cinnabar, Metacinnabar).....	A-134
KI Potassium Iodide.....	A-138
AgCl Silver Chloride (Cerargyrite).....	A-142
Ag ₃ SbS ₃ Silver Thioantimonite (Pyrargyrite).....	A-145
Ag ₃ AsS ₃ Silver Thioarsenite (Proustite).....	A-148
KCl Potassium Chloride (Sylvite).....	A-152
Si Silicon.....	A-157
KBr Potassium Bromide.....	A-162
AgGaS ₂	A-166
AgGaSe ₂	A-171
NaCl Sodium Chloride (Halite, Rocksalt).....	A-174
NaF Sodium Fluoride (Villiaumite).....	A-179
Te Tellurium.....	A-183
Tl ₃ AsS ₄	A-188
Tl ₃ AsSe ₃	A-192
Tl ₃ PSe ₄	A-197
TlBr-TlCl (KRS-6).....	A-201
TlBr-TlI (KRS-5).....	A-206
ZnSe Zinc Selenide.....	A-213
ZnS Zinc Sulfide (Sphalerite, Wurtzite).....	A-218
ZnGeP ₂	A-224
ZnSiAs ₂	A-228

1. INTRODUCTION

The properties of materials for optical components in optical systems in the infrared are of importance for the design of the system. A knowledge of the optical, physical, thermal, electrical and mechanical properties of the optical materials enables the selection and trade-off analysis for components and optical system requirements. The collection and compilation of the properties of optical materials in the infrared in a handbook form provides an accessible reference for various properties. In this "Handbook of Properties of Optical Materials" in the Infrared, four general classes of materials are included. They are: a) Electro-Optic Materials, b) Acousto-Optic Materials, c) Detector Materials, and d) Passive Components. The listed properties are:

- Structure: Crystal structure
Lattice constant
- Physical Properties: Molecular weight
Density
Solubility in water
- Thermal Properties: Melting/softening temperature
Linear expansion coefficient
Thermal conductivity
Specific heat
- Mechanical Properties: Young's modulus
Hardness
Elastic constants
Modulus of rigidity
- Electrical Properties: Dielectric constant
Resistivity
Band gap energy
Effective mass
Mobility
- Optical Properties: Transmission
Reflection
Expansion coefficient
Dispersion equation

In addition the relevant properties that characterize a particular physical process or phenomenon for each class of material are included.

The data is collected from a thorough literature search and presented in the form of tables and graphics. The literature search includes: a) technical journals, review articles and reports, b) text books, c) conference and symposia proceedings, d) indexing and abstract services, e) vendors' product specification sheets, f) bibliographies and g) private communications. The data collected is most recent to the extent possible; however, the reader should consult the original work to determine the reliability or accuracy of the measurements. References for the most pertinent properties are included for each material.

2. DEFINITIONS

The physical, thermal, mechanical, electrical and optical properties of several infrared materials are presented in Appendix A. The definitions of the properties described in this report are given below followed by the generic characteristics of the electro-optic acousto-optic, passive and detector materials.

2.1 Basic Properties Definitions

2.1.1 Physical Properties⁽¹⁾

Solubility, Molecular Weight, and Specific Gravity

The solubility of an optical material is a measure of its tendency to be attacked by water or other chemicals. When a sample is immersed in water long enough to establish a saturated solution, the sample's difference in weight (before and after) is a measure of the amount of solute, which is specified as the number of grams of the material in 100 g of water (100 ml). Many substances with values of the parameter less than 10^{-3} have been listed as insoluble.

Specific gravity is the ratio of the density of a substance to that of water. Since water has a density of about 1 g/ml, or 62.5 lb/ft³, one can easily calculate the density in either system of units, but specific gravity is dimensionless.

2.1.2 Thermal Properties⁽¹⁾

It generally requires different amounts of energy to increase equal masses of different materials by the same temperature increment. The energy required to raise a unit mass of material 1 degree is called the specific heat or specific-heat capacity. In the cgs system, the units are cal/(g)(°C). In the SI system they are J/(kg)(°C). In the English system they are Btu/(lb)(°F). The heat capacity can be defined thermodynamically as

$$C_v = \left. \frac{dQ}{dT} \right|_v \quad \text{or} \quad C_p = \left. \frac{dQ}{dT} \right|_{p_2}$$

$$c_v = \frac{1}{m} C_v \quad \text{and} \quad c_p = \frac{1}{m} C_p$$

The heat capacity at constant volume is the change in energy of a substance for a given change in temperature when the substance is held at constant volume. The heat capacity at constant pressure is the change in heat divided by the change in temperature at constant pressure. The corresponding specific heats normalize these to unit mass, as indicated. In practice, all specific-heat values for optical materials are at constant pressure, not constant volume. Thus, symbolically, all measurements given herein are for c_p . Specific heats are by definition equal in the cgs, mks [in which one uses kcal/(kg)(°C)], and English systems.

When heat is applied to one end of a bar of material, the heat is conducted by the bar along its length (ignoring end effects). The thermal conductivity of the material is a measure of its tendency to allow this heat to flow. The defining equation is

$$\frac{dQ}{dt} = kA \frac{dT}{dx}$$

where Q = heat energy

t = time

A = cross-sectional area

T = temperature

x = length coordinate of bar

k = thermal conductivity

The most common units for thermal conductivity are cal/(s)(cm)(°C) and Btu/(in)(h)(R); another useful unit is W/(m)(K). The relationship between them are

$$1 \text{ Btu/(in)(h)(R)} = 20.75 \text{ W/(cm)(K)} = 178.6 \text{ cal/(s)(cm)(K)}$$

When heat is applied uniformly to a bar of material, the bar changes its length. The change in length may be divided by the original length to obtain a relative change. This relative change in length per degree temperature change is the coefficient of linear expansion, usually designated α :

$$\alpha = \frac{1}{L} \frac{\partial L}{\partial T}$$

It can be shown that the bulk expansion, usually designated by β , is just 3 times α . The linear expansion can be expressed as a series:

$$\alpha = A \times 10^{-6} + B \times 10^{-8}T + C \times 10^{-11}T^2$$

The coefficient A corresponds to the linear change of the coefficient of linear expansion and has the dimensions of reciprocal temperature; B and C have units of reciprocal square and reciprocal cube of temperature, respectively.

2.1.3 Mechanical Properties⁽¹⁾

Elastic Coefficients

Hooke's law states that for small deformations the strain on a solid is proportional to the stress. The constants of proportionality in the different directions are the elastic stiffness constants c_{hk} , which have units of pressure in bars.

Elastic Moduli

Data sheets include data for Young's modulus. The units are pounds per square inch. Young's modulus is usually defined as the ratio of stress to strain. Here the stress is the force per unit normal area and strain is the fractional change in length.

Hardness

Values of hardness for several materials are given in Knoop values with the indenter aligned in either the [100] or the [110] direction and the indenter load is given when known. Where Knoop values were not available, Mohs or Vickers values are given.

2.1.4 Electrical Properties⁽¹⁾

Dielectric Constant

The dielectric constant is a variable depending upon frequency and temperature, among other things; permittivity may be a better name. The displacement D is related to the electric field strength E by the permittivity; $D = \epsilon E$. For free space $D = \epsilon_0 E$, and for most materials $\epsilon = \epsilon_r \epsilon_0$.

Resistivity

In an optical material where ohmic conduction occurs the current density J is given by $J = E/\rho$ where ρ is the resistivity and E is the applied electric field. In a homogeneous isothermal crystal ρ is a tensor having the symmetry of the crystal.

Band Gap Energy

According to quantum theory an electron bound to an atom can exist in only a limited number of discrete energy states. A large number of noninteracting identical atoms will all have the same set of allowed discrete energy states. If now the atoms are brought closer together and finally to their actual distance in a solid, they begin to interact and the energy levels will split. In a periodic array of atoms (crystalline solid), the allowed states tend to cluster into continuous groups of energy levels called energy bands. In an optical semiconductor, the highest occupied energy band (valence band) is completely filled at absolute zero. The band gap energy is the energy difference between the valence band and the next higher band (conduction band).

Effective Mass

Near the top or the bottom of a band, the energy is generally a quadratic function of the wave vectors, so that by analogy with the expression $E = p^2/2m = \hbar^2 k^2/2m$ for free electrons we can define an effective mass m^* such that $\partial^2 E / \partial k^2 = \hbar^2 / m^*$ (p = momentum, k = wavevector, $\hbar$ = Planck's constant/ 2π). The effective mass of an electron is positive. Near the top of a band m^* is negative, so that the motion corresponds to that of a positive charge (hole).

Mobility

The drift mobility of charge carriers is defined as the drift velocity per unit applied electric field.

2.1.5 Optical Properties

Absorption, Reflection, and Transmission

When light is incident on a plane-parallel plate of material, some is reflected, some is absorbed, and some is transmitted.

In general, the light is reflected many times from side to side. If the sum of all light is considered,

$$I_0 = I_R + I_A + I_T$$

$$1 = \frac{I_R}{I_0} + \frac{I_A}{I_0} + \frac{I_T}{I_0} = \rho + \alpha + \tau$$

where I_0 = incident flux density
 I_R = reflected flux density
 I_A = absorbed flux density
 I_T = transmitted flux density
 ρ = reflectance
 α = absorption
 τ = transmittance

Specifically, τ is the external transmittance, a measurable quantity. The ending "ance" is used to indicate that these are properties of a given sample. If the sample does not scatter but only absorbs and reflects, the relationship between I_1 and I_2 is exponential:

$$\frac{I_2}{I_1} = \tau_{int} = e^{-ax}$$

where a = absorption coefficient
 x = sample thickness
 τ_{int} = internal transmittance

Then it follows that

$$\tau = \frac{(1 - \rho)^2 e^{-ax}}{1 - \rho^2 e^{-2ax}}$$

A plane wave incident normally on a flat, specular, absorbing surface will have the reflectivity given by Fresnel

$$\rho = \left| \frac{n - ik - 1}{n - ik + 1} \right|^2$$

where $k = \text{extinction coefficient} = 4\pi a/\lambda = 4\pi a/n\lambda_0$

$\lambda = \text{wavelength of light in medium}$

$n = \text{refractive index of medium}$

$\lambda_0 = \text{wavelength of light in vacuum}$

The substitution of these equations into each other leads to complicated expressions omitted here. Transmission data given in this section is usually external transmittance. Absorption-coefficient data are for a , as in the equations above. Some extinction coefficients are given as defined above and not the quantity determined by

$$\tilde{n} = n(1 - ik)$$

External-transmittance data are usually those found experimentally with a double-beam spectrophotometer, or they are corrected data from a single-beam system. Absorption-coefficient data are usually obtained by measuring the transmittance of two samples:

$$\tau_1 = \frac{(1 - \rho_1)^2 e^{-a_1 x_1}}{1 - \rho_1^2 e^{-2a_2 x_2}} \quad \tau = \frac{(1 - \rho_2)^2 e^{-a_2 x_2}}{1 - \rho_2^2 e^{-2a_2 x_2}}$$

If the reflectances and absorption coefficients are the same ($\rho_1 = \rho_2$ and $a_1 = a_2$), then

$$a = \frac{\ln \tau_1 - \ln \tau_2}{x_1 - x_2}$$

but only if

$$\frac{1 - \rho^2 e^{-2ax_2}}{1 - \rho^2 e^{-2ax_1}} = 1$$

This correction factor can be accounted for by checking with the original equations.

A more elegant way to obtain an absorption coefficient is through the measurement of emittance. From the expressions given by McMahon⁽²⁾, sample emittance is given by

$$\epsilon^* = \frac{(1 - \rho)(1 - \tau_{int})}{1 - \rho\tau_{int}}$$

This equation for small "a" reduces to the simple relationship

$$a = \frac{\epsilon^*}{X}$$

Thus emittance data can be converted into absorption-coefficient data by dividing by the thickness.

Another method should be mentioned where the sample is illuminated with a single beam from a laser. The rise in temperature of the sample is related to the amount of energy absorbed and the thermal conductance, convective losses, and reradiation by the sample. This method is most useful for large input in a short time.

Refractive Index⁽²⁾

For a nonabsorbing medium the refractive index n is given simply as the ratio of the velocity of light in vacuum c to that in the sample v

$$n = \frac{c}{v}$$

The relative refractive index is the ratio of the index of one medium to that of another; for instance,

$$n_{\text{rel}} = \frac{n_{\text{mat}}}{n_{\text{air}}}$$

This is the refractive index of a material relative to that of air. All the data in this section are refractive indexes of the material relative to the refractive index of air rather than to that of vacuum. Of course materials vary from sample to sample, and these data are only representative.

For anisotropic materials, data are given for the direction of principal interest within the crystal.

Data for the change in refractive index with temperature are sometimes obtained by measuring the index at different temperatures and sometimes by interferometric measurements.

The dispersion curves are usually obtained by fitting the data to a Cauchy Sellmeier, or Herzberger equation. Least-squares fits are generally used.

2.2 Electro-Optical Materials

Control of optical path length may be accomplished by applying an electric field to certain types of optically transparent crystals. The change in path length can be employed to change the orientation of the polarization of a transmitted light wave. By using such crystals with polarizers, light modulation may be achieved by application of a time varying electric field. In principal, this modulating effect may be regarded as a second order effect in the superposed fields of the light wave and the applied control signal. The physical manifestation of the superposed fields is a change in the refractive index which is at best on the order of 10^{-3} . While this is marginal for steering of light beams by change of the deflection angles of prisms, it is more than adequate for modulating the phase, and hence by interference the intensity of visible or near infrared light.

The electro-optic coefficients do not exhibit much dependance on wavelength. However, the phase change for a given refractive index difference is inversely proportional to wavelength and substantial modulation becomes increasingly more difficult toward the farther infrared.

Refractive index changes proportional to the square of an applied field are permitted by symmetry in all materials, but are significant only in strongly polar substances. The linear electro-optic effect occurs only in acentric crystals. The form of the electro-optic tensor is determined by the point group symmetry of the crystal. Only the 21 acentric groups (those lacking a center of inversion) may have nonvanishing coefficients.

The electro-optic effect in crystals is essentially a change in the crystalline birefringence when an electric field is applied. The refractive index of a crystal is described by an index ellipsoid.

$$B_{ij} x_i x_j = 1 = B_{11} x_1^2 + B_{22} x_2^2 + B_{33} x_3^2 + 2B_{12} x_1 x_2 \\ + 2B_{13} x_1 x_3 + 2B_{23} x_2 x_3$$

with $B_{ij} = B_{ji}$

$$\text{and } B_{ij} = \epsilon_0 \frac{\partial E_i}{\partial D_j} = \frac{1}{\epsilon_{ij}} \text{ and}$$

where ϵ_0 = the vacuum permittivity and ϵ the relative dielectric constant.
The electro-optic coefficient $r_{ij,R} = r_{eR}$ is defined by

$$\Delta B_{ij} = r_{ijk} E_k$$

$$\Delta B_l = r_{lk} E_k$$

The indices i, j, k run from 1 to 3 and $l = (ij)$ refers to the six reduced combinations $1 = 11, 2 = 22, 3 = 33, 4 = 23, 5 = 13, 6 = 12$ of the electro-optic coefficients. If r_{ij} are determined at constant strain, for example at frequencies well above the acoustic resonances, the crystal is clamped and the electro-optic coefficients are denoted r_{ij}^S . If r_{ij} are determined at constant stress for example at low frequencies well below the acoustic resonances, the crystal is said to be free and the electro-optic coefficients are denoted r_{ij}^T . The symmetry of the crystal determines which electro-optic coefficients are non-zero.

The polarization P induced in a material subject to electromagnetic radiation with electric field E is given by

$$P = \epsilon_0 \chi^1 E$$

where ϵ_0 is the permittivity of the free space and χ^1 is the linear optical susceptibility of the medium. The linear susceptibility χ^1 is related to the index of refraction, n , of the medium by:

$$\chi^1 = n^2 - 1$$

For large values of optical electric field the induced polarization can be represented as a series:

$$P = \epsilon_0 [\chi^1 \cdot E + \chi^{(2)} \cdot E^2 + \chi^{(3)} \cdot E^3 + \dots]$$

where $\chi^{(2)}$ and $\chi^{(3)}$ are the non-linear optical susceptibilities of the medium and are responsible for a large variety of non-linear optical phenomena. For example, the quadratic polarization gives rise to the phenomena of second harmonic generation (SHG), d.c. rectification, linear electro-optic or Pockel's effect and parametric generation. For the case of SHG, the second order polarization at the harmonic frequency is given by:

$$P_i^{2\omega} = \epsilon_0 \sum_{j,k=1}^3 d_{ijk} E_j^\omega E_k^\omega$$

The SHG coefficient d_{ijk} is a third rank tensor and satisfies the permutation symmetry between j and k . In the reduced notation, j and k are replaced by l , which takes the values from 1 to 6. In the contracted form, the components of second order polarization at the harmonic frequency 2ω can be written in the form

$$\begin{bmatrix} P_x \\ P_y \\ P_z \end{bmatrix} = \begin{bmatrix} d_{11} & d_{12} & d_{13} & d_{14} & d_{15} & d_{16} \\ d_{21} & d_{22} & d_{23} & d_{24} & d_{25} & d_{26} \\ d_{31} & d_{32} & d_{33} & d_{34} & d_{35} & d_{36} \end{bmatrix} \begin{bmatrix} E_x^2 \\ E_y^2 \\ E_z^2 \\ 2E_y E_z \\ 2E_z E_x \\ 2E_x E_y \end{bmatrix}$$

The number of non-vanishing independent elements of the second harmonic tensor depends on the point symmetry group for the medium.

2.3 Acousto-Optic Materials

The interaction of light waves with sound waves in certain types of transparent crystals makes possible the control of optical beams in applications involving the transmission, display and processing of intelligence. A sound wave consists of sinusoidal perturbation of the density of the material, or strain which travels at the sound velocity. A change in the density of the medium causes a change in its index of refraction, which is to first order directly proportional. For an optical beam incident at an angle

on the sound wave in the material, the sound wave acts as a series of partially reflecting mirrors, which cause a diffraction of the beam.

The fraction of the power of the incident beam transferred in a distance l into the diffracted beam is

$$\frac{I_d}{I_i} = \sin^2 \frac{\omega l}{2c} \Delta n$$

It is advantageous to express the diffraction efficiency in terms of the acoustic intensity, I_a , in the diffraction medium. First it is necessary to relate the index change Δn to the strain s ,

$$\Delta n = - \frac{n^3 p}{2} s$$

where p is the photoelastic constant of the medium. The strain s is related to the acoustic intensity by

$$s = \sqrt{\frac{2I_a}{\rho v_s^3}}$$

where v_s is the velocity of sound in the medium and ρ is the mass density. In terms of the above, the fraction of the incident beam transferred to the diffracted beam is

$$\frac{I_d}{I_i} = \sin^2 \left(\frac{\pi l}{2\lambda} \sqrt{\frac{n^6 p^2}{\rho v_s^3} I_a} \right)$$

The diffraction figure of merit M is defined by the following

$$M = \frac{n^6 p^2}{\rho v_s^3}$$

The diffraction figure of merit is commonly referenced to that of water ($M_{\text{water}} = 1$). It should be noted that n , p and v_s are all related to tensor quantities and therefore vary with crystal orientation. A crystal cut to

maximize the figure of merit is, of course, chosen for a device. Frequently one finds several modified expressions for the figure of merit in the literature. Two alternate expressions are:

$$M = \frac{n^7 p^2}{\rho v_s}$$

$$M = \frac{n^7 p^2}{\rho v_s^2}$$

These are applicable to particular device designs where constraints placed on device geometry relate to material properties.

A high figure of merit is desirable, though not sufficient, for a material to be suitable for device applications. In addition, the material must have low optical and acoustic losses in its intended operating range and must be available in high optical quality. Other desirable features are good mechanical properties and low cost. There is no single material that is the best choice for all applications.

2.4 Passive Materials

The materials addressed in this section are among those that are routinely used to fabricate nonactive components in optical systems. They are generally not excited by an external stimulus to alter the properties of a light wave but may influence its direction by reflection, its intensity by absorption, the shape of its wavefront by geometric shape or its polarization by asymmetry of their crystalline structure.

2.5 Detectors Materials

Semiconductor detectors are radiation transducers that change incident radiation into an electrical signal. The methods of transduction can be separated into two groups: thermal detectors and photon detectors. The optical materials for thermal detectors are sensitive to changes in temperature brought about by changes in incident radiation. The optical materials for photon detectors are sensitive to changes in number or mobility of free charge carriers, i.e., electrons and/or holes, that are brought about by changes in the number of incident photons. Data on photon detector materials compiled in the following pages is applicable to detectors whose response depends on photoconductive and photovoltaic processes.

In the photoconductive mode, a change in the number of incident photons on a semiconductor causes a change in the average number of free charge-carriers in the material. The electrical conductivity of the semiconductor is directly proportional to the average number of free charge-carriers in the material. Therefore, the change in electrical conductivity is directly proportional to the change in the incident number of photons on the semiconductor.

In the photovoltaic mode a change in the number of photons incident on a semiconductor p-n junction causes a change in number of free electron-hole pairs which are separated by the internal electric field which is manifested as a change in output voltage.

Since fluctuations in temperature of these materials due to either radiative exchange with the background or conductive exchange with the heat sink produce a fluctuation in signal voltage, detectors operating at longer wavelengths are commonly reduced to temperatures far below ambient to suppress noise related to thermally induced transitions. For any detector whose performance is limited by noise due to fluctuations in the arrival rate of background photons, there can be associated an upper temperature limit of operation. This is referred to as the maximum temperature for BLIP (background limited impurity photoconductor).

The sensitivity of a detector is commonly specified in terms of NEP (noise equivalent power). The NEP is the RMS value of the sinusoidally modulated monochromatic radiant power incident upon a detector which gives rise to an RMS signal voltage equal to the RMS noise voltage from the detector in a 1 Hz bandwidth. Often the reciprocal of NEP, called the detectivity, is used to specify detector sensitivity. When the detectivity is normalized to take into account the detector area and electrical bandwidth dependence, the resulting quantity is referred to as D^* . This quantity is an inherent property of the detector material and is independent of a specific device design.

The response time of a detector material is a temporal figure of merit generally related to the detector time obtained for excitation by a step

function light pulse. The ultimate speed at which a photodetector responds to radiant signals is ultimately determined by the time it takes generated electrons and holes to be collected in the diode.

References

1. Driscoll and Vaughn, Handbook of Optics, McGraw Hill, Inc. (1978).
2. McMahon, H.O., J.O.S.A., 40, 376 (1950).

APPENDIX A
PROPERTIES OF MATERIALS

ARSENIC SELENIDE



STRUCTURE

AMORPHOUS SOLID

SYMMETRY

= --

LATTICE CONSTANTS

= --

PHYSICAL PROPERTIES

MOLECULAR WEIGHT

= 386.72

DENSITY

= 4.64

SOLUBILITY IN WATER (g/100g of H_2O)

= --

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE ($^{\circ}\text{K}$)

= 493

LINEAR EXPANSION COEFFICIENT ($^{\circ}\text{K}^{-1}$)

= 22×10^{-6}

THERMAL CONDUCTIVITY ($\text{cal/cm}\cdot\text{sec}\cdot^{\circ}\text{K}$)

= Not available

SPECIFIC HEAT ($\text{cal/g}/^{\circ}\text{K}$)

= Not available

MECHANICAL PROPERTIES

YOUNGS MODULUS ($\text{PSI} \times 10^6$)

= 25

HARDNESS (Knoop)

= 114

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT

= --

RESISTIVITY

= --

BAND GAP ENERGY

= --

EFFECTIVE MASS

= --

MOBILITY

= --

ARSENIC SELENIDE (As_2Se_3)

OPTICAL PROPERTIES

TRANSMISSION RANGE:	9 - 11 μm	Optical Absorption Coefficient
DISPERSION EQUATION:	--	$\alpha = 0.079 \text{ cm}^{-1} (\lambda = 1.153 \mu\text{m})$

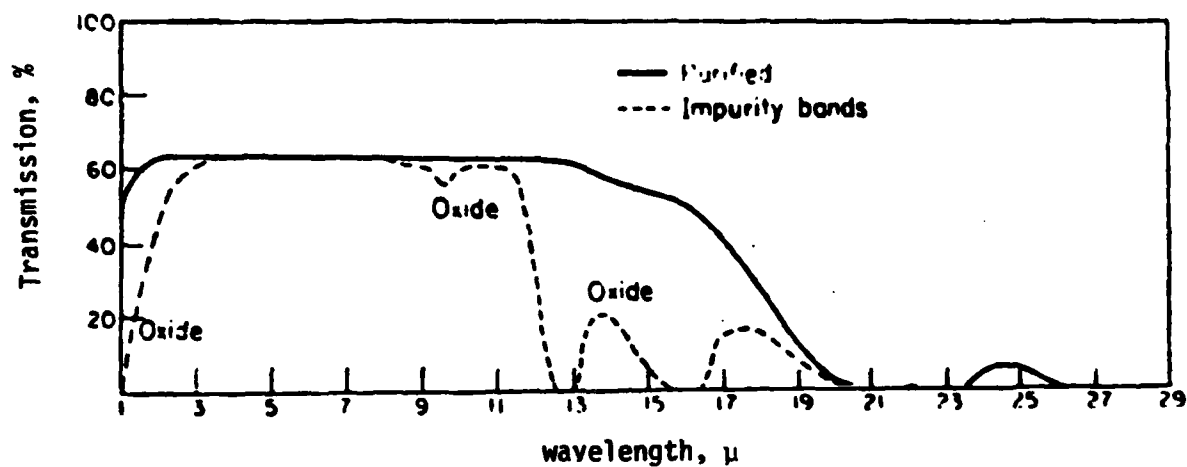
ACOUSTO-OPTIC PROPERTIES

ACOUSTIC VIBRATION POLARIZATION DIRECTION	=	Longitudinal
ACOUSTIC VELOCITY (km/sec)	=	2.25
LIGHT VIBRATION POLARIZATION DIRECTION ¹	=	Parallel
FIGURE OF MERIT ($M_2 = n^6 p^2 / \rho v^3$)	=	720
ACOUSTIC ATTENUATION (dB/cm) at 500 MHz	=	71.5

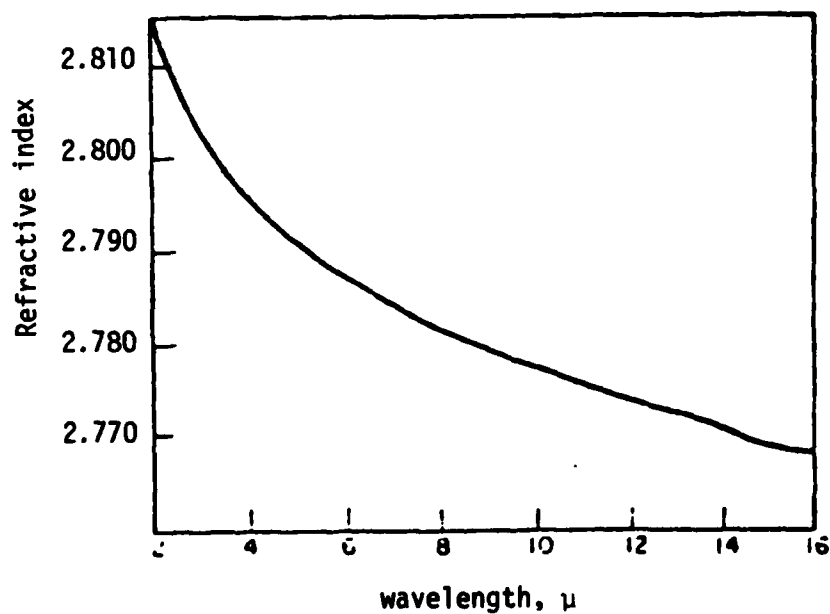
References:

1. Y. Ohmachi and N. Uchida, J. Appl. Phys. 43, 1709 (1972).
2. J.A. Savage and S. Nielsen, Infrared Phys. 5, 195 (1965).

ARSENSIC SELENIDE (As_2Se_3)



The infrared transmission of purified selenide glass. The dashed curve show impurity bands. $\text{As}_{40}\text{Se}_{60}$ specimen thickness 0.175 cm^2 .



Variation of refractive index with wavelength for $\text{As}_{40}\text{Se}_{60}$ Glass².

ARSENIC TRISULFIDE (Orpiment)**STRUCTURE**

AMORPHOUS SOLID

SYMMETRY = --

LATTICE CONSTANTS = --

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 246.04

DENSITY (g/cm^3) = 3.198SOLUBILITY IN WATER ($\text{g}/100\text{g}$ of H_2O) = 5×10^{-5} **THERMAL PROPERTIES**MELTING/SOFTENING TEMPERATURE ($^{\circ}\text{K}$) = 483LINEAR EXPANSION COEFFICIENT ($^{\circ}\text{K}^{-1}$) = 24.6×10^{-6} THERMAL CONDUCTIVITY ($\text{cal}/\text{cm}\cdot\text{sec}\cdot^{\circ}\text{K}$) = 4.0SPECIFIC HEAT ($\text{cal}/\text{g}/^{\circ}\text{K}$) = --**MECHANICAL PROPERTIES**YOUNGS MODULUS (PSI) = 2.3×10^6

HARDNESS (Knoop) = 109 (100g)

MODULUS OF RIGIDITY (PSI) = 9.4×10^5 MODULUS OF RUPTURE (PSI) = 2.4×10^3 **ELECTRICAL PROPERTIES**DIELECTRIC CONSTANT (frequency 10^3 to 10^6Hz) 8.1

RESISTIVITY --

BAND GAP ENERGY --

EFFECTIVE MASS --

MOBILITY --

ARSENIC TRISULFIDE (As₂S₃)

OPTICAL PROPERTIES

TRANSMISSION RANGE: 0.6 ~ 13 μ m

DISPERSION EQUATION: $n^2 - 1 = \sum_{i=1}^5 \frac{k_i \lambda^2}{\lambda^2 - \lambda_i^2}$
FOR INDEX OF REFRACTION

Values of Constants:

i	λ_i^2	k_i
1	0.0225	1.8983578
2	0.0625	1.9111979
3	0.1225	0.8765134
4	0.2025	0.1188704
5	750	0.0569903

ACOUSTO-OPTIC PROPERTIES

ACOUSTIC VIBRATION POLARIZATION DIRECTION
OF PROPOGATION¹ = Longitudinal

ACOUSTIC VELOCITY (km/s) = 2.6

LIGHT VIBRATION POLARIZATION DIRECTION
OF PROPOGATION = Parallel

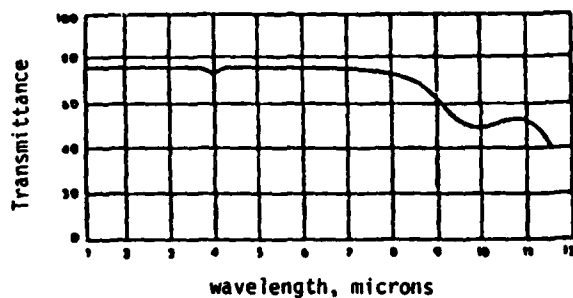
FIGURE OF MERIT ($M_2 = n^6 p^2 / \rho v^3$) = 230

ACOUSTIC ATTENUATION (dB/cm) at 500 MHz = 45

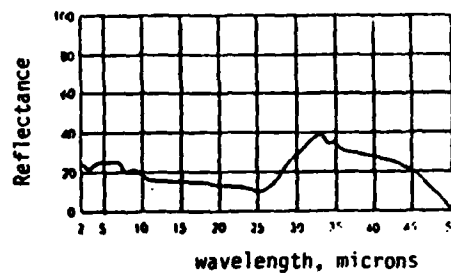
References:

1. R.W. Dixon, J. Appl. Phys. 38, 5149 (1967).
2. S.S. Ballard, K.A. McCarthy and W.L. Wolfe, Optical Materials for Infrared Instrumentation. IRIA Report No. 2389-11-S. Willow Run Laboratories, The University of Michigan, Ann Arbor.
3. D.E. McCarthy, Appl. Opt. 2, 591 (1963).
4. W.S. Rodney, I.H. Mattison and T.A. King, J. Opt. Soc. Am. 48, 633 (1958).

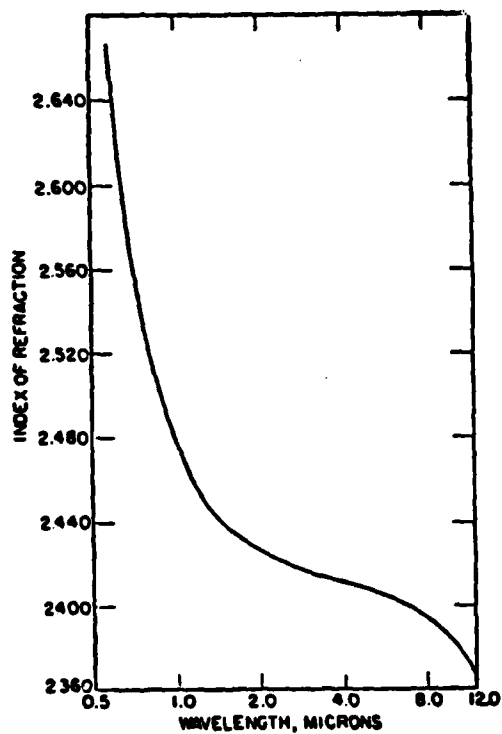
ARSENIC TRISULFIDE (As_2S_3)



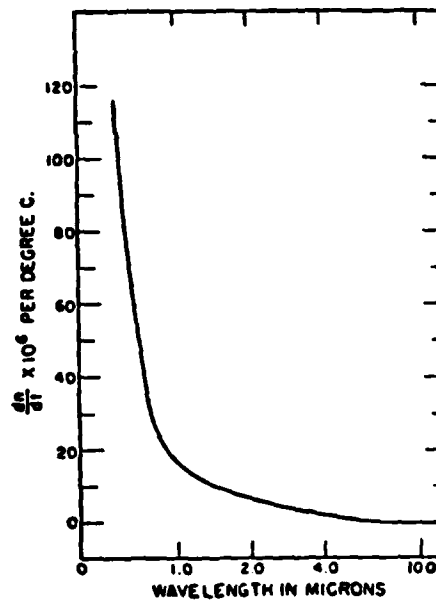
Transmission of arsenic trisulfide; 5mm thickness².



Reflectance of arsenic trisulfide³.



Refractive index versus wavelength of arsenic trisulfide⁴.



dn/dt versus wavelength of arsenic trisulfide⁴.

BARIUM FLUORIDE



STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, $Fm\bar{3}m$

LATTICE CONSTANTS (Å) = $a = 6.2007$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 175.36

DENSITY (g/cm^3) = 4.83

SOLUBILITY IN WATER ($\text{g/100g of H}_2\text{O}$) = 0.16

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE ($^{\circ}\text{K}$) = 1553

LINEAR EXPANSION COEFFICIENT ($^{\circ}\text{K}^{-1}$) = 18.4×10^{-6}

THERMAL CONDUCTIVITY ($\text{cal/cm}\cdot\text{sec}\cdot^{\circ}\text{K}$) = 28×10^{-3}

SPECIFIC HEAT ($\text{cal/g}/^{\circ}\text{K}$) = ---

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI) = 7.7×10^{-6}

HARDNESS (Knoop) = 82 (500g)

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = 7.33

RESISTIVITY = ---

BAND GAP ENERGY = ---

EFFECTIVE MASS = ---

MOBILITY = ---

BARIUM FLUORIDE (BaF₂)

OPTICAL PROPERTIES

DISPERSION EQUATION:

$$n^2 - 1 = \frac{0.643356 \lambda^2}{\lambda^2 - (0.057789)^2} + \frac{0.506762 \lambda^2}{\lambda^2 - (0.10968)^2} + \frac{3.8261 \lambda^2}{\lambda^2 - (46.3864)^2}$$

References:

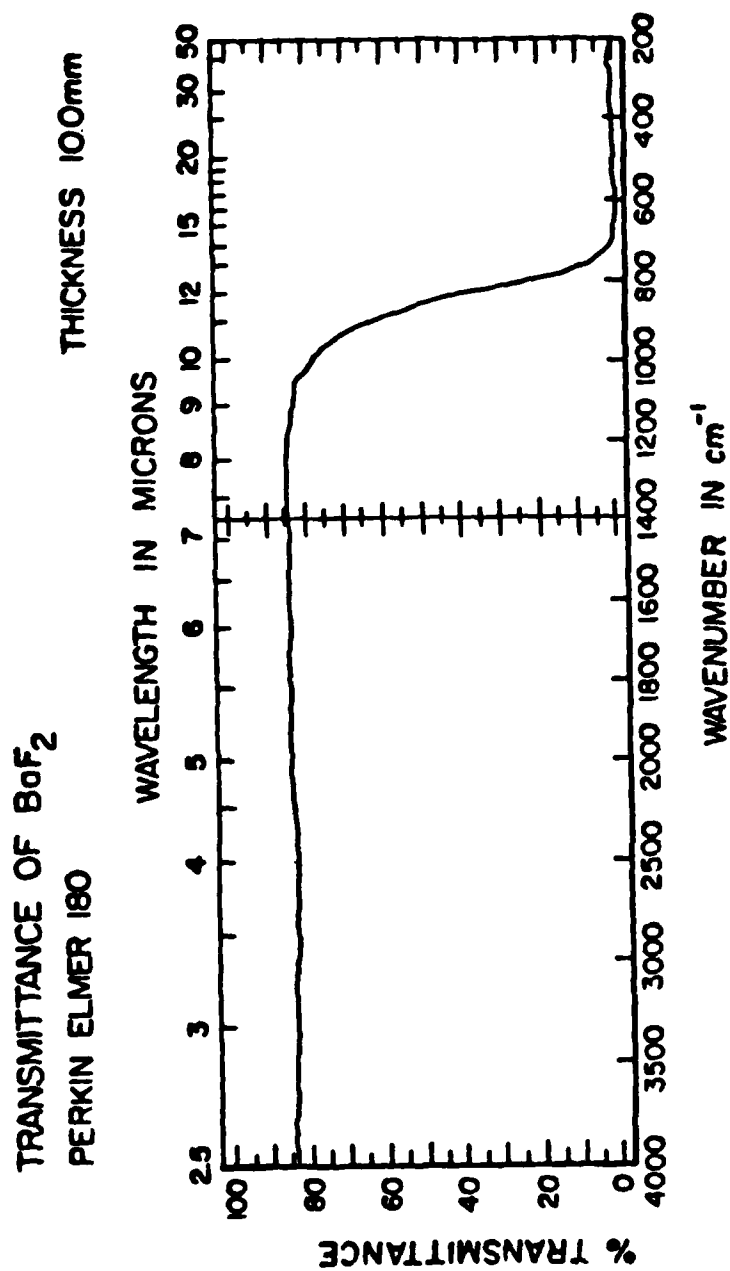
1. I.H. Malitson: J. Opt. Soc. Am. 54, 628 (1964).
2. N.C. Fernellius, D.V. Dempsey, D.A. Walsh and D.B. O'Quinn in Laser Induced Optical Materials: 1980, N.B.S. Special Publication 620. Eds. H.E. Bennet, A.J. Glass, A.H. Guenther and B.E. Newman.
3. W. Kaiser, W.G. Spitzer, R.H. Kaiser & L.E. Howarth, Phys. Rev. 127, 1950 (1962).

BARIUM FLUORIDE (BaF_2)

Refractive Index and Thermal Coefficient of Barium Fluoride (MIT experimental sample, year 1944)¹.

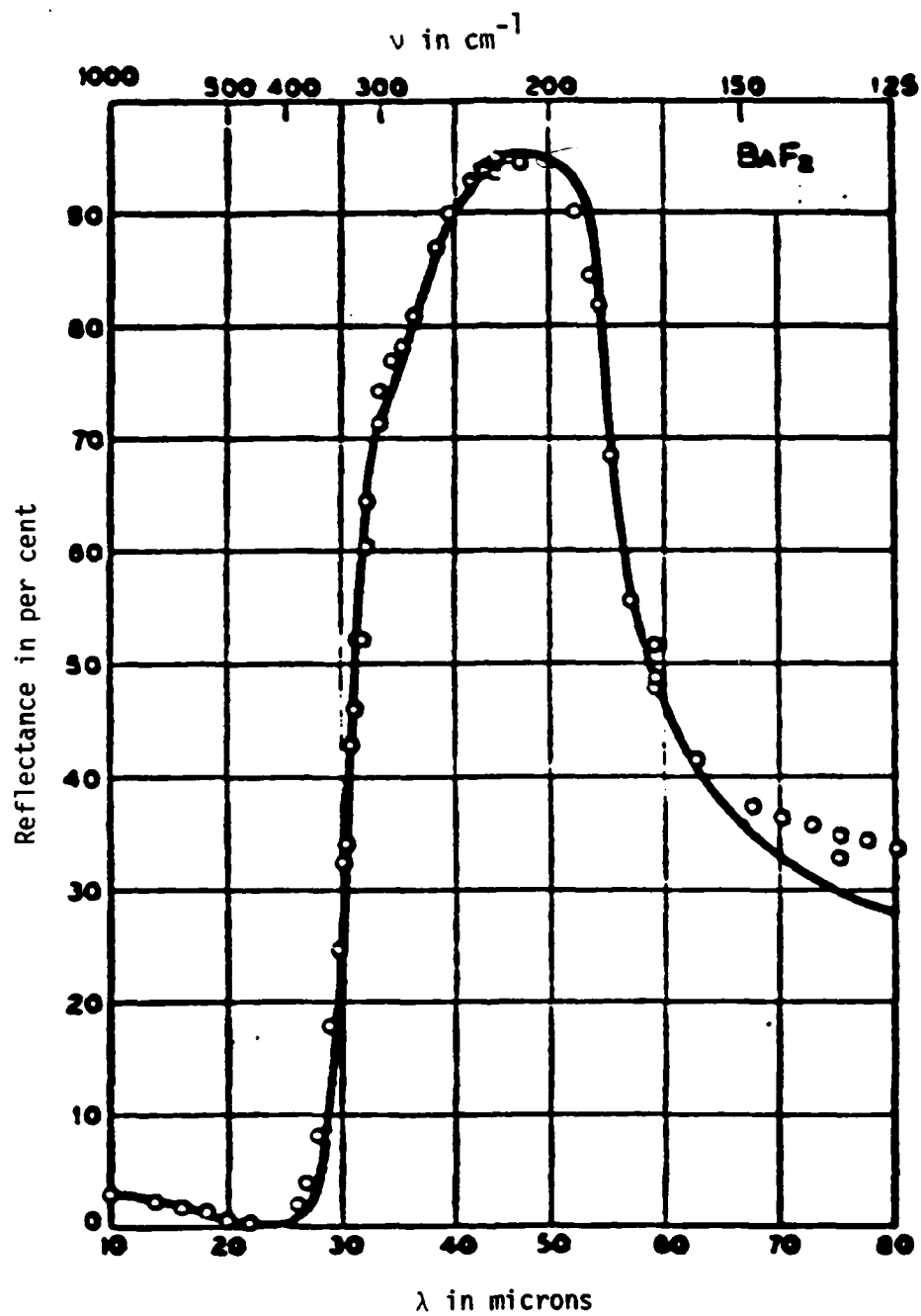
Wavelength (μ)	Refractive index			$-\text{dn}/\text{dt} \times 10^{-6}$ per $^{\circ}\text{C}$
	15 $^{\circ}\text{C}$	35 $^{\circ}\text{C}$	55 $^{\circ}\text{C}$	
0.4046563	1.484054	1.483753	1.483452	15.05
0.4358342	1.481416	1.481116	1.480816	15.05
0.4861327	1.478234	1.477930	1.477628	15.15
0.5460740	1.475559	1.475255	1.474951	15.20
0.589262	1.474124	1.473820	1.473515	15.22
0.6562793	1.472439	1.472135	1.471830	15.23
0.6678149	1.472196	1.471892	1.471586	15.25
0.7065188	1.471474	1.471167	1.470863	15.28
0.767858	1.470538	1.470230	1.469920	15.45
Abbe No.	81.82	81.76	81.67	

BARIUM FLUORIDE (BaF_2)



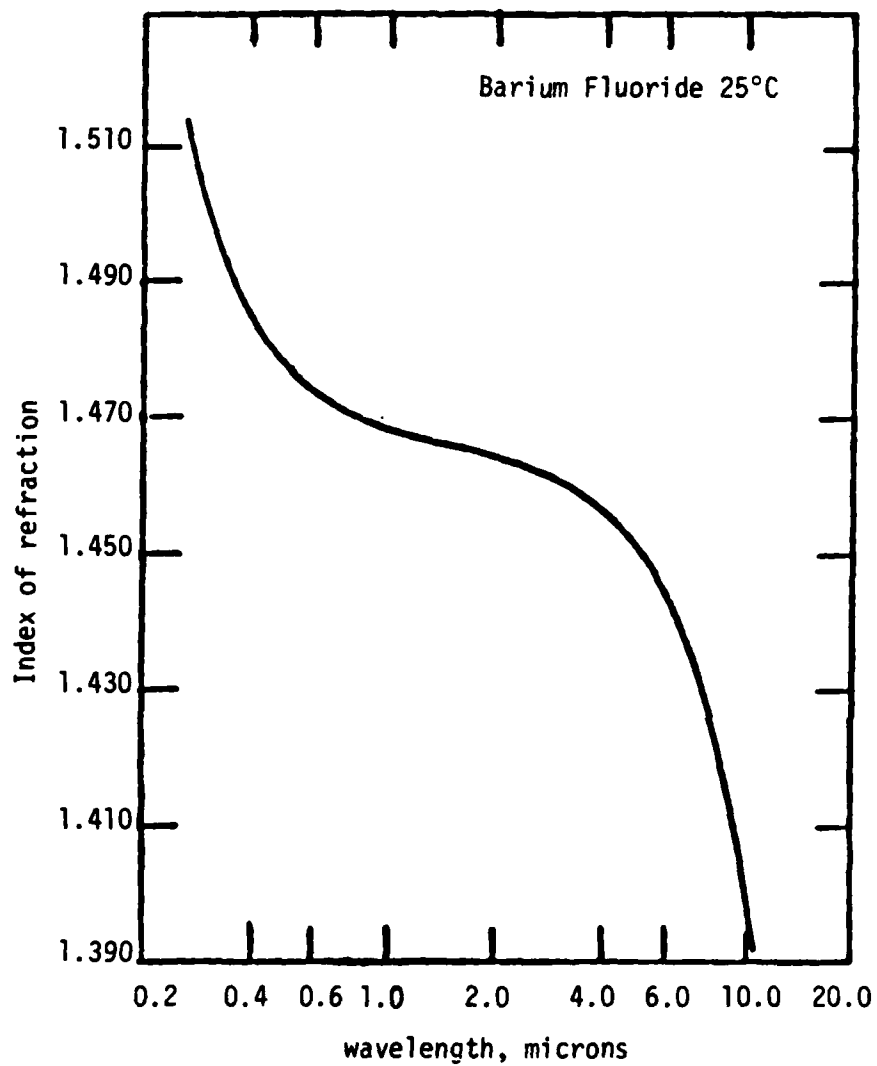
Transmittance of BaF_2 versus wavelength from 2.5 to 50 μm taken on a Perkin-Elmer 180².

BARIUM FLUORIDE (BaF_2)



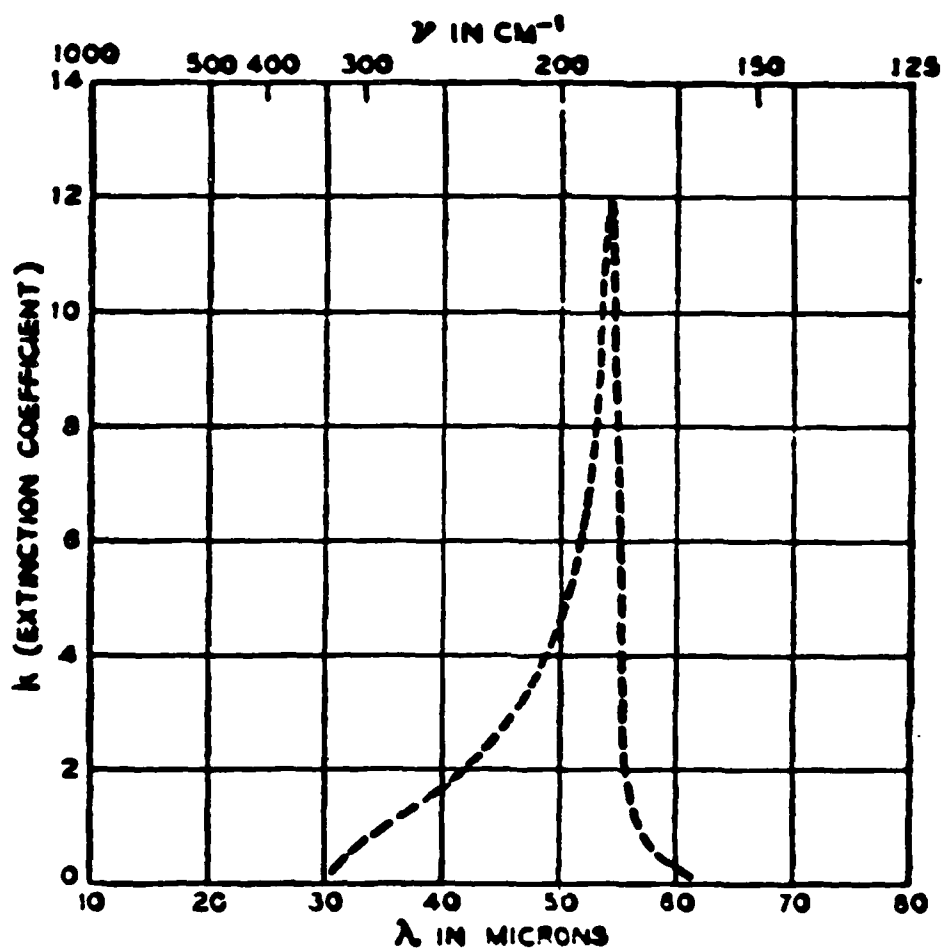
Reflectance versus wavelength of barium fluoride³.

BARIUM FLUORIDE (BaF_2)



Refractive index of barium fluoride. The dispersion formula is valid for interpolation to five decimal places over the measured wavelength range.

BARIUM FLUORIDE (BaF_2)



Extinction coefficient of barium fluoride as obtained from the dispersion analysis of the reflectivity³.

CADMIUM SELENIDE

CdSe

STRUCTURE

CRYSTALLINE

SYMMETRY

= Hexagonal, 6mm

LATTICE CONSTANTS (Å)

= $a = 4.309 \pm 0.003$

$c = 7.021 \pm 0.004$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT

= 191.36

DENSITY (g/cm^3)

= 5.81

SOLUBILITY IN WATER ($\text{g/100g of H}_2\text{O}$)

= Not available

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE ($^{\circ}\text{K}$)

= 1533

LINEAR EXPANSION COEFFICIENT ($^{\circ}\text{K}^{-1}$)

= Not available

THERMAL CONDUCTIVITY ($\text{cal/cm}\cdot\text{sec}\cdot^{\circ}\text{K}$)

= 0.043

SPECIFIC HEAT ($\text{cal/g}/^{\circ}\text{K}$)

= 92.8

MECHANICAL PROPERTIES

YOUNGS MODULUS

= Not available

HARDNESS

= Not available

ELASTIC CONSTANTS (10^{12}N/m^2)

= $C_{11}=7.4, C_{12}=4.52, C_{13}=3.93,$
 $C_{33}=8.36, C_{44}=4.317, C_{66}=1.445$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT

= 10.6

RESISTIVITY

= Not available

BAND GAP ENERGY (eV)

= 1.67

EFFECTIVE MASS m_e^*

= $0.13 m_0$

MOBILITY μ_e ($\text{cm}^2/\text{v}\cdot\text{sec}$)

= 650

CADMIUM SELENIDE (CdSe)

ELECTRO-OPTIC COEFFICIENTS (10^{-12} m/v)

$$r_{33} = 4.3 \quad \text{at } 3.39 \mu\text{m (Reference 1)}$$

$$r_{13} = 1.8 \quad \text{at } 3.39 \mu\text{m}$$

SECOND HARMONIC COEFFICIENTS (10^{12} m/v)

$$d_{33} = 79.6 \pm 4.9 \quad \text{at } 1.064 \mu\text{m (Reference 2)}$$

$$d_{15} = 31 \pm 7.5 \quad \text{at } 10.6 \mu\text{m (Reference 3)}$$

$$d_{31} = 28.5 \pm 6.3 \quad \text{at } 10.6 \mu\text{m}$$

$$d_{33} = 54.5 \pm 12.6 \quad \text{at } 10.6 \mu\text{m}$$

$$d_{31} = 26.8 \pm 9 \quad \text{at } 10.6 \mu\text{m}$$

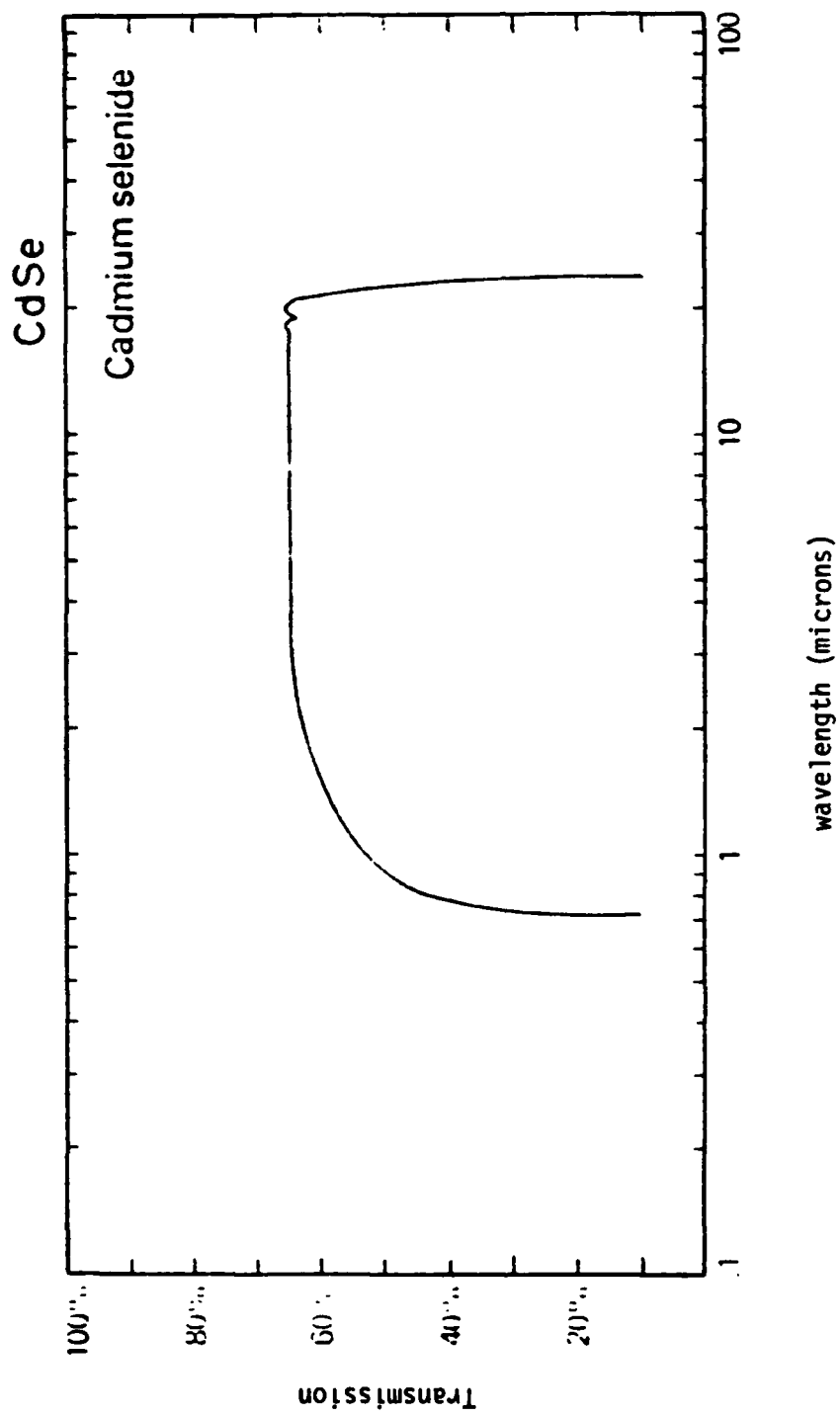
References:

1. I. Kamminow, in CRC Handbook of Lasers, ed. by R.J. Plersey, Chemical Rubber Company, Cleveland, Ohio, 447 (1971).
2. R.A. Soref and H.W. Moos, J. Appl. Phys. 35, 2152 (1964).
3. C.K.N. Patel, Phys. Rev. Lett. 16, 613 (1965).
4. W.L. Bond, J. Appl. Phys. 36, 1674 (1965).
5. D.E. McCarthy, Appl. Opt. 4, 317 (1965).

CADMIUM SELENIDE (CdSe)

Cadmium Selenide (CdSe) Room Temperature Birefringence Versus Wavelength⁴

Wavelength (μm)	n_o	n_e
0.8	2.6448	2.6607
0.9	2.5826	2.6027
1.0	2.5502	2.5696
1.2	2.5132	2.5331
1.4	2.4929	2.5133
1.6	2.4818	2.5008
1.8	2.4732	2.4930
2.0	2.4682	2.4873
2.2	2.4642	2.4840
2.4	2.4612	2.4798
2.6	2.4590	2.4784
2.8	2.4562	2.4757
3.0	2.4542	2.4741
3.2	2.4532	2.4726
3.4	2.4518	2.4714
3.6	2.4509	2.4702
3.8	2.4498	2.4694
4.0	2.4491	2.4685



Transmission versus wavelength of cadmium selenide⁵.

CADMIUM SULFIDE (GREENOCKITE)

CdS

STRUCTURE

CRYSTALLINE

SYMMETRY = Hexagonal, 6mm

LATTICE CONSTANTS (Å) = $a = 4.136$, $c = 6.713$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 144.8

DENSITY (g/cm³) = 4.82

SOLUBILITY IN WATER (g/100g of H₂O) = 1.3×10^{-4}

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 1252

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = 5.6×10^{-6} (⊥ c axis)
 3.5×10^{-6} (//c axis)

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = 380

SPECIFIC HEAT (cal/g)/°K = 0.088

MECHANICAL PROPERTIES

YOUNGS MODULUS = Not available

HARDNESS (kg/mm²) = 55, 80

ELASTIC COEFFICIENTS (bars) = $C_{11}=8.432$, $C_{12}=5.12$, $C_{13}=4.638$
 $C_{33}=9.397$, $C_{44}=1.489$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT (static) = 8.9

RESISTIVITY = Not available

BAND GAP ENERGY (eV) = 2.58

EFFECTIVE MASS m_e^* = $0.20m_0$

MOBILITY μ_e (cm²/v-sec) = 210

CADMIUM SULFIDE (CdS)

ELECTRO-OPTIC COEFFICIENTS MEASURED AT STRESS (10^{-12} v/m)

$$v_c = r_{33} - \frac{n_1^3}{n_3^3} \cdot r_{13} = 5.4 \text{ at } 10.6 \mu\text{m (Reference 1)}$$

SECOND HARMONIC COEFFICIENTS (10^{12} m/v)

$$d_{15} = 17.0 \pm 1.4 \quad \text{at } 1.0582 \mu\text{m (Reference 2)}$$

$$d_{31} = 15.6 \pm 0.9$$

$$d_{33} = 30.7 \pm 1.9$$

$$d_{15} = 28.9 \pm 7.1 \quad \text{at } 10.6 \mu\text{m (Reference 3)}$$

$$d_{31} = 9.83 \pm 1.1$$

$$d_{33} = 44.0 \pm 12.6$$

References:

1. I.P. Kamminone, IEEE J. Quant. El. 2E4, 23 (1968).
2. R.C. Miller, Appl. Phys. Lett. 5, 17 (1964).
3. C.K.N. Patel, Phys. Rev. Lett. 15, 613 (1965).
4. T.M. Bieniewski and S.J. Czyzak, J. Opt. Soc. Am. 53, 496 (1963).
5. A.B. Francis and A.I. Carlson, J. Opt. Soc. Am. 50, 118 (1960).
6. D.E. McCarthy, Appl. Opt. 7, 1997 (1968).

CADMIUM SULFIDE (CdS)

CADMIUM SULFIDE (CdS) Room Temperature Birefringence Versus Wavelength⁴

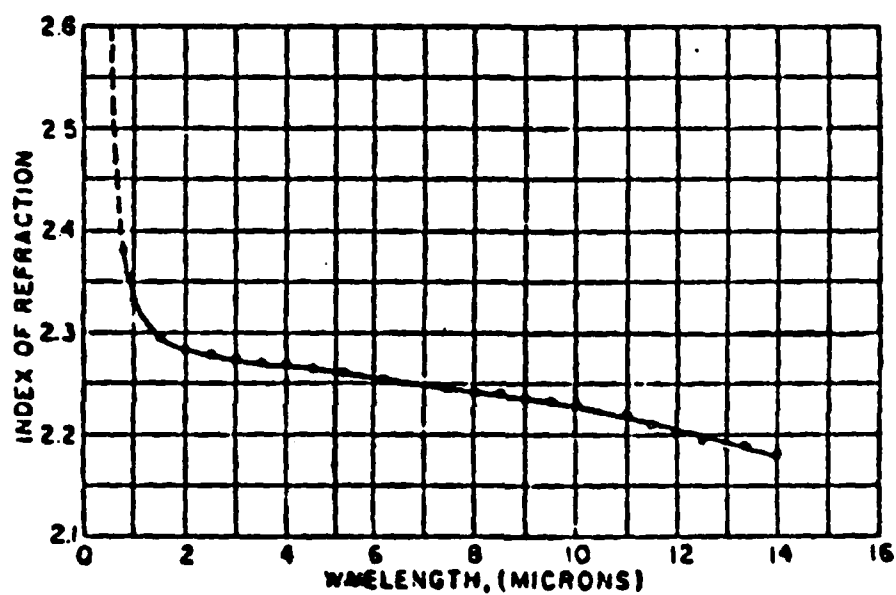
Wavelength (μm)	n_o	n_e
0.5120		2.751
0.5130		2.743
0.5140		2.737
0.5150	2.743	2.726
0.5160	2.735	2.720
0.5170	2.727	2.714
0.5180	2.718	2.706
0.5190	2.709	2.702
0.5200	2.702	2.698
0.5210	2.700	2.694
0.5220	2.694	2.689
0.5230	2.687	2.685
0.5240	2.681	2.680
0.5250	2.674	2.675
0.5275	2.661	2.665
0.5300	2.649	2.654
0.5325	2.638	2.644
0.5350	2.628	2.637
0.5375	2.617	2.628
0.5400	2.609	2.622
0.5425	2.602	2.612
0.5450	2.594	2.606
0.5475	2.587	2.600
0.5500	2.580	2.593
0.5750	2.528	2.545
0.6000	2.493	2.511
0.6250	2.467	2.484
0.6500	2.446	2.463
0.6750	2.427	2.446
0.7000	2.414	2.432
0.7500	2.390	2.409
0.8000	2.374	2.392
0.8500	2.364	2.378
0.9000	2.359	2.368
0.9500	2.344	2.359

CADMIUM SULFIDE (CdS)

CADMIUM SULFIDE (CdS) Room Temperature Birefringence Versus Wavelength⁴

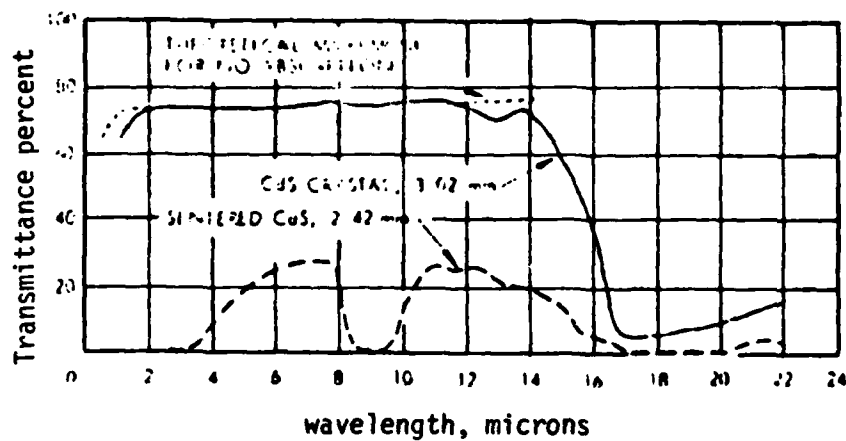
Wavelength (μm)	n_o	n_e
1.0000	2.334	2.352
1.0500	2.328	2.346
1.1000	2.324	2.340
1.1500	2.320	2.336
1.2000	2.316	2.332
1.2500	2.312	2.329
1.3000	2.309	2.326
1.3500	2.306	2.323
1.4000	2.304	2.321

CADMIUM SULFIDE (CdS)

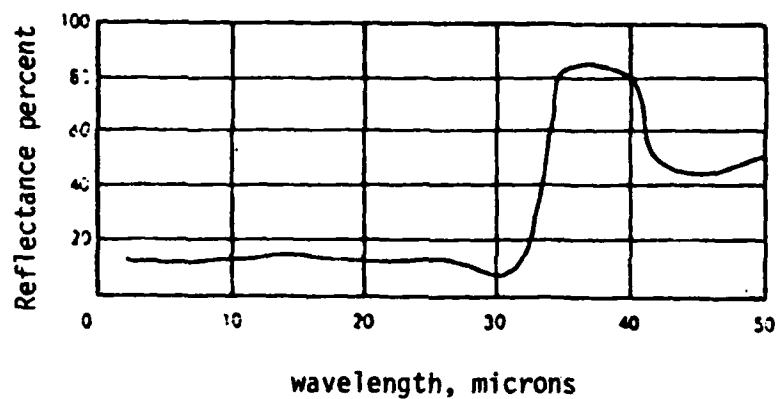


Refractive index of CdS versus wavelength. The dashed extension is by Reference 4.

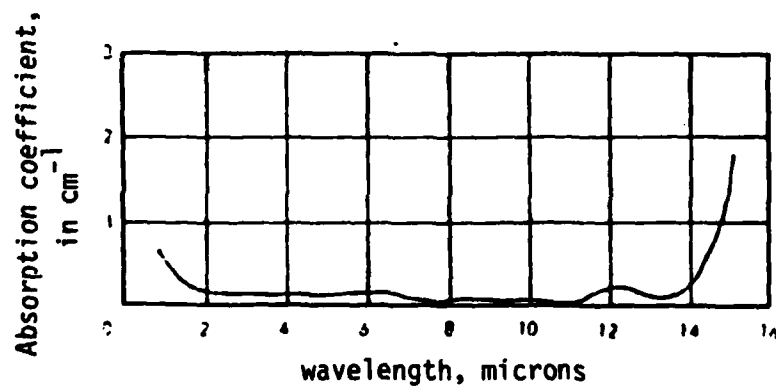
CADMIUM SULFIDE (CdS)



Transmittance versus wavelength⁵.



Reflectance versus wavelength⁶.



Absorption coefficient versus wavelength⁵.

CADMIUM TELLURIDE

CdTe

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, $\bar{4}3m$

LATTICE CONSTANTS (Å) = $a = 6.477$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 240.02

DENSITY (g/cm³) = 5.85

SOLUBILITY IN WATER (g/100g of H₂O) = Not available

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 1314 - 1323

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = 5.5×10^{-6}

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = 98

SPECIFIC HEAT (cal/g)/°K = 0.01875

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI) = 5.3×10^6

HARDNESS (Knoop) (kg/mm²) = 56

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT (static) = 10.9

RESISTIVITY = Not available

BAND GAP ENERGY (eV) = 1.5

EFFECTIVE MASS m_e^* = $.11 m_0$

MOBILITY μ_e (cm²/v-sec) = 600

CADMIUM TELLURIDE (CdTe)

OPTICAL PROPERTIES

DISPERSION EQUATION¹: $n^2 - 1 = 4.68 + 1.53\lambda^2/(\lambda^2 - 0.366)$
where λ is in μm .

THERMAL COEFFICIENT
OF REFRACTIVE INDEX: $\frac{1}{n} \frac{dn}{dT} = 4.4 \times 10^{-5}/^\circ\text{K}$ at $10.6\mu\text{m}$ (Reference 2)

PRESSURE COEFFICIENT
OF REFRACTIVE INDEX: $\frac{1}{n} \frac{dn}{dp} = 0.1 \pm 0.1 \times 10^{-6}/\text{bar}$ (calculated)

ELECTRO-OPTIC COEFFICIENTS (AT CONSTANT STRESS)

$r_{41} = 6.8$ at $3.39\mu\text{m}$ (Reference 3)

$r_{41} = 6.8$ at $10.6\mu\text{m}$

SECOND HARMONIC COEFFICIENTS (10^{12} m/v)

$d_{14} = 16.7 \pm 6.3$ at $10.6\mu\text{m}$ (Reference 4)

References:

1. D.F. Marple, J. Appl. Phys. 35, 539 (1964).
2. B. Bendow, P.D. Gianino, Y.F. Tsay and S.S. Mitra, Appl. Opt. 13, 2382 (1974).
3. J.E. Keifer, and A. Yariv, Appl. Phys. Lett. 15, 26 (1969).
4. R.C. Miller and W.A. Nordland, Optics Communications 1, 400 (1970).
5. A.G. Debell, E.L. Dereniak, J. Harvey, J. Nissley, J. Palmer, A. Selvarajan and W.L. Wolfe, Appl. Opt. 18, 3114 (1979).
6. L.S. Ladd, Infrared Physics 6, 145 (1966).
7. D.E. McCarthy, Appl. Opt. 7, 1997 (1968).

CADMIUM TELLURIDE (CdTe)

CADMIUM TELLURIDE (CdTe)
Room Temperature Refractive Index Versus Wavelength¹

Wavelength (μm)	n
0.903	2.91
1.0	2.84
1.1	2.81
1.0 - 1.3	2.82
7.0 - 10.0	2.69
10.0	2.69
14.0	2.69

CADMIUM TELLURIDE (CdTe)

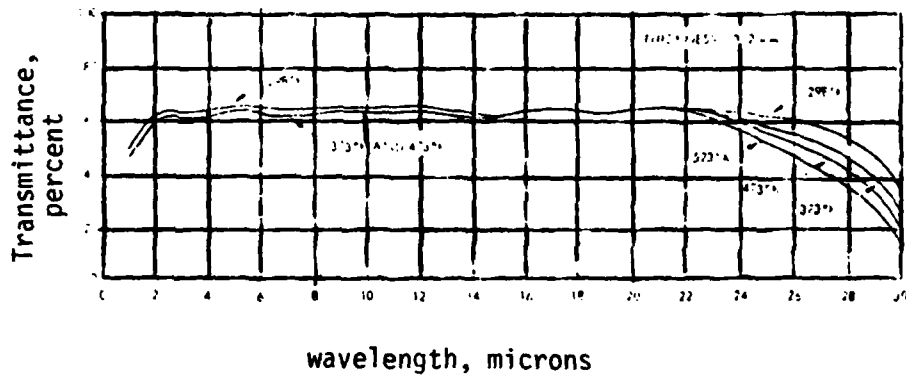
Refractive Index of CdTe as a Function of Wavelength⁵

Wavelength (μm)	Refractive Index		
	20 K	80 K	300 K
6	2.65607	2.65925	2.68198
8	2.65139	2.65459	2.67730
10	2.64661	2.64956	2.67242
12	2.64081	2.64408	2.66677
14	2.63413	2.63734	2.66020
16	2.62645	2.62981	2.65253
18	2.61789	2.62065	2.64366
20	2.60768	2.61039	2.63343
22	2.59604	2.59866	2.62177

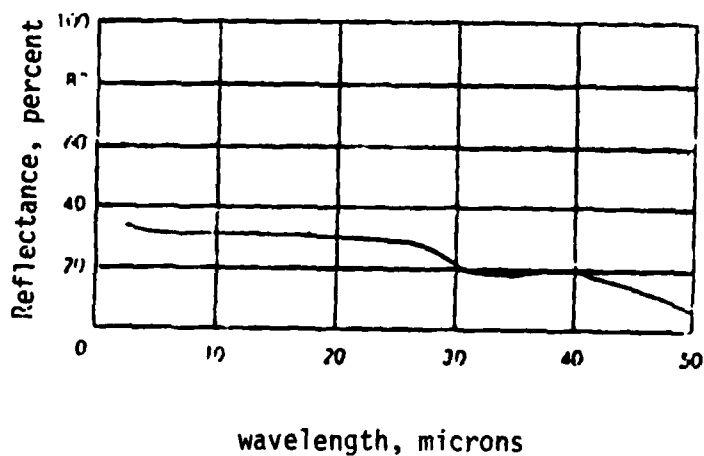
Refractive Index as a Function of Temperature and Temperature Coefficients⁵

Temperature (K)	10 μm	15 μm
20	2.64661	2.63066
30	2.64702	2.63098
40	2.64743	2.63142
50	2.64787	2.63195
60	2.64839	2.63249
70	2.64892	2.63308
80	2.64956	2.63370
Temperature coefficient:	$4.9 \times 10^{-5}/\text{K}$	$5.1 \times 10^{-5}/\text{K}$

CADMIUM TELLURIDE (CdTe)



Transmittance of cadmium telluride versus wavelength⁶.



Reflectance of cadmium telluride versus wavelength⁷.

CdGeAs₂

STRUCTURE

CRYSTALLINE

SYMMETRY = Tetragonal, $\bar{4}2m$ (chalcopyrite)

LATTICE CONSTANTS (Å) =
a = 5.942
c = 11.215

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 230.83

DENSITY (g/cm³) = 5.6

SOLUBILITY IN WATER (g/100g of H₂O) = --

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 903

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = --

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = --

SPECIFIC HEAT (cal/g)/°K = --

MECHANICAL PROPERTIES

YOUNGS MODULUS = --

HARDNESS (kg/mm²) = 471

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT =

RESISTIVITY =

BAND GAP ENERGY (eV) = 0.53

EFFECTIVE MASS =

MOBILITY =

CdGeAs₂

OPTICAL PROPERTIES

TRANSMISSION RANGE: 2 - 17 μm

SECOND HARMONIC COEFFICIENT (10^{12} m/v)

$$d_{36} = 351 \pm 105 \text{ at } 10.6 \mu\text{m} \text{ (Reference 1)}$$

References:

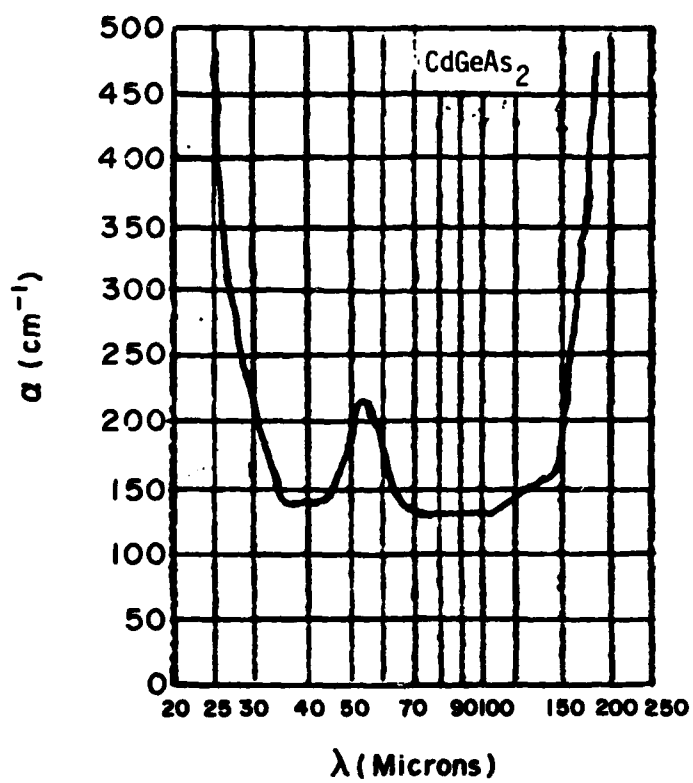
1. G.D. Boyd, E. Buehler, F. Storz and J.H. Wernick, IEEE J. Quant. El. QE8, 419 (1972).

CdGeAs₂Refractive Index¹ CdGeAs₂ Prism Angle A = 19.4022°

λ μ	$\nu = \lambda^{-1}$ μ^{-1}	n^o	n^e	$n^e - n^o$
2.3000	.4348	3.6076		
2.4000	.4167	3.5973	3.7545	.1572
2.5000	.4000	3.5893	3.7316	.1420
2.6000	.3846	3.5823	3.7156	.1333
2.7000	.3704	3.5773	3.7030	.1257
2.8000	.3571	3.5721	3.6926	.1206
2.9000	.3448	3.5684	3.6846	.1162
3.0000	.3333	3.5645	3.6775	.1131
3.1000	.3226	3.5615	3.6714	.1099
3.2000	.3125	3.5581	3.6661	.1080
3.4000	.2941	3.5536	3.6574	.1038
3.6000	.2778	3.5503	3.6508	.1005
3.8000	.2632	3.5468	3.6454	.0986
4.0000	.2500	3.5440	3.6402	.0962
4.2000	.2381	3.5415	3.6368	.0954
4.4000	.2273	3.5391	3.6329	.0938
4.6000	.2174	3.5372	3.6299	.0928
4.8000	.2083	3.5354	3.6273	.0919
5.0000	.2000	3.5336	3.6249	.0914
5.5000	.1818	3.5285	3.6178	.0893
6.0000	.1667	3.5251	3.6134	.0883
6.5000	.1538	3.5223	3.6104	.0881
7.0000	.1429	3.5200	3.6073	.0873
7.5000	.1333	3.5175	3.6050	.0875
8.0000	.1250	3.5157	3.6030	.0873
8.5000	.1176	3.5140	3.6009	.0869
9.0000	.1111	3.5120	3.5988	.0868
9.5000	.1053	3.5098	3.5966	.0867
10.0000	.1000	3.5078	3.5942	.0864
10.5000	.0952	3.5054	3.5922	.0868
11.0000	.0909	3.5031	3.5896	.0865
11.5000	.0870	3.5004	3.5871	.0868
12.0000	.0833	3.4977		
12.5000	.0800	3.4950		

Note: The material is transparent to 17 μ m, but measurements of index past 12.5 μ m where it was necessary to switch from a Hg:Ge to a Cu:Ge detector, were not possible.

CdGeAs₂



Absorption coefficient¹ in CdGeAs₂.

CdGeP₂

STRUCTURE

CRYSTALLINE

SYMMETRY	=	Tetragonal, $\bar{4}2m$ (chalcopyrite)
LATTICE CONSTANTS (Å)	=	$a = 5.740 \pm 0.001$ $c = 10.773 \pm 0.002$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	246.93
DENSITY (g/cm ³)	=	4.48
SOLUBILITY IN WATER (g/100g of H ₂ O)	=	Not available

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	1073
LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	--
THERMAL CONDUCTIVITY (W/cm·°K)	=	0.11
SPECIFIC HEAT (cal/gm)/°K	=	--

MECHANICAL PROPERTIES

YOUNGS MODULUS	=	--
HARDNESS (kg/mm ²)	=	460

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT	=	--
RESISTIVITY (Ohm-cm)	=	4.8×10^7
BAND GAP ENERGY (eV)	=	1.8
EFFECTIVE MASS	=	--
MOBILITY	=	--

CdGeP₂

OPTICAL PROPERTIES

TRANSMISSION RANGE: 8 - 12 μm

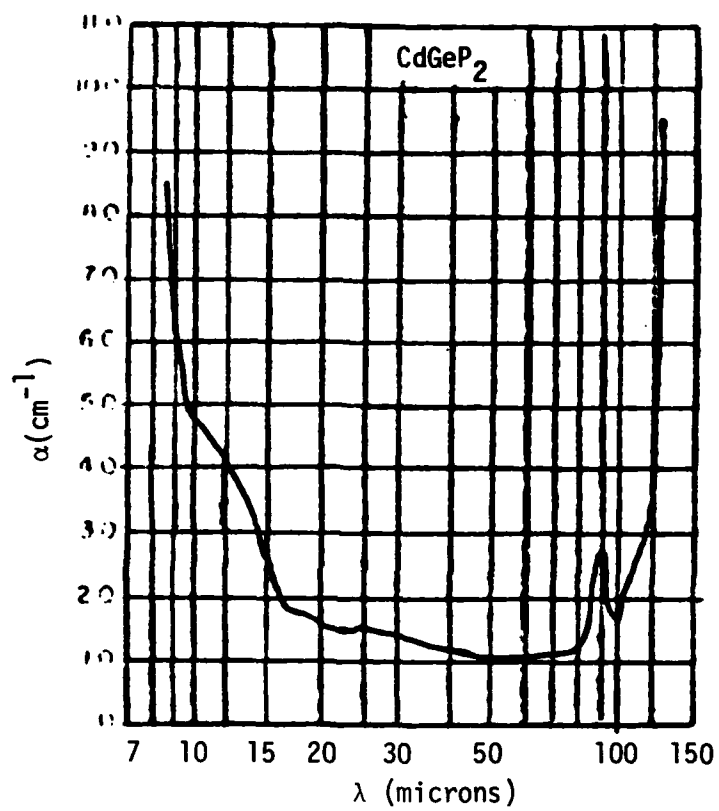
SECOND HARMONIC COEFFICIENTS (10^{12} m/v)

$d_{36} = 162 \pm 48$ at 10.6 μm (Reference 1)

References:

1. G.D. Boyd, E. Buehler, F.G. Storg and J.H. Wernick, IEEE Quant. El. QE8, 419 (1972).

CdGeP_2



Absorption coefficient¹ in CdGeP_2 .

CALCIUM CARBONATE (ARAGONITE, CALCITE)



STRUCTURE

CRYSTALLINE

SYMMETRY = Hexagonal $R\bar{3}C$

LATTICE CONSTANTS (Å) =
a = 4.9899
c = 17.062

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 100.09

DENSITY (g/cm³) = 2.7102

SOLUBILITY IN WATER (g/100g of H₂O) = 0.0014

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 1167

LINEAR EXPANSION COEFFICIENT (°K⁻¹) =
25 x 10⁻⁶ // c-axis
-5.8 x 10⁻⁶ ⊥ c-axis

THERMAL CONDUCTIVITY (cal/cm·sec·°K) =
132 x 10⁻⁴ // c-axis
111 x 10⁻⁴ ⊥ c-axis

SPECIFIC HEAT (cal/g)/°K = 0.203

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI) =
10.5 x 10⁶ // c-axis
12.8 x 10⁶ ⊥ c-axis

HARDNESS (Mohs) = 3

ELASTIC CONSTANTS (bars) =
C₁₁=13.7, C₁₂=4.56, C₁₃=4.51
C₁₄=-2.08, C₃₃=7.97, C₄₄=3.42

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT =
8.5 ⊥ c-axis
8.0 // c-axis at 10⁴ Hz

RESISTIVITY = ---

BAND GAP ENERGY = ---

EFFECTIVE MASS = ---

MOBILITY = ---

CALCIUM CARBONATE (CaCO_3)

References:

1. S.S. Ballard, K.A. McCarthy and W.L. Wolfe, Optical Materials for Infrared Instrumentation Report No. AD 217367 (1959).
2. D.E. McCarthy, Appl. Opt. 4, 317 (1965).
3. A. Smakula, Einkristalle, Springer-Verlag, Berlin, 1400 (1962).

CALCIUM CARBONATE (CaCO₃)

Brechzahlen des Kalkspats (von 0.198 bis 0.795 μm
bei 18° C, von 0.8007 bis 3.324 μm bei 20° C) ¹⁻³

λ (μm)	n_o	n_e	λ (μm)	n_o	n_e
0.198	----	1.57796	0.768	1.64974	1.48259
0.200	1.90284	1.57649	0.795	1.64886	1.48216
0.204	1.88242	1.57081	0.801	1.64869	1.48216
0.208	1.86733	1.56640	0.833	1.64772	1.48176
0.211	1.85692	1.56327	0.867	1.64676	1.48137
0.214	1.84558	1.55976	0.905	1.64578	1.48098
0.219	1.83075	1.55496	0.946	1.64480	1.48060
0.226	1.81309	1.54921	0.991	1.64380	1.48022
0.231	1.80233	1.54541	1.042	1.64276	1.47985
0.242	1.78111	1.53782	1.097	1.64167	1.47948
0.257	1.76038	1.53005	1.159	1.64051	1.47910
0.263	1.75343	1.52736	1.229	1.63926	1.47870
0.267	1.74864	1.52547	1.273	1.63849	----
0.274	1.74139	1.52261	1.307	1.63789	1.47831
0.291	1.72774	1.51705	1.320	1.63767	----
0.303	1.71959	1.51365	1.369	1.63681	----
0.312	1.71425	1.51140	1.396	1.63637	1.47789
0.330	1.70515	1.50746	1.422	1.63590	----
0.340	1.70078	1.50562	1.479	1.63490	----
0.346	1.69833	1.50450	1.497	1.63457	1.47744
0.361	1.69317	1.50228	1.541	1.63381	----
0.394	1.68374	1.49810	1.609	1.63261	----
0.410	1.68014	1.49640	1.615	----	1.47695
0.434	1.67552	1.49430	1.682	1.63127	----
0.441	1.67423	1.49373	1.749	----	1.47638
0.508	1.66527	1.48956	1.761	1.62974	----
0.533	1.66277	1.48841	1.849	1.62800	----
0.560	1.66046	1.48736	1.909	----	1.47573
0.589	1.65835	1.48640	1.946	1.62602	----
0.643	1.65504	1.48490	2.053	1.62372	----
0.656	1.65437	1.48459	2.100	----	1.4792
0.670	1.65367	1.47426	2.172	1.62099	----
0.706	1.65207	1.48353	3.324	----	1.47392

CALCIUM CARBONATE (CaCO₃)

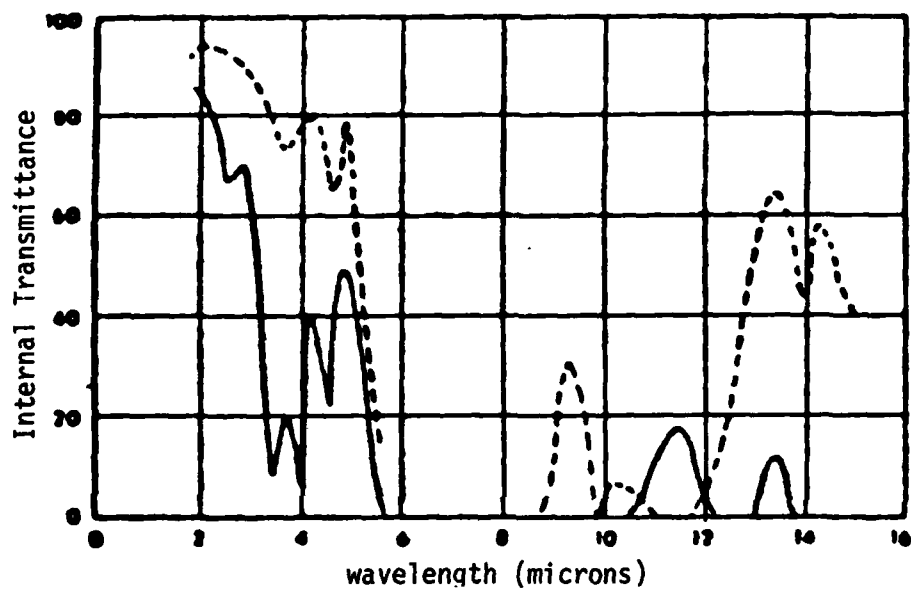
Temperaturkoeffizienten der Brechzahlen $10^5 \times dn/dT$ von Kalkspat¹

λ (nm)	dn_o/dT	dn_e/dT
0.211	+2.150	---
0.214	2.025	+2.599
0.219	1.814	2.474
0.224	1.643	---
0.226	---	2.290
0.231	1.397	2.198
0.257	0.950	1.876
0.274	0.772	1.748
0.288	0.670	1.688
0.298	0.604	1.641
0.313	0.510	---
0.325	0.469	1.548
0.340	0.397	1.475
0.361	0.360	1.449
0.441	0.325	1.318
0.467	0.319	---
0.480	0.305	1.287
0.508	0.287	1.234
0.589	0.240	1.213
0.643	0.208	1.185

Einfluß der Temperatur auf die Brechzahlen n_o für ordentlichen und n_e für außerordentlichen Strahl des Kalkspats² bei $\lambda = 0.547 \text{ } \mu\text{m}$

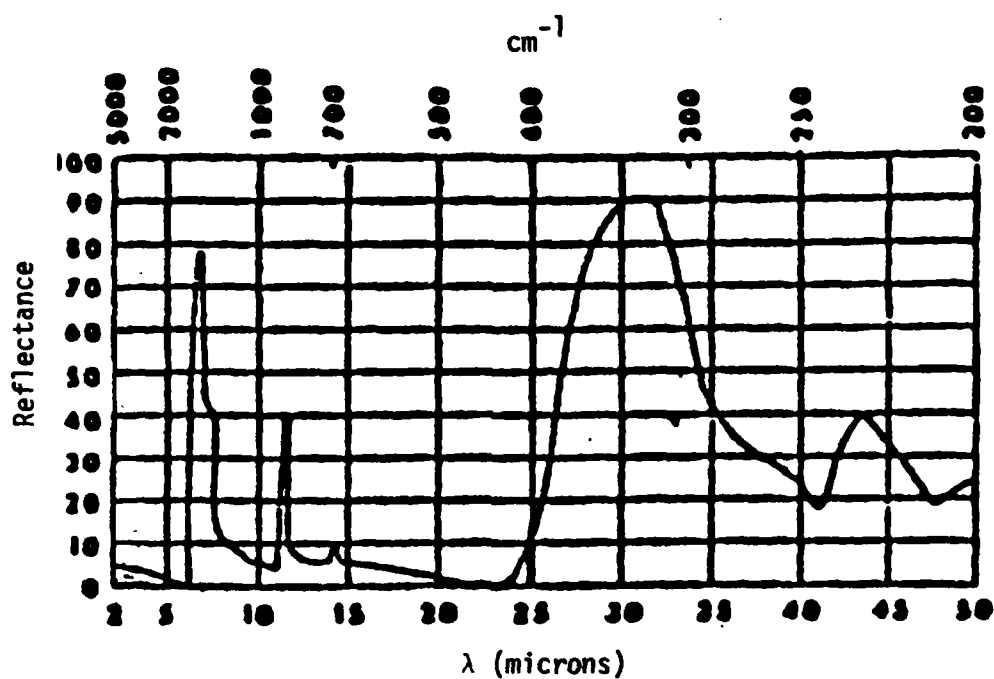
Temperature °C	n_o	n_e
-200	1.66167	1.48596
-150	1.66180	1.48646
-100	1.66187	1.48700
- 50	1.66180	1.48758
0	1.66192	1.48818
+ 18	1.66193	1.48840

CALCIUM CARBONATE (CaCO_3)



The transmission of calcium carbonate for the ordinary ray(—) and for the extraordinary ray(---); 1mm thickness¹.

CALCIUM CARBONATE (CaCO_3)



Reflectance of calcium carbonate².

CESIUM BROMIDE

CsBr

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, Fm3m

LATTICE CONSTANTS (Å) = $a = 4.296$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 212.83

DENSITY = 4.44

SOLUBILITY IN WATER (g/100g of H₂O) = 124

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 909

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = 47.96×10^{-6}

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = 0.023×10^{-4}

SPECIFIC HEAT (cal/g)/°K = 0.063

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI) = 2.3×10^6

HARDNESS (Knoop) = 19.5 (200g)

ELASTIC CONSTANTS = $C_{11}=3.097, C_{12}=0.403, C_{44}=0.7500$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = 6.51 at 2.5×10^6 Hz

RESISTIVITY = ---

BAND GAP ENERGY = ---

EFFECTIVE MASS = ---

MOBILITY = ---

CESIUM BROMIDE (CsBr)

OPTICAL PROPERTIES

TRANSMISSION RANGE: 0.2 - 45 μm

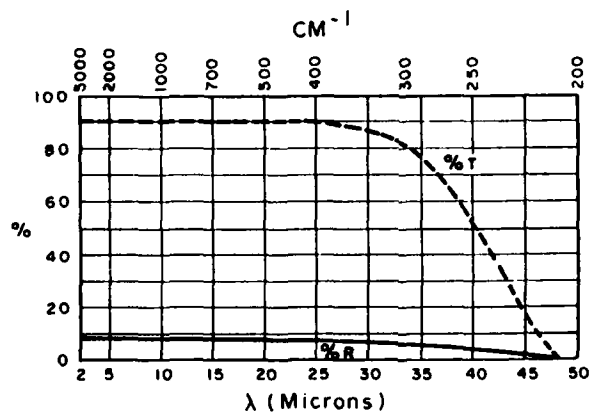
DISPERSION EQUATION:

$$n^2 = 5.640752 - 0.00000338^2 + \frac{0.0018612}{\lambda^2} \\ + \frac{41110.49}{\lambda^2 - 14390.4} + \frac{0.00290764}{\lambda^2 - 0.024964}$$

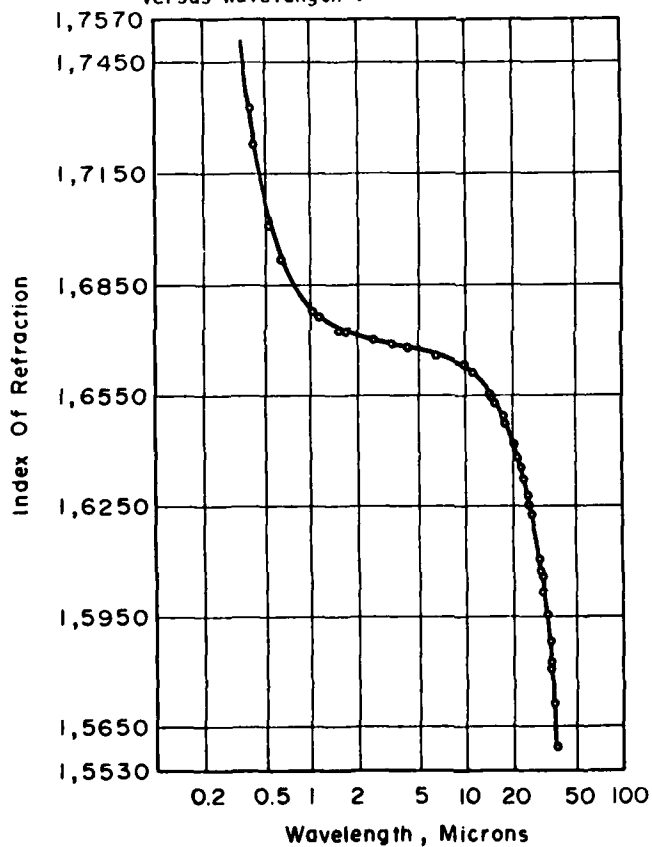
References:

1. D.E. McCarthy, Appl. Opt. 2, 591 (1963).
2. W.S. Rodney and R.J. Spindler, J. Res. NBS 51, 123-126 (1953).
3. E.M. Dianov, Soviet Phys. Solid State 9, 464 (1967).

CESIUM BROMIDE (CsBr)

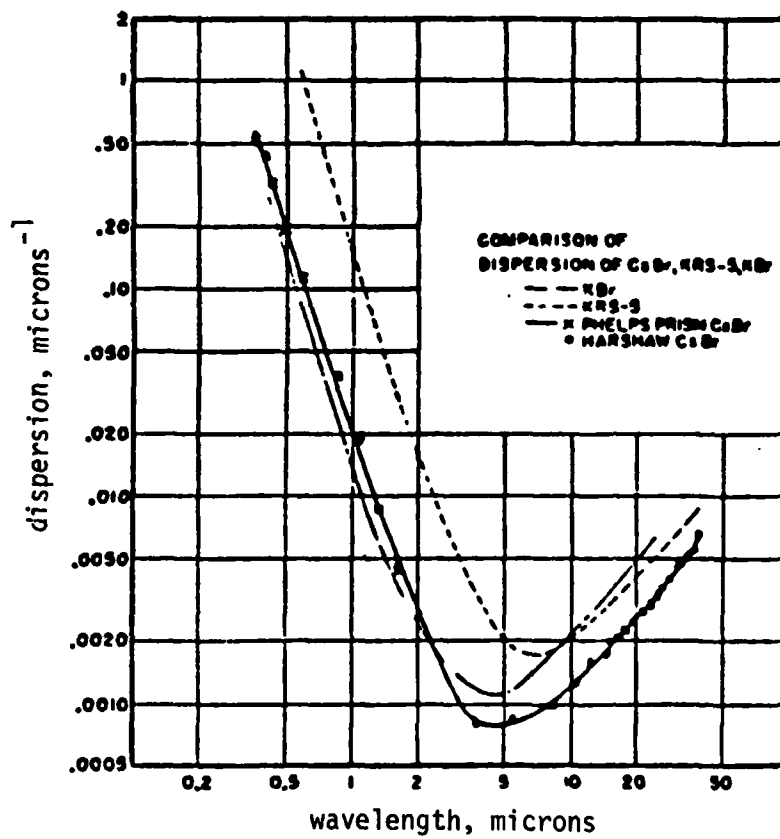


Transmittance and reflectance of CsBr(1cm)
versus wavelength¹.



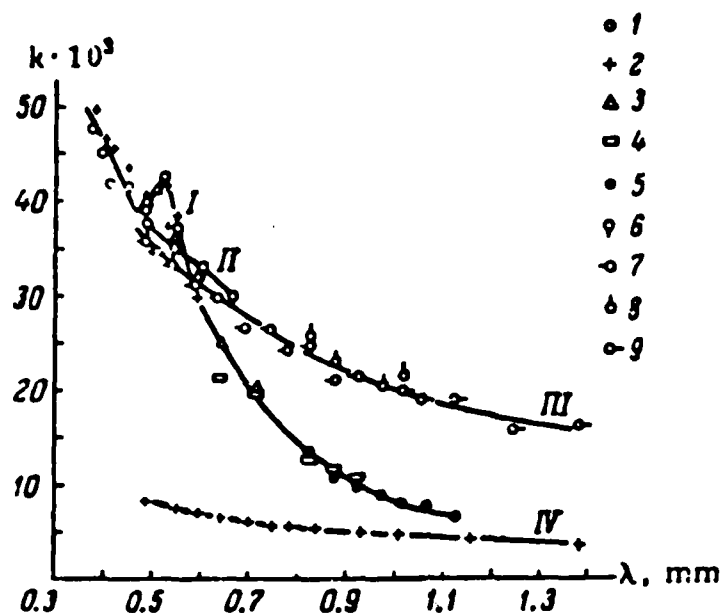
Index of refraction of CsBr as a function of wavelength²
(wavelength scale is logarithmically grauated).

CESIUM BROMIDE (CsBr)



Dispersion of CsBr versus wavelength² (both scales are logarithmic).

CESIUM BROMIDE (CsBr)



Dependence of the absorption coefficient of CsBr (I) and CsI (II-IV) crystals on the wavelength at temperatures of 293°K (I-III) 78°K (IV). Curves II and III represents CsI samples from different batches. The points on curve IV represent the average values of the absorption coefficients for samples of various thicknesses. The sample thickness $d(\text{mm})$: 1) 1.96; 2) 2.47; 3) 3.41; 4) 8.53; 5) 15.06; 6) 3.28; 7) 4.14; 8) 6.11; 9) 12.56.

CESIUM IODIDE

CsI

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, Fm3m

LATTICE CONSTANTS (Å) = $a = 4.5679$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 259.83

DENSITY (g/cm³) = 4.51

SOLUBILITY IN WATER (g/100g of H₂O) = 44

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 894

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = 50×10^{-6}

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = 27×10^{-4}

SPECIFIC HEAT (cal/g)/°K = 0.048

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI) = 0.769×10^6

HARDNESS = ---

ELASTIC CONSTANTS (bars) = $C_{11}=2.46, C_{12}=0.67, C_{44}=0.624$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = 5.65 at 10^6 Hz

RESISTIVITY = ---

BAND GAP ENERGY = ---

EFFECTIVE MASS = ---

MOBILITY = ---

CESIUM IODIDE (CsI)

OPTICAL PROPERTIES

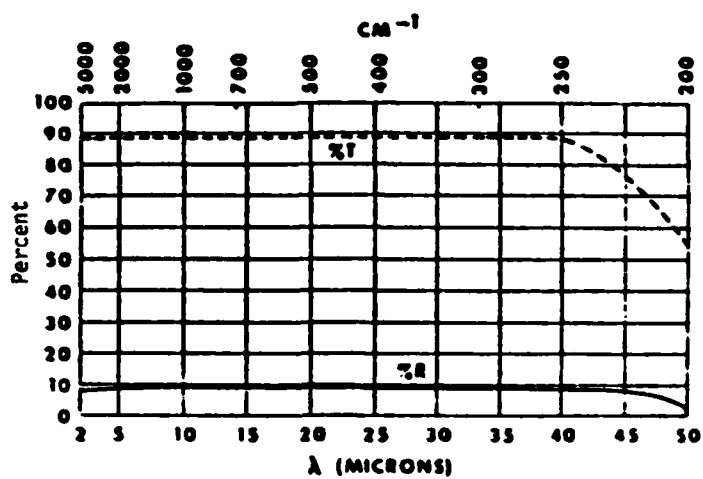
DISPERSION EQUATION:

$$\begin{aligned} n^2 - 1 = & \frac{0.34617251 \lambda^2}{\lambda^2 - 0.00052701} + \frac{1.0080886 \lambda^2}{\lambda^2 - 0.002149156} \\ & + \frac{0.28551800 \lambda^2}{\lambda^2 - 0.0032761} + \frac{0.39743178 \lambda^2}{\lambda^2 - 0.044944} \\ & + \frac{3.3605359 \lambda^2}{\lambda^2 - 25921} \end{aligned}$$

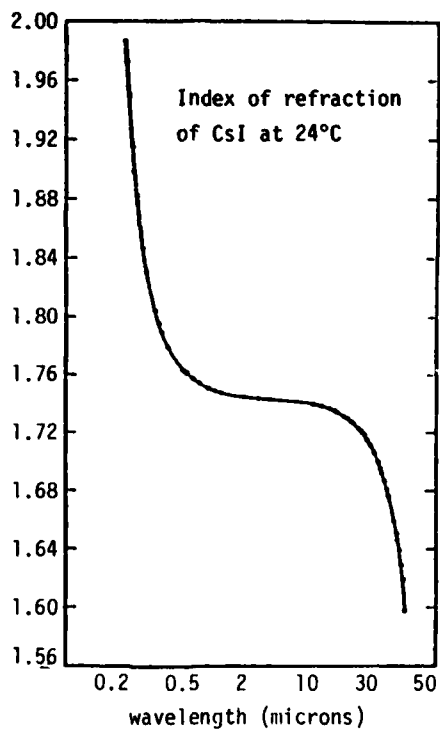
References:

1. D.E. McCarthy, Appl. Opt. 2, 591 (1963).
2. W.S. Rodney, J. Opt. Soc. Am. 45, 987 (1955).

CESIUM IODIDE (CsI)

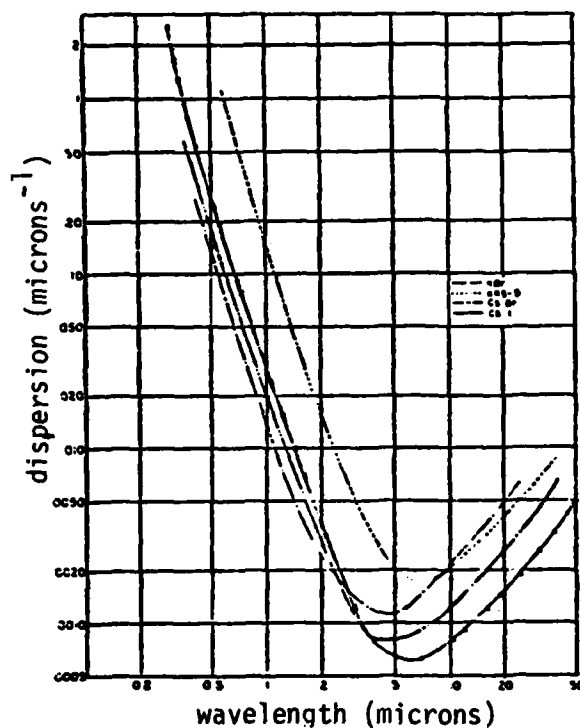


Transmittance and reflectance of CsI versus wavelength¹.

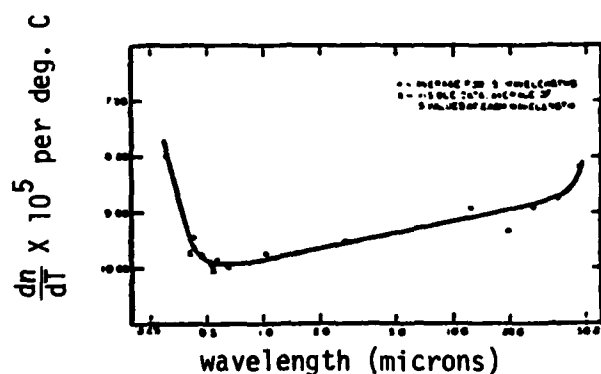


Refractive index of CsI as a function of wavelength² (wavelength scale is logarithmically graduated).

CESIUM IODIDE (CsI)



Comparison of the dispersion of CsI with several other infrared transmitting media² (both scales are logarithmic).



The thermal coefficient of refractive index of CsI as a function of wavelength² (wavelength scale is logarithmic and ordinate values are negative).

COPPER CHLORIDE (NANTOKITE)

CuCl

STRUCTURE

CRYSTALLINE

SYMMETRY	=	Cubic, $\bar{4}3m$
LATTICE CONSTANTS (Å)	=	$a = 5.418 \pm 0.002$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	98.99
DENSITY (g/cm ³)	=	4.14
SOLUBILITY IN WATER (g/100g of H ₂ O)	=	1.5

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	703
LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	13.6×10^{-6}
THERMAL CONDUCTIVITY (cal/cm·sec·°K)	=	Not available
SPECIFIC HEAT (cal/g)/°K	=	0.12

MECHANICAL PROPERTIES

YOUNGS MODULUS	=	Not available
HARDNESS (kg/mm ²)	=	11

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT (ϵ_0)	=	7.5
RESISTIVITY (Ω·cm)	=	3.5×10^8
BAND GAP ENERGY	=	--
EFFECTIVE MASS	=	--
MOBILITY	=	--

COPPER CHLORIDE (CuCl)

OPTICAL PROPERTIES

TRANSMISSION RANGE: 0.4 to 20 μm

$$\text{DISPERSION EQUATION: } n^2 = \frac{[3.580 + 3.16 \times 10^{-2}] \lambda^2}{\lambda^2 - 0.16} + \frac{9.3 \times 10^{-2}}{\lambda^2}$$

ELECTRO-OPTIC COEFFICIENTS (10^{-12} m/v)

$$r_{41}^T = 3.2 \quad \text{at } 10.6 \mu\text{m} \text{ (Reference 1)}$$

$$r_{41}^S = 2.20 \quad \text{at } 3.39 \mu\text{m}$$

SECOND HARMONIC COEFFICIENTS (10^{12} m/v)

$$d_{14} = 4.19 \quad \text{at } 10.6 \mu\text{m} \text{ (Reference 2)}$$

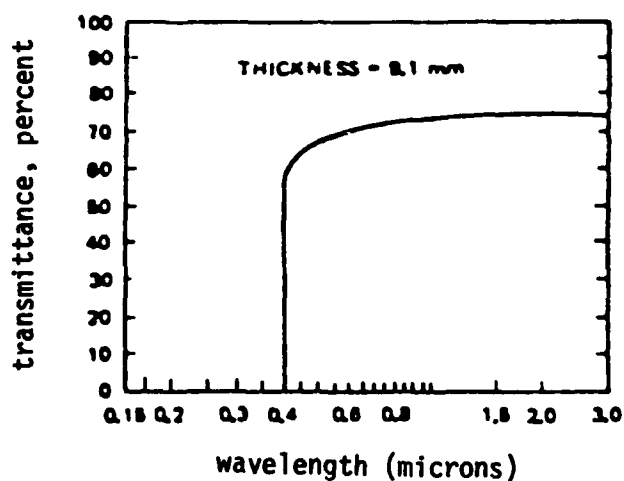
$$d_{14} = 6.7 \pm 2.2 \quad \text{at } 10.6 \mu\text{m} \text{ (Reference 3)}$$

$$d_{14} = 9.1 \pm 4.1$$

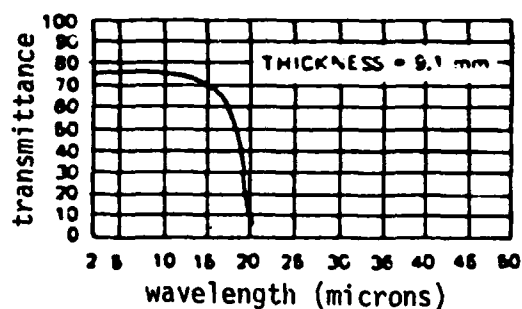
References:

1. T. Sueta, T. Matusnima, T. Nishimoto and T. Makimoto, Proc. IEEE 58, 1378 (1970).
2. J. Jerphagnon, C. Schwab and D. Chemla, C.R. Acad. Sci., Paris, B265, 495, (1967).
3. D. Chemla, P. Kupecek, C. Schwartz, C. Schwab and A. Goltzene, IEEE J. Quant. Ed. QE7, 126 (1971).
4. D.E. McCarthy, Appl. Opt. 6, 1896 (1967).
5. D.E. McCarthy, Appl. Opt. 4, 317 (1965).
6. A. Feldman and D. Horowitz, J. Opt. Soc. Am. 59, 1406 (1969).

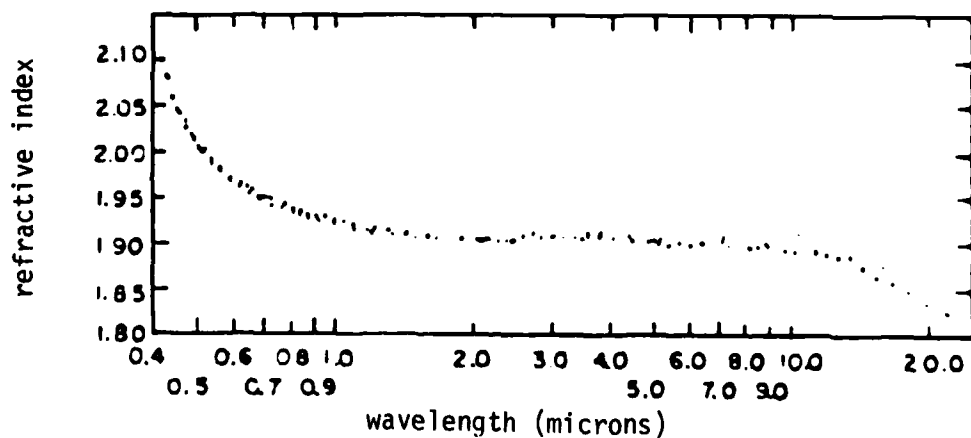
COPPER CHLORIDE (CuCl)



Transmittance of CuCl versus wavelength⁴.



Transmittance of CuCl versus wavelength⁵.



Refractive index of CuCl versus wavelength⁶.

GALLIUM ANTIMONIDE

GaSb

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, $\bar{4}3m$

LATTICE CONSTANTS (Å) = $a = 6.094$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 191.48

DENSITY (g/cm³) = 5.6137

SOLUBILITY IN WATER (g/100g of H₂O) = Insoluble

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 1271

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = 6.9×10^{-6}

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = 0.105

SPECIFIC HEAT (cal/g)/°K = 0.01828

MECHANICAL PROPERTIES

YOUNGS MODULUS (10⁶ PSI) = 9.19

HARDNESS (kg/mm²) = 469

ELASTIC CONSTANTS (bars) = $c_{11}=8.849$, $c_{12}=4.037$, $c_{44}=4.325$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT (static) = 15

RESISTIVITY = Not available

BAND GAP ENERGY (eV) = 0.69

EFFECTIVE MASS m_e^* = $0.045 m_0$

MOBILITY μ_e (cm²/v-sec) = 4000

GALLIUM ANTIMONIDE (GaSb)

OPTICAL PROPERTIES

THERMAL COEFFICIENT OF REFRACTIVE INDEX: $\frac{1}{n} \frac{dn}{dT} = 8.2 \times 10^{-5}/^{\circ}\text{K}$ at 5 - 20 μm (Reference 1)

PRESSURE COEFFICIENT OF REFRACTIVE INDEX: $\frac{1}{n} \frac{dn}{dp} = 0.8 \pm 0.2 \times 10^{-6}/\text{bar}$ (calculated)

SECOND HARMONIC COEFFICIENTS (10^{12} m/v)

$d_{14} = 628 \pm 63$ at 10.6 μm (Reference 2)

$d_{14} = 419$ at 1.06 μm (Reference 3)

References:

1. B. Bendow, P.D. Gianino, Y.F. Tsay and S.S. Mitra, Appl. Opt. 13, 2382 (1974).
2. J.J. Wynne and N. Bloembergen, Phys. Rev. 188, 1211 (1969).
3. R.K. Chang, J. Ducuing and N. Bloembergen, Phys. Rev. Lett. 15, 415 (1965).
4. B.O. Serraphin and H.E. Bennet, in Semiconductors and Semimetals, ed. by R.K. Willardson and A.C. Beer Academic Press, New York, p. 525-526 (1967).
5. D.E. McCarthy, Appl. Opt. 7, 1997 (1968).

GALLIUM ANTIMONIDE (GaSb)

Refractive Index and Extinction Coefficient of Gallium Antimonide⁴

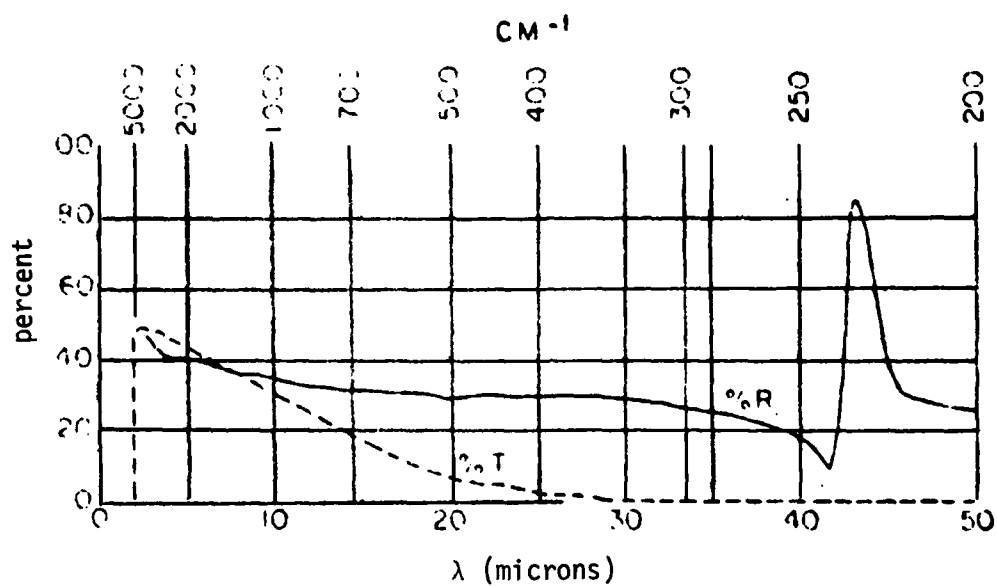
λ (μm)	n	k	λ (μm)	n	k
1.49	--	9.70×10^{-2}	1.88	--	2.00×10^{-4}
1.51	--	9.45×10^{-2}			
1.53	--	9.06×10^{-2}	1.88	--	1.41×10^{-4}
1.55	--	8.67×10^{-2}	1.90	3.802	--
1.56	--	8.52×10^{-2}	1.91	--	1.41×10^{-4}
			1.94	--	1.18×10^{-4}
1.57	--	8.16×10^{-2}	1.97	--	1.10×10^{-4}
1.58	--	7.90×10^{-2}			
1.59	--	7.68×10^{-2}	2.00	--	1.08×10^{-4}
1.60	--	7.39×10^{-2}	2.00	--	9.87×10^{-3}
1.61	--	7.10×10^{-2}	2.00	3.789	--
			2.03	--	1.09×10^{-4}
1.62	--	6.80×10^{-2}	2.07	--	1.13×10^{-4}
1.63	--	6.49×10^{-2}			
1.64	--	6.14×10^{-2}	2.10	3.780	--
1.65	--	5.82×10^{-2}	2.20	3.764	--
1.66	--	5.47×10^{-2}	2.30	3.758	--
			2.40	3.755	--
1.68	--	5.10×10^{-2}	2.40	--	1.43×10^{-4}
1.69	--	4.70×10^{-2}	2.50	--	1.65×10^{-4}
1.70	--	4.06×10^{-2}	2.50	3.749	--
1.71	--	2.51×10^{-2}	2.80	--	2.65×10^{-4}
1.72	--	7.48×10^{-3}	3.00	--	3.65×10^{-4}
			3.00	3.898	--
1.73	--	6.68×10^{-3}			
1.73	--	2.14×10^{-3}	3.40	--	6.66×10^{-4}
1.74	--	3.05×10^{-3}	3.50	--	7.46×10^{-4}
1.75	--	1.83×10^{-3}	3.50	3.861	--
1.76	--	1.24×10^{-3}	3.70	--	9.25×10^{-4}
			4.00	--	1.26×10^{-3}
1.77	--	9.18×10^{-4}			
1.77	--	1.23×10^{-3}	4.00	3.833	--
1.80	--	5.40×10^{-4}	4.50	--	1.88×10^{-3}
1.80	--	5.51×10^{-4}	5.00	--	2.53×10^{-3}
1.80	3.820	--	5.00	3.824	--
			5.40	--	3.13×10^{-3}
1.82	--	3.56×10^{-4}			
1.82	--	3.55×10^{-4}	5.80	--	3.66×10^{-3}
1.84	--	1.96×10^{-4}	6.00	--	3.94×10^{-3}
1.85	--	2.52×10^{-4}	6.00	3.824	--

GALLIUM ANTIMONIDE (GaSb)

Refractive Index and Extinction Coefficient of Gallium Antimonide⁴ (Continued)

λ (μm)	n	k	λ (μm)	n	k
6.20	--	4.22×10^{-3}	12.00	3.843	--
6.70	--	4.90×10^{-3}			
7.00	--	5.33×10^{-3}	12.40	--	1.21×10^{-2}
7.00	3.843	--	12.80	--	1.26×10^{-2}
7.40	--	5.90×10^{-3}	13.40	--	1.41×10^{-2}
8.00	--	6.68×10^{-3}	14.00	--	1.40×10^{-2}
8.00	3.843	--	14.00	3.861	--
			14.90	3.880	--
8.40	--	7.21×10^{-3}	--	--	--
9.00	--	7.99×10^{-3}	--	--	--
9.00	3.843	--	--	--	--
9.50	--	8.63×10^{-3}	--	--	--
10.00	--	9.26×10^{-3}	--	--	--
10.00	3.843	--	--	--	--
10.60	--	9.95×10^{-3}	--	--	--
11.10	--	1.06×10^{-2}	--	--	--
12.00	--	1.16×10^{-2}	--	--	--

GALLIUM ANTIMONIDE (GaSb)



Transmittance and reflectance of gallium antimonide versus wavelength⁵.

GALLIUM ARSENIDE

GaAs

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, $\bar{4}3m$

LATTICE CONSTANTS (Å) = $a = 5.652$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 144.63

DENSITY (g/cm³) = 5.307

SOLUBILITY IN WATER (g/100g of H₂O) = <0.005

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 1151

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = 6.8×10^{-6}

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = .0108

SPECIFIC HEAT (cal/g)/°K = 0.076

MECHANICAL PROPERTIES

YOUNGS MODULUS = Not available

HARDNESS = 721

ELASTIC CONSTANTS (bars) = $C_{11}=1.192$, $C_{12}=0.05986$, $C_{44}=0.538$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = 12

RESISTIVITY = --

BAND GAP ENERGY = 1.4257

EFFECTIVE MASS m_e^* = $0.07 m_0$

MOBILITY μ_e (cm²/v-sec) = 3600

GALLIUM ARSENIDE (GaAs)

OPTICAL PROPERTIES

TRANSMISSION RANGE: = 1 - 21 μm

DISPERSION EQUATION: = ---

THERMAL COEFFICIENT
OF REFRACTIVE INDEX: $\frac{1}{n} \frac{dn}{dT} = 5.7 \times 10^{-5}/^{\circ}\text{K}$ at 5-20 μm

PRESSURE COEFFICIENT
OF REFRACTIVE INDEX: $\frac{1}{n} \frac{dn}{dP} = (0.7 \pm 0.1) \times 10^{-6}/\text{bar}$

ELECTRO-OPTIC PROPERTIES

PHOTO-ELASTIC CONSTANTS: $P_{11} = -0.165$, $P_{12} = -0.140$, $P_{44} = -0.072$ at 1.15 μm

ELECTRO-OPTIC COEFFICIENTS (10^{-12} m/v)

S-CONSTANT STRESS

T-CONSTANT STRAIN

REFERENCES

r_{41}^S	=	1.2	at	.9-1.08 μm	(1)
r_{41}^S	=	1.5	at	3.39 μm	(2)
r_{41}^T	=	1.6	at	10.6 μm	(3,4)
r_{41}^T	=	1.0-1.2	at	4-12 μm	(5)

ACOUSTO-OPTIC PROPERTIES

ACOUSTIC VIBRATION POLARIZATION DIRECTION = Long.

ACOUSTIC VELOCITY (km/s) = 5.3

LIGHT VIBRATION POLARIZATION DIRECTION = Parallel

FIGURE OF MERIT ($M_2 = n^6 p^2 / \rho v^3$) at $\lambda = 1.15 \mu\text{m}$ = 96

ACOUSTIC ATTENUATION (dB/cm) at 500 MHz = 7.55

GALLIUM ARSENIDE (GaAs)

SECOND HARMONIC COEFFICIENTS (10^{-12}v/m)

REFERENCES

d_{14}	=	274 ± 66	at	$1.0582 \mu\text{m}$	(6)
d_{14}	=	387 ± 126	at	$10.6 \mu\text{m}$	(7)
	=	274.3 ± 37.8	at	$1.582 \mu\text{m}$	(8)
d_{36}	=	249 ± 15	at	$1.582 \mu\text{m}$	(9)
d_{14}	=	188.5 ± 19	at	$10.6 \mu\text{m}$	(10)
d_{14}	=	134 ± 42	at	$10.6 \mu\text{m}$	(11)
d_{14}	=	140 ± 10	at	$1.06 \mu\text{m}$	(12)
d_{14}	=	100 ± 5.21	at	$1.06 \mu\text{m}$	(13)
d_{14}	=	191 ± 64	at	$1.058 \mu\text{m}$	(14)
d_{14}	=	137	at	$0.8435 \mu\text{m}$	(15)

GALLIUM ARSENIDE (GaAs)

References:

1. E.H. Turner & I.P. Kamminone, J. Opt. Sov. Am. 53, 523 (1963).
2. I.P. Kamminone, CRC Handbook of Lasers (R.J. Pressley Ed.), Chemical Rubber Co., Cleveland, Ohio (1971).
3. A. Yariv, C.A. Mead and J.V. Parker, IEEE J. Quant. Ed QE2, 243 (1966).
4. I.P. Kamminone, IEEE J. Quant. Ed. QE4, 23 (1968).
5. T.E. Walsh, RCA Review XXVIII, 323 (1966).
6. R.C. Miller, Appl. Phys. Lett. 5, 17 (1964).
7. C.K.N. Patel, Phys. Rev. Lett. 16, 613 (1966).
8. R.K. Chang, J. Ducuing and N. Bloembergen, Phys. Rev. Lett. 15, 415 (1965).
9. R.A. Soref and H.W. Moos, J. Appl. Phys. 35, 2152 (1968).
10. J.J. Wynne and N.B. Bloembergen, Phys. Rev. 188, 1211 (1969).
11. J.H. McFee, G.D. Boyd and P.H. Schmidt, Appl. Phys. Lett. 17, 576 (1970).
12. W.D. Johnston & I.P. Kamminone, Phys. Rev. 188, 1209 (1969).
13. A. Mooradian & A.L. McWhorter in International Conference on Light Scattering in Solids, 1968 ed. by G.B. Wright, C. Springer, New York (1969).
14. R. Braunstein and N. Ockman, Interaction of Coherent Optical Radiation With Solids, ONR Contract No. NONR-4128110, Office of Naval Research, Department of the Navy, Washington, D.C.
15. M. Garfinkel and W.F. Engeler, Appl. Phys. Lett. 3, 178 (1965).
16. D.T.F. Marple, J. Appl. Phys. 35, 1241 (1964).
17. W.L. Wolfe & G. Zissis, The Infrared Handbook, ERIM, Michigan, 7-63 (1978).
18. D.E. McCarthy, Appl. Opt. 7 1997 (1968).
19. E. Hirshmann and T.E. Walsh, Report No. NASA TN D-4049, (June 1967).
20. B. Bendow, P.D. Gianino, Y.F. Tsay and S.S. Mitra, Appl. Opt. 13, 2382 (1974).
21. H.R. Caketon and R.A. Sorej, Appl. Phys. Lett. 9, 110 (1966).

GALLIUM ARSENIDE (GaAs)

GALLIUM ARSENIDE (GaAs)

Room Temperature Refractive Index versus Wavelength¹⁶.

Wavelength (μm)	n
1.127	3.455
1.239	3.425
1.377	3.400
1.550	3.375
1.652	3.366

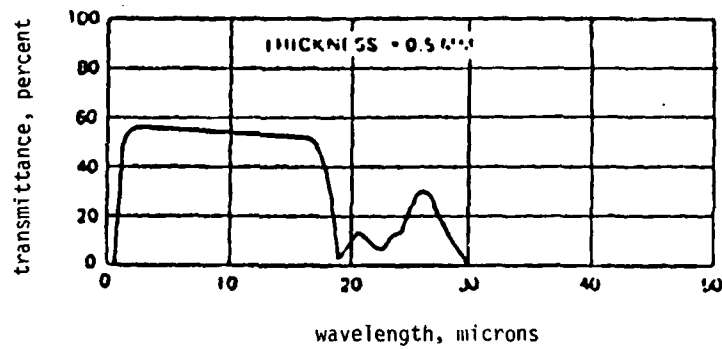
GALLIUM ARSENIDE (GaAs)

Refractive Index[†] of Gallium Arsenide versus Wavelength¹⁷.

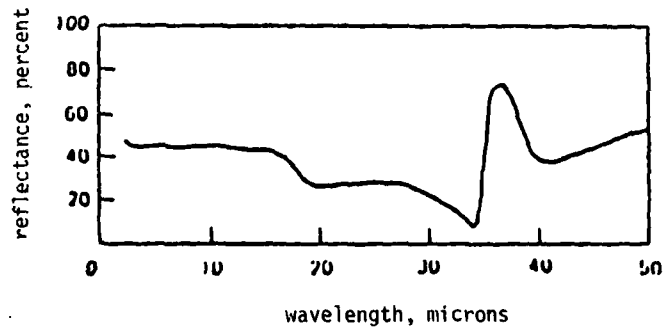
λ (μm)	n	λ (μm)	n
0.78 $\pm$ 0.01	3.34 $\pm$ 0.04	14.5 $\pm$ 0.05	2.82 $\pm$ 0.04
8.0 $\pm$ 0.05	3.34 $\pm$ 0.04	15.0 $\pm$ 0.05	2.73 $\pm$ 0.04
10.0 $\pm$ 0.05	3.135 $\pm$ 0.04	17.0 $\pm$ 0.05	2.59 $\pm$ 0.04
11.0 $\pm$ 0.05	3.045 $\pm$ 0.04	19.0 $\pm$ 0.05	2.41 $\pm$ 0.04
13.0 $\pm$ 0.05	2.97 $\pm$ 0.04	21.9 $\pm$ 0.1	2.12 $\pm$ 0.04
13.7 $\pm$ 0.05	2.895 $\pm$ 0.04	--	--

[†]The experimental data seem to be somewhat more scattered than the reported experimental errors indicate.

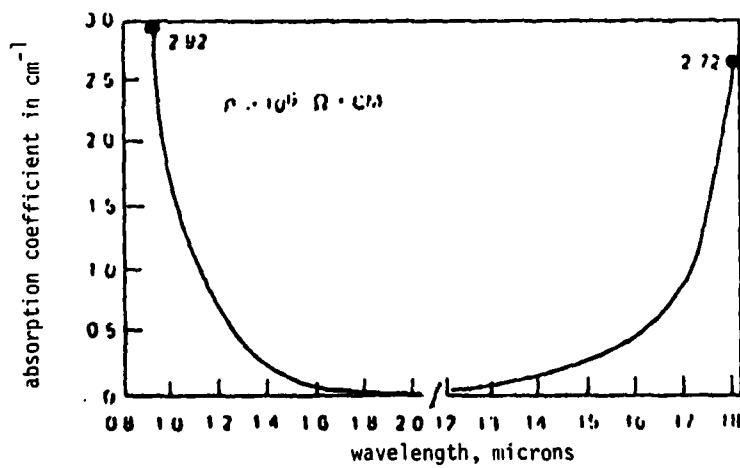
GALLIUM ARSENIDE (GaAs)



Transmittance of GaAs versus wavelength¹⁸.



Reflectance of GaAs versus wavelength¹⁹.



Absorption coefficient of GaAs versus wavelength¹⁹.

GERMANIUM

Ge

STRUCTURE

CRYSTALLINE

SYMMETRY	=	Cubic, m3m
LATTICE CONSTANTS (Å)	=	a = 5.66

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	72.60
DENSITY (g/cm ³)	=	5.33
SOLUBILITY IN WATER (g/100g of H ₂ O)	=	<0.005

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	1209
LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	5.56 x 10 ⁻⁶
THERMAL CONDUCTIVITY (cal/cm·sec·°K)	=	0.14
SPECIFIC HEAT (cal/g)/°K	=	0.074

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI)	=	14.9 x 10 ⁶
HARDNESS (Knoop)	=	700 - 880
ELASTIC CONSTANTS (bars)	=	C ₁₁ =1.29, C ₁₂ =4.83, C ₄₄ =6.7

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT (static)	=	16.3
RESISTIVITY	=	---
BAND GAP ENERGY	=	---
EFFECTIVE MASS m _e [*]	=	0.08 m ₀
MOBILITY μ _e (cm ² /v-sec)	=	2000

GERMANIUM (Ge)

OPTICAL PROPERTIES

TRANSMISSION RANGE: 2-20 μm

ABSORPTION COEFFICIENT $\alpha(\text{cm}^{-1})$: = 1.2×10^{-2} at 10.6 μm
= 1.8×10^{-3} at 5.25 μm

DISPERSION EQUATION¹: $n = A + BL + CL^2 + D\lambda^2 + E\lambda^4$

where $A = 3.99931$
 $B = 0.391707$
 $C = 0.163492$
 $D = -0.0000060$
 $E = 0.000000053$
 $L = (\lambda^2 - 0.028)^{-1}$

PRESSURE COEFFICIENT OF REFRACTIVE INDEX: $\frac{1}{n} \frac{dn}{dp} = -0.7$ to -1.0 ($10^{-6}/\text{bar}$)

PHOTOELASTIC CONSTANTS²: $p_{11}=0.27$, $p_{12}=0.235$, $p_{44}=0.125$ at 10.6 μm

ACOUSTO-OPTIC PROPERTIES

ACOUSTIC VIBRATION POLARIZATION DIRECTION = Longitudinal
ACOUSTIC VELOCITY (km/s) = 5.50 (Reference 3)
LIGHT VIBRATION POLARIZATION DIRECTION = Parallel
FIGURE OF MERIT ($M_2 = n^6 p^2 / \rho v^3$) = 540
ACOUSTIC ATTENUATION (dB/cm) at 500 MHz = 7.65

DETECTOR PROPERTIES		Ge: Au	Ge: Cd	Ge: Cu	Ge: Hg	Ge: Zn
OPERATING MODE	=	PC	PC	PC	PC	PC
OPERATING TEMPERATURE ($^{\circ}\text{K}$)	=	77	<26	<14	<30	<10
MAXIMUM TEMPERATURE FOR BLIP ($^{\circ}\text{K}$)	=	60	--	17	35	--
WAVELENGTH REGION (μm)	=	1.0-10.6	2-23	2-30	2-14	2-40

GERMANIUM (Ge)

DETECTOR PROPERTIES (Continued)		Ge: Au	Ge: Cd	Ge: Cu	Ge: Hg	Ge: Zn
DETECTIVITY, D^* ($\text{cmHz}^{1/2}/\text{Watt}$)	=	$>1.5 \times 10^9$	$>2 \times 10^{10}$	$>1.5 \times 10^{10}$	$>1 \times 10^{10}$	$>1 \times 10^{10}$
RESPONSE TIME (μsec)	=	$<2 \times 10^{-3}$	.1	$<1 \times 10^{-3}$	<.1	$<2 \times 10^{-2}$

References:

1. C.D. Salzberg and J.J. Villa, J. Opt. Soc. Am. 48, 579 (1958).
2. R.L. Abrams and D.A. Pinnow, J. Appl. Phys. 41, 2765 (1970).
3. R.L. Abrams and D.A. Pinnow, IEEE J. Quant. El. QE7, 135 (1971).
4. D.H. Rank and H.E. Bennet, J. Opt. Soc. Am. 44, 13 (1954).
5. D.E. McCarthy, Appl. Opt. 2, 591 (1963).
6. C.D. Salzberg and J.J. Villa, J. Opt. Soc. Am. 47, 244 (1957).
7. Santa Barbara Research Center Bulletin.

GERMANIUM (Ge)

Germanium¹: Refractive Index versus Wavelength at 27°C

$\lambda, \mu\text{m}$	n	$\lambda, \mu\text{m}$	n
2.0581	4.1016	4.258	4.0216
2.1526	4.0919	4.866	4.0170
2.3126	4.0786	6.233	4.0094
2.4374	4.0708	8.66	4.0043
2.577	4.0609	9.72	4.0034
2.7144	4.0552	11.04	4.0026
2.998	4.0452	12.20	4.0023
3.3033	4.0369	13.02	4.0021
3.4188	4.0334	--	--

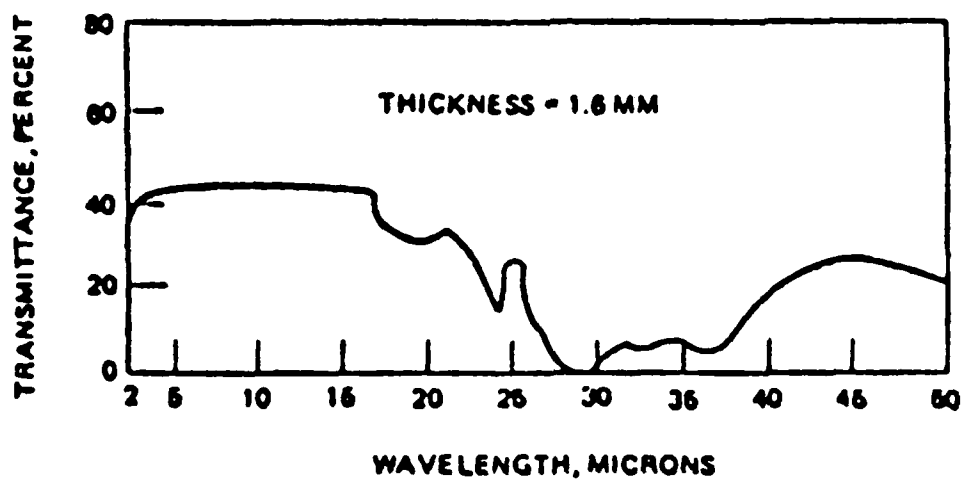
Germanium⁴: Wavelength Dependence of Temperature Coefficient of Refractive Index at 24.5°C

$\lambda, \mu\text{m}$	$\frac{dn}{dT}, 10^{-4}/^{\circ}\text{C}$	$\lambda, \mu\text{m}$	$\frac{dn}{dT}, 10^{-4}/^{\circ}\text{C}$
1.934	5.919	2.246	5.251
2.174	5.285	2.401	5.037

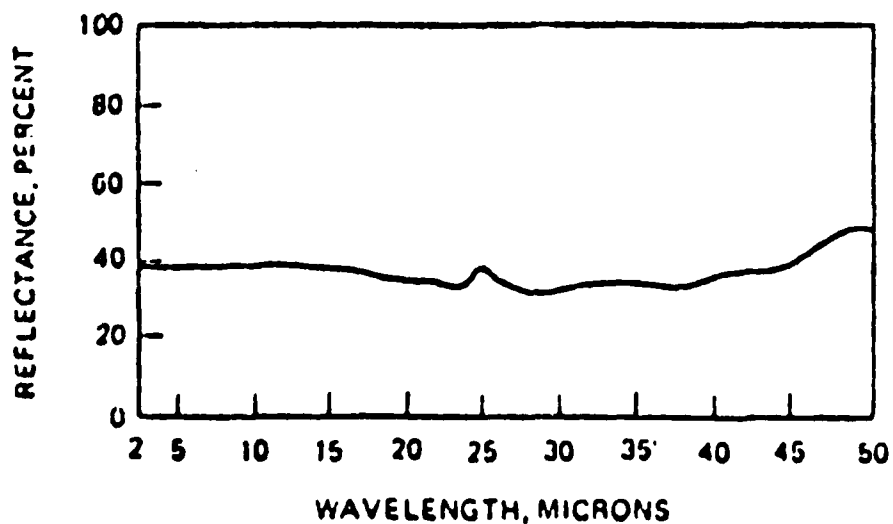
Germanium: Wavelength Dependence of Temperature Coefficient of Refractive Index (95 °K to 298 °K)¹

λ (μm)	$\frac{dn}{dT}$ $10^{-4} \text{ }^{\circ}\text{C}^{-1}$
2	1.5 ± 0.2
4	1.5 ± 0.2
10	1.5 ± 0.3
12	1.5 ± 0.4

GERMANIUM (Ge)

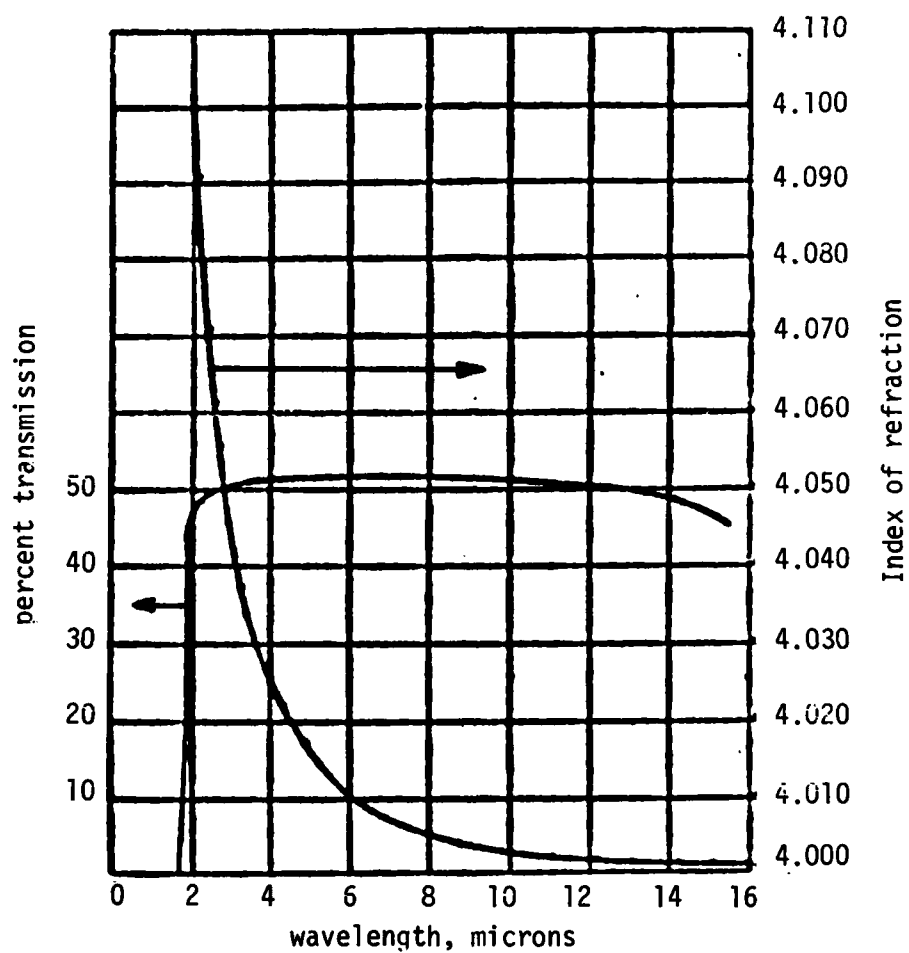


Transmittance versus wavelength of Germanium⁵, 1.6mm.



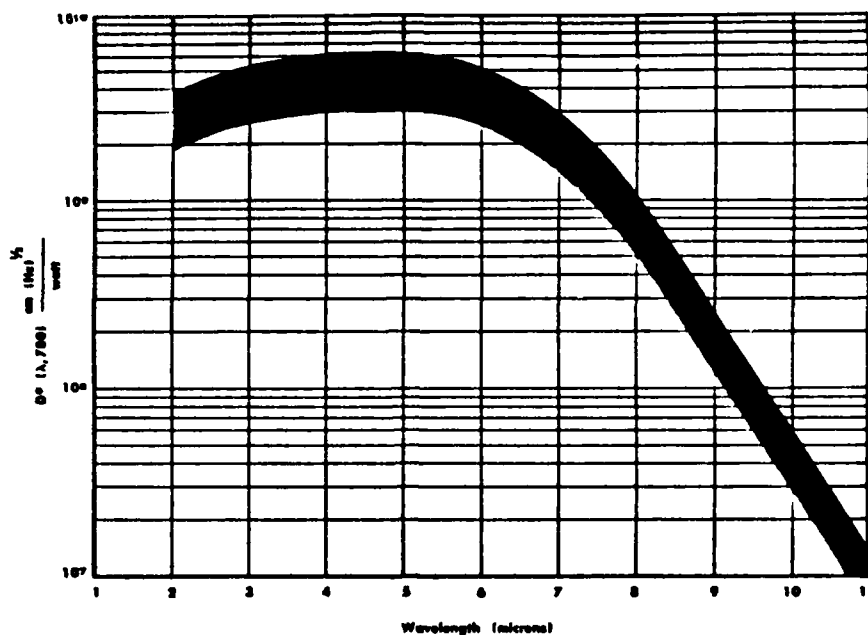
Reflectance versus wavelength of Germanium⁵.

GERMANIUM (Ge)



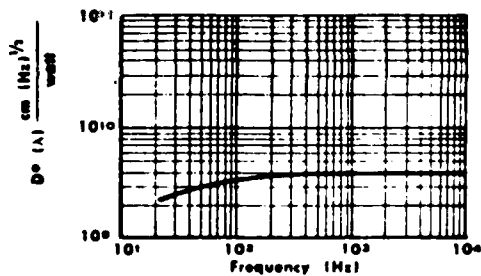
Index of refraction of single-crystal germanium and transmission through a 1.0mm thick sample⁶.

GERMANIUM (Ge)

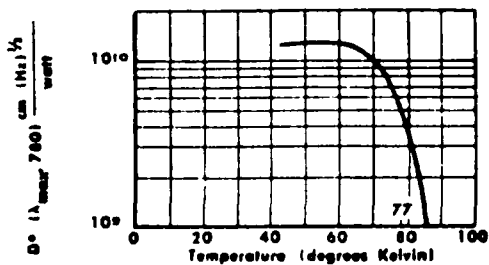


Typical range of spectral detectivities for Ge:Au IR detectors at 77°K, with Irtran 2 window⁷.

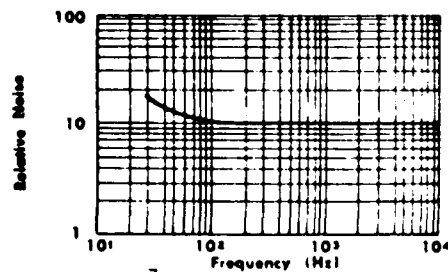
**2π STERADIANS FOV,
295°K BACKGROUND**



Example⁷ of detectivity vs. frequency for Ge:Au IR detectors at 77°K

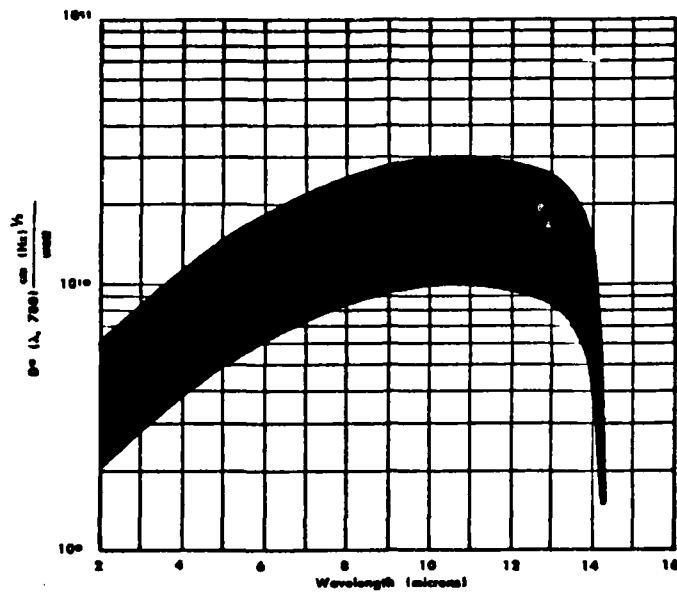


Example of detectivity vs. temperature for Ge:Au IR detectors⁷.



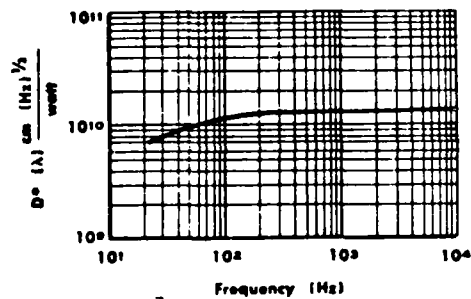
Example⁷ of noise vs. frequency for Ge:Au IR detectors at 77°K.

GERMANIUM (Ge)

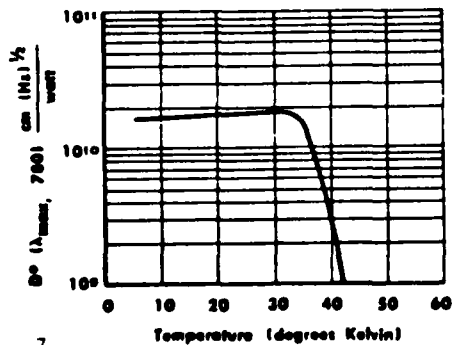


Range of spectral detectivities of Ge:Hg IR detectors at 5°K, 60° FOV, 295°K°background⁷.

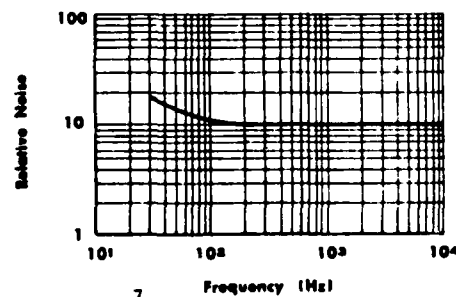
60° FOV, 295° Background



Example⁷ of detectivity vs. frequency for Ge:Hg IR detectors at 5°K.

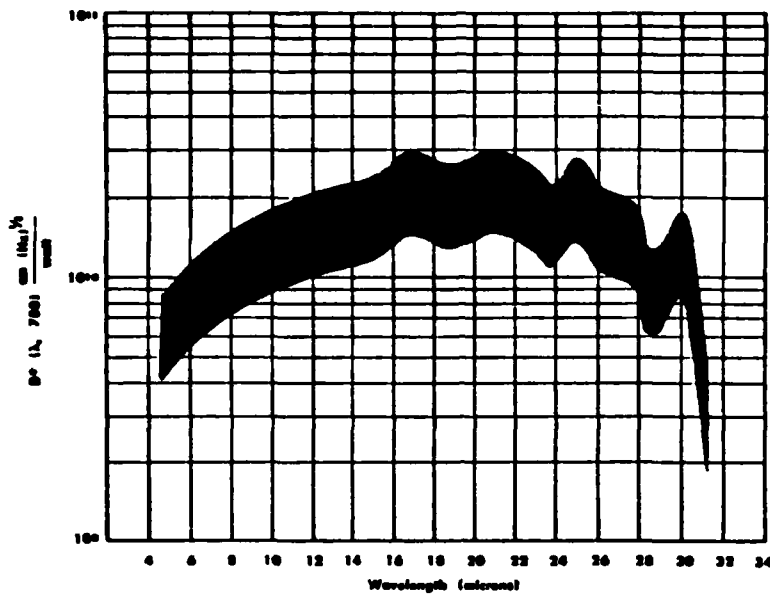


Example⁷ of detectivity vs. temperature for Ge:Hg IR detectors.



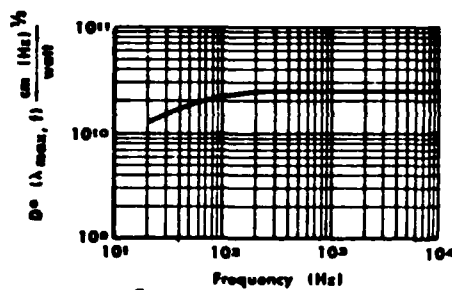
Example⁷ of noise vs. frequency for Ge:Hg IR detectors at 5°K.

GERMANIUM (Ge)

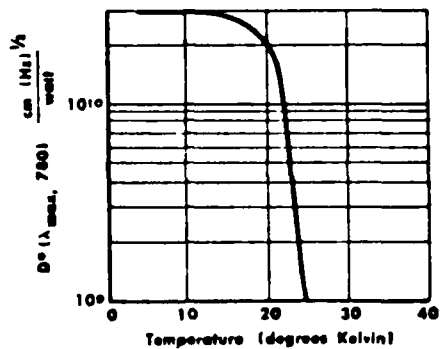


Range of spectral detectivities for Ge:Cu IR detectors at 5°K, 60° field of view⁷.

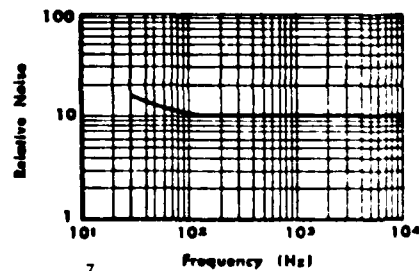
60° FOV, 295° BACKGROUND



Example⁷ of detectivity vs. frequency for Ge:Cu IR detectors at 4.2°K.

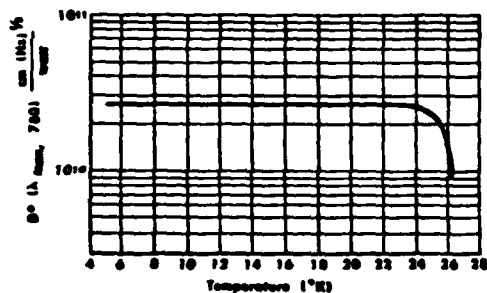


Example of detectivity vs. temperature for Ge:Cu IR detectors⁷.

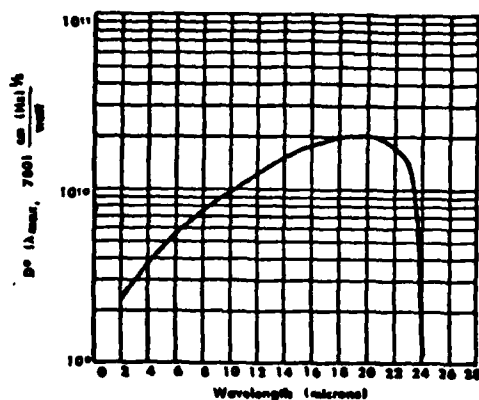


Example⁷ of noise vs. frequency for Ge:Cu IR detectors at 4.2°K.

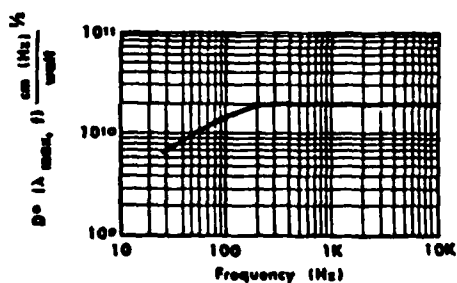
GERMANIUM (Ge)



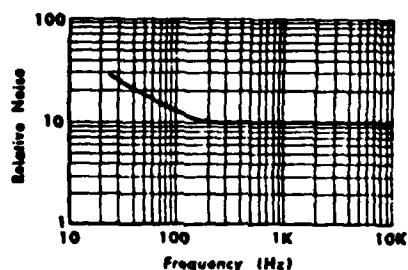
Example of detectivity vs. temperature for Ge:Cd IR detectors, 60°K FOV, 295°K background⁷.



Example⁷ of spectral detectivity for Ge:Cd IR detectors at 5°K, 60° FOV.

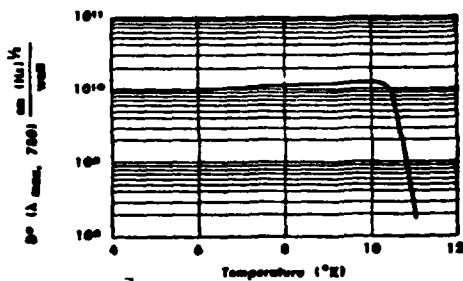


Example⁷ of detectivity vs. frequency for Ge:Cd IR detectors at 5°K.

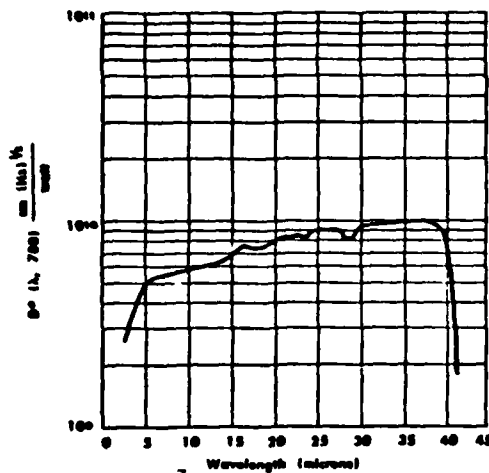


Example of noise voltage vs. frequency for Ge:Cd IR detectors at 5°K, 60° FOV, 295°K background⁷.

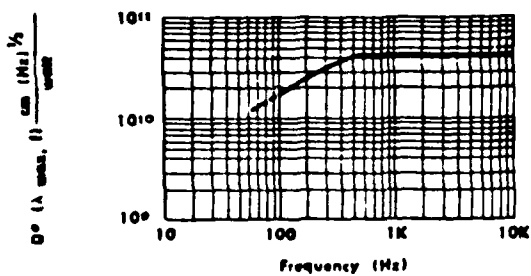
GERMANIUM (Ge)



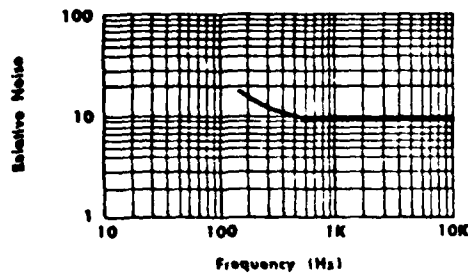
Example⁷ of detectivity vs. temperature for Ge:Zn IR detectors, 60° FOV, 295°K background.



Example⁷ of spectral detectivity for Ge:Zn IR detectors at 5°K, 60° FOV.

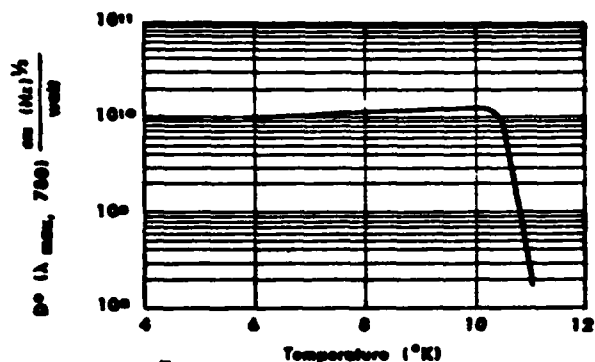


Example of detectivity vs. frequency for Ge:Zn IR detectors, 60° FOV, 295°K background⁷.

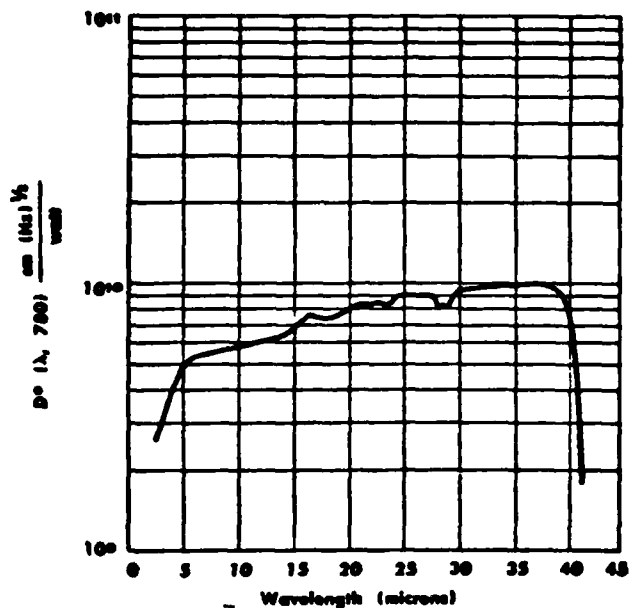


Example of detector noise voltage vs. frequency for Ge:Zn IR detectors, 5°K, 60° FOV, 295°K background⁷.

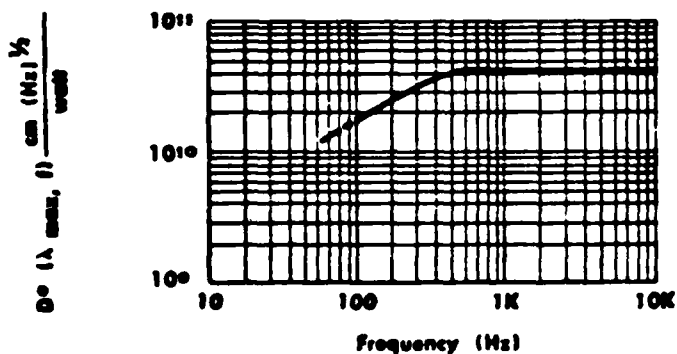
GERMANIUM (Ge)



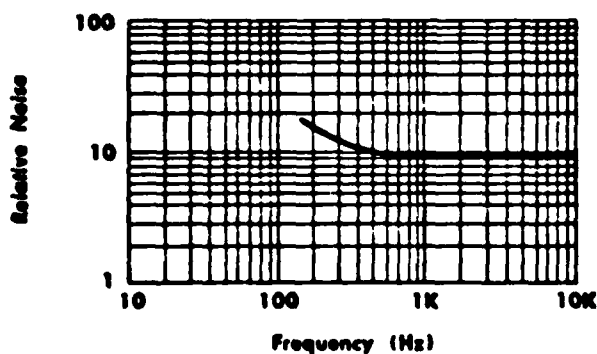
Example⁷ of detectivity vs. temperature for Ge:Zn IR detectors, 60° FOV, 295°K background.



Example⁷ of spectral detectivity for Ge:Zn IR detectors at 5°K, 60° FOV.



Example of detectivity vs. frequency for Ge:Zn IR detectors, 60° FOV, 295°K background⁷.



Example of detector noise voltage vs. frequency for Ge:Zn IR detectors, 5°K, 60° FOV, 295°K background⁷.

INDIUM ANTIMONIDE

InSb

STRUCTURE

CRYSTALLINE

SYMMETRY	=	Cubic, 43m
LATTICE CONSTANTS (Å)	=	a = 6.4787

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	237
DENSITY (g/cm ³)	=	5.78
SOLUBILITY IN WATER (g/100g of H ₂ O)	=	Insoluble

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	796
LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	4.9 x 10 ⁻⁶
THERMAL CONDUCTIVITY (cal/cm·sec·°K)	=	8.5 x 10 ⁻²
SPECIFIC HEAT (cal/g)/°K	=	---

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI)	=	6.21
HARDNESS	=	---
ELASTIC CONSTANTS (bars)	=	C ₁₁ =6.472, C ₁₂ =3.265, C ₄₄ =3.07

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT	=	18
RESISTIVITY	=	---
BAND GAP ENERGY (eV)	=	0.36
EFFECTIVE MASS m _e [*]	=	0.0133 m ₀
MOBILITY μ _e (cm ² /v-sec)	=	7.6 x 10 ⁴

INDIUM ANTIMONIDE (InSb)

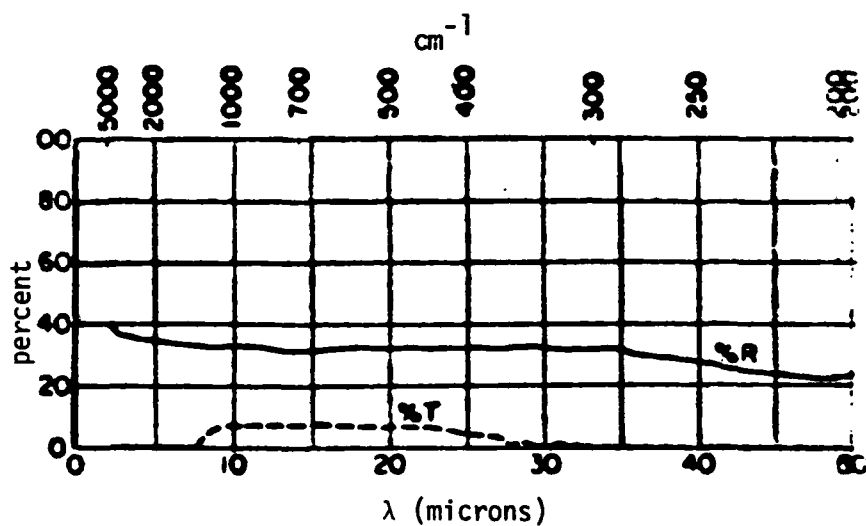
DETECTOR PROPERTIES

OPERATING MODE	=	Photovoltaic
OPERATING TEMPERATURE (°K)	=	77
MAXIMUM TEMPERATURE FOR BLIP (°K)	=	110
WAVELENGTH REGION (μm)	=	2-5.5
DETECTIVITY, D* (cmHz ^{1/2} /Watt)	=	$6 \times 10^{10} - 1 \times 10^{11}$
RESPONSE TIME (μsec)	=	<1

References:

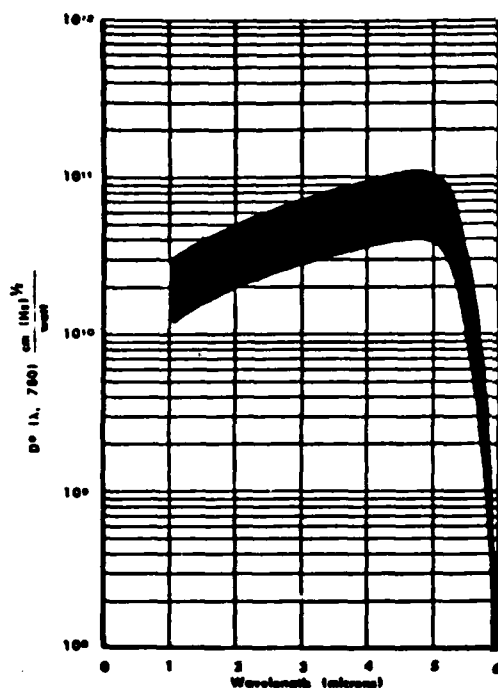
1. Santa Barbara Research Center Bulletin.

INDIUM ANTIMONIDE (InSb)



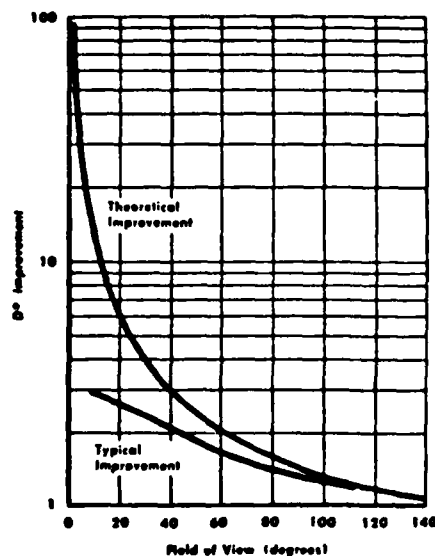
Transmittance and reflectance of Indium antimonide,
1.0 mm.

INDIUM ANTIMONIDE (InSb)

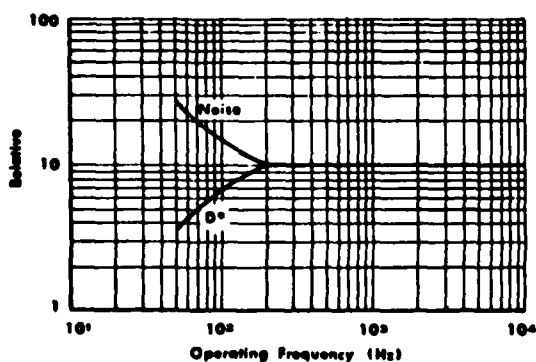


Range of spectral detectivity¹ for InSb (PV) detectors at 77°K, 180° FOV.

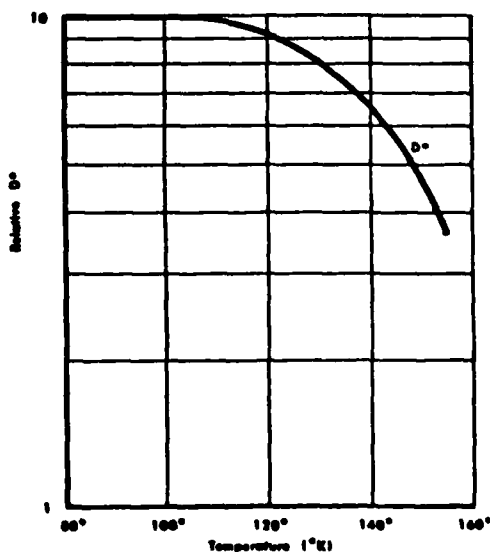
2π STERADIANS FIELD OF VIEW (FOV), 295° BACKGROUND



Typical dependence of detectivity improvement on field of view¹.



Typical noise and D^* values vs. operating frequency¹.



Typical D^* vs. temperature¹.

INDIUM ARSENIDE

InAs

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, $\bar{4}3m$

LATTICE CONSTANTS (Å) = $a = 6.06$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 189.73

DENSITY (g/cm³) = 5.66

SOLUBILITY IN WATER (g/100g of H₂O) = <0.005

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 1215

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = 5.67×10^{-6}

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = 0.014

SPECIFIC HEAT (cal/g)/°K = 0.061

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI) = Not available

HARDNESS (Knoop) = 380

ELASTIC CONSTANTS (bars) = $C_{11}=8.329$, $C_{12}=4.526$, $C_{44}=3.959$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = 12.5

RESISTIVITY = --

BAND GAP ENERGY (eV) = 0.36

EFFECTIVE MASS m_e^* = 0.028 m_0

MOBILITY μ_e (cm²/v-sec) = 1.3×10^4

INDIUM ARSENIDE (InAs)

OPTICAL PROPERTIES

DISPERSION EQUATION¹:

$$n^2 = 11.1 + \frac{0.71}{1 - (1/3922\lambda)^2} + \frac{2.75}{1 - (1/218.9\lambda)^2} - 6 \times 10^4 \lambda^2$$

THERMAL COEFFICIENT² $\frac{1}{n} \frac{dn}{dT}$ = $6.7 \times 10^{-5}/^\circ\text{K}$ (5 - 20 μm)
OF REFRACTIVE INDEX: = $0.7 \pm 0.2 \times 10^{-6}/\text{bar}$ (calculated)

SECOND HARMONIC COEFFICIENTS

$$d_{14} = 364 \pm 47 \times 10^{12} \text{m/v} \quad \text{at } \lambda = 1.058 \mu\text{m} \quad (\text{Reference 3})$$

$$d_{14} = 418.9 \pm 12.6 \times 10^{12} \text{m/v} \quad \text{at } \lambda = 10.6 \mu\text{m} \quad (\text{Reference 4})$$

DETECTOR PROPERTIES

OPERATING MODE	= Photovoltaic
OPERATING TEMPERATURE ($^\circ\text{K}$)	= 77
MAXIMUM TEMPERATURE FOR BLIP ($^\circ\text{K}$)	= --
WAVELENGTH REGION (μm)	= 1 to 3
DETECTIVITY, D^* ($\text{cmHz}^{1/2}/\text{Watt}$)	= $>4 \times 10^{11}$
RESPONSE TIME (μsec)	= <1

References:

1. B.O. Serraphin and H.E. Bennet, in Semiconductors and Semimetals, ed. by R.K. Willardson and A.C. Beer, Vol. 3, Academic Press, N.Y. (1967).
2. B. Bendow, P.D. Gianino, Y.F. Tsay and S.S. Mitra, Appl. Opt. **13**, 2382 (1974).

INDIUM ARSENIDE (InAs)

References Cont.

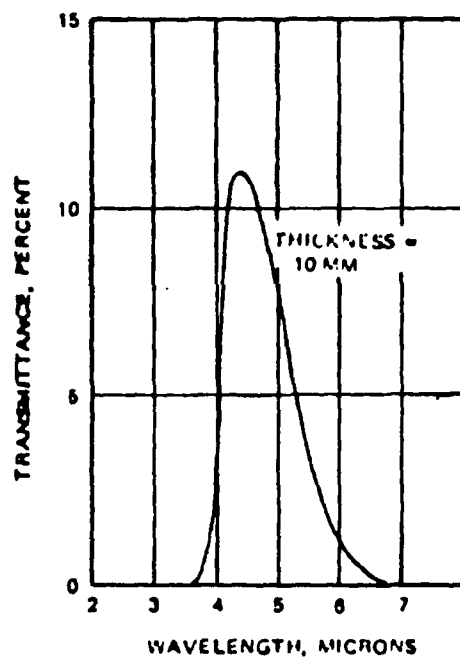
3. R.K. Chang, J. Ducuing and N. Bloembergen, Phys. Rev. Lett. 15, 415 (1965).
4. J.J. Wynne and N. Bloembergen, Phys. Rev. 188, 1211 (1969).
5. P. Billard, Acta Electronica 6, 75 (1962).
6. D.E. McCarthy, Appl. Opt. 7, 1997 (1968).
7. F. Oswald and R. Schade, Z. Naturforschah 9a, 611 (1954).
8. Santa Barbara Research Center Bullentin 67.

INDIUM ARSENIDE (InAs)

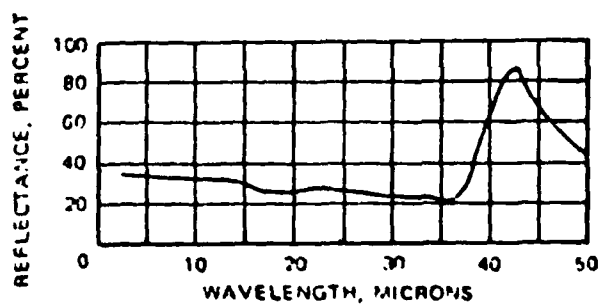
Indium Arsenide: Refractive Index and Extinction Coefficient versus Wavelength¹

$\lambda, \mu\text{m}$	n	k	$\lambda, \mu\text{m}$	n	k	$\lambda, \mu\text{m}$	n	k
0.049	1.139	0.168	0.248	1.987	2.647	1.38	3.516	0.047
0.051	1.135	0.195	0.259	2.288	3.086	1.68	.....	0.200
0.054	1.135	0.207	0.264	2.617	3.264	1.80	.....	0.185
0.056	1.133	0.215	0.269	3.060	3.274	2.00	.....	0.168
0.059	1.131	0.222	0.222	3.800	2.735	2.07	.....	0.162
0.062	1.125	0.225	0.310	3.678	1.508	2.25	.....	0.149
0.064	1.120	0.224	0.335	3.359	1.340	2.50	.....	0.133
0.067	1.110	0.215	0.344	3.271	1.363	2.76	.....	0.119
0.070	1.047	0.189	0.354	3.227	1.411	3.00	.....	0.102
0.077	0.948	0.272	0.387	3.484	1.547	3.35	.....	0.064
0.082	0.894	0.336	0.413	3.331	1.787	3.40	.....	0.052
0.089	0.829	0.426	0.443	3.817	1.954	3.44	.....	0.037
0.095	0.766	0.563	0.451	3.980	1.865	3.50	.....	0.018
0.103	0.745	0.727	0.459	4.087	1.748	3.65	.....	0.002
0.108	0.751	0.830	0.468	4.119	1.644	3.74	3.52	
0.112	0.775	0.905	0.477	4.192	1.618	4.00	3.51	
0.123	0.835	1.071	0.496	4.489	1.452	5.00	3.46	
0.136	0.890	1.260	0.517	4.558	1.047	6.67	3.45	
0.153	0.967	1.552	0.563	4.320	0.554	10.0	3.42	
0.172	1.184	1.889	0.620	4.101	0.348	14.3	3.39	
0.180	1.332	1.998	0.689	3.934	0.231	16.7	3.38	
0.188	1.483	2.020	0.775	3.800	0.157	20.0	3.35	
0.195	1.583	2.120	0.885	3.696	0.100	25.0	3.26	
0.211	1.782	2.011	1.03	3.613	0.076	33.3	2.95	
0.225	1.765	2.202	1.24	3.548	0.051			

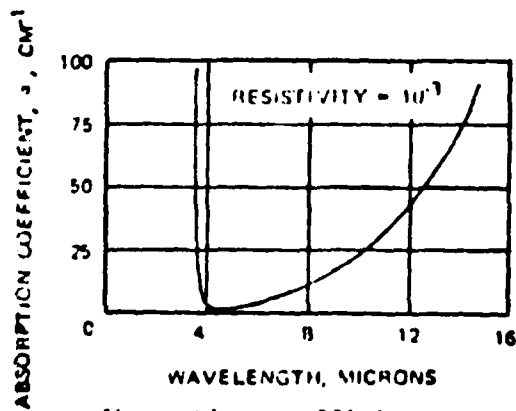
INDIUM ARSENIDE (InAs)



Transmittance versus wavelength⁵.

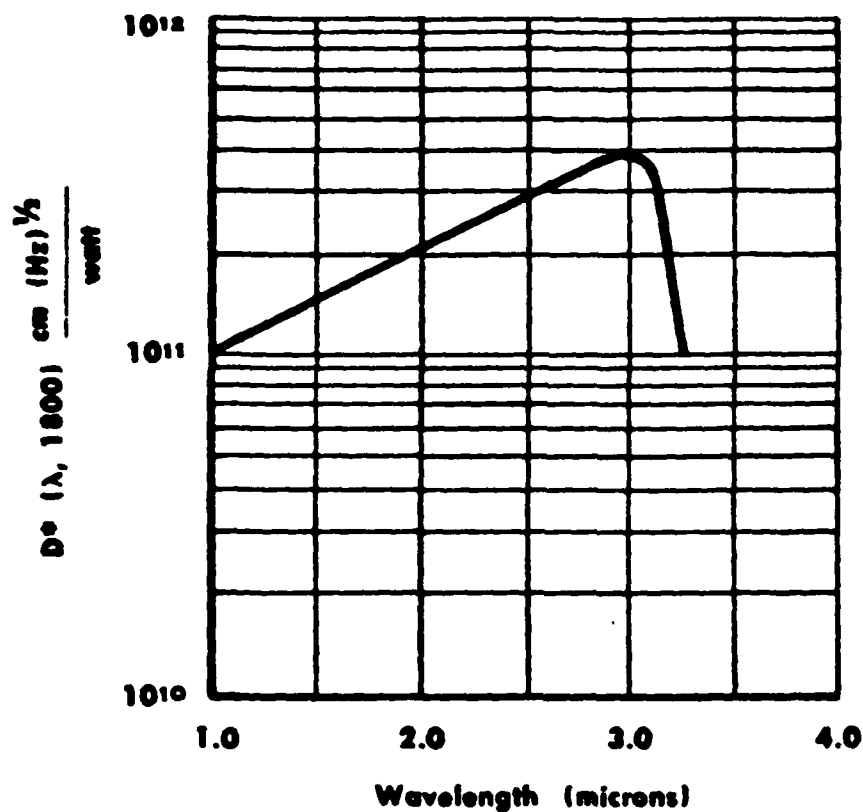


Reflectance versus wavelength⁶.

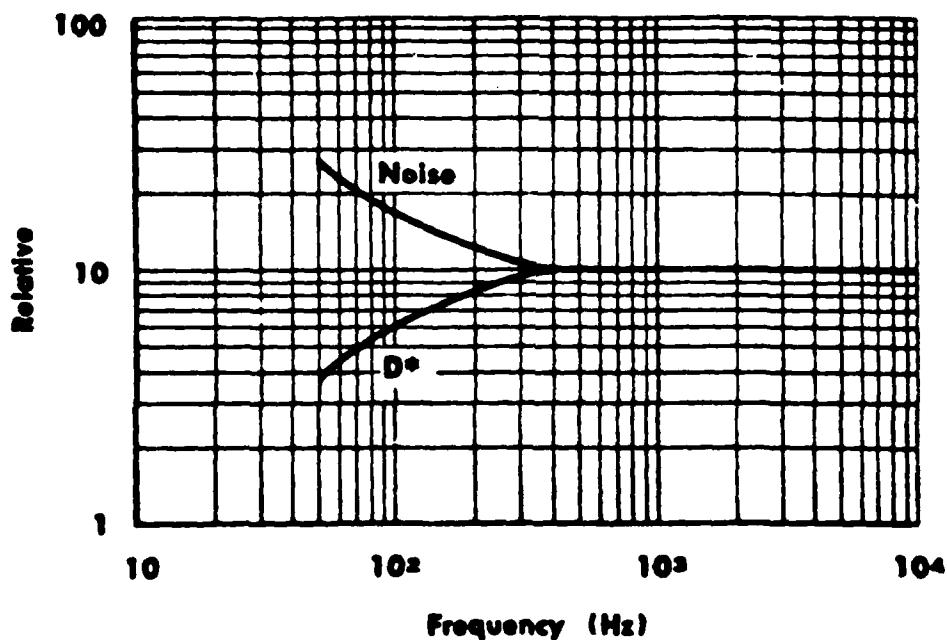


Absorption coefficient versus wavelength⁷.

INDIUM ARSENIDE (InAs)



Minimum spectral detectivity⁸ for InAs (LT0)
IR detectors at 77°K.



Relative noise current and relative D^* vs.
frequency⁸ for InAs (LT0) detectors at 77°K.

INDIUM PHOSPHIDE

InP

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, $\bar{4}3m$

LATTICE CONSTANTS (Å) = $a = 5.86875$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 145.80

DENSITY (g/cm^3) = 4.8

SOLUBILITY IN WATER ($\text{g/100g of H}_2\text{O}$) = Not available

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE ($^{\circ}\text{K}$) = 5.3

LINEAR EXPANSION COEFFICIENT ($^{\circ}\text{K}^{-1}$) = 4.5×10^{-6}

THERMAL CONDUCTIVITY ($\text{cal/cm}\cdot\text{sec}\cdot^{\circ}\text{K}$) = 0.68

SPECIFIC HEAT ($\text{cal/g}/^{\circ}\text{K}$) = 5.3

MECHANICAL PROPERTIES

YOUNGS MODULUS = Not available

HARDNESS (kg/mm^2) = 430

ELASTIC CONSTANTS = $C_{11}=10.7$, C_{12} =not available

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = 12.1

RESISTIVITY = Not available

BAND GAP ENERGY (eV) = 1.34

EFFECTIVE MASS m_e^* = $0.07 m_0$

MOBILITY μ_e ($\text{cm}^2/\text{v}\cdot\text{sec}$) = 6000

INDIUM PHOSPHIDE (InP)

OPTICAL PROPERTIES¹

THERMAL COEFFICIENT
OF REFRACTIVE INDEX: $\frac{1}{n} \frac{dn}{dT} = 2.7 \times 10^{-5} / ^\circ K$ (5 - 20 μm)

PRESSURE COEFFICIENT
OF REFRACTIVE INDEX: $\frac{1}{n} \frac{dn}{dp} = 0.4 \pm 0.2 \times 10^{-6} / \text{bar}$ (calculated)

SECOND HARMONIC COEFFICIENTS

$$d_{14} = 520 \pm 47 \text{ (} \times 10^{12} \text{ m/v) at } 1.058 \mu m \text{ (Reference 2)}$$

References:

1. B. Bendow, P.D. Gianino, Y.F. Tsay and S.S. Mitra, Appl. Opt. 13, 2382 (1974).
2. R. Braunstein and N. Ockmen, Introaction of Coherent Optical Radiation with Solids, Final Report prepared for Office of Naval Research, Department of Navy, Washington, D.C., Contract No. NONR-4128100, Aug. 1964.
3. B.O. Serraphin and H.E. Bennet, in Semiconductors and Semimetals, ed. by R.K. Willardson and A.C. Beer, Vol. 3, Academic Press, N.Y. (1967).
4. D.E. McCarthy, Appl. Opt. 7, 1997 (1968).

INDIUM PHOSPHIDE (InP)

Indium Phosphide: Refractive Index and Extinction Coefficient³

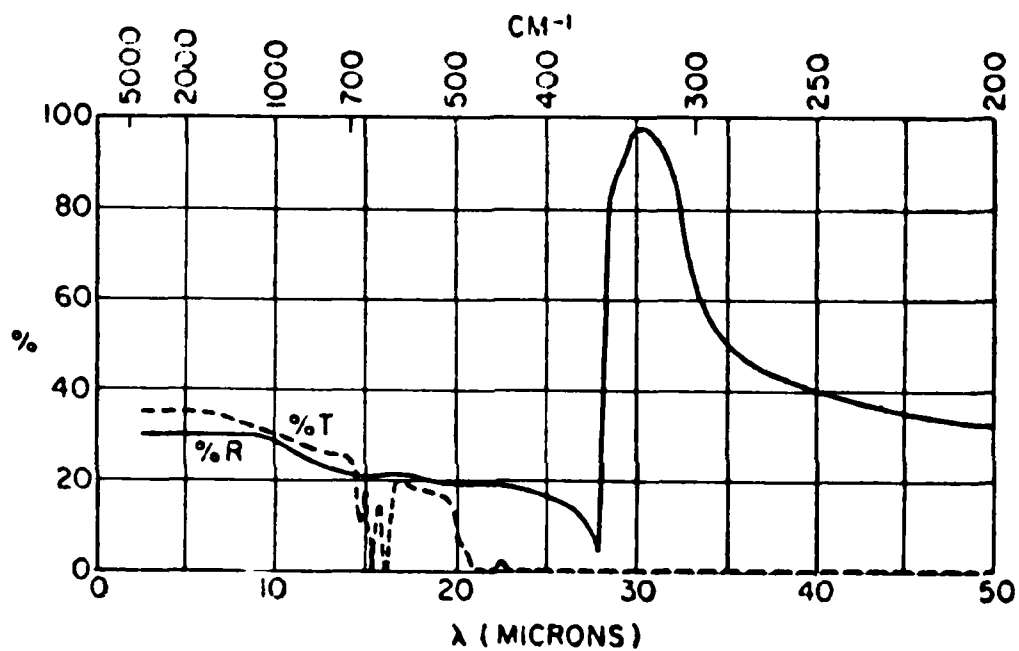
$\lambda, \mu\text{m}$	n	k	$\lambda, \mu\text{m}$	n	k	$\lambda, \mu\text{m}$	n	k
0.062	0.793	0.494	0.197	1.526	1.991	0.945	3.374	0.000967
0.064	0.815	0.499	0.200	1.525	1.982	0.950	3.369	0.000527
0.065	0.834	0.493	0.203	1.508	2.005	0.953	.....	0.000281
0.067	0.843	0.487	0.207	1.500	2.063	0.955	3.364	
0.069	0.846	0.477	0.210	1.516	2.130	0.957	.....	0.000145
0.071	0.840	0.469	0.214	1.544	2.191	0.960	3.359	0.0000739
0.073	0.824	0.454	0.217	1.573	2.267	0.965	3.355	0.0000392
0.075	0.785	0.457	0.221	1.616	2.349	0.968	.....	0.0000246
0.077	0.742	0.491	0.225	1.668	2.442	0.970	3.351	
0.079	0.719	0.529	0.229	1.737	2.553	0.972	.....	0.0000166
0.083	0.695	0.574	0.234	1.834	2.675	0.975	3.346	0.0000113
0.085	0.675	0.645	0.238	1.960	2.801	1.00	3.327	
0.089	0.688	0.706	0.243	2.132	2.982	1.10	3.268	
0.092	0.701	0.765	0.248	2.451	3.166	1.20	3.231	
0.095	0.726	0.820	0.253	2.885	3.144	1.30	3.205	
0.099	0.754	0.861	0.258	3.335	3.039	1.40	3.186	
0.103	0.771	0.899	0.264	3.729	2.635	1.50	3.172	
0.108	0.781	0.946	0.269	3.849	2.117	1.60	3.161	
0.113	0.793	0.996	0.275	3.655	1.691	1.70	3.152	
0.118	0.797	1.056	0.282	3.473	1.549	1.80	3.145	
0.124	0.806	1.154	0.288	3.347	1.468	1.90	3.139	
0.125	0.820	1.172	0.295	3.248	1.415	2.00	3.134	
0.126	0.832	1.185	0.302	3.162	1.389	5.00	3.08	
0.128	0.840	1.198	0.310	3.105	1.392	6.00	3.07	
0.129	0.847	1.210	0.318	3.054	1.401	7.00	3.07	
0.130	0.852	1.225	0.326	3.027	1.440	8.00	3.06	
0.132	0.859	1.237	0.335	3.024	1.489	9.00	3.06	
0.133	0.861	1.253	0.344	3.047	1.550	10.00	3.05	
0.135	0.865	1.269	0.354	3.082	1.622	12.00	3.05	0.000527
0.136	0.868	1.287	0.364	3.192	1.747	13.08	....	0.000667
0.138	0.872	1.304	0.375	3.441	1.857	14.00	3.04	0.000886
0.139	0.874	1.324	0.387	3.835	1.804	14.40	....	0.00128
0.141	0.875	1.346	0.399	4.100	1.439	14.85	3.03	0.00300
0.142	0.877	1.375	0.413	4.083	1.056	15.00	....	0.00371
0.144	0.885	1.403	0.427	3.982	0.816	15.24	....	0.00525
0.146	0.894	1.433	0.443	3.833	0.670	15.32	....	0.00617
0.148	0.909	1.458	0.459	3.754	0.599	15.45	....	0.00626
0.149	0.919	1.486	0.477	3.675	0.531	15.52	....	0.00563
0.151	0.934	1.512	0.496	3.621	0.480	15.74	....	0.00522
0.153	0.947	1.539	0.517	3.567	0.430	15.85	....	0.00613
0.155	0.960	1.566	0.539	3.521	0.389	16.00	....	0.00712
0.157	0.973	1.594	0.563	3.472	0.358	16.14	....	0.00746
0.159	0.984	1.627	0.590	3.450	0.334	16.21	....	0.00667
0.161	1.000	1.664	0.620	3.430	0.298	16.28	....	0.00516

INDIUM PHOSPHIDE (InP)

Indium Phosphide: Refractive Index and Extinction Coefficient³ (Continued)

$\lambda, \mu\text{m}$	n	k	$\lambda, \mu\text{m}$	n	k	$\lambda, \mu\text{m}$	n	k
0.163	1.022	1.700	0.652	3.410	0.253	16.39	....	0.00333
0.165	1.046	1.736	0.689	.....	0.206	16.55	....	0.00231
0.167	1.072	1.771	0.729	.....	0.176	17.00	....	0.00177
0.170	1.100	1.812	0.775	.....	0.163	18.00	....	0.00181
0.172	1.136	1.847	0.826	.....	0.140	18.93	....	0.002320.
0.175	1.174	1.882	0.885	.....	0.0906	19.51	....	0.00384
0.177	1.215	1.915	0.921	.....	0.0571	19.62	....	0.00473
0.180	1.261	1.941	0.925	3.396	0.0355	19.78	....	0.00602
0.182	1.307	1.966	0.928	.....	0.0204	20.00	....	0.00794
0.185	1.354	1.986	0.930	3.390	0.0109	20.19	....	0.00949
0.188	1.402	2.004	0.935	3.385	0.00590	20.34	....	0.0108
0.191	1.453	2.010	0.940	3.379	0.00318	20.42	....	0.0115
0.194	1.496	2.008	0.942	.....	0.00171	20.57	....	0.0130

INDIUM PHOSPHIDE (InP)



Transmittance and reflectance of indium phosphide versus wavelength⁴.

LEAD SELENIDE

PbSe

STRUCTURE

CRYSTALLINE

SYMMETRY

= Cubic, Fm3m

LATTICE CONSTANTS (Å)

= $a = 6.124$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT

= 286.17

DENSITY

= 8.10

SOLUBILITY IN WATER (g/100g of H₂O)

= Insoluble

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)

= 1358

LINEAR EXPANSION COEFFICIENT (°K⁻¹)

= 7.65×10^{-6}

THERMAL CONDUCTIVITY (cal/cm·sec·°K)

= 100×10^{-4}

SPECIFIC HEAT (cal/g)/°K

= ---

MECHANICAL PROPERTIES

YOUNGS MODULUS

= ---

HARDNESS

= ---

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT

= 250

RESISTIVITY

= ---

BAND GAP ENERGY (eV)

= 0.26

EFFECTIVE MASS m_e^*

= $m_1 = 0.07 m_0, m_t = 0.039 m_0$

MOBILITY μ_e (cm²/v-sec)

= 1020

LEAD SELENIDE (PbSe)

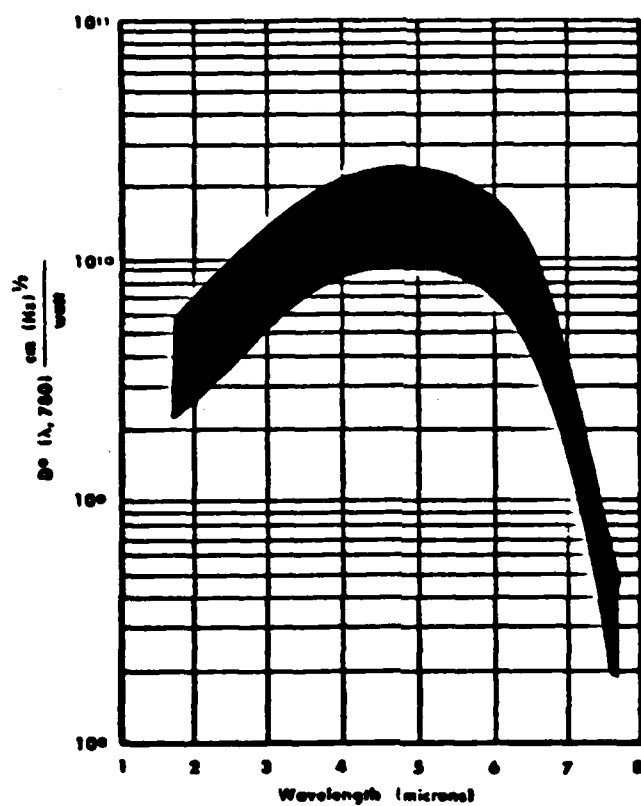
DETECTOR PROPERTIES¹

OPERATING MODE	=	Photoconductive		
OPERATING TEMPERATURE (°K)	=	77	145-235	295
MAXIMUM TEMPERATURE FOR BLIP (°K)	=	---	---	---
WAVELENGTH REGION (μm)	=	1-7	1-6	1-4.5
DETECTIVITY, D* (cmHz ^{1/2} /Watt)=		1-2.5x10 ¹⁰	1-3x10 ¹⁰	1-5x10 ⁹
RESPONSE TIME (μsec)	=	15-150	10-40	1-3

References:

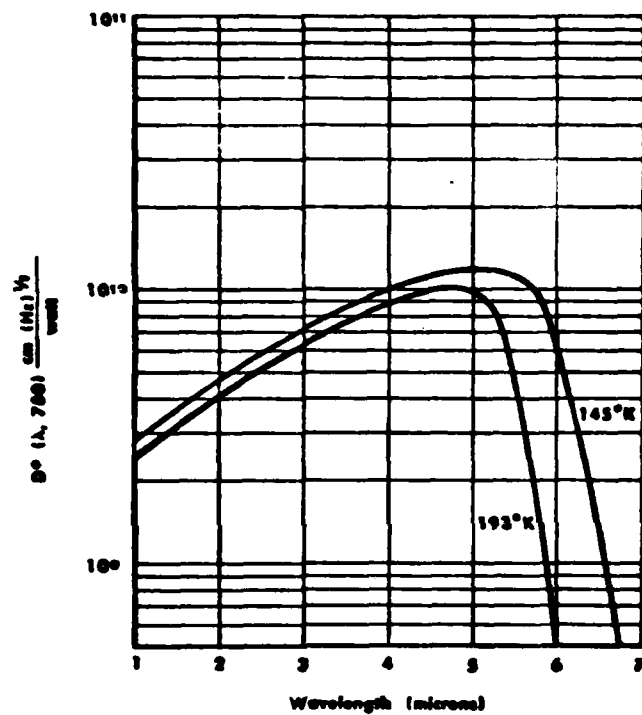
1. Santa Barbara Research Bulletin #67.

LEAD SELENIDE (PbSe)



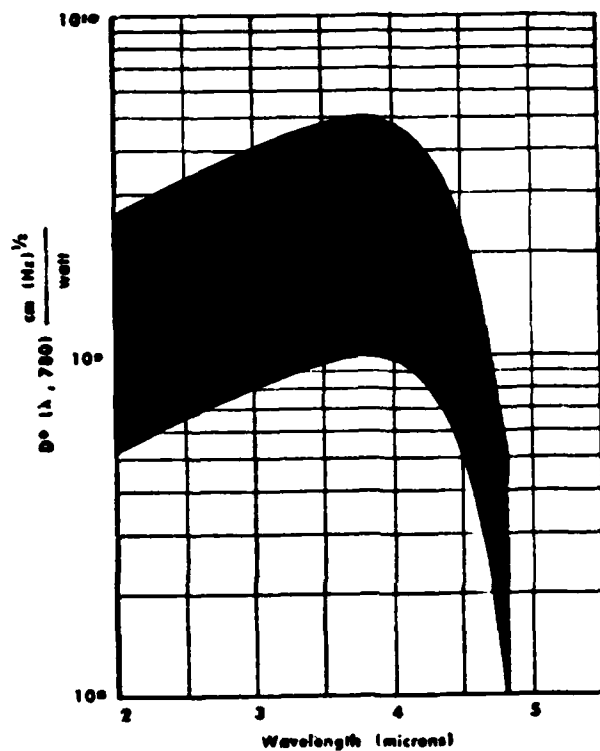
Range of spectral detectivities, PbSe (LT0) IR detectors with silicon window (no cold filter or shields)¹.

LEAD SELENIDE (PbSe)



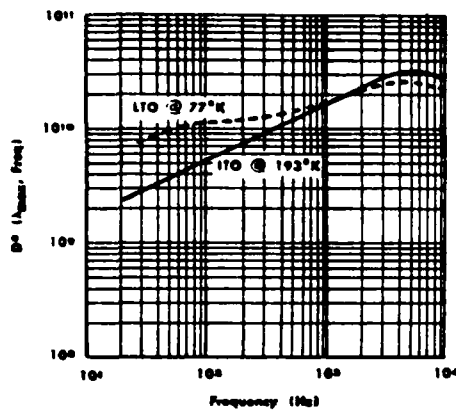
Examples of spectral detectivities of PbSe (ITO) detectors, 2π steradians FOV, 295°K background¹.

LEAD SELENIDE (PbSe)

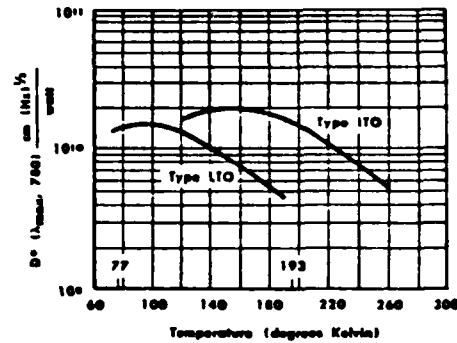


Range of spectral detectivities for PbSe (ATO) IR detectors at 295°K¹.

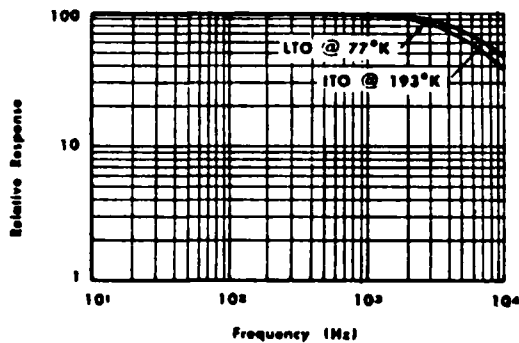
LEAD SELENIDE (PbSe)



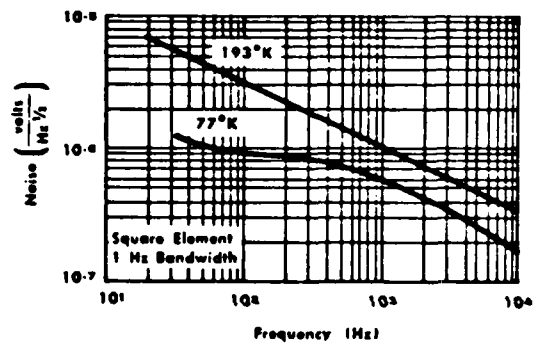
Example of detectivity vs. frequency for PbSe (ITO and LTO) cooled detectors¹.



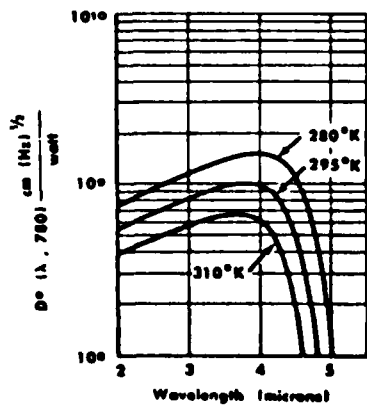
Example of detectivity vs. temperature for PbSe (ITO and LTO) cooled detectors¹.



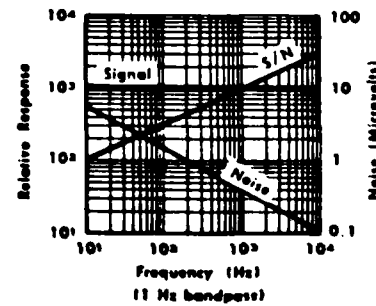
Example of signal vs. frequency for PbSe (ITO and LTO) cooled detectors¹.



Example of noise vs. frequency for PbSe (ITO and LTO) cooled detectors¹.



Example of detectivity vs. temperature for PbSe (ATO) IR detectors¹.



Example of response vs. frequency for PbSe (ATO) IR detectors¹.

ALL 2π STERADIANS FIELD OF VIEW (FOV), 295° BACKGROUND.

LEAD SULFIDE (Galena)

PbS

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, Fm3m

LATTICE CONSTANTS (Å) = $a = 5.936$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 239.28

DENSITY (g/cm³) = 7.5

SOLUBILITY IN WATER (g/100g of H₂O) = 3×10^{-6}

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 1392

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = 24×10^{-6}

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = 500×10^{-4}

SPECIFIC HEAT (cal/g)/°K = 0.039

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI) = 1.64×10^{-6}

HARDNESS (mohs) = 2.5

ELASTIC CONSTANTS (bars) = $C_{11}=12.7, C_{12}=2.98, C_{44}=2.48$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = 170

RESISTIVITY = ---

BAND GAP ENERGY (eV) = 0.37

EFFECTIVE MASS m_e^* = $0.1 m_0$

MOBILITY μ_e (cm²/v-sec) = 550

LEAD SULFIDE (PbS)

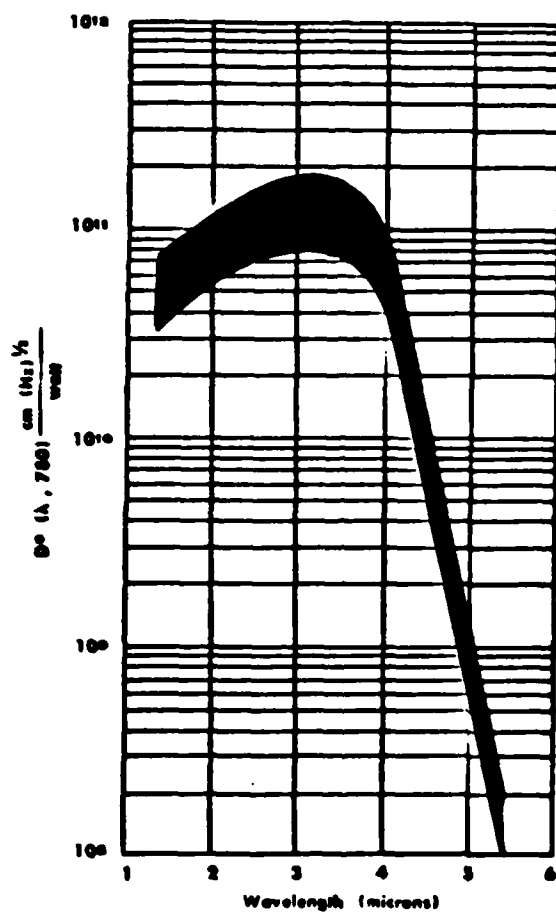
DETECTOR PROPERTIES¹

OPERATING MODE	=	Photoconductive
OPERATING TEMPERATURE (°K)	=	77, 193, 295
MAXIMUM TEMPERATURE FOR BLIP (°K)	=	---
WAVELENGTH REGION (μm)	=	1.45, 1-4, 1-35
DETECTIVITY, D* (cmHz ^{1/2} /Watt)	=	1 x 10 ¹¹ , 4 x 10 ¹¹ , 8 x 10 ¹⁰
RESPONSE TIME (μsec)	=	3000, 5000, 100-500

References:

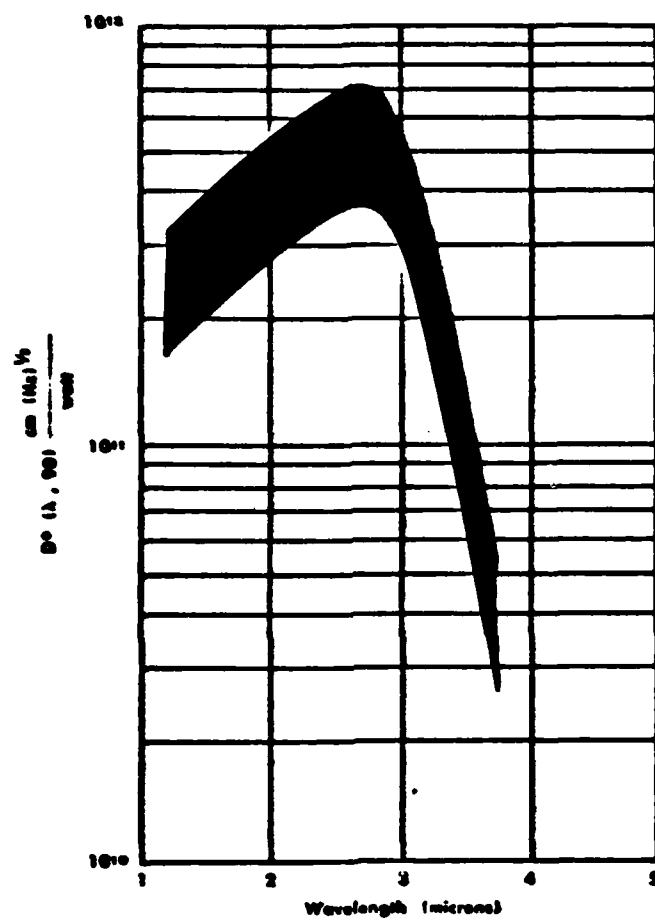
1. Santa Barbara Research Center Bulletin.

LEAD SULFIDE (PbS)



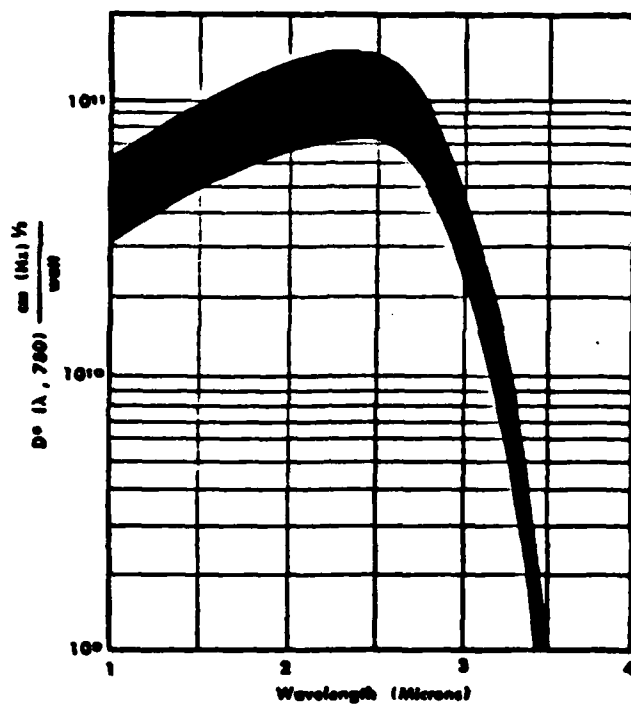
Range of spectral detectivities¹ for PbS (LT0) at 77°K.

LEAD SULFIDE (PbS)



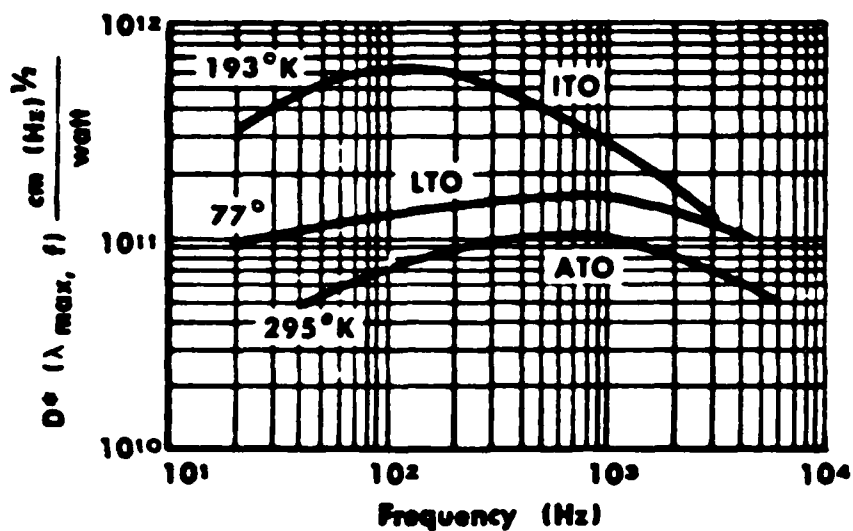
Range of spectral detectivities¹ for PbS (ITO) at 193°K.

LEAD SULFIDE (PbS)

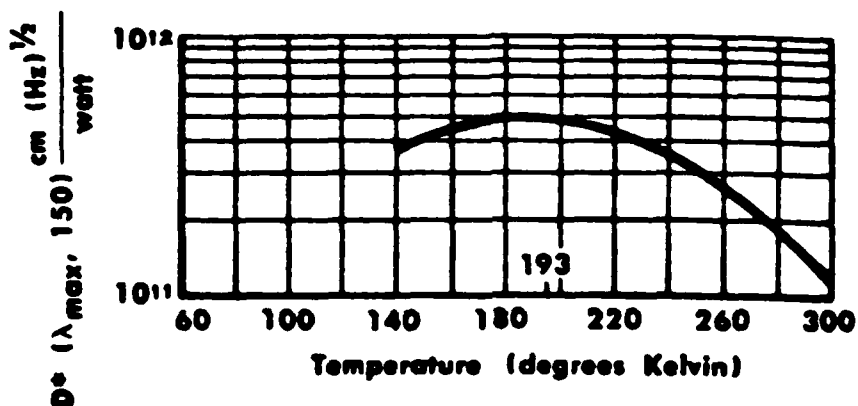


Range of spectral detectivities¹ for
PbS (AT0) at 295°K.

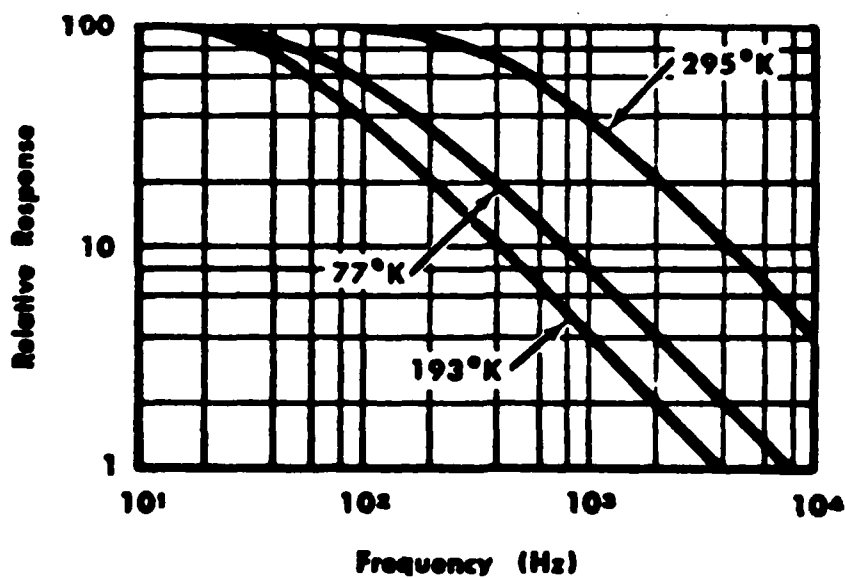
LEAD SULFIDE (PbS)



Example of detectivity vs. frequency for PbS detectors¹.

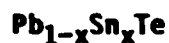


Example of detectivity vs. temperature for PbS (ITO) detectors¹.



Example of signal vs. frequency for PbS detectors¹.

LEAD-TIN-TELLURIDE



STRUCTURE

CRYSTALLINE

SYMMETRY

= Cubic, Fm3m

LATTICE CONSTANTS (Å)

= "a" varies with x from
6.312±0.001 to 6.461±0.002

PHYSICAL PROPERTIES

MOLECULAR WEIGHT

= ---

DENSITY (g/cm³)

= ---

SOLUBILITY IN WATER (g/100g of H₂O)

= ---

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)

= varies from 1079 to 1197
depending on x

LINEAR EXPANSION COEFFICIENT (°K⁻¹)

= ---

THERMAL CONDUCTIVITY (cal/cm·sec·°K)

= ---

SPECIFIC HEAT (cal/g)/°K

= ---

MECHANICAL PROPERTIES

YOUNGS MODULUS

= ---

HARDNESS (Vickers: kg/mm²)

= 30 to 62

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT

= ---

RESISTIVITY

= ---

BAND GAP ENERGY (eV)

= varies with x from 0.32 to 0.2

EFFECTIVE MASS m_e^*

= ---

MOBILITY μ_e (cm²/v-sec)

= varies from 8192 to 121

LEAD-TIN-TELLURIDE ($Pb_{1-x}Sn_xTe$)

DETECTOR PROPERTIES

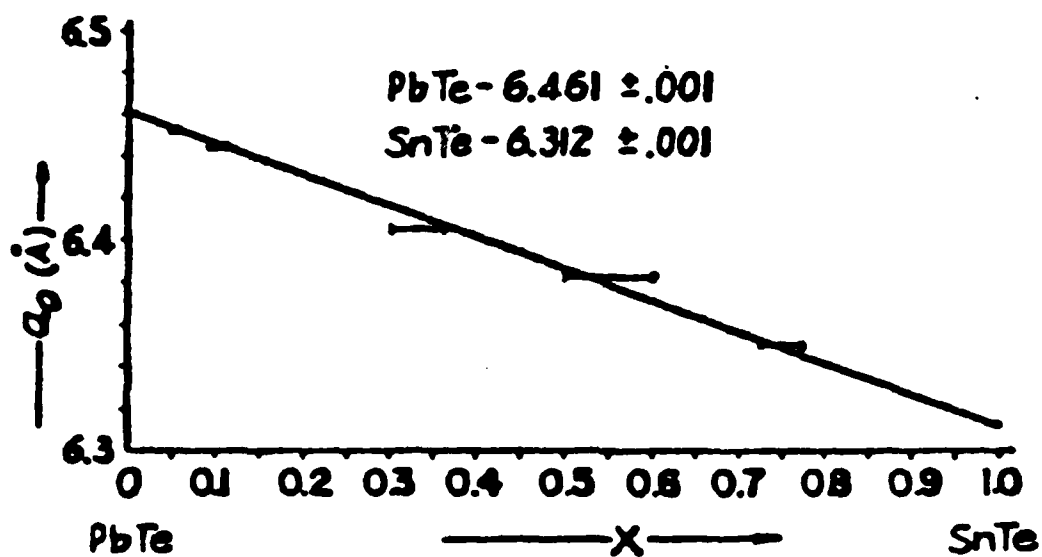
OPERATING MODE	=	PC	PV
OPERATING TEMPERATURE ($^{\circ}K$)	=	77	77
MAXIMUM TEMPERATURE FOR BLIP ($^{\circ}K$)	=	--	--
WAVELENGTH REGION (μm)	=	2-11	2-14
Detectivity, D^* ($cmHz^{1/2}/Watt$)	=	3×10^8	2×10^{10}
RESPONSE TIME (μsec)	=	1.5×10^{-2}	2×10^{-2}

References:

1. J.W. Wagner and R.K. Willardson, Trans. AIME 242, 366 (1968).
2. I. Melngailis and T.C. Harman, Appl. Phys. Lett. 13, 180 (1968).
3. The Infrared Handbook, ed. by W.L. Wolfe and G.J. Zissis, The Infrared Information and Analysis Center, ERIM (1978).

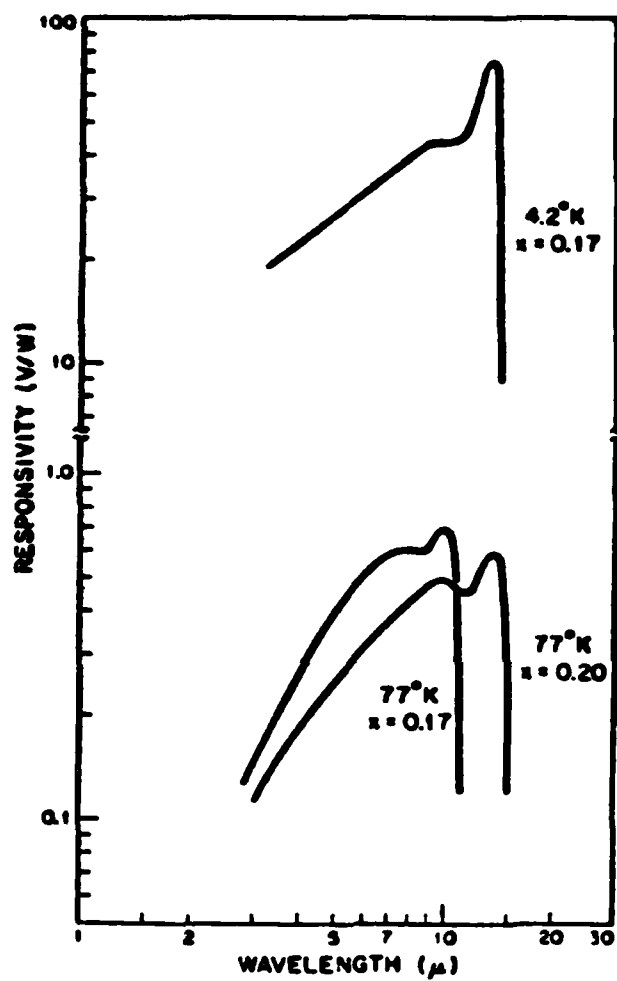
LEAD-TIN-TELLURIDE ($\text{Pb}_{1-x}\text{Sn}_x\text{Te}$)

LATTICE PARAMETERS



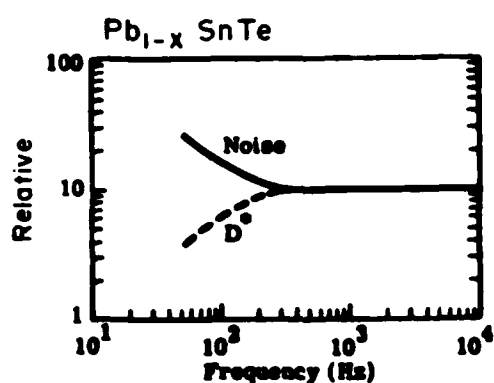
Lattice parameters¹ of single crystals of PbTe-SnTe.

LEAD-TIN-TELLURIDE ($\text{Pb}_{1-x}\text{Sn}_x\text{Te}$)

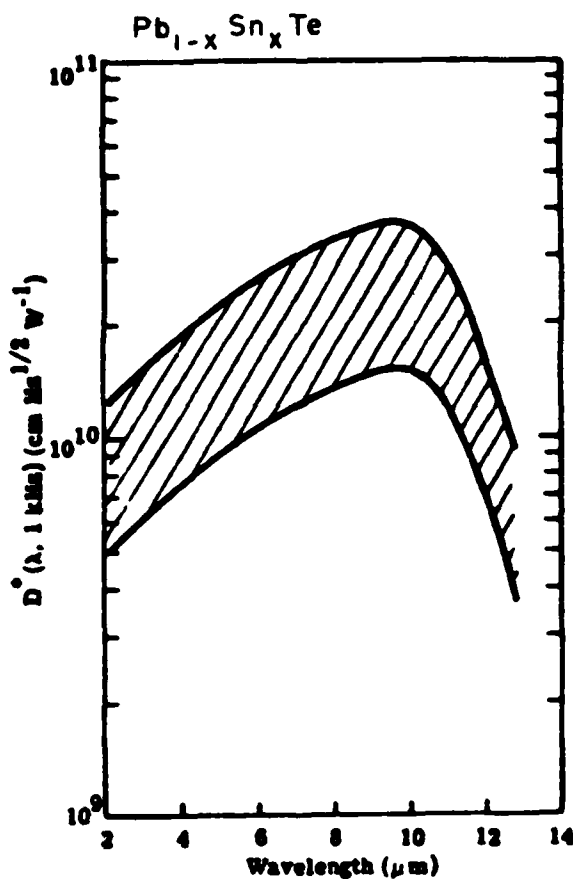


Responsivity spectra of $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$ photoconductors².

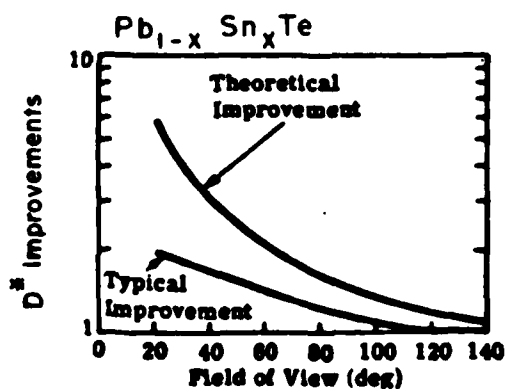
LEAD-TIN-TELLURIDE ($\text{Pb}_{1-x}\text{Sn}_x\text{Te}$)



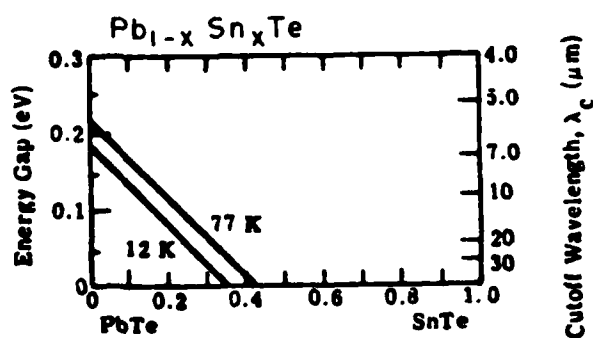
Frequency response of detector D^* and noise³.



Spectral response³ of detector D^* ($\lambda, 1 \text{ kHz}$).



Dependence of detectivity³ improvement on FOV.



Energy gap³ of $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$ as a function of x , the mole fraction of Sn Te.

LITHIUM FLUORIDE
LiF

STRUCTURE

CRYSTALLINE

SYMMETRY	=	Cubic, Fm3m
LATTICE CONSTANTS (Å)	=	a = 4.0270

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	25.94
DENSITY (g/cm ³)	=	2.639
SOLUBILITY IN WATER (g/100g of H ₂ O)	=	0.27

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	1403
LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	37 x 10 ⁻⁶
THERMAL CONDUCTIVITY (cal/cm·sec·°K)	=	340 x 10 ⁻⁴
SPECIFIC HEAT (cal/g)/°K	=	0.373

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI)	=	9.4 x 10 ⁶
HARDNESS	=	113 (at 600g)
ELASTIC CONSTANTS (bars)	=	C ₁₁ =9.74, C ₁₂ =4.04, C ₄₄ =5.54

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT	=	9.0 in the range 10 ² - 10 ¹⁰ Hz
RESISTIVITY	=	---
BAND GAP ENERGY	=	---
EFFECTIVE MASS	=	---
MOBILITY	=	---

LITHIUM FLUORIDE (LiF)

OPTICAL PROPERTIES

DISPERSION EQUATION:

$$n = A + BL + CL^2 + D\lambda^2 + E\lambda^2$$

where

$$\begin{aligned} A &= 1.38761 \\ B &= 0.001796 \\ C &= 0.000041 \\ D &= -0.0023045 \\ E &= -0.00000557 \end{aligned}$$

References:

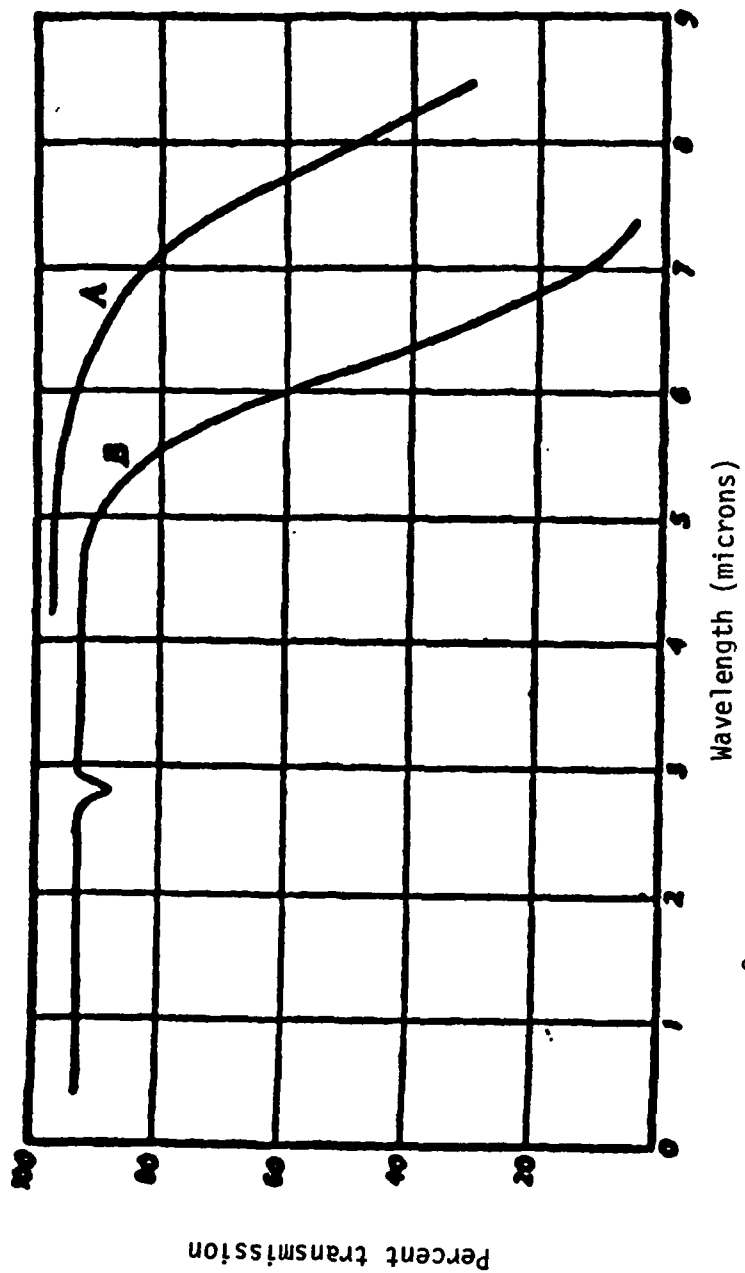
1. L.F. Tilton & E.K. Plyler, J. Research NBS 47, 25 (1951); M. Herzberger and C.D. Salzberg, J. Opt. Soc. Am. 52, 420 (1962).
2. R.A. Smith, F.E. Jones and R.P. Chasmar in The Detection and Measurement of Infrared Radiation, The Clarendon Press, Oxford, p. 337 (1957).
3. D.E. McCarthy, App. Opt. 2, 591 (1965).
4. M. Klier, Z. Physik 150, 49 (1958).

LITHIUM FLUORIDE (LiF)

The Refractive Index of Lithium Fluoride¹ at 23.6°C

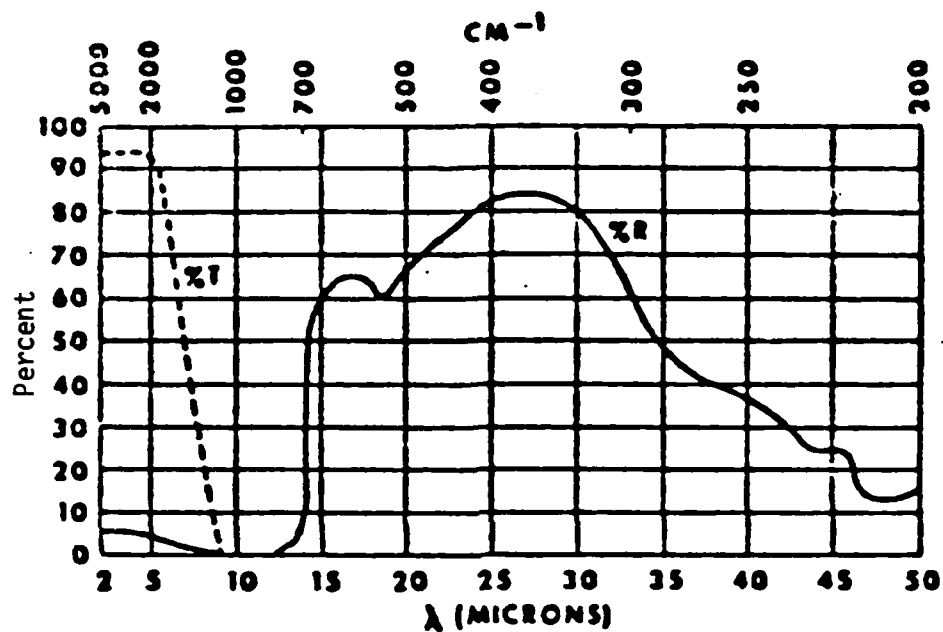
Wave-length (μ)	Refractive Index	Wave-length (μ)	Refractive Index	Wave-length (μ)	Refractive Index
0.5	1.39430	2.4	1.37446	4.3	1.34319
0.6	1.39181	2.5	1.37327	4.4	1.34100
0.7	1.39017	2.6	1.37203	4.5	1.33875
0.8	1.38896	2.7	1.37075	4.6	1.33645
0.9	1.38797	2.8	1.36942	4.7	1.33408
1.0	1.38711	2.9	1.36804	4.8	1.33165
1.1	1.38631	3.0	1.36660	4.9	1.32916
1.2	1.38554	3.1	1.36512	5.0	1.32661
1.3	1.38477	3.2	1.36359	5.1	1.32399
1.4	1.38400	3.3	1.36201	5.2	1.32131
1.5	1.38320	3.4	1.36037	5.3	1.31856
1.6	1.38238	3.5	1.35868	5.4	1.31575
1.7	1.38153	3.6	1.35693	5.5	1.31287
1.8	1.38064	3.7	1.35514	5.6	1.30993
1.9	1.37971	3.8	1.35329	5.7	1.30692
2.0	1.37875	3.9	1.35138	5.8	1.30384
2.1	1.37774	4.0	1.34942	5.9	1.30068
2.2	1.37669	4.1	1.34740	6.0	1.29745
2.3	1.37560	4.2	1.34533		

LITHIUM FLUORIDE (LiF)



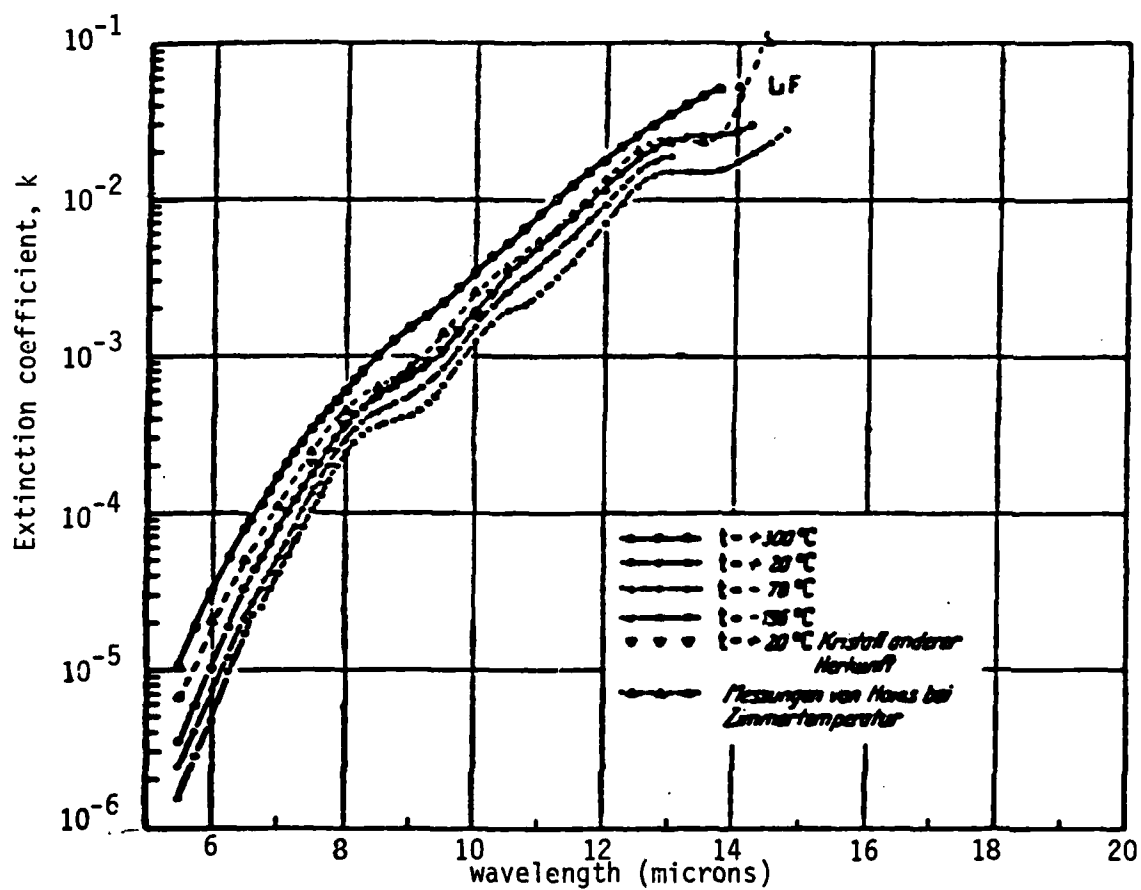
Transmission² of LiF. Sample A, 0.1 cm thick. Sample B, 1.2 cm thick.

LITHIUM FLUORIDE (LiF)



Transmittance and reflectance of LiF versus wavelength³, 5 mm.

LITHIUM FLUORIDE (LiF)



Temperature dependence of extinction coefficient of LiF.

LITHIUM NIOBATE
 LiNbO_3

STRUCTURE

CRYSTALLINE

SYMMETRY

= Rhombohedral, 3m

LATTICE CONSTANTS (Å)

= $a_{Rh} = 5.492$ (Rhombohedral)
 $\alpha_{Rh} = 55^\circ 53'$
 $a_H = 5.147$ (Hexagonal)
 $c_H = 13.857$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT

= 147.85

DENSITY (g/cm^3)

= 4.70

SOLUBILITY IN WATER ($\text{g/100g of H}_2\text{O}$)

= <0.005

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE ($^\circ\text{K}$)

= 1533

LINEAR EXPANSION COEFFICIENT ($^\circ\text{K}^{-1}$)

= 16.7×10^{-6}

THERMAL CONDUCTIVITY ($\text{cal/cm}\cdot\text{sec}\cdot^\circ\text{K}$)

= 0.1

SPECIFIC HEAT ($\text{cal/g}/^\circ\text{K}$)

= 0.153

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI)

= Not Available

HARDNESS (Moh)

= -5

ELASTIC CONSTANTS (10^{10}N/m^2)

= $C_{11} \ C_{12} \ C_{13} \ C_{14} \ C_{33} \ C_{44} \ C_{66}$
Constant Field 20.3 5.3 7.5 0.9 24.5 6.0 7.5
Constant Displacement 21.9 3.7 7.6 -1.5 25.2 9.5 9.1

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT

= ---

RESISTIVITY ($\Omega\text{cm-cm}$)

= 5×10^8 at 400°C
140 at 1000°C
 $\log \rho = \frac{7150}{T} - 2.823$ (T in $^\circ\text{K}$)

LITHIUM NIOBATE (LiNbO₃)

ELECTRICAL PROPERTIES (CONTINUED)

BAND GAP ENERGY = ---

EFFECTIVE MASS = ---

MOBILITY = ---

ELECTRO-OPTIC COEFFICIENTS¹ (10⁻¹²m/v)

$r_{22} = 5.7$ at $1.15 \mu\text{m}$

$r_{22} = 3.1$ at $3.39 \mu\text{m}$

SECOND HARMONIC COEFFICIENTS^{2,3} (10¹²m/v)

$d_{22} = 3.07 \pm 0.28$

$d_{31} = 5.82 \pm 0.85$

$d_{33} = 40.68 \pm 10.4$

$d_{31} = 5.01 \pm 0.47$

$d_{22} = 2.41 \pm 0.95$

PIEZOELECTRIC CONSTANTS (ROOM TEMPERATURE)

$d_{15} = 6.8 \times 10^{-11} \text{ C/N}$

= (7.4)*

$e_{15} = 3.7 \text{ C/m}^2$

$d_{22} = 2.1$ (2.1)

$e_{22} = 2.5$

$d_{31} = -0.1$ (-0.086)

$e_{31} = 0.2$

$d_{33} = 0.6$ (1.62)

$e_{33} = 1.3$

$h_{15} = 9.5 \times 10^9 \text{ N/C}$

$g_{15} = 9.1 \times 10^{-2} \text{ m}^2/\text{C}$

$h_{22} = 6.4$

$g_{22} = 2.8$

$h_{31} = 0.8$

$g_{31} = -0.4$

$h_{33} = 5.1$

$g_{33} = 2.3$

LITHIUM NIOBATE (LiNbO_3)

PIEZOELECTRIC CONSTANTS* (TEMPERATURE DEPENDENCE)

$$d_{33} = 1.62[1 + (T-20)2.9 \times 10^{-4}] \times 10^{-11} \text{ C/N}$$

$$d_{31} = -0.086[1 + (T-20)11 \times 10^{-4}]$$

$$d_{22} = 2.1[1 + (T-20)2.4 \times 10^{-4}]$$

$$d_{15} = 7.4[1 + (T-20)2.8 \times 10^{-4}]$$

References:

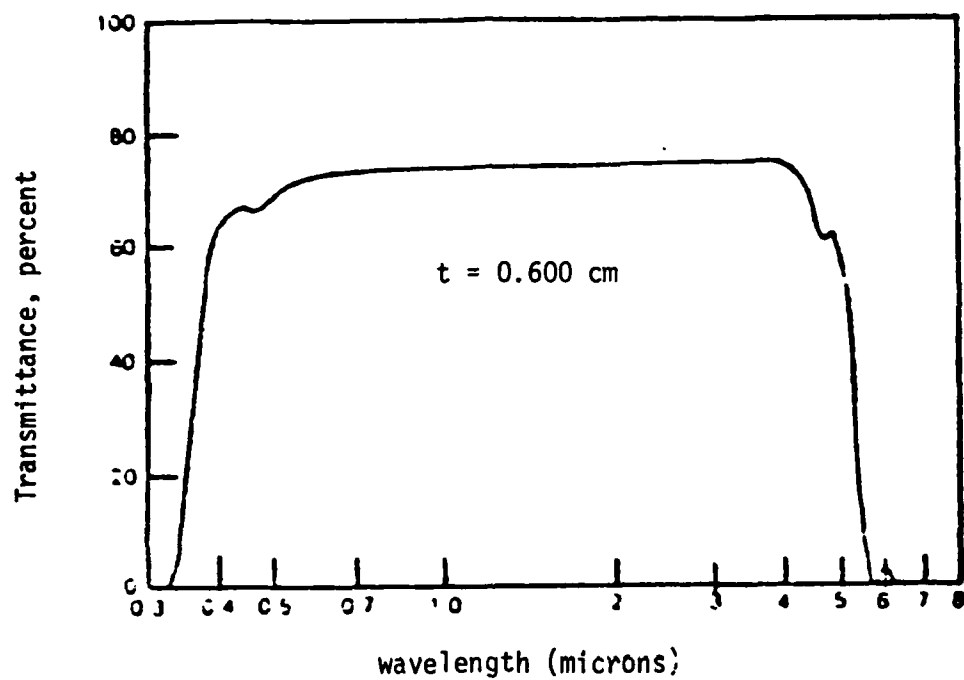
1. P.H. Smabula and P.C. Claspy, Trans. AMIE 239, 421 (1967).
2. G.D. Boyd, R.C. Miller, K. Nassau, W.L. Bond and A. Savage, Appl. Phys. Lett. 5, 234 (1964).
3. R.C. Miller and A. Savage, Appl. Phys. Lett. 9, 169 (1966).
4. T. Yamada, et. al, Jap. J. Appl. Phys. 6, 151 (1967).
5. K. Nassau, et. al, J. Phys. Chem. Solids 27, 989 (1966).

LITHIUM NIOBATE (LiNbO₃)

LITHIUM NIOBATE REFRACTIVE INDICES OF LiNbO₃

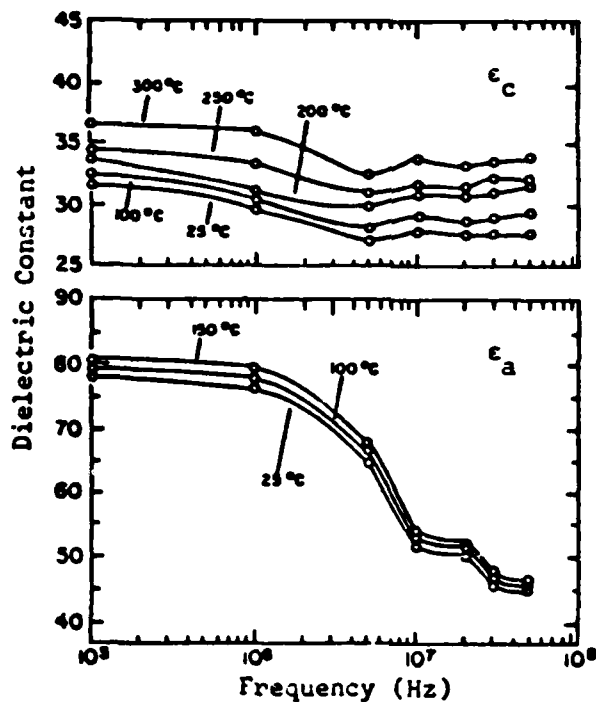
Wavelength	T = 25°C		T = 80°C	
(microns)	n _e	n _o	n _e	n _o
0.42	2.3038	2.4144	2.3090	2.4170
0.45	2.2765	2.3814	2.2814	2.3836
0.50	2.2446	2.3444	2.2498	2.3462
0.55	2.2241	2.3188	2.2276	2.3199
0.60	2.2083	2.3002	2.2118	2.3013
0.65	2.1964	2.2862	2.1993	2.2865
0.70	2.1874	2.2756	2.1900	2.2758
0.80	2.1741	2.2598	2.1766	2.2600
0.90	2.1647	2.2487	2.1671	2.2490
1.00	2.1580	2.2407	2.1601	2.2407
1.20	2.1481	2.2291	2.1503	2.2293
1.40	2.1410	2.2208	2.1426	2.2208
1.60	2.1351	2.2139	2.1372	2.2138
1.80	2.1297	2.2074	2.1318	2.2074
2.00	2.1244	2.2015	2.1265	2.2011
2.20	2.1187	2.1948	2.1211	2.1947
2.40	2.1138	2.1882	2.1156	2.1881
2.60	2.1080	2.1814	2.1099	2.1812
2.80	2.1020	2.1741	2.1037	2.1738
3.00	2.0955	2.1663	2.0972	2.1660
3.20	2.0886	2.1580	2.0903	2.1577
3.40	2.0814	2.1493	2.0830	2.1490
3.60	2.0735	2.1398	2.0746	2.1396
3.80	2.0652	2.1299	2.0669	2.1298
4.00	2.0564	2.1193	2.0582	2.1193

LITHIUM NIOBATE (LiNbO_3)

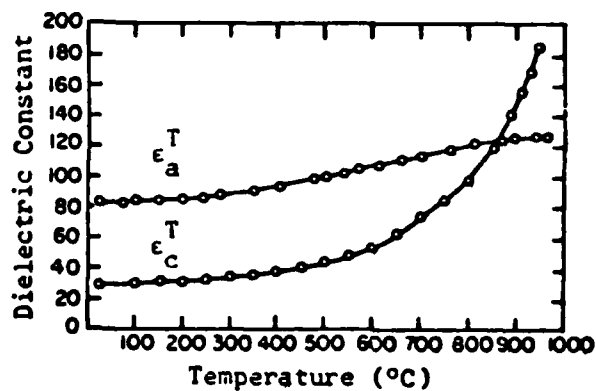


Transmittance versus wavelength⁵ of LiNbO_3 , 0.600 cm.

LITHIUM NIOBATE (LiNbO_3)

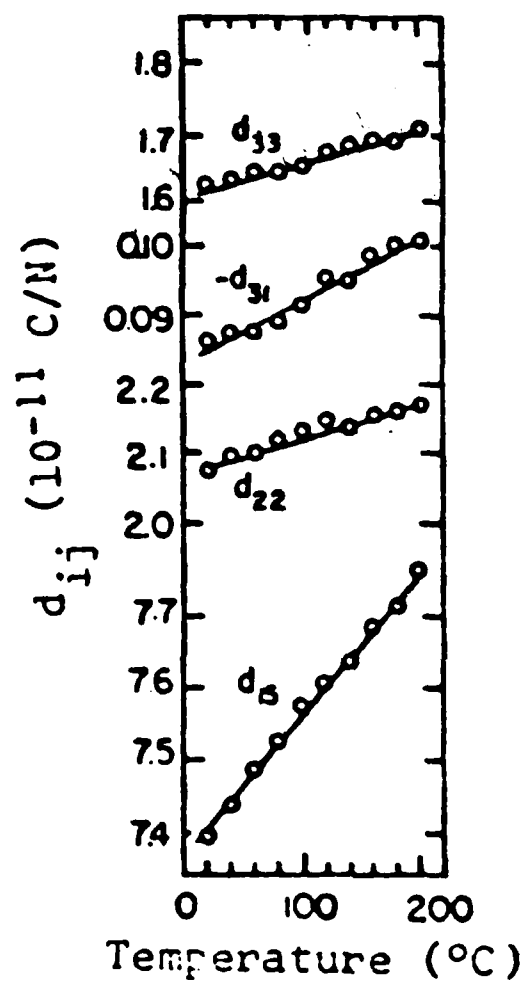


Dielectric constants of LiNbO_3 as a function of frequency at several temperatures⁴.



Dielectric constants of LiNbO_3 as a function of temperature at 10^5 Hz. The ϵ_c^T curve shows the expected high temperature increase as the Curie temperature is approached.

LITHIUM NIOBATE (LiNbO_3)



Temperature dependence⁴ of piezoelectric constant of LiNbO_3 .

LITHIUM TANTALATE



STRUCTURE

CRYSTALLINE

SYMMETRY

= Rhombohedral, 3m

LATTICE CONSTANTS (Å)

= $a_{Rh} = 5.470$ (Rhombohedral)
 $c_{Rh} = 56^\circ 12'$
 $a_H = 5.153$ (Hexagonal)
 $c_H = 13.756$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT

= 235.885

DENSITY (g/cm^3)

= 7.3, 7.454

SOLUBILITY IN WATER (g/100g of H_2O)

= ---

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE ($^\circ\text{K}$)

= 1833

THERMAL EXPANSION COEFFICIENT ($^\circ\text{K}^{-1}$)

= $\alpha_c = 5.7 \times 10^{-6}$, $\alpha_a = 21 \times 10^{-6}$

THERMAL CONDUCTIVITY ($\text{W/cm}^\circ\text{K}$)

= 0.05 at 300°K , 0.45 at 20°K

PHASE TRANSITION TEMPERATURE ($^\circ\text{K}$)
(Ferroelectric - Paraelectric)

= 933

MECHANICAL PROPERTIES

YOUNGS MODULUS

= ---

HARDNESS

= ---

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT

= ---

RESISTIVITY

= ---

BAND GAP ENERGY

= ---

EFFECTIVE MASS

= ---

MOBILITY

= ---

LITHIUM TANTALATE (LiTaO₃)

OPTICAL PROPERTIES

TRANSMISSION RANGE : = up to 6 μm

DISPERSION EQUATION : = ---

ELECTRO-OPTIC COEFFICIENTS¹ (10^{-12} m/v)

$$r_{33}^S = 27$$

$$r_{51} = 15$$

(all at 3.39 μm)

$$r_{13} = 4.5$$

$$r_{22} = .3$$

SECOND HARMONIC COEFFICIENTS² (10^{12} m/v)

$$d_{22} = (2.08 \pm 0.24) \text{ at } 1.0582 \mu\text{m}$$

$$d_{31} = (1.28 \pm 0.24) \text{ at } 1.0582 \mu\text{m}$$

$$d_{33} = (19.39 \pm 2.36) \text{ at } 1.0582 \mu\text{m}$$

RELATIVE DIELECTRIC CONSTANTS (ROOM TEMPERATURE)

ϵ_a^S	ϵ_c^S	ϵ_a^T	ϵ_c^T
41	43	51	45
	43		47
41	42	53	44
38.3	46.2		

PIEZO-ELASTIC CONSTANTS (10^{-11} C/N)

d_{ij}	a	b
d_{15}	2.6	2.6
d_{22}	0.7	0.85
d_{31}	-0.2	-0.30
d_{33}	0.8	0.92

LITHIUM TANTALATE (LiTaO_3)

ELASTIC STIFFNESS CONSTANTS (10^{10} N/m^2) AT ROOM TEMPERATURE CONSTANT FIELD (E)

C_{11}	C_{12}	C_{13}	C_{14}	C_{33}	C_{44}	C_{66}
22.98	4.41	8.11	-1.04	27.81	9.68	9.29
23.3	4.7	8.0	-1.1	27.5	9.4	9.3
22.8	3.1	7.4	-1.2	27.1	9.6	9.8

CONSTANT DISPLACEMENT (D)

C_{11}	C_{12}	C_{13}	C_{14}	C_{33}	C_{44}	C_{66}
23.8	2.1	7.3	-2.7	28.2	11.7	10.9
23.9	4.1	8.0	-2.2	28.4	11.3	9.9

References:

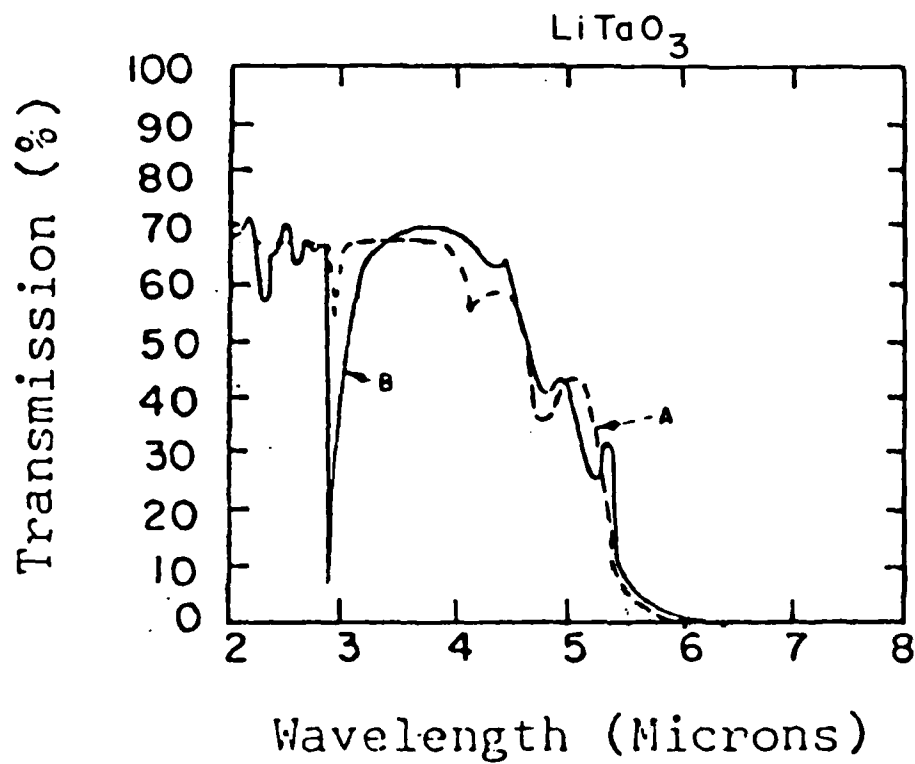
1. E.H. Tarner, J. Opt. Soc. Am. 56, 1426 (1966).
2. R.C. Miller, Appl. Phys. Lett. 9, 169 (1966).
3. W.L. Bond, J. Appl. Phys. 36, 1674 (1965).
4. G.M. Loicono, Appl. Opt. 7, 555 (1968).
5. A.A. Ballman, et al, Amer. Ceram. Soc. J. 50, 657 (1967).
6. T. Yamada, et al, Japan J. Appl. Phys. 7, 292 (1968).

LITHIUM TANTALATE (LiTaO₃)

LITHIUM TANTALATE (LiTaO₃) Refractive Indices at Room Temperature³

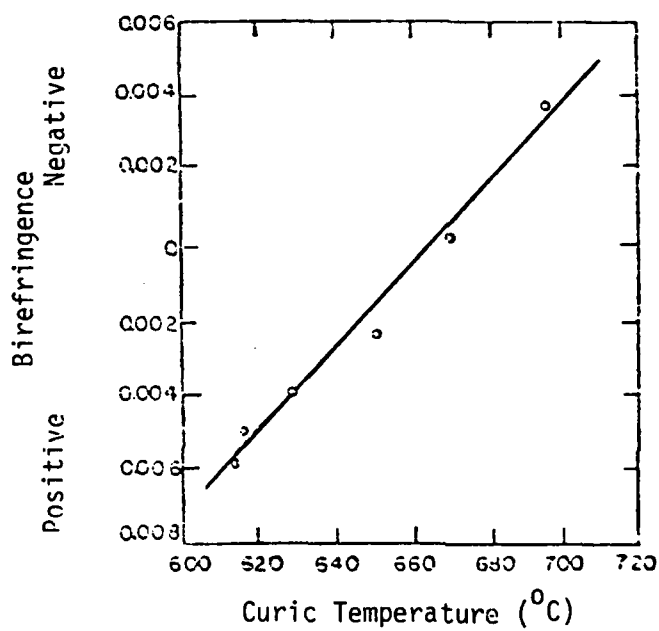
Wavelength	n _o	n _e
0.45	2.2420	2.2468
0.50	2.2160	2.2205
0.60	2.1834	2.1878
0.70	2.1652	2.1696
0.80	2.1538	2.1578
0.90	2.1454	2.1493
1.00	2.1391	2.1432
1.20	2.1305	2.1341
1.40	2.1236	2.1273
1.60	2.1174	2.1213
1.80	2.1120	2.1170
2.00	2.1066	2.1115
2.20	2.1009	2.1053
2.40	2.0951	2.0993
2.60	2.0891	2.0936
2.80	2.0825	2.0871
3.00	2.0755	2.0799
3.20	2.0680	2.0727
3.40	2.0601	2.0649
3.60	2.0513	2.0561
3.80	2.0424	2.0473
4.00	2.0335	2.0377

LITHIUM TANTALATE (LiTaO_3)



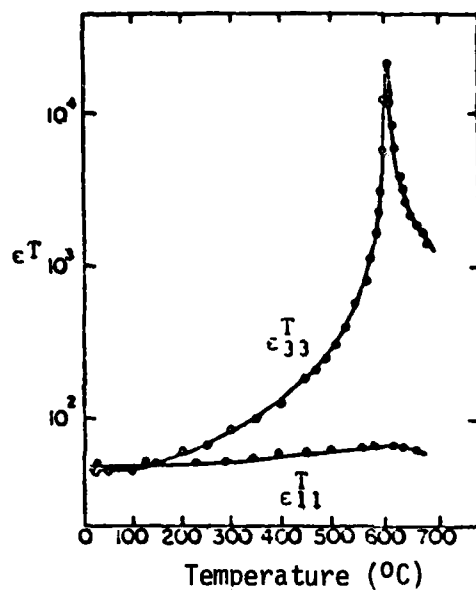
Transmission versus wavelength⁴ of LiTaO_3 : a) 8mm thick and annealed, b) 8mm thick and poled at 250 V/cm.

LITHIUM TANTALATE (LiTaO_3)



Birefringence as a function of Curie temperature⁵
for single crystal LiTaO_3 .

LITHIUM TANTALATE (LiTaO_3)



Dielectric constants of LiTaO_3 as a function of temperature. The ϵ_{33}^T curve shows the expected high temperature increase as the Curie temperature is approached⁶.

MERCURY CADMIUM TELLURIDE



STRUCTURE

CRYSTALLINE

SYMMETRY

= Cubic, 43m

LATTICE CONSTANTS (Å)

= varies linearly with x from
a = 6.482 to 6.462

PHYSICAL PROPERTIES

MOLECULAR WEIGHT

= ---

DENSITY (g/cm³)

= varies linearly with x from
5.7 to 8.1

SOLUBILITY IN WATER (g/100g of H₂O)

= ---

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)

= varies from 946 to 1366

LINEAR EXPANSION COEFFICIENT (°K⁻¹)

= 4.3×10^{-6} at x = 0.2

THERMAL CONDUCTIVITY (cal/cm·sec·°K)

= 0.2 at x = 0.2

SPECIFIC HEAT

(cal/gm)/°K

= ---

MECHANICAL PROPERTIES

YOUNGS MODULUS

= ---

HARDNESS

= ---

ELASTIC CONSTANTS (10¹¹ dyn/cm²)

= C₁₁=5.39, C₁₂=3.78, C₄₄=2.04

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT

= ---

RESISTIVITY

= ---

BAND GAP ENERGY (eV)

= varies from 0.15 at x = 0.2
to 1.54 at x = 1

EFFECTIVE MASS

= ---

MOBILITY μ_e (cm²/v-sec)

= 2.5×10^5 at x = 0.2

MERCURY CADMIUM TELLURIDE ($\text{Hg}_{1-x}\text{Cd}_x\text{Te}$)

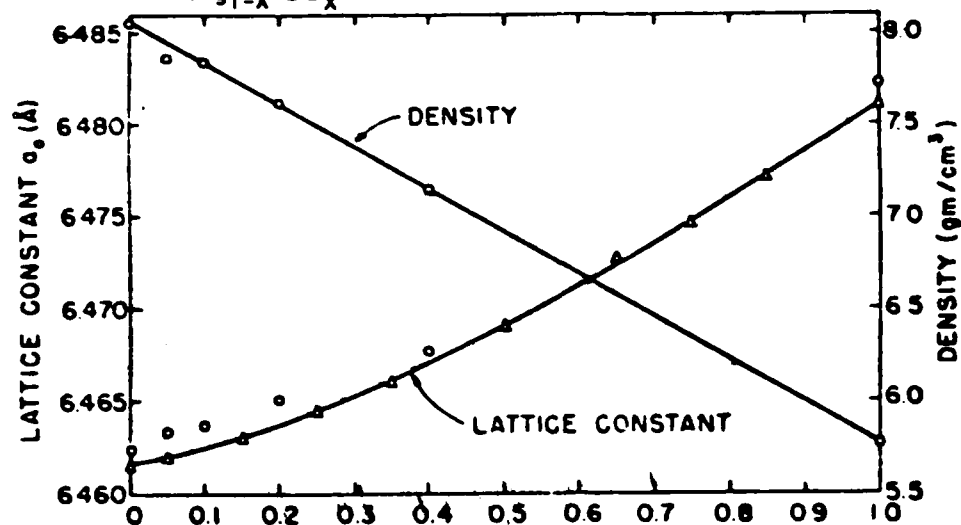
DETECTOR PROPERTIES

OPERATING MODE	=	Photoconductive	Photovoltaic
OPERATING TEMPERATURE ($^{\circ}\text{K}$)	=	77	77
MAXIMUM TEMPERATURE FOR BLIP ($^{\circ}\text{K}$)	=	--	--
WAVELENGTH REGION (μm)	=	Function of composition	Function of composition
DETECTIVITY, D^* ($\text{cmHz}^{1/2}/\text{Watt}$)	=	2×10^{10}	2×10^{10}
RESPONSE TIME (μsec)	=	0.001 to .008	0.001 to .008

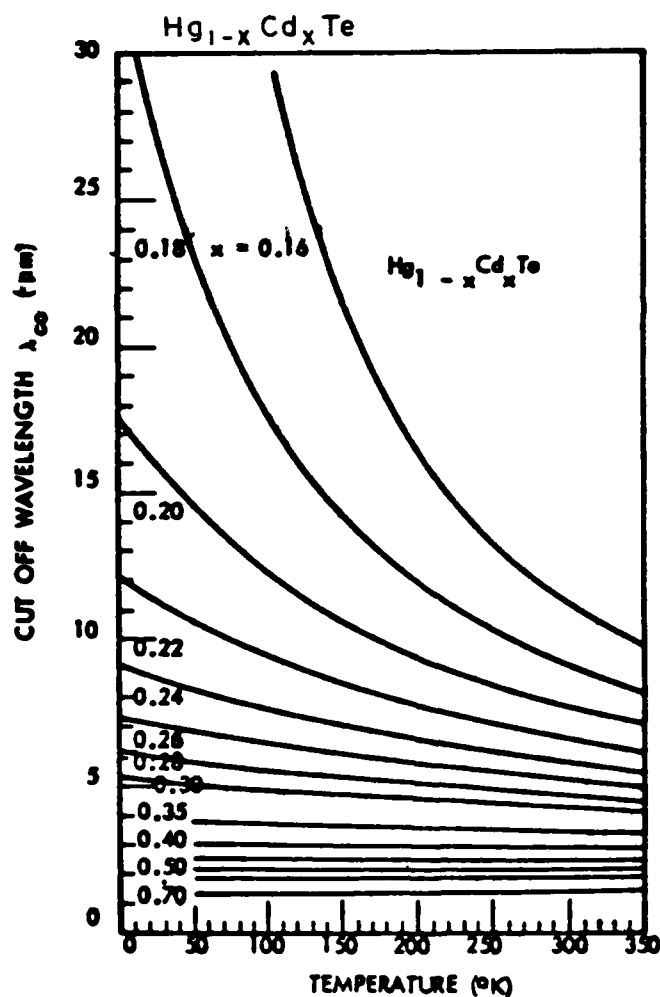
References:

1. D. Long and J.L. Schmit, in Semiconductors and Semimetals, Vol. 5, ed. by R.K. Willardson and A.C. Beer, Academic Press, New York, p. 183 (1970).
2. M.B. Reine and R.M. Broudy, SPIE Proceedings, 124, 80 (1977).
3. Santa Barbara Research Center Bulletin.

MERCURY CADMIUM TELLURIDE ($\text{Hg}_{1-x}\text{Cd}_x\text{Te}$)
 $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$

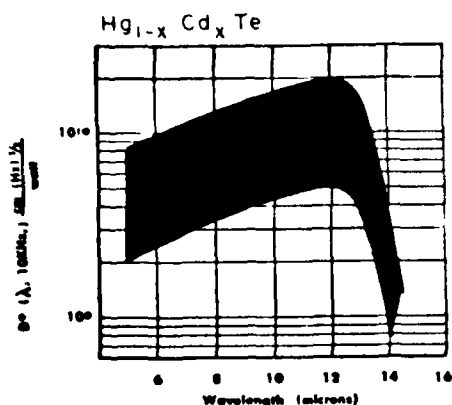


Lattice constant and density¹ versus alloy composition x in $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$.

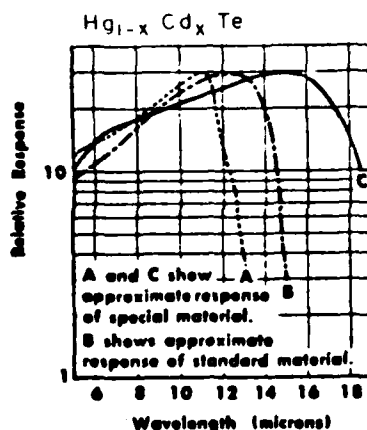


Cut-off wavelength for $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ as a function of temperature and alloy composition².

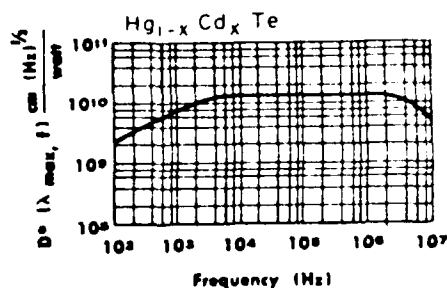
MERCURY CADMIUM TELLURIDE ($\text{Hg}_{1-x}\text{Cd}_x\text{Te}$)



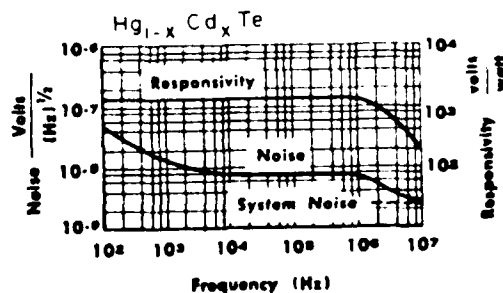
Range of spectral detectivity of typical HgCdTe IR detectors for standard material³.



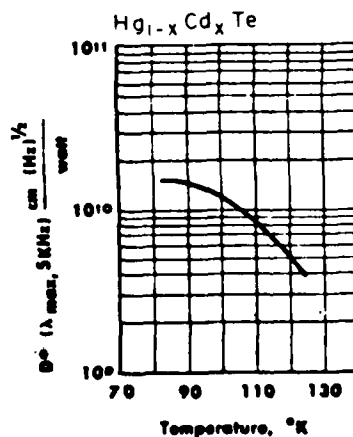
Relative response of typical HgCdTe IR detectors. Wavelength of peak response can be adjusted by varying alloy composition³.



Example of detectivity vs. frequency for HgCdTe IR detectors³.



Example of responsivity and noise vs. frequency for HgCdTe IR detectors³.



Example of detectivity vs. temperature for HgCdTe IR detectors³. (peak response at 77°K = 1 microns).

MERCURY SULFIDE (Cinnabar, Metacinnabar)

HgS

STRUCTURE

CRYSTALLINE

SYMMETRY	=	Trigonal, 32
LATTICE CONSTANTS (Å)	=	a = 4.149 ± 0.001 c = 9.495 ± 0.002

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	232.65
DENSITY	=	8.10
SOLUBILITY IN WATER (g/100g of H ₂ O)	=	0.00001

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	856
LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	--
THERMAL CONDUCTIVITY (cal/cm·sec·°K)	=	--
SPECIFIC HEAT (cal/g)/°K	=	--

MECHANICAL PROPERTIES

YOUNGS MODULUS	=	Not available
HARDNESS	=	Not available

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT	=	--
RESISTIVITY	=	--
BAND GAP ENERGY (eV)	=	2.75
EFFECTIVE MASS	=	--
MOBILITY	=	--

MERCURY SULFIDE (HgS)

OPTICAL PROPERTIES

TRANSMISSION RANGE: 0.6 to 14 μm

DISPERSION EQUATION: ---

ACOUSTO-OPTIC PROPERTIES

ACOUSTIC VIBRATION POLARIZATION DIRECTION	=	Long. (Reference 1)
ACOUSTIC VELOCITY (km/s)	=	2.45
LIGHT VIBRATION POLARIZATION DIRECTION	=	Ordinary
FIGURE OF MERIT ($M_2 = n^6 p^2 / \rho v^3$)	=	296
ACOUSTIC ATTENUATION (dB/cm) at 500 MHz	=	7.1

ELECTRO-OPTIC COEFFICIENTS (10^{-12} m/v)

r_{11} = 4.2 at 3.39 μm (Reference 2)

r_{11} = 2.4 at 3.39 μm

SECOND HARMONIC COEFFICIENTS (10^{12} m/v)

d_{11} = 62.8 ± 21 (Reference 3)

d_{11} = 50.3 ± 17 (Reference 4)

References:

1. J. Spariel, Appl. Phys. Lett. 19, 533 (1971).
2. E.H. Turner, IEEE. J. Quant. Elec. QE3, 695 (1967).
3. J. Jerphagnon, E. Batifol, G. Tsoucaris and M. Sourbe, C.R. Acad. Sci. Paris B265, 495 (1967).
4. G.D. Boyd, T.J. Bridges, and E.G. Burkhardt, IEEE. J. Quant. Ed. QE4, 515 (1968).
5. W.L. Bond, G.D. Boyd, and H.L. Carter, J. Appl. Phys. 38, 4090 (1967).
6. Y. Toudic and R. Aumont, J. Crystal Growth 10, 170 (1971).

MERCURY SULFIDE (HgS)

MERCURY SULFIDE (α -HgS) REFRACTIVE INDICIES AT ROOM TEMPERATURE⁵

Wavelength (μ m)	n_o	n_e
0.62	2.9028	3.2560
0.65	2.8655	3.2064
0.68	2.8384	3.1703
0.70	2.8224	3.1489
0.80	2.7704	3.0743
0.90	2.7383	3.0340
1.00	2.7120	3.0050
1.20	2.6884	2.9680
1.40	2.6730	2.9475
1.60	2.6633	2.9344
1.80	2.6567	2.9258
2.00	2.6518	2.9194
2.20	2.6483	2.9146
2.40	2.6455	2.9108
2.60	2.6433	2.9079
2.80	2.6414	2.9052
3.00	2.6401	2.9036
3.20	2.6387	2.9017
3.40	2.6375	2.9001
3.60	2.6358	2.8987
3.80	2.6563	2.8971
4.00	2.6348	2.8963
5.00	2.6267	2.8863
6.00	2.6233	2.8799
7.00	2.6156	2.8741
8.00	2.6112	2.8674
9.00	2.6066	2.8608
10.00	2.6018	2.8522
11.00	2.5914	2.8434

MERCURY SULFIDE (HgS)

OPTICAL PROPERTIES

TRANSMISSION RANGE: 0.6 to 14 μm

DISPERSION EQUATION: ---

ACOUSTO-OPTIC PROPERTIES

ACOUSTIC VIBRATION POLARIZATION DIRECTION	=	Long. (Reference 1)
ACOUSTIC VELOCITY (km/s)	=	2.45
LIGHT VIBRATION POLARIZATION DIRECTION	=	Ordinary
FIGURE OF MERIT ($M_2 = n^6 p^2 / \rho v^3$)	=	296
ACOUSTIC ATTENUATION (dB/cm) at 500 MHz	=	7.1

ELECTRO-OPTIC COEFFICIENTS (10^{-12} m/v)

$r_{11} = 4.2$ at 3.39 μm (Reference 2)

$r_{11} = 2.4$ at 3.39 μm

SECOND HARMONIC COEFFICIENTS (10^{12} m/v)

$d_{11} = 62.8 \pm 21$ (Reference 3)

$d_{11} = 50.3 \pm 17$ (Reference 4)

References:

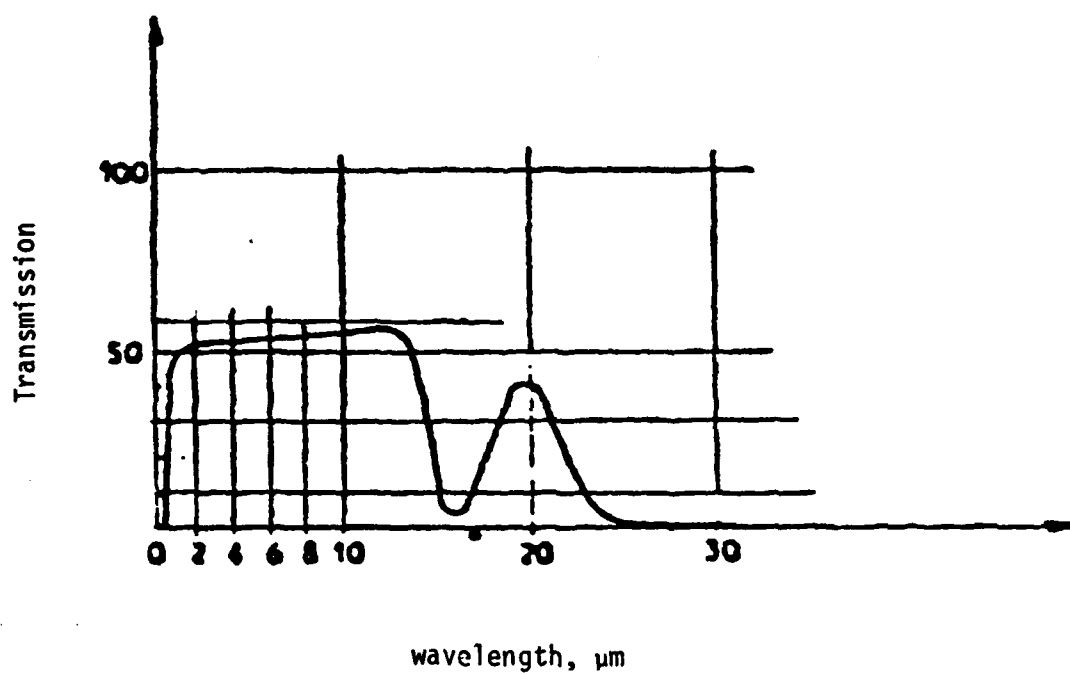
1. J. Spariel, Appl. Phys. Lett. 19, 533 (1971).
2. E.H. Turner, IEEE. J. Quant. Elec. QE3, 695 (1967).
3. J. Jerphagnon, E. Batifol, G. Tsoucaris and M. Sourbe, C.R. Acad. Sci. Paris B265, 495 (1967).
4. G.D. Boyd, T.J. Bridges, and E.G. Burkhardt, IEEE. J. Quant. Ed. QE4, 515 (1968).
5. W.L. Bond, G.D. Boyd, and H.L. Carter, J. Appl. Phys. 38, 4090 (1967).
6. Y. Toudic and R. Aumont, J. Crystal Growth 10, 170 (1971).

MERCURY SULFIDE (HgS)

MERCURY SULFIDE (α -HgS) REFRACTIVE INDICIES AT ROOM TEMPERATURE⁵

Wavelength (μ m)	n_o	n_e
0.62	2.9028	3.2560
0.65	2.8655	3.2064
0.68	2.8384	3.1703
0.70	2.8224	3.1489
0.80	2.7704	3.0743
0.90	2.7383	3.0340
1.00	2.7120	3.0050
1.20	2.6884	2.9680
1.40	2.6730	2.9475
1.60	2.6633	2.9344
1.80	2.6567	2.9258
2.00	2.6518	2.9194
2.20	2.6483	2.9146
2.40	2.6455	2.9108
2.60	2.6433	2.9079
2.80	2.6414	2.9052
3.00	2.6401	2.9036
3.20	2.6387	2.9017
3.40	2.6375	2.9001
3.60	2.6358	2.8987
3.80	2.6563	2.8971
4.00	2.6348	2.8963
5.00	2.6267	2.8863
6.00	2.6233	2.8799
7.00	2.6156	2.8741
8.00	2.6112	2.8674
9.00	2.6066	2.8608
10.00	2.6018	2.8522
11.00	2.5914	2.8434

MERCURY SULFIDE (HgS)



Transmission versus wavelength of mercury sulfide⁶, 1mm.

POTASSIUM IODIDE

KI

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, Fm3m

LATTICE CONSTANTS (Å) = $a = 7.0655$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 166.02

DENSITY (g/cm³) = 3.13

SOLUBILITY IN WATER (g/100g of H₂O) = 144.5

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 996

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = 42.6×10^{-6}

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = 50.1×10^{-4}

SPECIFIC HEAT (cal/g)/°K = 0.0725

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI) = 4.57×10^{-6}

HARDNESS = 5

ELASTIC CONSTANTS (bars) = $C_{11}=3.32, C_{12}=0.578, C_{44}=0.620$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = 4.94 at 2×10^6 Hz

RESISTIVITY = ---

BAND GAP ENERGY = ---

EFFECTIVE MASS = ---

MOBILITY = ---

POTASSIUM IODIDE (KI)

References:

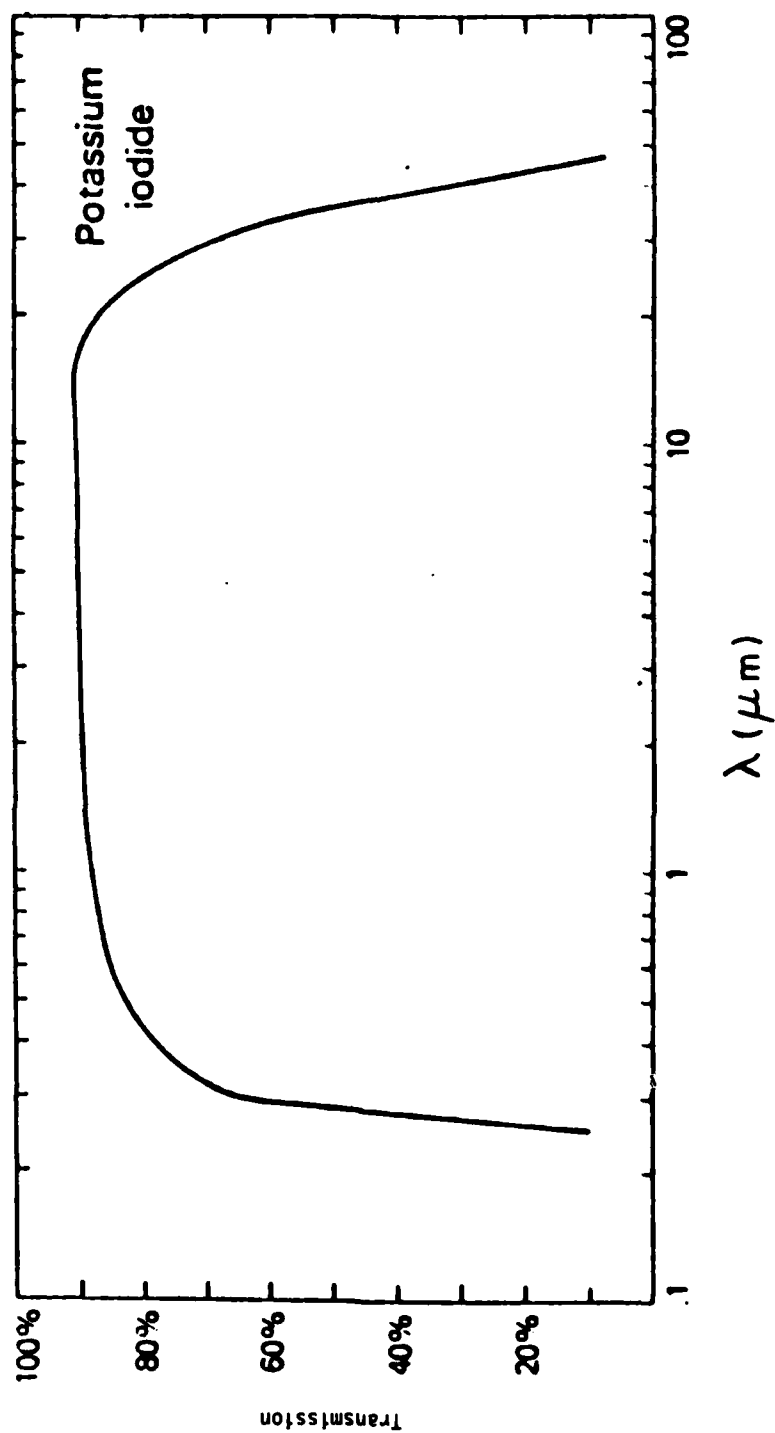
1. A. Smakula; Einkristalle, Springer-Verlog, Berlin, p. 388 (1962).
2. Isomet Corporation, Optical Crystals, Bull. No. 1011.

POTASSIUM IODIDE (KI)**POTASSIUM IODIDE**

Refractive Index versus Wavelength of Potassium Iodide¹
(from 0.248 - 1.083 μ m at 20°C; from 1.18 - 29.0 μ m at 38°C)

λ_{μ}	n	λ_{μ}	n	λ_{μ}	n
0.248	2.0548	0.656	1.65809	10.02	1.6201
0.254	2.0105	0.707	1.6537	11.79	1.6172
0.265	1.9424	0.728	1.6520	12.97	1.6150
0.270	1.9221	0.768	1.6494	14.14	1.6127
0.280	1.8837	0.811	1.6471	15.91	1.6085
0.289	1.85746	0.842	1.6456	18.10	1.6030
0.297	1.83967	0.912	1.6427	19	1.5997
0.302	1.82769	1.014	1.6396	20	1.5964
0.313	1.80707	1.083	1.6381	21	1.5930
0.334	1.77664	1.18	1.6366	22	1.5895
0.366	1.74416	1.77	1.6313	23	1.5858
0.391	1.72671	2.36	1.6295	24	1.5819
0.405	1.71843	3.54	1.6275	25	1.5775
0.436	1.70350	4.13	1.6268	26	1.5729
0.486	1.68664	5.89	1.6252	27	1.5681
0.546	1.67310	7.66	1.6235	28	1.5629
0.588	1.66654	8.84	1.6218	29	1.5571
0.589	1.66643				

POTASSIUM IODIDE (KI)



Transmittance versus wavelength of potassium iodide¹.

SILVER CHLORIDE (CERARGYRITE)

AgCl

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, Fm3m

LATTICE CONSTANTS (A) = $a = 5.549$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 143.34

DENSITY (g/cm³) = 5.56

SOLUBILITY IN WATER (g/100g of H₂O) = 1.5×10^{-4}

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 731

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = 30×10^{-6}

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = 27.5×10^{-4}

SPECIFIC HEAT (cal/g)/°K = 0.0848

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI) = 2.9×10^6

HARDNESS = 9.5 (200g)

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = 12.3

RESISTIVITY = ---

BAND GAP ENERGY = ---

EFFECTIVE MASS = ---

MOBILITY = ---

SILVER CHLORIDE (AgCl)

OPTICAL PROPERTIES:

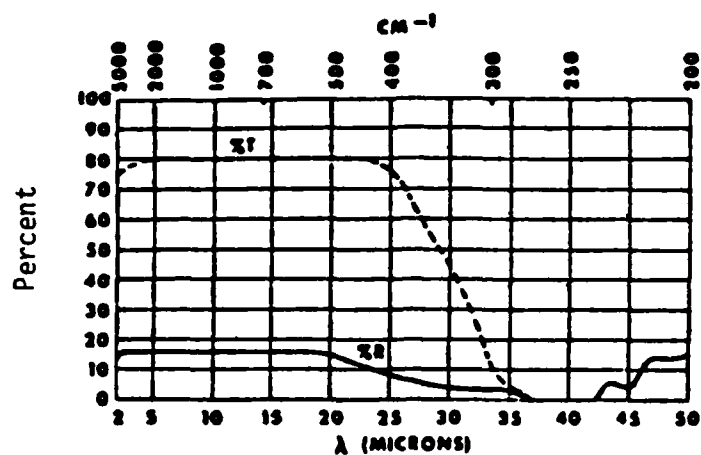
DISPERSION EQUATION:

$$\begin{aligned} n^2 = & 4.00804 - 0.00085111\lambda^2 \\ & - 0.00000019762\lambda^4 \\ & + 0.079086/(\lambda^2 - 0.04584) \end{aligned}$$

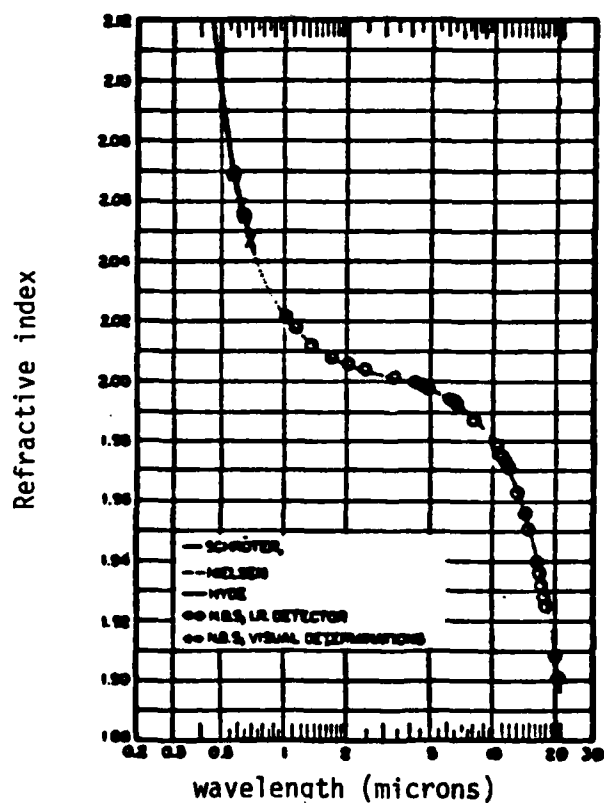
References:

1. D.E. McCarthy, Appl. Opt. 2, 591 (1963).
2. L.W. Tilton, E.K. Plyler and R.E. Stephens, J. Opt. Soc. Am. 40, 540 (1950).

SILVER CHLORIDE (AgCl)



Transmittance and Reflectance versus wavelength of silver chloride¹, 0.5mm.



Refractive index versus wavelength of silver chloride².

SILVER THIOANTIMONITE (PYRARGYRITE)



STRUCTURE

CRYSTALLINE

SYMMETRY = Trigonal, 3m

LATTICE CONSTANTS (Å) =
a = 3.084
c = 2.881

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 541.55

DENSITY (g/cm^3) = 5.76

SOLUBILITY IN WATER ($\text{g/100g of H}_2\text{O}$) = ---

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE ($^{\circ}\text{K}$) = 879

LINEAR EXPANSION COEFFICIENT ($^{\circ}\text{K}^{-1}$) = --

THERMAL CONDUCTIVITY ($\text{cal/cm}\cdot\text{sec}\cdot^{\circ}\text{K}$) = --

SPECIFIC HEAT ($\text{cal/g}/^{\circ}\text{K}$) = --

MECHANICAL PROPERTIES

YOUNGS MODULUS = --

HARDNESS = --

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = --

RESISTIVITY = --

BAND GAP ENERGY = --

EFFECTIVE MASS = --

MOBILITY = --

SILVER THIOANTIMONITE (Ag_3SbS_3)

OPTICAL PROPERTIES

ABSORPTION COEFFICIENT ($\lambda = 10.6\mu\text{m}$): $\alpha^0 = 0.34 \pm 0.05 \text{ cm}^{-1}$

$$\alpha^E = 0.08 \pm 0.04 \text{ cm}^{-1}$$

REFLECTION LOSSES: 20 - 24% for $\lambda = 0.75 - 13\mu\text{m}$

SECOND HARMONIC COEFFICIENTS (10^{12} m/v)

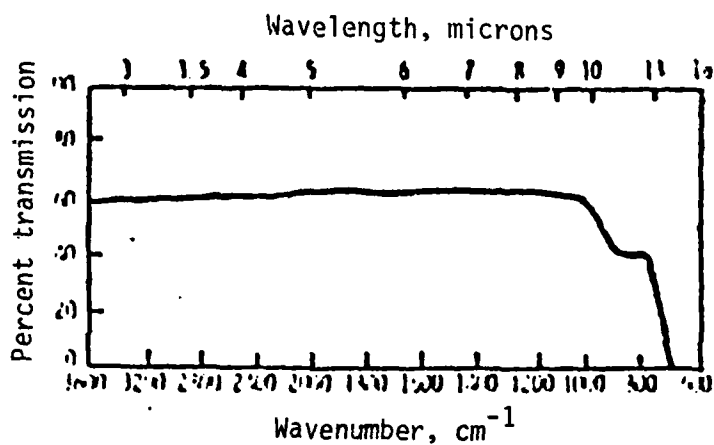
$$d_{31} = 12.6 \pm 4 \quad \text{at} \quad 10.6\mu\text{m}$$

$$d_{22} = 13.4 \pm 4$$

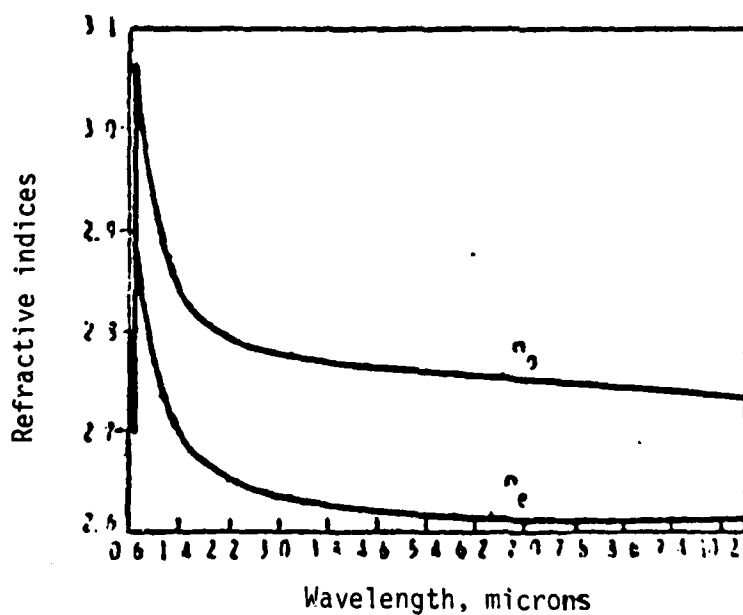
References:

1. J.D. Feichtner, R. Johannes and G.W. Roland, Appl. Opt. 9, 1716 (1970).
2. W.B. Gandrud, G.D. Boyd, J.H. McFee and F.H. Wehmeier, Appl. Phys. Lett. 16, 59 (1970).

SILVER THIOANTIMONITE (Ag_3SbS_3)



Transmission of Ag_3SbS_3 in the 2.5-15 μm range¹.



Refractive indices of Ag_3SbS_3 in the 0.65-10.6 μm range.

SILVER THIOARSENITE (PROUSTITE)**STRUCTURE****CRYSTALLINE****SYMMETRY**

= Trigonal, 3m

LATTICE CONSTANTS (Å)

	a	c	
	10.76	8.64	(Reference 1)
	10.77	8.67	(Reference 2)
	10.78	8.682	(Reference 3)
	10.80	8.69	(Reference 4)

PHYSICAL PROPERTIES**MOLECULAR WEIGHT**

= --

DENSITY (g/cm³)

= 5.49

SOLUBILITY IN WATER (g/100g of H₂O)

= --

THERMAL PROPERTIES**MELTING/SOFTENING TEMPERATURE (°K)**

= 761

LINEAR EXPANSION COEFFICIENT (°K⁻¹)

= Not available

THERMAL CONDUCTIVITY (cal/cm·sec·°K)

= Not available

SPECIFIC HEAT (cal/g)/°K

= Not available

MECHANICAL PROPERTIES**YOUNGS MODULUS**

= --

HARDNESS

= --

ELECTRICAL PROPERTIES**DIELECTRIC CONSTANT**

$\epsilon_{11}^S = 14.5$	$\epsilon_{33}^S = 18$
$\epsilon_{11}^I = 16.5$	$\epsilon_{33}^I = 20.0$

RESISTIVITY

= --

BAND GAP ENERGY

= --

EFFECTIVE MASS

= --

MOBILITY

= --

SILVER THIOARSENITE (Ag_3AsS_3)

OPTICAL PROPERTIES

DISPERSION EQUATION¹: $n_o^2 = 7.483 + 0.474/(\lambda^2 - 0.09) - 0.0019\lambda^2$

$$n_e^2 = 6.346 + 0.342/(\lambda^2 - 0.09) - 0.0011\lambda^2$$

SECOND HARMONIC COEFFICIENTS (10^{12} m/v)

$$d_{31} = 12.6 \text{ at } 1.152 \text{ } \mu\text{m} \text{ (Reference 1)}$$

$$d_{15} + d_{22} = (28.38) \pm 1.8 \text{ at } 10.6 \text{ } \mu\text{m} \text{ (Reference 5)}$$

References:

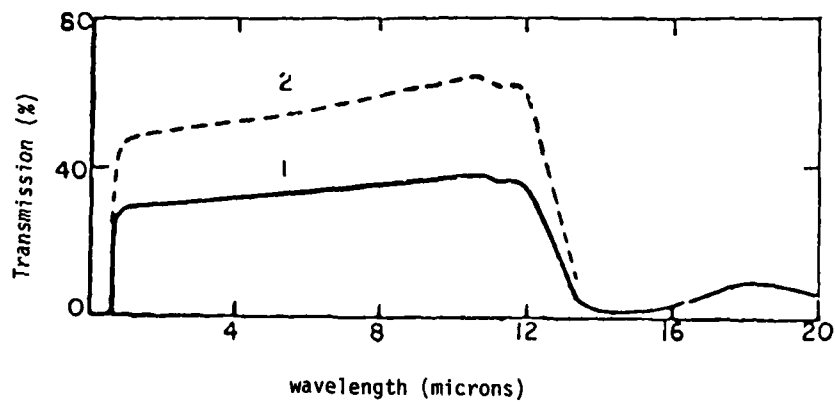
1. K.F. Huline, O. Jones, P.H. Davies and M.V. Hoben, Appl. Phys. Lett. 10, 133 (1967).
2. M.I. Butsko et al, Ukr. Fig. Zh (Kiev) 12, 2052 (1967).
3. Landott and Bornstein, Numerical Data and Functional Relationships in Science and Technology, Springer-Verlag, New York (1969).
4. J.D.H. Donnay (Ed), Crystal Data Determinative Tables, 2nd Ed., American Crystallographic Association, April 1963, ACA Monograph No. 5.
5. D.M. Bogget and A.F. Gibson, Phys. Lett. 28A, 33 (1968).
6. L.M. Guseva et al, Opt. and Spectroscopy 24, 156 (1968).

SILVER THIOARSENITE (Ag_3AsS_3)

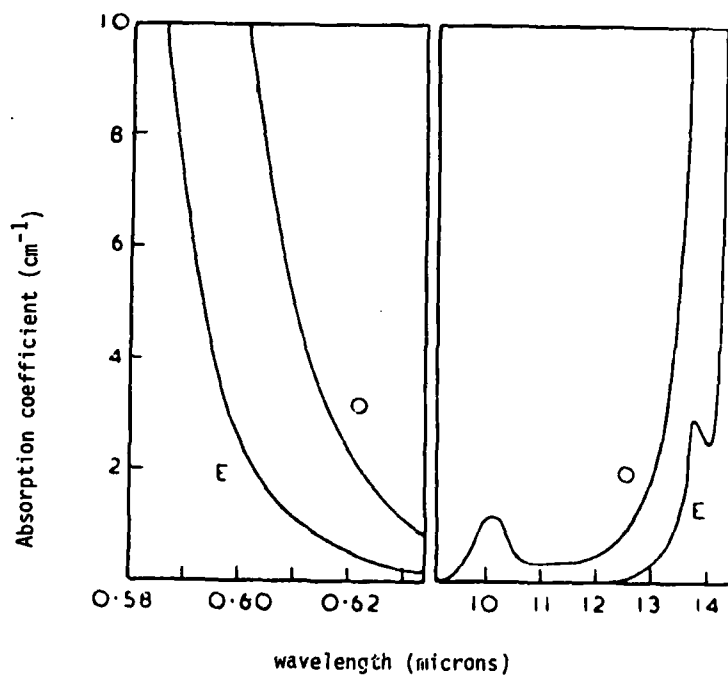
**SILVER THIOARSENITE (Ag_3AsS_3)
Refractive Indices versus Wavelength¹.**

Wavelength (μm)	n_o	n_e
0.5876		2.7896
0.6328	3.0190	2.7391
0.6678	2.9804	2.7094
1.0140	2.8264	2.5901
1.1290	2.8067	2.5756
1.3670	2.7833	2.5570
1.530	2.7728	2.5485
1.709	2.7654	2.5423
2.50	2.7478	2.5282
3.56	2.7379	2.5213
4.62	2.7318	2.5178

SILVER THIOARSENITE (Ag_3AsS_3)



Transmission of a proustite crystal 1.72 mm thick as a function of wavelength. (1) without including reflection: (2) with reflection losses included⁶.



Absorption coefficient of Ag_3AsS_3 as a function of wavelength¹.

POTASSIUM CHLORIDE (SYLVITE)

KCl

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, Fm3m

LATTICE CONSTANTS (A) = $a = 6.2931$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 74.55

DENSITY (g/cm³) = 1.9865

SOLUBILITY IN WATER (g/100g of H₂O) = 34.7

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 1049

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = 36×10^{-6}

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = 156×10^{-4}

SPECIFIC HEAT (cal/g)/°K = 0.162

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI) = 4.3×10^6

HARDNESS (Knoop) = 9.3 in <100> direction

ELASTIC CONSTANTS (bars) = $C_{11}=3.98, C_{12}=0.62, C_{44}=0.625$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = 4.64 at 10^6 Hz

RESISTIVITY = ---

BAND GAP ENERGY = ---

EFFECTIVE MASS = ---

MOBILITY = ---

POTASSIUM CHLORIDE (KCl)

References:

1. A. Smakula, Einkristalle, Springer-Verlag, Berlin, p. 386 (1962).
2. D.E. McCarthy, Appl. Opt. 4, 317 (1964).
3. J.N. Plendl and P.J. Gielesse, Appl. Opt. 3, 943 (1964).

POTASSIUM CHLORIDE (KCl)

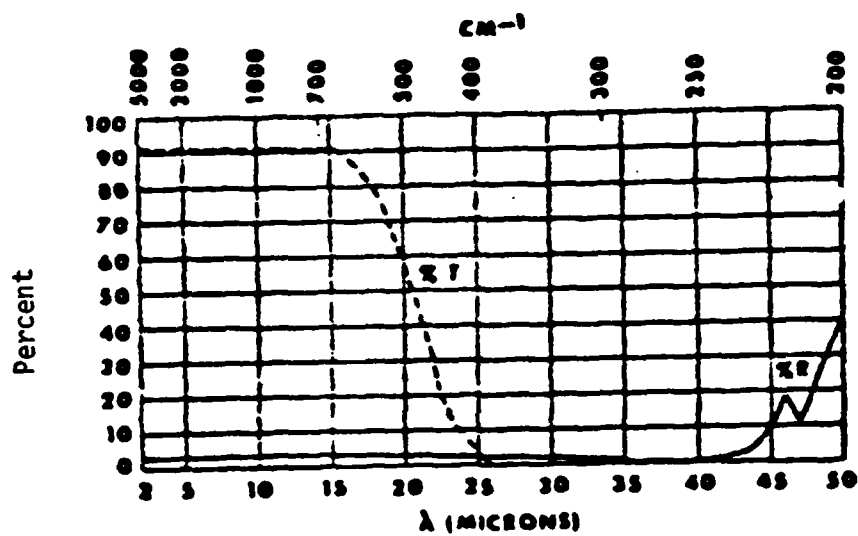
POTASSIUM CHLORIDE
Refractive Index versus Wavelength¹ AT 20°C

λ_{μ}	n	λ_{μ}	n	λ_{μ}	n
0.190	1.78373	0.436	1.50454	3.536	1.472881
0.200	1.71904	0.486	1.49818	4.715	1.470956
0.214	1.6645	0.546	1.49293	5.304	1.469850
0.225	1.6345	0.586	1.49028	5.894	1.468642
0.240	1.60500	0.589	1.49020	8.250	1.462568
0.248	1.59265	0.656	1.48700	8.840	1.460701
0.254	1.58569	0.707	1.48519	10.108	1.45658
0.265	1.57270	0.728	1.48454	11.786	1.44908
0.270	1.56833	0.768	1.48349	12.965	1.44334
0.280	1.55939	0.811	1.48257	14.144	1.43711
0.289	1.55272	0.843	1.48196	15.912	1.42608
0.297	1.54796	0.912	1.48085	17.680	1.41392
0.302	1.54468	1.014	1.47950	18.0	1.41075
0.313	1.53875	1.083	1.47878	19.0	1.4026
0.334	1.52949	1.179	1.478142	20.0	1.3938
0.366	1.51889	1.768	1.475721	21.0	1.3844
0.391	1.51286	2.357	1.474582	22.0	1.3742
0.405	1.50993	2.945	1.473665	23.0	1.3632

TEMPERATURE COEFFICIENT OF REFRACTIVE INDEX
($10^5 \times dn/dT$) of Potassium Chloride¹

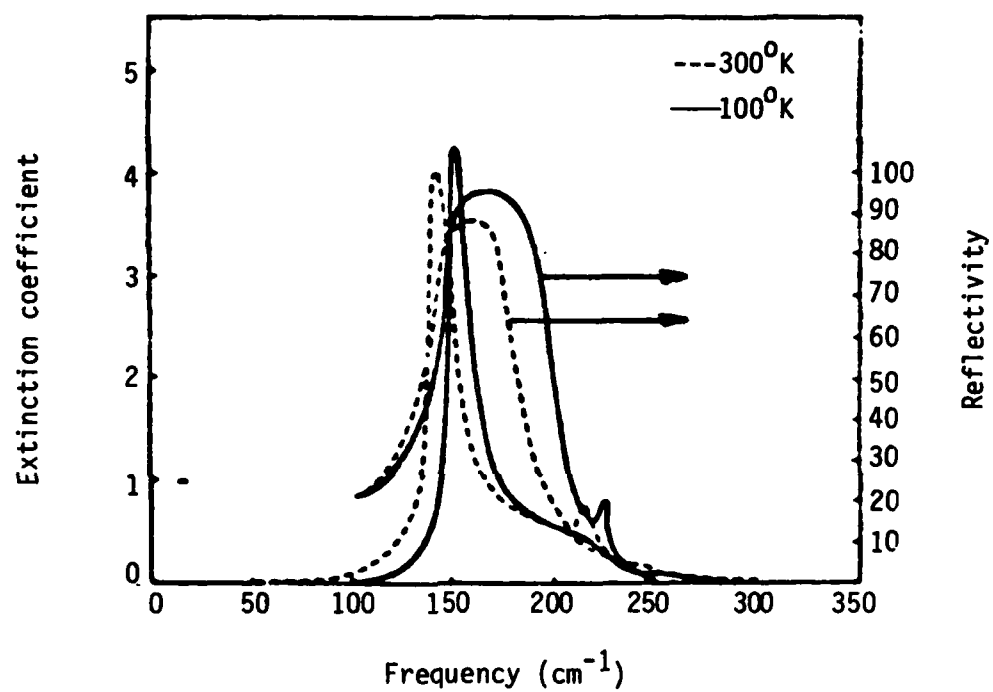
λ_{μ}	dn/dT	λ_{μ}	dn/dT
0.589	-3.25	5.893	-3.10
0.786	-3.26	8.250	-2.92
0.884	-3.27	8.840	-2.87
0.982	-3.28	10.018	-2.75
1.179	-3.29	11.786	-2.48
1.768	-3.30	12.965	-2.30
2.357	-3.32	14.144	-2.06
2.945	-3.31	15.912	-1.70
3.563	-3.28	17.680	-1.26
4.715	-3.20	20.60	-0.5
5.304	-3.15	22.50	-0

POTASSIUM CHLORIDE (KCl)



Reflectance and Transmittance versus wavelength
of Potassium chloride², 10 mm.

POTASSIUM CHLORIDE (KCl)



Reflectance and extinction coefficient versus frequency of potassium chloride at 100°K and 300°K.

SILICON

Si

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, m3m

LATTICE CONSTANTS (Å) = $a = 5.43$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = ---

DENSITY (g/cm³) = ---

SOLUBILITY IN WATER (g/100g of H₂O) = < 0.005

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 1693

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = 4.7×10^{-6}

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = .39

SPECIFIC HEAT (cal/g)/°K = 0.168

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI) = 1.90×10^6

HARDNESS (Knoop) = 1100 - 1400

ELASTIC CONSTANTS (bars) = $C_{11}=1.67, C_{12}=0.65, C_{44}=0.80$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT (static) = 11.7

RESISTIVITY = ---

BAND GAP ENERGY (eV) = 1.11

EFFECTIVE MASS m_e^*, m_{et}^* = $0.98m_0, 0.19m_0$

MOBILITY μ_e (cm²/v-sec) = 1350

SILICON (Si)

OPTICAL PROPERTIES

DISPERSION EQUATION¹:

$$n = A + BL + CL^2 + D\lambda^2 + E\lambda^4$$

where

$$\begin{aligned} A &= 3.41696 \\ B &= 0.138497 \\ C &= 0.013924 \\ D &= -0.0000209 \\ E &= 0.000000148 \\ L &= \frac{1}{\lambda^2 - 0.028} \end{aligned}$$

DETECTOR PROPERTIES

OPERATING MODE	=	PC	PV
OPERATING TEMPERATURE (°K)	=	<25	<20
MAXIMUM TEMPERATURE FOR BLIP (°K)	=	---	---
WAVELENGTH REGION (μm)	=	1-17	1-23
DETECTIVITY, D* (cmHz ^{1/2} /watt)	=	>9 x 10 ⁹	>1.3 x 10 ¹⁰
RESPONSE TIME (μsec)	=		.1

References:

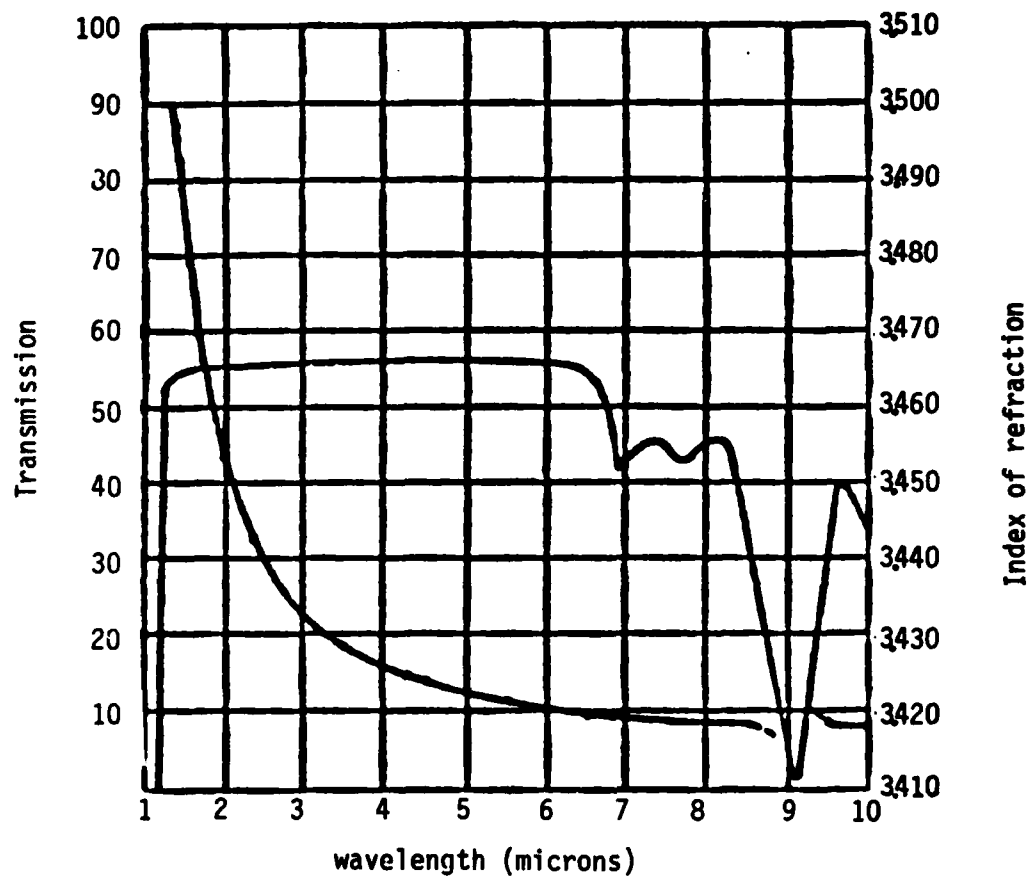
1. C.D. Salzberg and J.J. Villa, J. Opt. Soc. Am. 47, 244 (1957).
2. Santa Barbara Research Center Bulletin.

SILICON (Si)

Silicon: Refractive Index¹ at 26°C

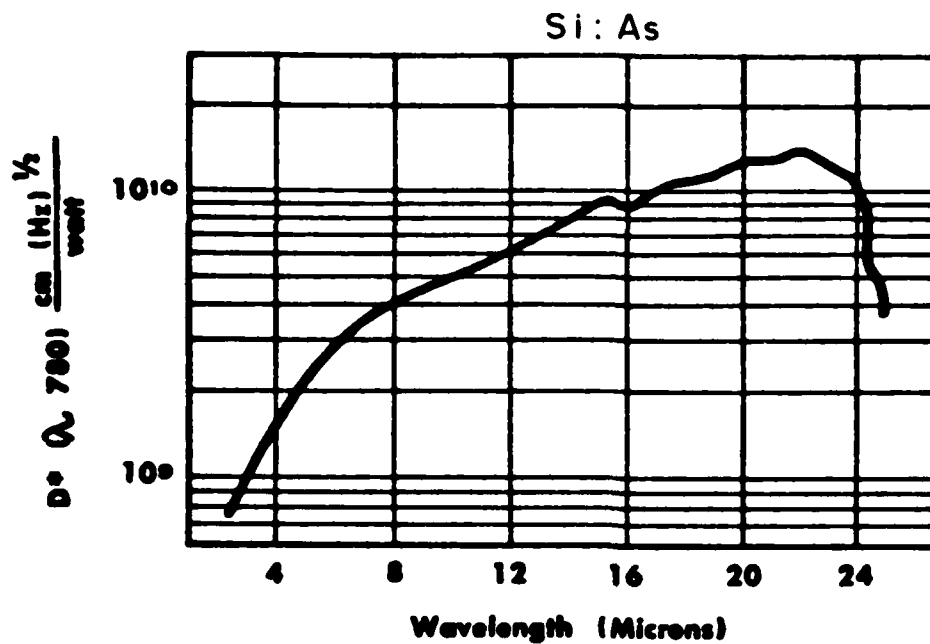
$\lambda, \mu\text{m}$	n	$\lambda, \mu\text{m}$	n	$\lambda, \mu\text{m}$	n	$\lambda, \mu\text{m}$	n
1.3570	3.4975	2.1526	3.4476	4.00	3.4255	7.00	3.4189
1.3673	3.4962	2.3254	3.4430	4.258	3.4242	7.50	3.4186
1.3951	3.4929	2.4373	3.4408	4.50	3.4236	8.00	3.4184
1.3295	3.4795	2.7144	3.4358	5.00	3.4223	8.50	3.4182
1.6606	3.4696	3.00	3.4320	5.50	3.4213	10.00	3.4179
1.7092	3.4664	3.3033	3.4297	6.00	3.4202	10.50	3.4178
1.8134	3.4608	3.4188	3.4286	6.50	3.4195	11.04	3.4176
1.9704	3.4537	3.50	3.4284				

SILICON (Si)

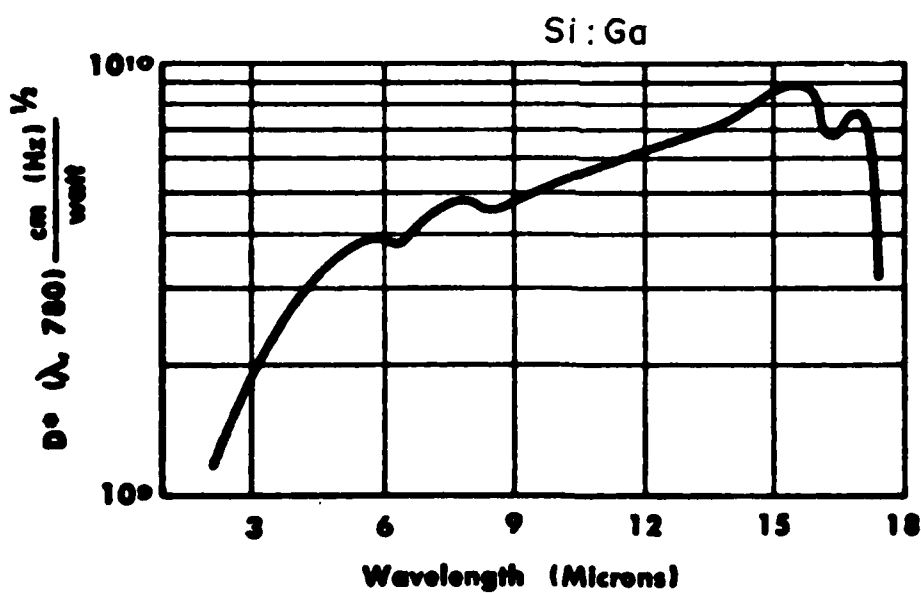


Index of refraction of single-crystal silicon and transmission through a 2.0 mm thick sample

SILICON (Si)



Spectral Detectivity of Si:As IR Detectors².



Relative Response of Si:Ga IR Detectors².

POTASSIUM BROMIDE

KBr

STRUCTURE

CRYSTALLINE

SYMMETRY	=	Cubic, Fm3m
LATTICE CONSTANTS (Å)	=	a = 6.5966

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	119.01
DENSITY (g/cm ³)	=	2.75
SOLUBILITY IN WATER (g/100g of H ₂ O)	=	53.48

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	1003
LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	43 x 10 ⁻⁶
THERMAL CONDUCTIVITY (cal/cm·sec·°K)	=	115 x 10 ⁻⁴
SPECIFIC HEAT (cal/g)/°K	=	0.104

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI)	=	3.9 x 10 ⁶
HARDNESS	=	7.0: (200g load)
ELASTIC CONSTANTS (bars)	=	C ₁₁ =3.45, C ₁₂ =0.54, C ₄₄ =0.508

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT	=	4.9 at 100 - 10 ¹⁰ Hz
RESISTIVITY	=	---
BAND GAP ENERGY	=	---
EFFECTIVE MASS	=	---
MOBILITY	=	---

POTASSIUM BROMIDE (KBr)

OPTICAL PROPERTIES

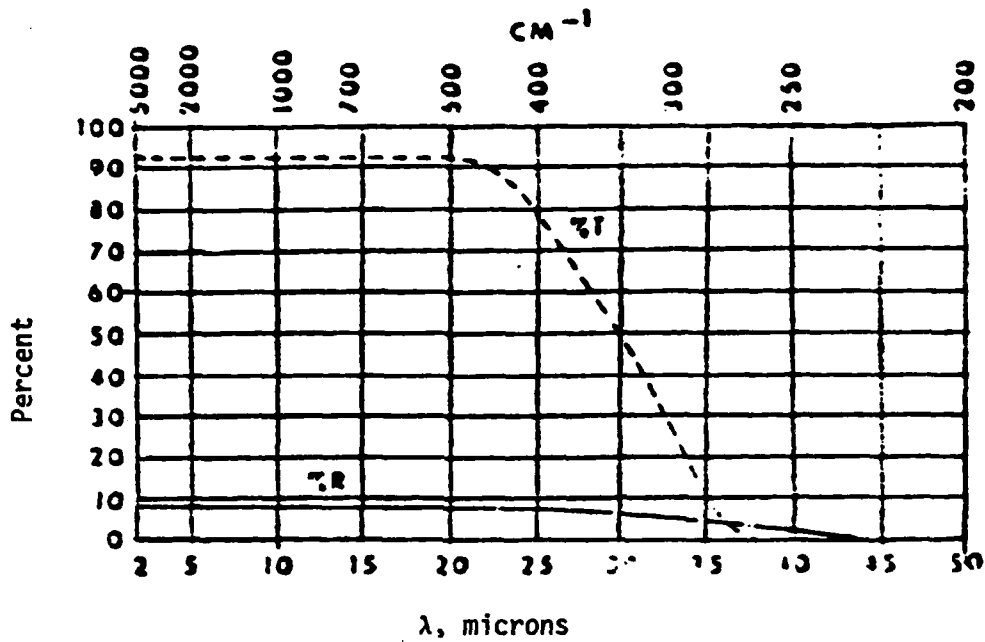
DISPERSION EQUATION:

$$n^2 = 2.361323 - 0.000311497\lambda^2 - 0.000000058613\lambda^4 + \frac{0.007676}{\lambda^2} + \frac{0.0156569}{\lambda^2 - 0.0324}$$

References:

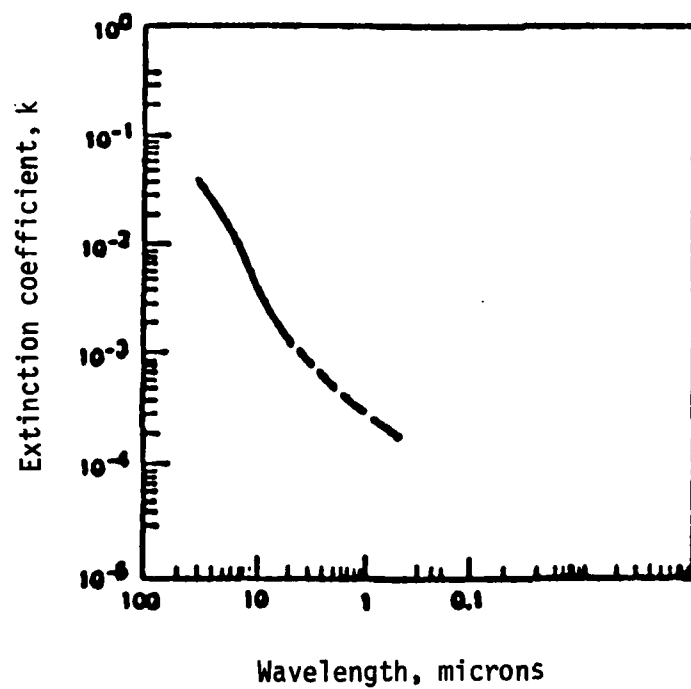
1. D.E. McCarthy, Appl. Opt. 2, 591 (1963).
2. J.C. Owens, Phys. Rev. 181, 1228 (1969).
3. R.E. Stephens, E.K. Plyler, W.S. Rodney and R.J. Spindler, J. Opt. Am. 43, 111 (1953).

POTASSIUM BROMIDE (KBr)



Transmittance and reflectance versus wavelength of
of potassium bromide, 5 mm.

POTASSIUM BROMIDE (KBr)



Extinction coefficient versus wavelength
of potassium bromide.

AgGaS₂

STRUCTURE

CRYSTALLINE

SYMMETRY = Tetragonal, $\bar{4}2m$ (chalcopyrite)

LATTICE CONSTANTS (Å) =
a = 5.757
c = 10.305

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 241.71

DENSITY (g/cm³) = 4.72

SOLUBILITY IN WATER (g/100g of H₂O) = --

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 1100

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = --

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = --

SPECIFIC HEAT (cal/g)/°K = --

MECHANICAL PROPERTIES

YOUNGS MODULUS = --

HARDNESS = --

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = --

RESISTIVITY = --

BAND GAP ENERGY (eV) = 2.75

EFFECTIVE MASS =

MOBILITY =

AgGaS₂

OPTICAL PROPERTIES

TRANSMISSION RANGE: 5 to 12 μm

SECOND HARMONIC COEFFICIENTS (10^{12} m/v)

$$d_{36} = (18 \pm 5.4) \quad \text{at } 10.6 \mu\text{m} \quad (\text{Reference 1})$$

$$d_{14} = (56.5 \pm 19) \quad \text{at } 10.6 \mu\text{m} \quad (\text{Reference 2})$$

References:

1. G.D. Boyd, H. Kasper, and J.H. McFee, IEEE J. Quant El. QE7, 563 (1971).
2. D.S. Chemlas, P. Kupecek, D.S. Robertson, and R.C. Smith, Opt. Communications 3, 29 (1971).
3. G.C. Bhar and R.C. Smith, Phys. Stat. Sol. A13, 157 (1972).

AgGaS₂

AgGaS₂
REFRACTIVE INDEX¹ OF AgGaS₂ versus WAVELENGTH (μm)

λ μm	ν = λ ⁻¹ μm ⁻¹	n ^o	n ^e	n ^e - n ^o
.4900	2.0408	2.7148	2.7287	.0138
.5000	2.0000	2.6916	2.6867	-.0049
.5250	1.9048	2.6303	2.6239	-.0264
.5500	1.8182	2.6190	2.5834	-.0356
.5750	1.7391	2.5944	2.5537	-.0407
.6000	1.6667	2.5748	2.5303	-.0444
.6250	1.6000	2.5577	2.5116	-.0461
.6500	1.5385	2.5437	2.4961	-.0476
.6750	1.4815	2.5310	2.4824	-.0486
.7000	1.4286	2.5205	2.4706	-.0499
.7500	1.3333	2.5049	2.4540	-.0509
.8000	1.2500	2.4909	2.4395	-.0514
.8500	1.1765	2.4802	2.4279	-.0522
.9000	1.1111	2.4716	2.4192	-.0525
.9500	1.0526	2.4644	2.4118	-.0526
1.0000	1.0000	2.4582	2.4053	-.0529
1.1000	.9091	2.4486	2.3954	-.0532
1.2000	.8333	2.4414	2.3881	-.0533
1.3000	.7692	2.4359	2.3819	-.0540
1.4000	.7143	2.4315	2.3781	-.0534
1.5000	.6667	2.4280	2.3745	-.0535
1.6000	.6250	2.4252	2.3716	-.0535
1.8000	.5556	2.4206	2.3670	-.0536
2.0000	.5000	2.4164	2.3637	-.0527
2.2000	.4545	2.4142	2.3604	-.0537
2.4000	.4167	2.4119	2.3583	-.0535
2.6000	.3846	2.4102	2.3567	-.0535
2.8000	.3571	2.4094	2.3559	-.0535
3.0000	.3333	2.4080	2.3545	-.0535
3.2000	.3125	2.4068	2.3534	-.0534
3.4000	.2941	2.4062	2.3522	-.0545
3.6000	.2778	2.4046	2.3511	-.0535
3.8000	.2632	2.4024	2.3491	-.0535
4.0000	.2500	2.4024	2.3488	-.0536
4.5000	.2222	2.4003	2.3461	-.0542
5.0000	.2000	2.3955	2.3419	-.0536
5.5000	.1818	2.3938	2.3401	-.0537
6.0000	.1667	2.3908	2.3369	-.0539
6.5000	.1538	2.3874	2.3334	-.0540
7.0000	.1429	2.3827	2.3291	-.0536
7.5000	.1333	2.3787	2.3252	-.0535
8.0000	.1250	2.3757	2.3219	-.0538
8.5000	.1176	2.3699	2.3163	-.0536
9.0000	.1111	2.3663	2.3121	-.0542

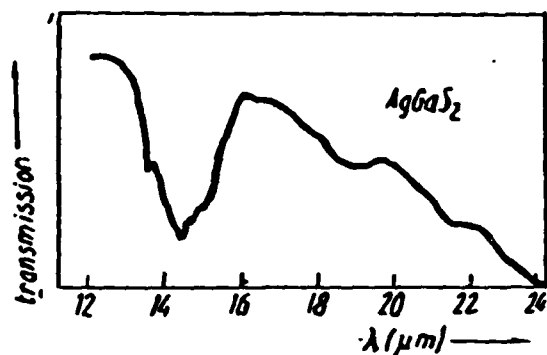
AgGaS₂

AgGaS₂
REFRACTIVE INDEX¹ OF AgGaS₂ versus WAVELENGTH (μm) (Continued)

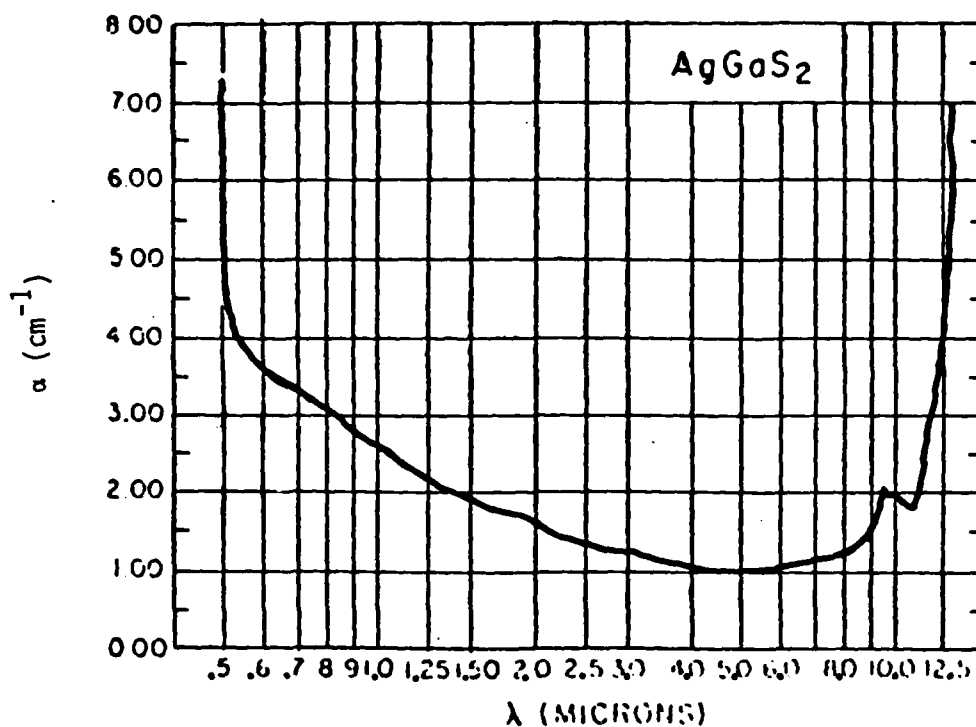
λ μm	$\nu = \lambda^{-1}$ μm ⁻¹	n^o	n^e	$n^e - n^o$
9.5000	.1053	2.3606	2.3064	-.0542
10.0000	.1000	2.3548	2.3012	-.0536
10.5000	.0952	2.3486	2.2948	-.0538
11.0000	.0909	2.3417	2.2880	-.0537
11.5000	.0870	2.3329	2.2789	-.0540
12.0000	.0833	2.3266	2.2716	-.0550
12.5000	.0800	2.3177		
13.0000	.0769	2.3076		

Prism angle A = 29.2755°. Birefringence B = $n^e - n^o$. All index values are actual data points.

AgGaS₂



Transmission of AgGaS₂ versus wavelength².



Room temperature absorption coefficient $\alpha(\text{cm}^{-1})$ versus wavelength for AgGaS₂ as determined from a sample of thickness 0.226 cm. Because of cracks and voids the minimum value of 1.0 cm^{-1} at $\lambda = 5 \mu\text{m}$ is unreliable. Relative values of α are of greater significance³.

AgGaSe₂

STRUCTURE

CRYSTALLINE

SYMMETRY	=	Tetragonal, $\bar{4}2m$ (chalcopyrite)
LATTICE CONSTANTS (Å)	=	a = 5.985 c = 10.90

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	335.51
DENSITY (g/cm ³)	=	5.84
SOLUBILITY IN WATER (g/100g of H ₂ O)	=	---

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	---
LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	---
THERMAL CONDUCTIVITY (cal/cm·sec·°K)	=	---
SPECIFIC HEAT (cal/g)/°K	=	---

MECHANICAL PROPERTIES

YOUNGS MODULUS	=	---
HARDNESS	=	---

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT	=	---
RESISTIVITY	=	---
BAND GAP ENERGY (eV)	=	1.66
EFFECTIVE MASS	=	---
MOBILITY	=	---

AgGaSe₂

OPTICAL PROPERTIES

TRANSMISSION RANGE: 7 - 20 μm

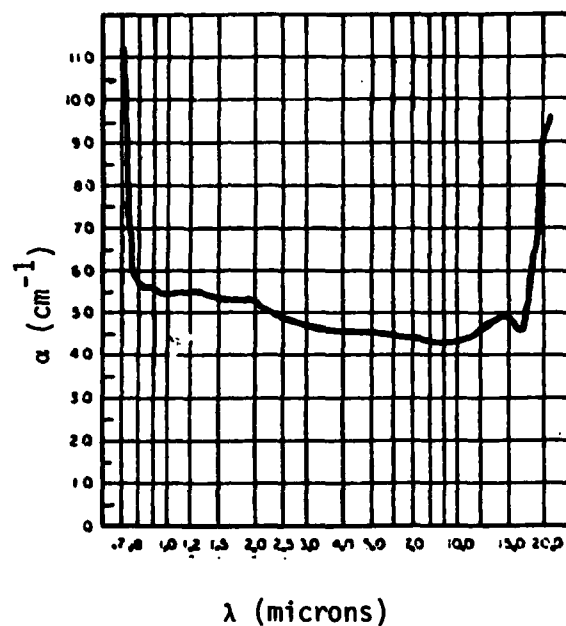
SECOND HARMONIC COEFFICIENTS

$$d_{36} = (3.74 \pm 0.6) \times 10^{11} \text{ m/v} \quad \text{at } 10.6 \mu\text{m} \text{ (Reference 1)}$$

$$d_{36} = 33 \times 10^{12} \text{ m/v} \quad \text{at } 10.6 \mu\text{m} \text{ (Reference 2)}$$

References:

1. R.L. Byer, M.M. Choy, R.L. Herbst, D.S. Chemla and R.S. Feigelson, Appl. Phys. Lett. 24, 65 (1974).
2. G.D. Boyd, H.M. Casper, J.H. McFee and F. Storg, IEEE J. Quant. El. QE8, 900 (1972).



Room temperature absorption coefficient versus wavelength for AgGaSe₂ as determined from a sample of 0.208 cm thickness. Because of the presence of imperfections in the sample, the minimum value of 4.4 cm⁻¹ at $\lambda = 8.5 \mu\text{m}$ is not characteristic of AgGaSe₂. However, relative values of α have meaning¹.

SODIUM CHLORIDE (HALITE, ROCKSALT)

NaCl

STRUCTURE

CRYSTALLINE

SYMMETRY	=	Cubic, Fm3m
LATTICE CONSTANTS (Å)	=	a = 5.6402 ± 0.0002

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	58.45
------------------	---	-------

DENSITY	=	2.164
---------	---	-------

SOLUBILITY IN WATER (g/100g of H ₂ O)	=	35.7
--	---	------

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	1090
------------------------------------	---	------

LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	44 × 10 ⁻⁶
--	---	-----------------------

THERMAL CONDUCTIVITY (cal/cm·sec·°K)	=	155 × 10 ⁻⁵
--------------------------------------	---	------------------------

SPECIFIC HEAT (cal/g)/°K	=	0.204
--------------------------	---	-------

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI)	=	5.8 × 10 ⁻⁶
----------------------	---	------------------------

HARDNESS (Knoop)	=	17
------------------	---	----

ELASTIC CONSTANTS (bars)	=	C ₁₁ =4.85, C ₁₂ =1.23, C ₄₄ =1.26
--------------------------	---	---

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT	=	5.9 (100 - 2.5 × 10 ¹⁰ Hz)
---------------------	---	---------------------------------------

RESISTIVITY	=	---
-------------	---	-----

BAND GAP ENERGY	=	---
-----------------	---	-----

EFFECTIVE MASS	=	---
----------------	---	-----

MOBILITY	=	---
----------	---	-----

SODIUM CHLORIDE (NaCl)

References:

1. A. Smakula; Einkristalle, Springer-Verlag, Berlin, p. 384 (1962).
2. D.E. McCarthy, Appl. Opt. 2, 591 (1963).
3. J.C. Owens, Phys. Rev. 181, 1228 (1969).

SODIUM CHLORIDE (NaCl)

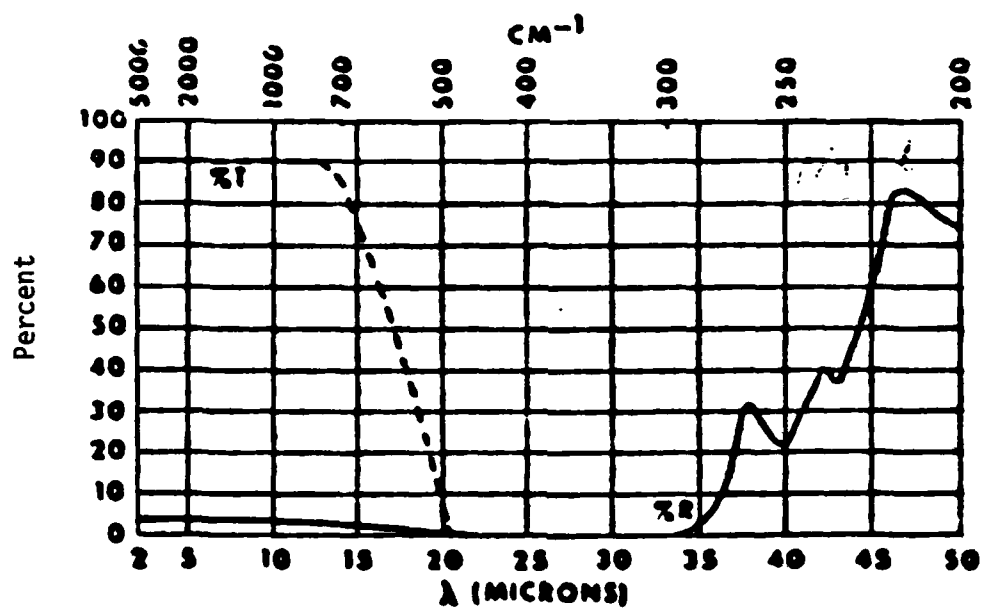
SODIUM CHLORIDE (NaCl)

Refractive Index of Sodium Chloride

(from 0.199 - 22.30 μ m at 20°C; from 22.8 - 27.3 μ m at 18°C)¹

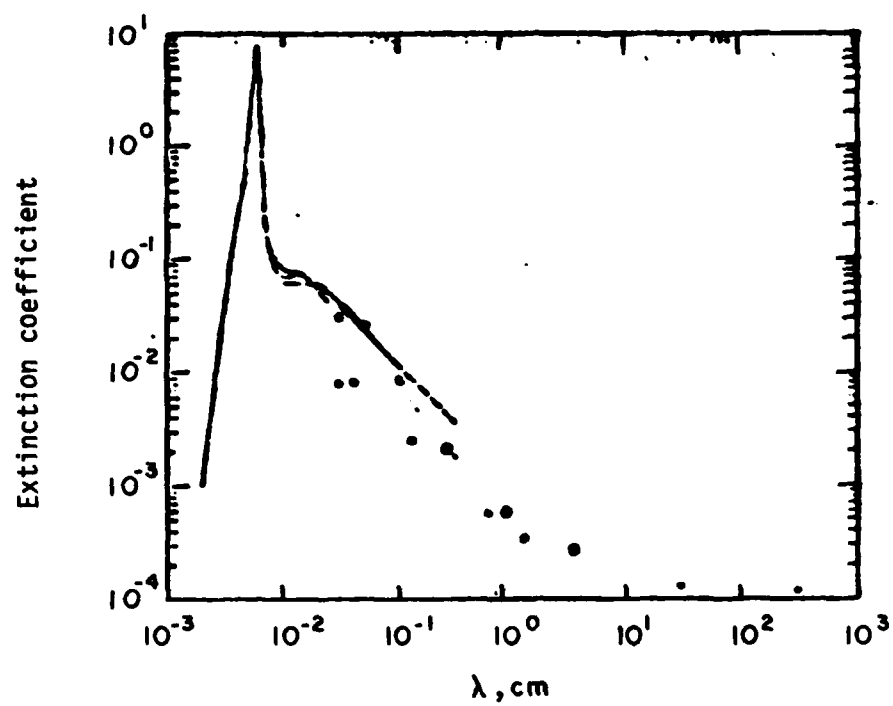
λ_{μ}	n	λ_{μ}	n	λ_{μ}	n
0.199	1.7963	0.587	1.54428	7.072	1.51109
0.214	1.7355	0.589	1.54416	7.661	1.508268
0.225	1.7038	0.656	1.54052	7.956	1.516765
0.240	1.6721	0.707	1.53851	8.840	1.512006
0.248	1.65878	0.728	1.53777	10.02	1.494701
0.254	1.65112	0.768	1.53654	11.79	1.481823
0.265	1.63680	0.811	1.53547	12.97	1.471743
0.270	1.63202	0.843	1.53476	14.14	1.460572
0.280	1.62214	0.912	1.53346	14.73	1.454459
0.289	1.61470	1.014	1.53191	15.32	1.447499
0.297	1.60943	1.083	1.53116	15.91	1.441108
0.302	1.60578	1.179	1.530305	17.93	1.4149
0.313	1.59915	1.768	1.527374	20.57	1.3735
0.334	1.58874	2.357	1.525799	22.30	1.3403
0.366	1.57684	2.947	1.524471	22.8	1.318
0.390	1.56996	3.536	1.523109	23.6	1.299
0.405	1.56660	4.125	1.521584	24.2	1.278
0.436	1.56050	5.009	1.518919	25.0	1.254
0.486	1.55327	5.893	1.515952	25.8	1.229
0.546	1.54730	6.483	1.513663	26.6	1.203
				27.3	1.175

SODIUM CHLORIDE (NaCl)



Transmittance and reflectance of NaCl (5 mm thickness) versus wavelength².

SODIUM CHLORIDE (NaCl)



Extinction coefficient of NaCl at 25°C versus wavelength³.

SODIUM FLUORIDE (Villiaumite)

NaF

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, Fm3m

LATTICE CONSTANTS (Å) = $a = 4.64$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 42

DENSITY (g/cm³) = 2.79

SOLUBILITY IN WATER (g/100g of H₂O) = 4.22

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 1270

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = 36×10^{-6}

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = 505×10^{-4}

SPECIFIC HEAT (cal/g)/°K = 0.26

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI) = 1.41×10^7

HARDNESS (Knoop) = 60

ELASTIC CONSTANTS (bars) = $C_{11}=9.09, C_{12}=2.64, C_{44}=1.27$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = 6.0 at 2×10^6 Hz

RESISTIVITY = ---

BAND GAP ENERGY = ---

EFFECTIVE MASS = ---

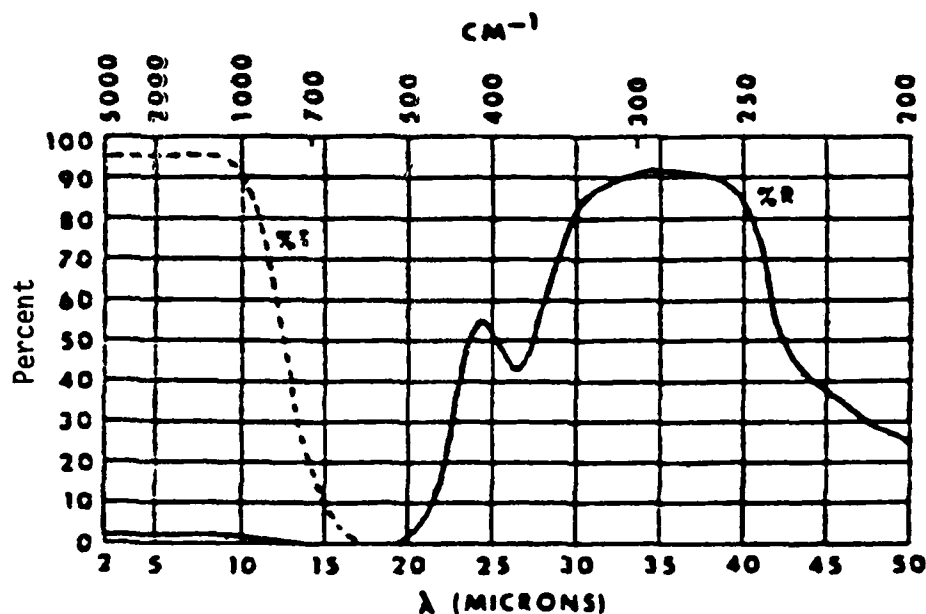
MOBILITY = ---

SODIUM FLUORIDE (NaF)

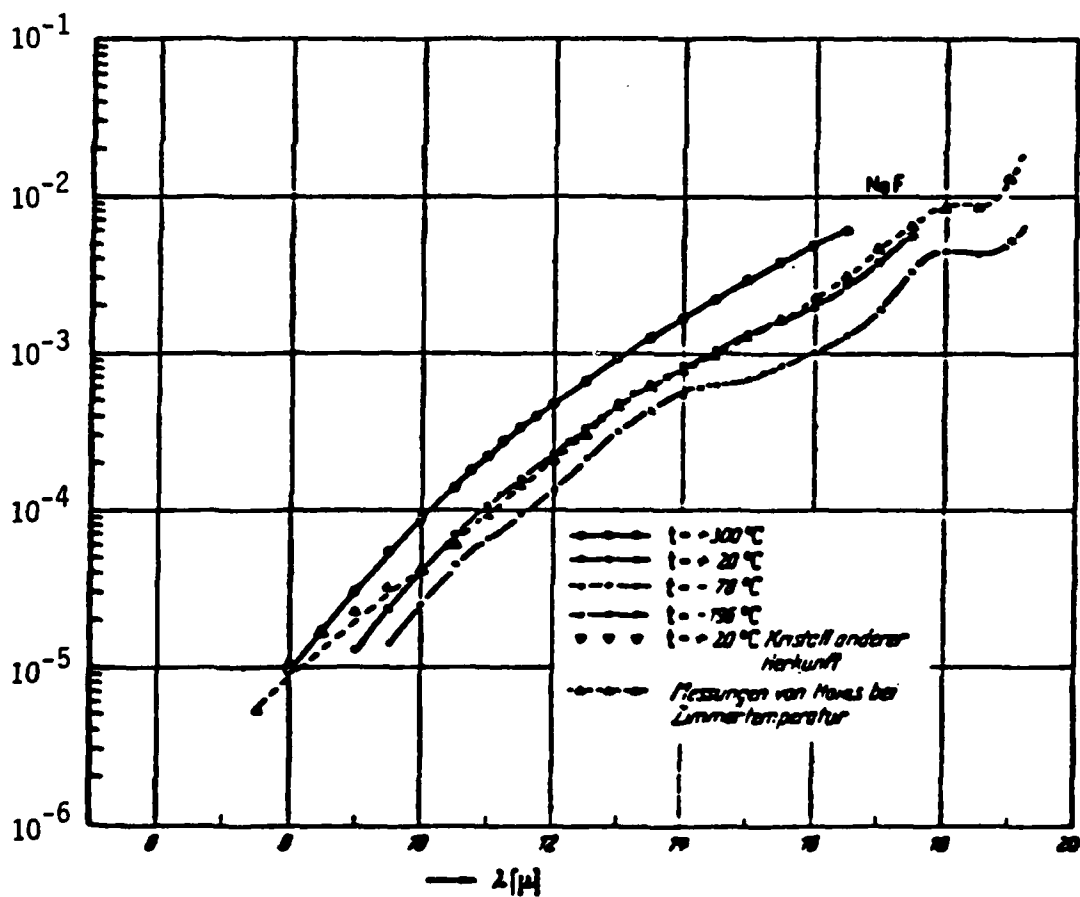
References:

1. D.E. McCarthy, Appl. Opt. 4, 317 (1965).
2. M. Klier, Z. Physik. 150, 49 (1958).
3. A. Smakula, Opt. Acta. 9, 205 (1962).

SODIUM FLUORIDE (NaF)

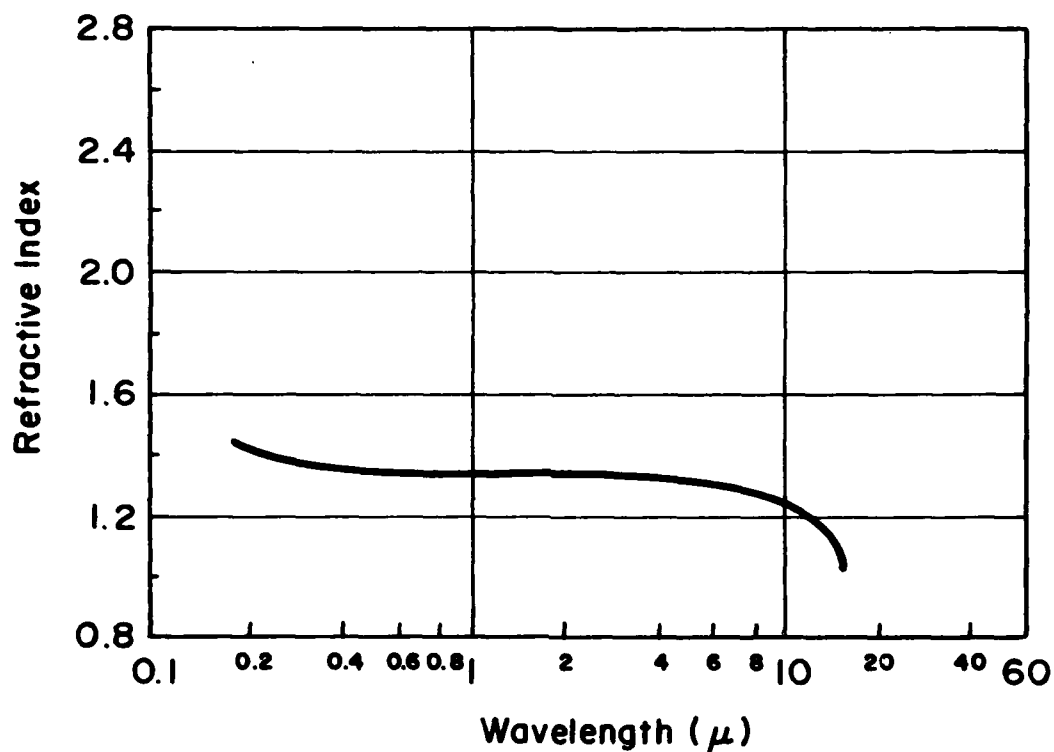


Transmittance and reflectance of NaF (2.16 mm thickness) versus wavelength¹.

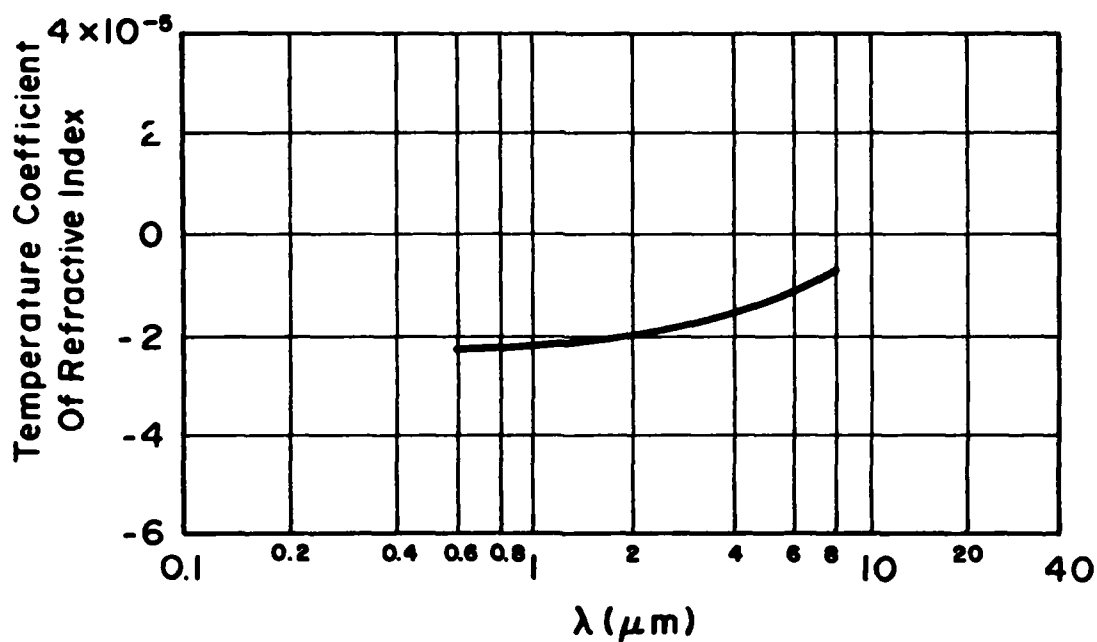


Extinction coefficient of NaF versus wavelength².

SODIUM FLUORIDE (NaF)



Refractive index of NaF versus wavelength³.



Temperature coefficient of refractive index of NaF versus wavelength³.

TELLURIUM

Te

STRUCTURE

CRYSTALLINE

SYMMETRY	=	32
LATTICE CONSTANTS (Å)	=	a = 4.559 c = 5.9268

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	127.60
DENSITY (g/cm ³)	=	6.25
SOLUBILITY IN WATER (g/100g of H ₂ O)	=	<0.005

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	725
LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	(-1.7, 27) × 10 ⁻⁶ (//, ⊥ c-axis)
THERMAL CONDUCTIVITY (cal/cm·sec·°K)	=	1.5 × 10 ⁻²
SPECIFIC HEAT (cal/g)/°K	=	0.048

MECHANICAL PROPERTIES

YOUNGS MODULUS	=	N/A
HARDNESS	=	18.4
ELASTIC CONSTANTS (bars)	=	C ₁₁ = 3.265, C ₁₂ = 0.195, C ₁₃ = 2.493 C ₃₃ = 7.22, C ₄₄ = 3.121

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT	=	5 (// c-axis) 2 (⊥ c-axis)
RESISTIVITY	=	N/A
BAND GAP ENERGY	=	0.33
EFFECTIVE MASS m _e [*]	=	0.038 m ₀
MOBILITY μ _e (cm ² /v-sec)	=	1,100

TELLURIUM (Te)

OPTICAL PROPERTIES

TRANSMISSION RANGE: 5 - 20 μm

DISPERSION EQUATION: ---

ACOUSTO-OPTIC PROPERTIES

ACOUSTIC VIBRATION POLARIZATION DIRECTION = Longitudinal (Reference 1)

ACOUSTIC VELOCITY (km/s) = 2.2

LIGHT VIBRATION POLARIZATION DIRECTION = Parallel

FIGURE OF MERIT ($M_2 \mp v^6 p^2 / \rho v^3$) = 2920

ACOUSTIC ATTENUATION (dB/cm) at 550 MHz = 45

SECOND HARMONIC COEFFICIENTS (10^{-12} m/v)

d_{11}	=	5319.87 $\pm$ 837.7	at λ = 10.6	(Reference 2)
	=	4188 $\pm$ 2094.4	at λ = 10.6	(Reference 3)
	=	3351.03	at λ = 10.6	(Reference 4)
	=	5864.3	at λ = 10.6	(Reference 5)
	=	1549.8 $\pm$ 387.5	at λ = 10.6	(Reference 6)
	=	921.5 $\pm$ 293.2	at λ = 10.6	(Reference 7)

TELLURIUM (Te)

References:

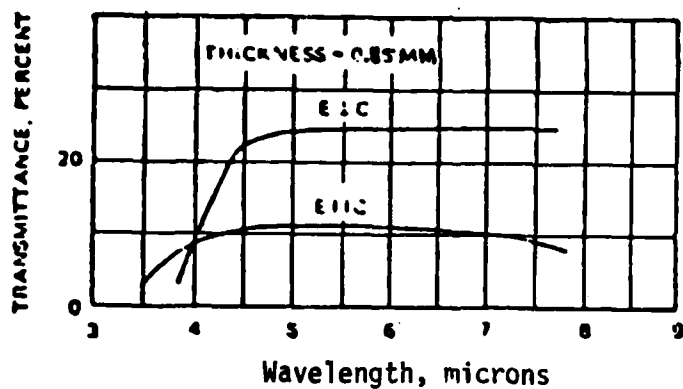
1. R.W. Dixon and A.N. Chester, Appl. Phys. Lett. 9, 190 (1966).
2. C.K.N. Patel, Phys. Rev. Lett. 16, 613 (1966).
3. J. Jerphagnon, E. Batifol et M. Sourbe. C.R. Acad. Su Paris 263, 1067 (1966).
4. N. Van Tran, L'Onde Electrique, 48, 965 (1967).
5. J. Jerphagnon, Ann. Telecomm. 23, 203 (1968).
6. J.J. Wynne and N. Bloembergen, Phys. Rev. 188, 1211 (1969).
7. J.H. McFee, G.D. Boyd and P.H. Schmidt, Appl. Phys. Lett. 17, 57 (1970).
8. R.S. Caldwell, Contract No. DA36-039-SC-71131, Purdue University, Dept. of Physics (1958).
9. P. Billard, Acta Electronica, 6, 75 (1962).
10. P. Grosse et al., Solid State Comm. 5, 99 (1967).
11. H.Y. Fan, Reports in Progress in Physics.

TELLURIUM (Te)

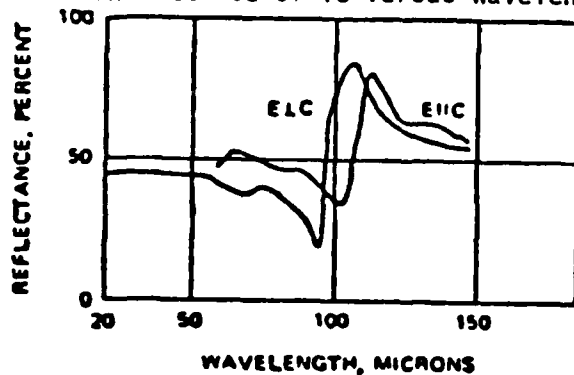
TELLURIUM (Te)
Refractive Indices at Room Temperature⁸

Wavelength (μm)	n_o	n_e
4.0	6.372	4.929
5.0	6.316	4.864
6.0	6.286	4.838
7.0	6.270	4.821
8.0	6.257	4.809
9.0	6.253	4.802
10.0	6.246	4.796
12.0	6.237	4.789
14.0	6.230	4.785

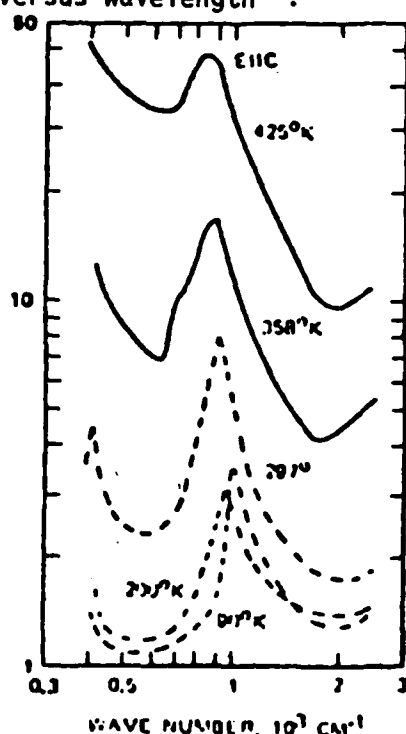
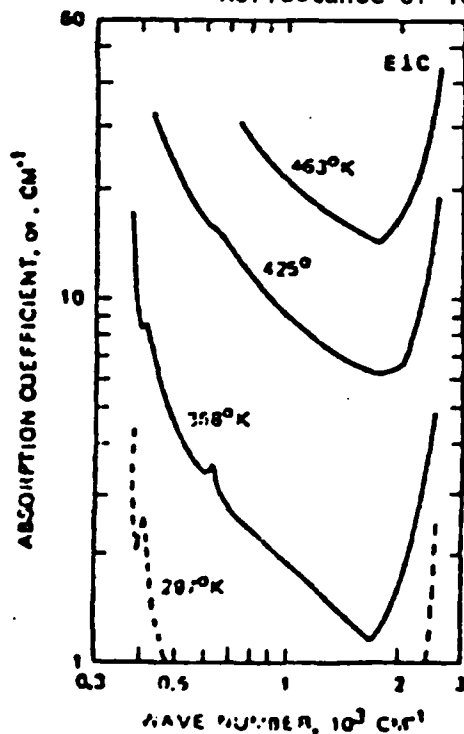
TELLURIUM (Te)



Transmittance of Te versus wavelength⁹.



Reflectance of Te versus wavelength¹⁰.



WAVELENGTH, MICRONS

Absorption coefficient of Te versus wavelength¹¹.

Tl₃AsS₄

STRUCTURE

CRYSTALLINE	=	Orthorhombic
SYMMETRY	=	---
LATTICE CONSTANTS (Å)	=	a = 8.98, b = 10.8, c = 8.86

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	818.4
DENSITY	=	6.2 ± 0.4
SOLUBILITY IN WATER (g/100g of H ₂ O)	=	Not Available

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	Not Available
LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	Not Available
THERMAL CONDUCTIVITY (cal/cm·sec·°K)	=	Not Available
SPECIFIC HEAT (cal/g)/°K	=	Not Available

MECHANICAL PROPERTIES

YOUNGS MODULUS	=	---
HARDNESS Microhardness (Moh)	=	2.8

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT	=	Not Available
RESISTIVITY	=	Not Available
BAND GAP ENERGY	=	Not Available
EFFECTIVE MASS	=	Not Available
MOBILITY	=	Not Available

Tl₃AsS₄

OPTICAL PROPERTIES

TRANSMISSION RANGE¹: .6 - 12 μ m

DISPERSION EQUATION: ---

ACOUSTO-OPTIC PROPERTIES

ACOUSTIC VIBRATION POLARIZATION DIRECTION = ? (Reference 1)

ACOUSTIC VELOCITY (km/s) = 2.0

LIGHT VIBRATION POLARIZATION DIRECTION = --

FIGURE OF MERIT ($M_2 = n^6 p^2 / \rho v^3$) = 332

ACOUSTIC ATTENUATION (dB/cm) at 500 MHz = 1

LONGITUDINAL WAVE = Parallel

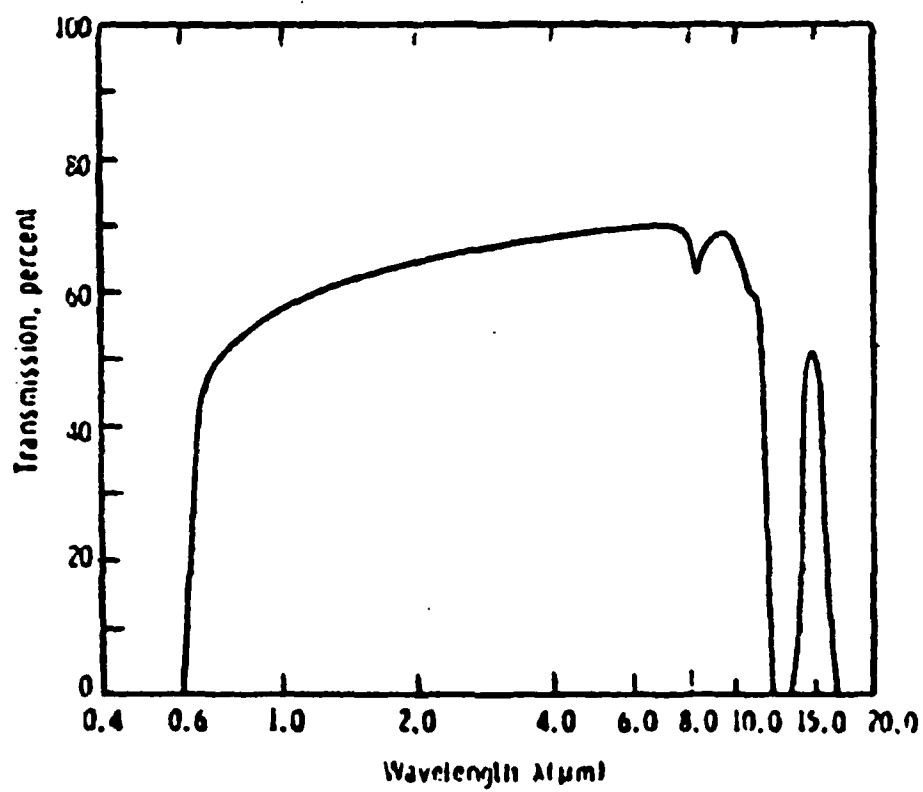
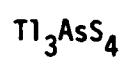
References:

1. G.W. Roland, M. Gottlieb, and J.D. Feichtner, Appl. Phys. Lett. 21, 52 (1972).

Tl₃AsS₄

Measured Refractive Indices of Tl₃AsS₄ (n_i is the refractive index for light polarized // to i axis).¹

Wavelength (μm)	n_a	n_b	n_c
0.6328	2.829	2.774	2.825
0.6943	2.772	2.721	2.770
0.7490	2.738	....	....
0.8250	2.704	....	....
1.06	2.646	2.598	2.642
1.15	2.634	2.580	2.626
1.553	2.603	2.566	2.599
3.38	2.567	2.525	2.569
4.35	2.563	2.521	2.566
4.47	2.560	2.518	2.563
5.26	2.557	2.513	2.558
5.3	2.556	2.513	2.560
10.6	2.542	2.498	2.541



Optical transmission of Ti_3AsS_4 in the 0.6-20 μm region. Sample thickness 0.22 cm. Curve uncorrected for reflection losses¹.

Tl₃AsSe₃

STRUCTURE

CRYSTALLINE

SYMMETRY	=	Trigonal, 3m
LATTICE CONSTANTS (Å)	=	a = 9.80 c = 7.08

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	920.3
DENSITY (g/cm ³)	=	7.832
SOLUBILITY IN WATER (g/100g of H ₂ O)	=	---

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	---
LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	---
THERMAL CONDUCTIVITY (cal/cm·sec·°K)	=	---
SPECIFIC HEAT (cal/g)/°K	=	---

MECHANICAL PROPERTIES

YOUNGS MODULUS	=	---
HARDNESS (Moh)	=	2 - 3

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT	=	---
RESISTIVITY	=	---
BAND GAP ENERGY	=	---
EFFECTIVE MASS	=	---
MOBILITY	=	---



OPTICAL PROPERTIES

TRANSMISSION RANGE: 1.2 - 18 μm

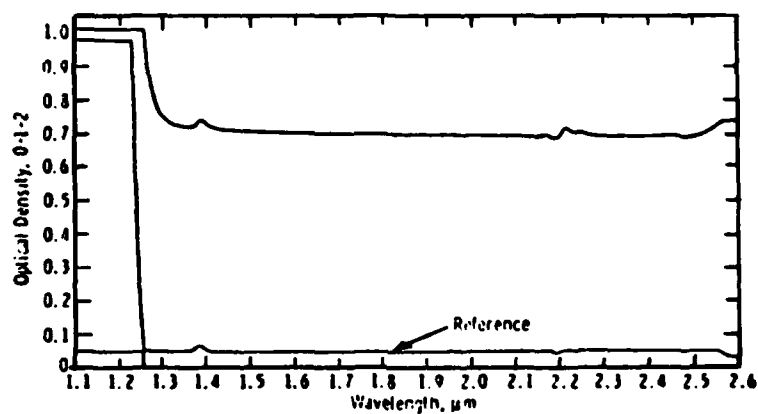
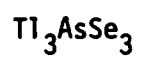
References:

1. J.D. Feichtner and G.W. Roland, Appl. Opt. 11, 993 (1972).
2. R.L. Byer, Ann. Rev. Nat. Sci. 4, 147 (1974).

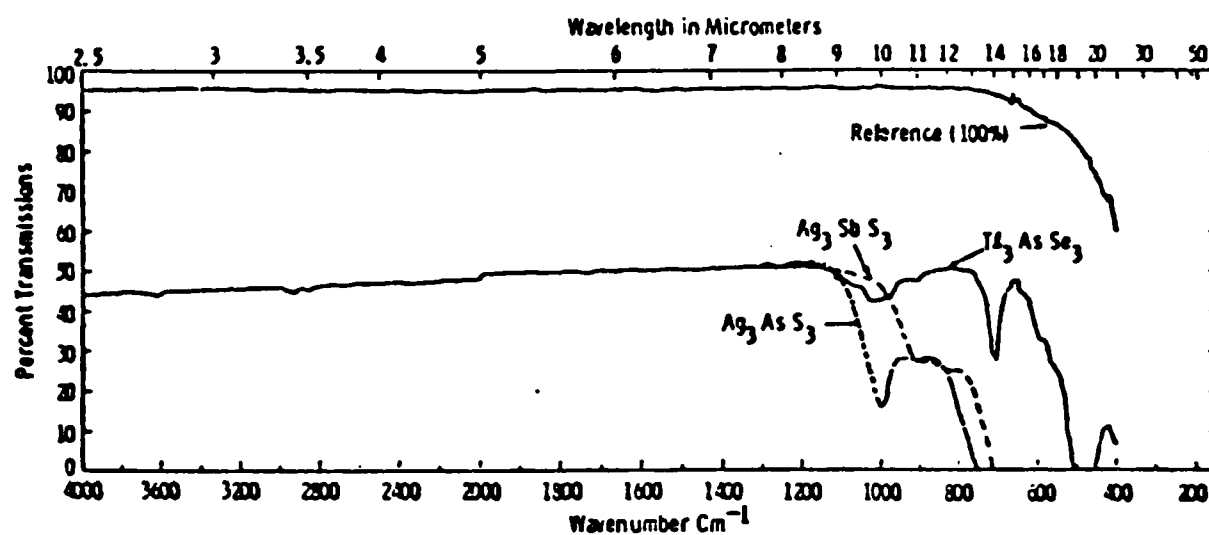
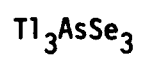
Tl₃AsSe₃

Tl₃AsSe₃
Measured Refractive Indices of Tl₃AsSe₃ versus Wavelength¹.

Wavelength (μm)	n _o	n _e
1.553 ± 0.03	3.443	3.248
2.66 ± 0.05	3.356	3.170
3.29 ± 0.1	3.339	3.152
3.365 ± 0.065	3.337	3.155
3.38 ± 0.16	3.339	3.152
4.35 ± 0.09	3.332	3.148
4.46 ± 0.17	3.334	3.142
4.55 ± 0.2	3.326	3.142
5.26 ± 0.3	3.321	3.141
5.3 ± 0.1	3.326	3.142



Optical density of Ti_3AsSe_3 in the 1.1 - 2.6 μm region. Sample thickness 0.545 cm. Curve uncorrected for reflection losses¹.



Comparison of optical transmissions of Ag_3AsS_3 , Ag_3SbS_3 and Ti_3AsSe_3 versus wavelength¹.

Tl₃PSe₄

STRUCTURE

CRYSTALLINE	=	Orthorhombic
SYMMETRY	=	---
LATTICE CONSTANTS (Å)	=	a = 9.27 ± 0.005 b = 11.047 ± 0.005 c = 9.059 ± 0.005

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	962.93
DENSITY (g/cm ³)	=	6.31
SOLUBILITY IN WATER (g/100g of H ₂ O)	=	Not Available

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	609
LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	Not Available
THERMAL CONDUCTIVITY (cal/cm·sec·°K)	=	Not Available
SPECIFIC HEAT (cal/g)/°K	=	---

MECHANICAL PROPERTIES

YOUNGS MODULUS	=	---
HARDNESS Microhardness (Moh)	=	2.5 - 3

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT	=	---
RESISTIVITY	=	---
BAND GAP ENERGY	=	---
EFFECTIVE MASS	=	---
MOBILITY	=	---

Tl₃PSe₄

OPTICAL PROPERTIES

TRANSMISSION RANGE: 0.85 - 20 μ m

DISPERSION EQUATION: --

ACOUSTO-OPTIC PROPERTIES

ACOUSTIC VIBRATION POLARIZATION DIRECTION = Parallel

ACOUSTIC VELOCITY (km/s) = 2.0

LIGHT VIBRATION POLARIZATION DIRECTION = ---

FIGURE OF MERIT ($M_2 = n^6 p^2 / \rho v^3$) = 1370

ACOUSTIC ATTENUATION (dB/cm at 500 MHz) =

ULTRASONIC ATTENUATION (db/ μ sec at 500 MHz) = 1

References:

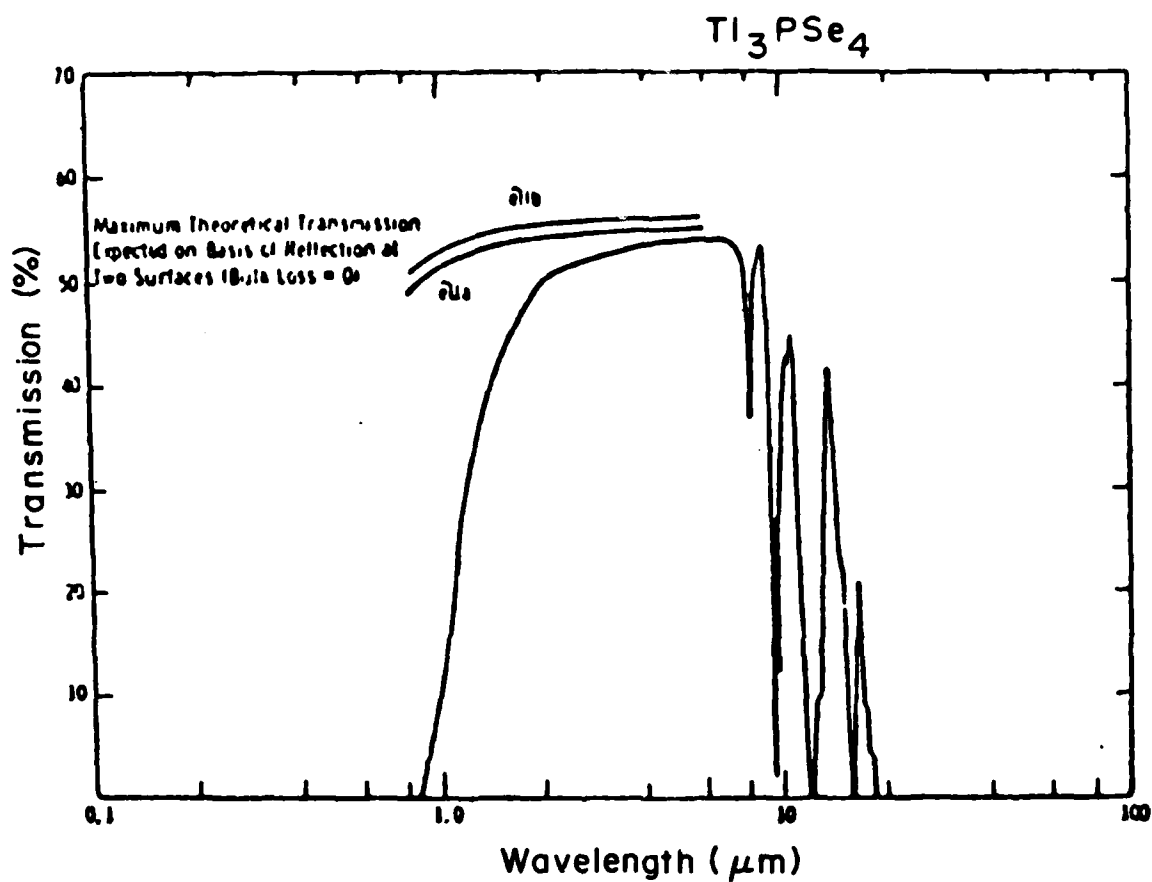
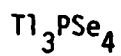
1. T.J. Isaacs, M. Gottlieb, and J.D. Feichtner, Appl. Phys. Lett. 24 107 (1974).

Tl₃PSe₄

Tl₃PSe₄

Measured refractive indices of Tl₃PSe₄ (n_a is refractive index for light polarized perpendicular to the a axis, where a, b, and c are the crystallographically defined axes such that a=9.270, b=11.047, c=9.059 Å)¹.

Wavelength (μm)	Refractive index		
	n_a	n_b	n_c
0.749	3.088	3.027	3.056
0.825	3.028	2.967	3.000
1.06	2.933	2.870	2.904
1.15	2.916	2.857	2.883
1.553	2.865	2.807	2.839
2.66	2.834	2.773	2.808
3.29	2.826	2.768	2.799
3.365	2.825	2.765	2.798
3.38	2.824	2.765	2.798
4.35	2.820	2.760	2.795
4.46	2.817	2.758	2.792
5.26	2.815	2.756	2.791



Optical transmission of Ti_3PSe_4 (Sample Thickness: 0.38 cm)¹.

TlBr-TlCl (KRS-6)

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic

LATTICE CONSTANTS =

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = N/A

DENSITY = 7.192

SOLUBILITY IN WATER (g/100g of H₂O) = 0.32

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K) = 697

LINEAR EXPANSION COEFFICIENT (°K⁻¹) = 50×10^{-6}

THERMAL CONDUCTIVITY (cal/cm·sec·°K) = 17.1×10^{-4}

SPECIFIC HEAT (cal/g)/°K = 0.0482

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI) = 3×10^6

HARDNESS (Knoop) = 30 (500g load)

ELASTIC CONSTANTS (bars) = $C_{11}=3.85, C_{12}=1.49, C_{44}=0.737$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = 329 (at $100 - 10^5$ Hz)

RESISTIVITY = ---

BAND GAP ENERGY = ---

EFFECTIVE MASS = ---

MOBILITY = ---

TlBr-TlCl (KRS-6)

References:

1. G. Hetlner and G. Liesegang, Optik. 3, 305 (1968).
2. D.E. McCarthy, Appl. Opt. 4, 317 (1965).
3. R.A. Smith, F.E. Jones, R.P. Chasmar in The Detection and Measurement of Infrared Radiation, The Clarendon Press, Oxford, p. 369 (1957).

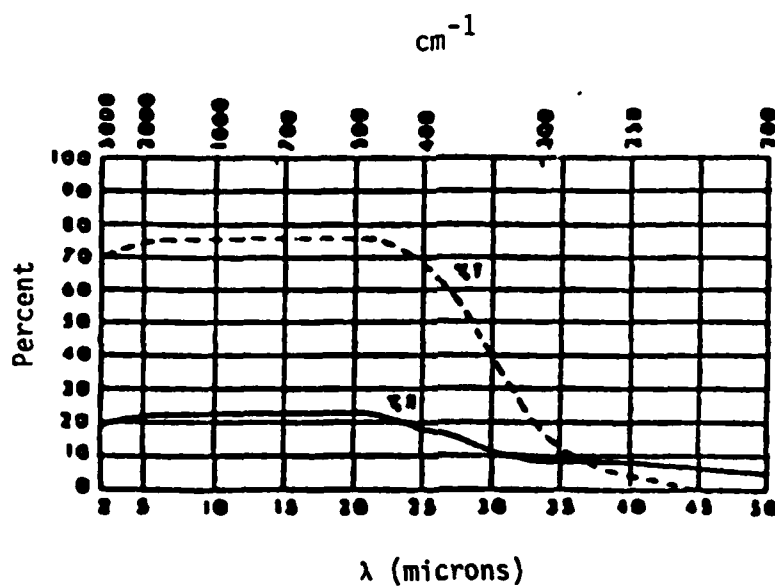
TlBr-TlCl (KRS-6)

KRS-6

Refractive Index of KRS-6 versus Wavelength¹

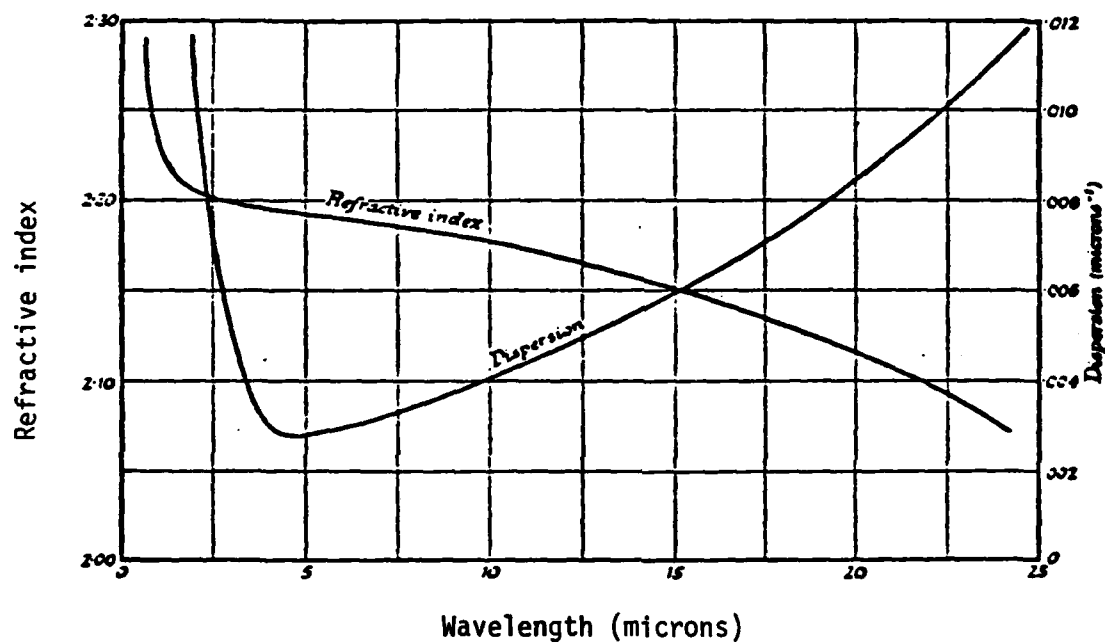
λ	μ	λ	μ
0.6	2.3294	4.5	2.1942
0.7	2.2892	5.0	2.1928
0.8	2.2660	6.0	2.1900
0.9	2.2510	7.0	2.1870
1.0	2.2404	8.0	2.1839
1.1	2.2321	9.0	2.1805
1.2	2.2255	10.0	2.1767
1.3	2.2212	11.0	2.1723
1.4	2.2176	12.0	2.1674
1.5	2.2148	13.0	2.1620
1.6	2.2124	14.0	2.1563
1.7	2.2103	15.0	2.1504
1.8	2.2086	16.0	2.1442
1.9	2.2071	17.0	2.1377
2.0	2.2059	18.0	2.1309
2.2	2.2039	19.0	2.1236
2.4	2.2024	20.0	2.1154
2.6	2.2016	21.0	2.1067
2.8	2.2001	22.0	2.0976
3.0	2.1990	23.0	2.0869
3.5	2.1972	24.0	2.0752
4.0	2.1956		

TlBr-TlCl (KRS-6)



Transmittance and reflectance of KRS-6 versus wavelength (sample thickness 1.65 mm)².

TlBr-TlCl (KRS-6)



Refractive index and dispersion of KRS-6 versus wavelength³.

TlBr-TlI (KRS-5)

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, $m\bar{3}m$

LATTICE CONSTANTS =

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = N/A

DENSITY (g/cm^3) = 7.371

SOLUBILITY IN WATER ($\text{g}/100\text{g}$ of H_2O) = 0.05

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE ($^{\circ}\text{K}$) = 688

LINEAR EXPANSION COEFFICIENT ($^{\circ}\text{K}^{-1}$) = 58×10^{-6}

THERMAL CONDUCTIVITY ($\text{cal}/\text{cm}\cdot\text{sec}\cdot^{\circ}\text{K}$) = 1.3×10^{-3}

SPECIFIC HEAT ($\text{cal}/\text{g}/^{\circ}\text{K}$) = N/A

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI) = 2.36×10^6

HARDNESS (Knoop) = 40.2

ELASTIC CONSTANTS (bars) = $C_{11}=3.31, C_{12}=1.32, C_{44}=0.579$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT = 32.9

RESISTIVITY = ---

BAND GAP ENERGY = ---

EFFECTIVE MASS = ---

MOBILITY = ---

TlBr-TlI (KRS-5)

OPTICAL PROPERTIES

DISPERSION EQUATION¹:

$$n^2 - 1 = \sum_i \frac{K_i \lambda^2}{\lambda^2 - \lambda_i^2}$$

where $K_1 = 1.829358$

$\lambda_1^2 = 0.0225$

$K_2 = 1.6675593$

$\lambda_2^2 = 0.0625$

$K_3 = 1.1210424$

$\lambda_3^2 = 0.1225$

$K_4 = 0.04513366$

$\lambda_4^2 = 0.2025$

$K_5 = 12.380234$

$\lambda_5^2 = 27089.737$

References:

1. W.S. Rodney and I.H. Maltison, J. Opt. Soc. Am. 46, 956 (1956).
2. D.E. McCarthy, Appl. Opt. 2, 591 (1968).
3. A. Smakula: "Harshaw Optical Crystals".

TlBr-TlI (KRS-5)

Computed refractive index of the 55 KRS-5 at 25° C
for regular wavelength intervals (λ = wavelength in μm)¹.

λ	n	λ	n	λ	n	λ	n
0.540	2.68059	5.60	2.37867	21.9	2.33251	31.0	2.28212
0.560	2.64959	5.80	2.37832	22.0	2.33206	31.1	2.28145
0.580	2.62390	6.00	2.37797	22.1	2.33161	31.2	2.28078
0.600	2.60221	6.20	2.37763	22.2	2.33116	31.3	2.28011
0.620	2.58261	6.40	2.37729	22.3	2.33070	31.4	2.27943
0.640	2.56748	6.60	2.37695	22.4	2.33025	31.5	2.27875
0.660	2.55337	6.80	2.37661	22.5	2.32979	31.6	2.27807
0.680	2.54092	7.00	2.37627	22.6	2.32933	31.7	2.27738
0.700	2.52986	7.20	2.37592	22.7	2.32887	31.8	2.27669
0.720	2.51998	7.40	2.37558	22.8	2.32840	31.9	2.27600
0.740	2.51110	7.60	2.37523	22.9	2.32793	32.0	2.27531
0.760	2.50309	7.80	2.37488	23.0	2.32746	32.1	2.27461
0.780	2.49583	8.00	2.37452	23.1	2.32699	32.2	2.27391
0.800	2.48922	8.20	2.37416	23.2	2.32652	32.3	2.27321
0.820	2.48313	8.40	2.37380	23.3	2.32604	32.4	2.27251
0.840	2.47766	8.60	2.37343	23.4	2.32556	32.5	2.27180
0.860	2.47258	8.80	2.37305	23.5	2.32508	32.6	2.27109
0.880	2.46790	9.00	2.37267	23.6	2.32460	32.7	2.27088
0.900	2.46358	9.20	2.37229	23.7	2.32411	32.8	2.26966
0.920	2.45958	9.40	2.37190	23.8	2.32362	32.9	2.26895
0.940	2.45587	9.60	2.37150	23.9	2.32313	33.0	2.26823
0.960	2.45242	9.80	2.37110	24.0	2.32264	33.1	2.26750
0.980	2.44920	10.0	2.37069	24.1	2.32215	33.2	2.26678
1.00	2.44620	10.2	2.37027	24.2	2.32165	33.3	2.26605
1.02	2.44339	10.4	2.36985	24.3	2.32115	33.4	2.26532
1.04	2.44076	10.6	2.36942	24.4	2.32065	33.5	2.26458
1.06	2.43830	10.8	2.36898	24.5	2.32014	33.6	2.26384
1.08	2.43598	11.0	2.36854	24.6	2.31964	33.7	2.26310
1.10	2.43380	11.2	2.36809	24.7	2.31913	33.8	2.26236
1.12	2.43175	11.4	2.36763	24.8	2.31861	33.9	2.26161
1.14	2.42981	11.6	2.36717	24.9	2.31810	34.0	2.26087
1.16	2.42798	11.8	2.36669	25.0	2.31758	34.1	2.26011
1.18	2.42625	12.0	2.36622	25.1	2.31707	34.2	2.25936
1.20	2.42462	12.2	2.36573	25.2	2.31655	34.3	2.25860
1.22	2.42307	12.4	2.36523	25.3	2.31602	34.4	2.25784
1.24	2.42159	12.6	2.36473	25.4	2.31550	34.5	2.25708
1.26	2.42020	12.8	2.36422	25.5	2.31497	34.6	2.25631
1.28	2.41887	13.0	2.36371	25.6	2.31444	34.7	2.25554
1.30	2.41760	13.2	2.36318	25.7	2.31391	34.8	2.25477
1.32	2.41640	13.4	2.36265	25.8	2.31337	34.9	2.25400
1.34	2.41525	13.6	2.36211	25.9	2.31283	35.0	2.25322
1.36	2.41416	13.8	2.36157	26.0	2.31229	35.1	2.25244
1.38	2.41312	14.0	2.36101	26.1	2.31175	35.2	2.25166
1.40	2.41212	14.2	2.36045	26.2	2.31121	35.3	2.25087
1.42	2.41117	14.4	2.35988	26.3	2.31066	35.4	2.25008
1.44	2.41025	14.6	2.35930	26.4	2.31011	35.5	2.24929
1.46	2.40938	14.8	2.35871	26.5	2.30956	35.6	2.24849

TIBr-TII (KRS-5)

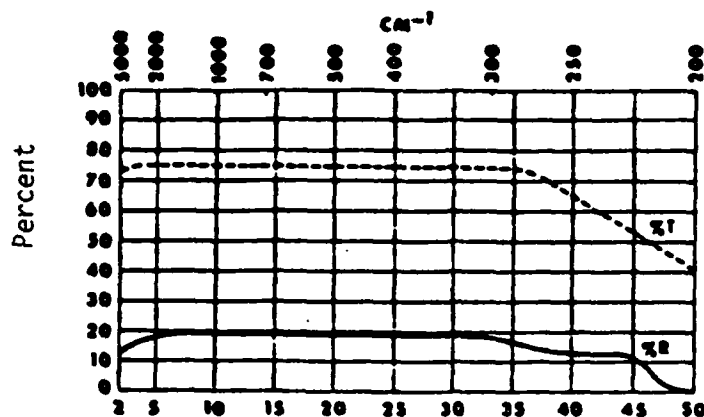
Computed refractive index of the 55 KRS-5 at 25° C
for regular wavelength intervals (λ = wavelength in μm)¹. (Continued)

λ	n	λ	n	λ	n	λ	n
1.48	2.40854	15.0	2.35812	26.6	2.30900	35.7	2.24769
1.50	2.40774	15.2	2.35751	26.7	2.30844	35.8	2.24689
1.52	2.40697	15.4	2.35690	26.8	2.30789	35.9	2.24609
1.54	2.40623	15.6	2.35629	26.9	2.30732	36.0	2.24528
1.56	2.40552	15.8	2.35566	27.0	2.30676	36.1	2.24447
1.58	2.40484	16.0	2.35502	27.1	2.30619	36.2	2.24366
1.60	2.40419	16.2	2.35438	27.2	2.30562	36.3	2.24284
1.62	2.40355	16.4	2.35373	27.3	2.30505	36.4	2.24202
1.64	2.40295	16.6	2.35307	27.4	2.30448	36.5	2.24120
1.66	2.40236	16.8	2.35240	27.5	2.30390	36.6	2.24038
1.68	2.40180	17.0	2.35173	27.6	2.30332	36.7	2.23955
1.70	2.40125	17.2	2.35104	27.7	2.30274	36.8	2.23872
1.72	2.40073	17.4	2.35035	27.8	2.30216	36.9	2.23788
1.74	2.40022	17.6	2.34965	27.9	2.30157	37.0	2.23705
1.76	2.39974	17.8	2.34894	28.0	2.30098	37.1	2.23621
1.78	2.39926	18.0	2.34822	28.1	2.30039	37.2	2.23516
1.80	2.39881	18.2	2.34750	28.2	2.29979	37.3	2.23452
1.82	2.39837	18.4	2.34676	28.3	2.29920	37.4	2.23367
1.84	2.39794	18.6	2.34602	28.4	2.29860	37.5	2.23281
1.86	2.39753	18.8	2.34527	28.5	2.29800	37.6	2.23196
1.88	2.39713	19.0	2.34451	28.6	2.29739	37.7	2.23110
1.90	2.39674	19.2	2.34374	28.7	2.29679	37.8	2.23024
1.92	2.39637	19.4	2.34296	29.8	2.29618	37.9	2.22937
1.94	2.39600	19.6	2.34217	28.9	2.29556	38.0	2.22850
1.96	2.39565	19.8	2.34138	29.0	2.29495	38.1	2.22763
1.98	2.39531	20.0	2.34058	29.1	2.29433	38.2	2.22676
2.00	2.39498	20.1	2.34017	29.2	2.29371	38.3	2.22588
2.20	2.39214	20.2	2.33976	29.3	2.29309	38.4	2.22500
2.40	2.38997	20.3	2.33935	29.4	2.29247	38.5	2.22412
2.60	2.38826	20.4	2.33894	29.5	2.29184	38.6	2.22323
2.80	2.38688	20.5	2.33853	29.6	2.29121	38.7	2.22234
3.00	2.38574	20.6	2.33811	29.7	2.29058	38.8	2.22145
3.20	2.38478	20.7	2.33770	29.8	2.28994	38.9	2.22055
3.40	2.38396	20.8	2.33727	29.9	2.28931	39.0	2.21965
3.60	2.38325	20.9	2.33685	30.0	2.28867	39.1	2.21875
3.80	2.38261	21.0	2.33643	30.1	2.28802	39.2	2.21784
4.00	2.38204	21.1	2.33600	30.2	2.28738	39.3	2.21693
4.20	2.38153	21.2	2.33557	30.3	2.28673	39.4	2.21602
4.40	2.38105	21.3	2.33514	30.4	2.28608	39.5	2.21510
4.60	2.38061	21.4	2.33471	30.5	2.28543	39.6	2.21418
4.80	2.38019	21.5	2.33427	30.6	2.28477	39.7	2.21326
5.00	2.37979	21.6	2.33383	30.7	2.28411	39.8	2.21233
5.20	2.37940	21.7	2.33339	30.8	2.28345	39.9	2.21140
5.40	2.37903	21.8	2.33295	30.9	2.28279	40.0	2.21047

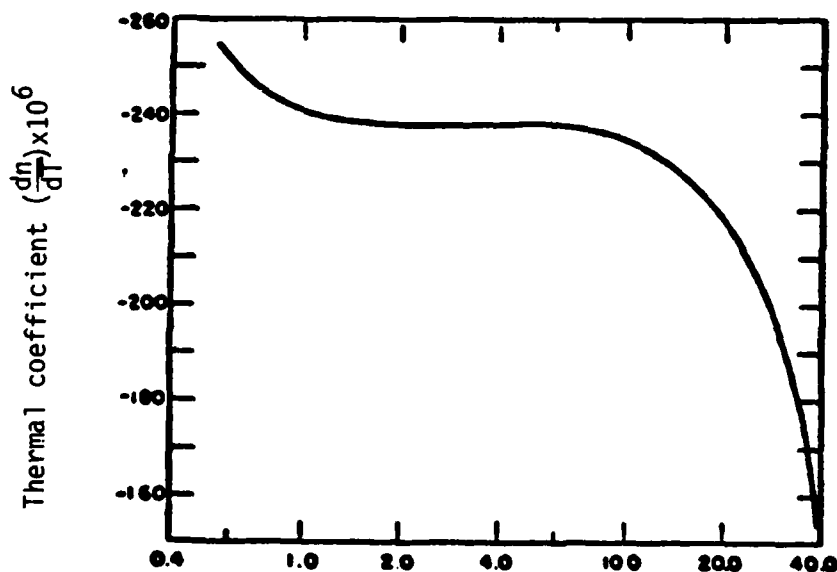
TlBr-TlI (KRS-5)

Average thermal coefficients of KRS-5 near
room temperature (λ = wavelength in μm)¹.

λ	$-\frac{dn}{dT} \times 10^4$	$-\frac{dn}{dT} \times 10^4$	$-\frac{dn}{dT} \times 10^4$
0.576960	254	11.035	233
0.579016	253	14.29	228
0.643857	249	14.98	227
0.69075	247	15.48	226
0.85212	242	17.40	223
0.89440	241	18.16	220
1.01398	240	20.57	216
1.12866	240	21.79	214
1.3673	238	22.76	212
1.3950	238	23.82	210
1.52952	238	25.16	207
1.6921	238	25.97	206
1.709136	238	26.63	202
1.8333	238	29.81	195
1.9701	238	31.70	188
2.3253	238	33.00	183
3.4188	237	34.48	177
4.258	237	37.56	165
6.692	237	39.38	154
9.724	235		

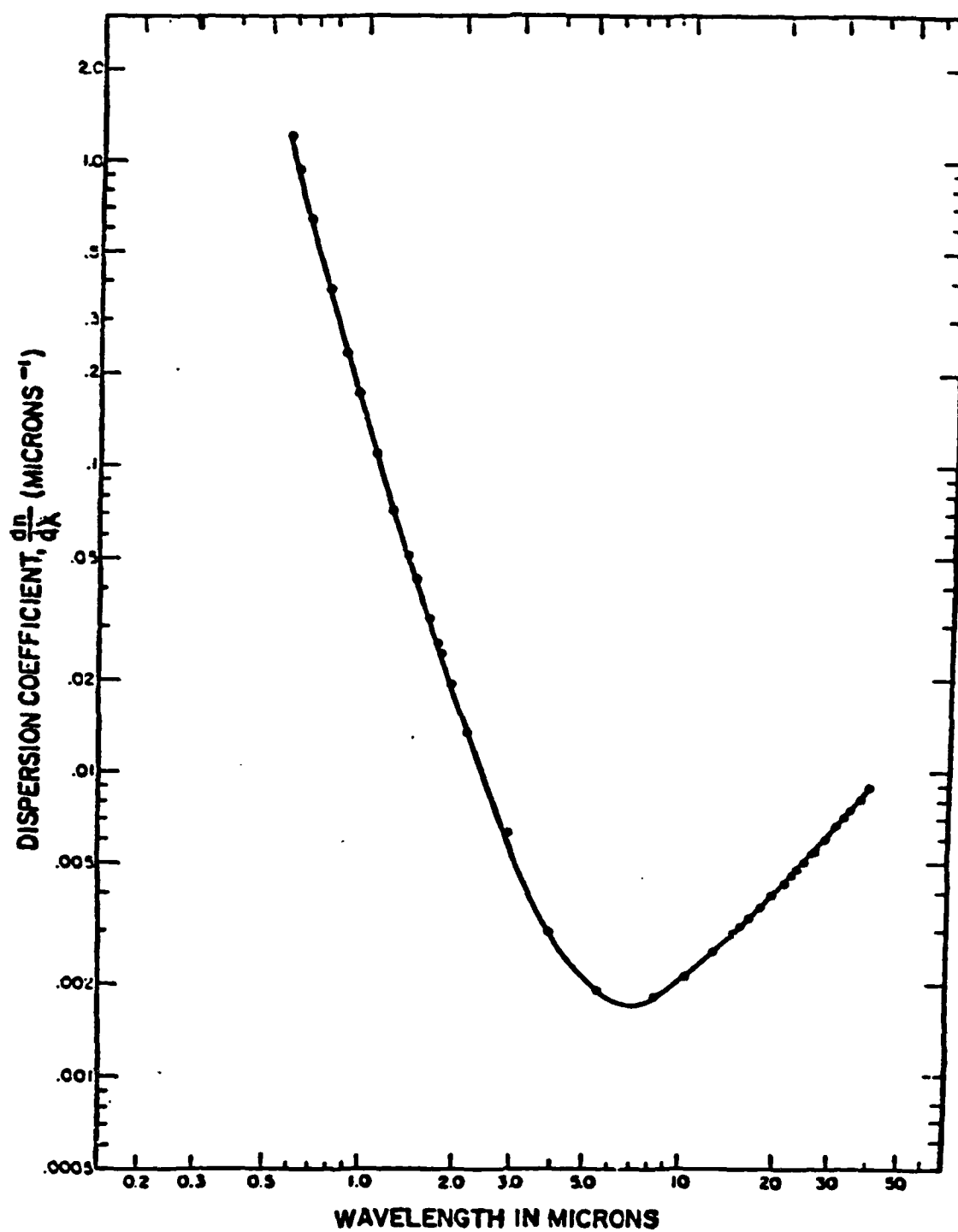


Transmittance and reflectance of KRS-5 versus wavelength², 2 mm.



Average thermal coefficient near room temperature as a function of wavelength. The values plotted are weighed averages of the coefficients computed from the raw data and those computed using the formula values of index¹.

TlBr-TlI (KRS-5)



Dispersion coefficients of 55 KRS-5 as a function of wavelength¹.

ZINC SELENIDE

ZnSe

STRUCTURE

CRYSTALLINE

SYMMETRY = Cubic, $\bar{4}3m$

LATTICE CONSTANTS (Å) = $a = 5.667$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT = 144.33

DENSITY (g/cm^3) = 5.651

SOLUBILITY IN WATER ($\text{g/100g of H}_2\text{O}$) = <0.001

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE ($^{\circ}\text{K}$) = 1373

LINEAR EXPANSION COEFFICIENT ($^{\circ}\text{K}^{-1}$) = 7×10^{-6}

THERMAL CONDUCTIVITY ($\text{cal/cm}\cdot\text{sec}\cdot^{\circ}\text{K}$) = 290×10^4

SPECIFIC HEAT ($\text{cal/g}/^{\circ}\text{K}$) = 0.016

MECHANICAL PROPERTIES

YOUNGS MODULUS = Not Available

HARDNESS (Mohs) = 3-4

ELASTIC CONSTANTS (10^{10} N/m^2) = $C_{11}=8.10, C_{12}=4.88, C_{41}=4.41$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT (static) = 8.1

RESISTIVITY =

BAND GAP ENERGY (eV) = 2.58

EFFECTIVE MASS m_e^* = $0.17 m_0$

MOBILITY μ_e ($\text{cm}^2/\text{v}\cdot\text{sec}$) = 530

ZINC SELENIDE (ZnSe)

OPTICAL PROPERTIES

DISPERSION EQUATION¹:

$$n^2 - 1 = 2.855 + 2.045\lambda^2/(\lambda^2 - 0.109) \quad (\lambda \text{ in microns})$$

ELECTRO-OPTIC COEFFICIENTS² (10^{-12} m/v)

$$\gamma_{41} = 2.2 \text{ at } 10.6\mu\text{m}$$

SECOND HARMONIC COEFFICIENTS (10^{-12} m/v)

$$d_{36} = 31.7 \pm 1.95 \text{ at } 1.058\mu\text{m} \text{ (Reference 3)}$$

$$d_{14} = 78.3 \pm 29.3 \text{ at } 10.6\mu\text{m} \text{ (Reference 4)}$$

PHOTOELASTIC PROPERTIES⁵ (10^{-12} Pa⁻¹)(CVD ZnSe)

	$\lambda = 0.6328\mu\text{m}$	$\lambda = 10.6\mu\text{m}$
q_{11}	$= -1.44 \pm 0.04, -1.48 \pm 0.05^a$	-1.46 ± 0.07
q_{12}	$= 0.17 \pm 0.05, 0.22 \pm 0.05^a$	0.51 ± 0.07
$q_{11}-q_{12}$	$= -1.60 \pm 0.01$	-1.97 ± 0.02
p_{11}	$= -0.13$	-0.10
p_{12}	$= -0.04$	0.007

^aStandard deviation from a third degree polynomial fit.

References:

1. D.T.F. Marple, J. Appl. Phys. 35, 539 (1964).
2. C. Kojima, T. Shikama, S. Kuninoku, A. Kawabata, and T. Tanaka, Jap. J. Appl. Phys. 8, 1361 (1961).
3. R.A. Soref and H.W. Moos, J. Appl. Phys. 35, 2152 (1967).
4. C.K.N. Patel, Phys. Rev. Lett. 15, 613 (1966).
5. A. Feldman, D. Horowitz, R.M. Waxler, and J. Dodge, Optical Materials Characterization, Final Technical Report, NBS Technical Note 993, U.S. Department of Commerce, Washington, D.C.
6. K.K. Dubenskiy, Soviet J. of Opt. Tech. 36, 118 (1969).
7. M. Aven, et al, J. Appl. Phys. Suppl. 32, 2261 (1961).

ZINC SELENIDE (ZnS)

ZINC SELENIDE (ZnSe)

Refractive Index of ZnSe versus Wavelength at Room Temperature¹.

Wavelength (μm)	n
0.589	2.61
1.0	2.48
1.5	2.45
2.0	2.44

ZINC SELENIDE (ZnSe)

Refractive Index of CVD ZnSe Specimen at
Discrete Wavelengths (T = 20.3° C)⁵.

λ_{μ}	n	λ_{μ}	n	λ_{μ}	n
0.55	2.66246	4.00	2.43316	11.50	2.39650
0.60	2.61380	4.50	2.43132	12.00	2.39281
0.65	2.58054	5.00	2.42953	12.50	2.38892
0.70	2.55636	5.50	2.42772	13.00	2.38481
0.75	2.53804	6.00	2.42584	13.50	2.38048
0.80	2.52373	6.50	2.42388	14.00	2.37593
0.85	2.51230	7.00	2.42181	14.50	2.37114
0.90	2.50298	7.50	2.41961	15.00	2.36610
0.95	2.49528	8.00	2.41728	15.50	2.36080
1.00	2.48882	8.50	2.41481	16.00	2.35523
1.50	2.45708	9.00	2.41218	16.50	2.34937
2.00	2.44620	9.50	2.40939	17.00	2.34322
2.50	2.44087	10.00	2.40644	17.50	2.33675
3.00	2.43758	10.50	2.40331	18.00	2.32996
3.50	2.43517	11.00	2.40000		

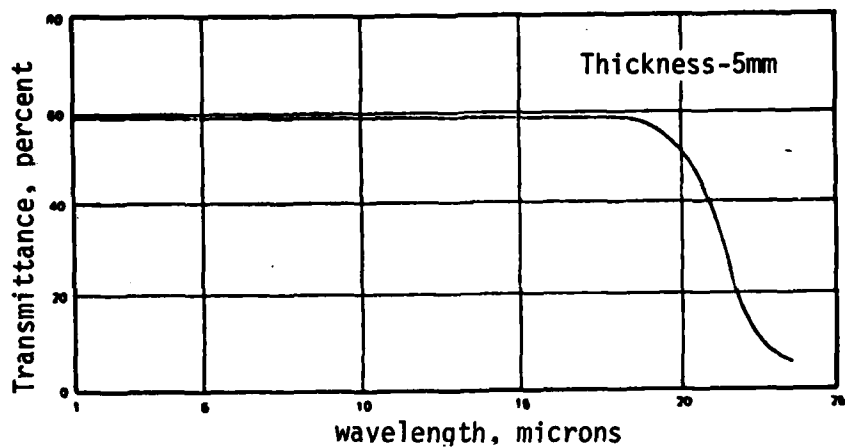
ZINC SELENIDE (ZnSe)

ZINC SELENIDE (ZnSe) dn/dT of CVD ZnSe (10^{-5} K^{-1})^a

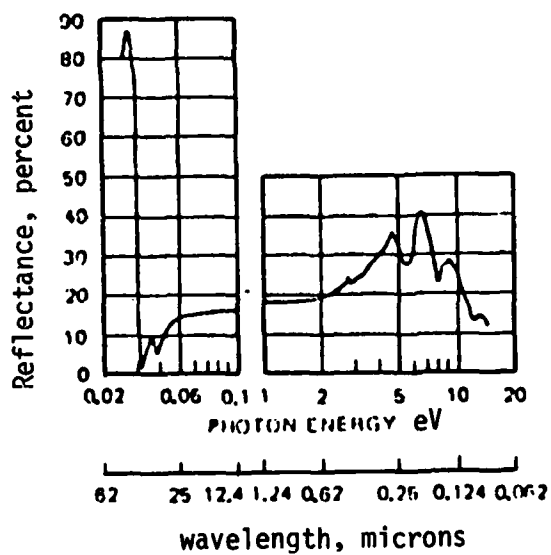
Temperature (°C)	Wavelength (μm)			
	0.6328	1.15	3.39	10.6
-180	7.6	5.4	5.0	4.9
-160	8.2	5.7	5.2	5.1
-140	8.7	6.0	5.4	5.4
-120	9.1	6.3	5.6	5.5
-100	9.4	6.5	5.8	5.7
- 80	9.7	6.6	5.9	5.8
- 60	10.0	6.7	6.0	5.9
- 40	10.2	6.8	6.1	6.0
- 20	10.3	6.9	6.1	6.0
0	10.5	7.0	6.2	6.1
20	10.6	7.0	6.2	6.1
40	10.7	7.0	6.2	6.1
60	10.8	7.1	6.3	6.1
80	10.9	7.1	6.3	6.2
100	11.0	7.2	6.3	6.2
120	11.1	7.2	6.4	6.3
140	11.3	7.3	6.4	6.3
160	11.5	7.4	6.5	6.4
180	11.8	7.6	6.6	6.6
200	12.1	7.8	6.7	6.7
σ^a	0.1	0.1	0.1	0.1

^aStandard deviation from a third degree polynomial fit.

ZINC SELENIDE (ZnSe)



Transmittance versus wavelength of 5 mm thick ZnSe sample⁶.



Reflectance of ZnSe versus wavelength⁷.

ZINC SULFIDE (SPHALERITE, WURTZITE)
ZnS

STRUCTURE

CRYSTALLINE

SYMMETRY	=	Cubic, $\bar{4}3m$
LATTICE CONSTANTS (A)	=	$a = 5.4109$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	97.43
DENSITY (g/cm^3)	=	4.09
SOLUBILITY IN WATER ($\text{g/100g of H}_2\text{O}$)	=	6.5×10^{-5}

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE ($^{\circ}\text{K}$)	=	1293
LINEAR EXPANSION COEFFICIENT ($^{\circ}\text{K}^{-1}$)	=	6.14×10^{-6}
THERMAL CONDUCTIVITY ($\text{cal/cm}\cdot\text{sec}\cdot^{\circ}\text{K}$)	=	635
SPECIFIC HEAT ($\text{cal/g}/^{\circ}\text{K}$)	=	0.116

MECHANICAL PROPERTIES

YOUNGS MODULUS (PSI)	=	1.65×10^6
HARDNESS (kg/mm^2)	=	178
ELASTIC CONSTANTS (10^{10} N/m^2)	=	$C_{11}=10.46, C_{12}=6.53, C_{44}=4.613$

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT (static)	=	8.3
RESISTIVITY	=	Not Available
BAND GAP ENERGY (eV)	=	3.6
EFFECTIVE MASS m_e^*	=	$0.25 m_0$
MOBILITY μ_e ($\text{cm}^2/\text{v}\cdot\text{sec}$)	=	140

ZINC SULFIDE (ZnS)

ELECTRO-OPTIC COEFFICIENTS¹ (10^{-12} m/v)

$$r_{41} = 1.4 \text{ at } 3.39 \mu\text{m}$$

$$r_{33} = 1.7 \text{ at } 3.39 \mu\text{m}$$

SECOND HARMONIC COEFFICIENTS (10^{-12} m/v)

$$d_{36} = 24.6 \pm 1.5 \text{ at } 1.058 \mu\text{m} \text{ (Reference 2)}$$

$$d_{14} = 30.6 \pm 8.4 \text{ at } 10.6 \mu\text{m} \text{ (Reference 3)}$$

References:

1. I.P. Kamminow, in CRC Handbook of Lasers, ed. by R.J. Plessey, p 447, Chemical Rubber Company, Cleveland, Ohio (1971).
2. R.A. Soref and H.W. Moos, J. Appl. Phys. 35, 2152 (1964).
3. C.K.N. Patel, Phys. Rev. Lett. 16, 613 (1966).
4. T.M. Bieniewski and S.J. Czyzak, J. Opt. Soc. Am. 53, 496 (1963).
5. W.L. Bond, J. Appl. Phys. 36, 1674 (1965).
6. A. Feldman, D. Horowitz, R.M. Waxler and J. Dodge, Optical Materials Characterization, Final Technical Report, NBS Technical Note 993, U.S. Department of Commerce, Washington, D.C.
7. T. Deutsch, Int. Conf. on the Phys. of Semiconductors Proc. Exeter, A.C. Strickland, Ed., Inst. of Phys. and Phys. Soc., London, 505 (1962).
8. A. Manabe, et al., Jap. J. Appl. Phys. 6, 593 (1967).

ZINC SULFIDE (ZnS)

ZINC SULFIDE (ZnS) Refractive Index of ZnS versus Wavelength at Room Temperature⁴.

Wavelength (μm)	n_o	n_e
0.3600	2.705	2.709
0.3750	2.637	2.640
0.4000	2.560	2.564
0.4100	2.539	2.544
0.4200	2.522	2.525
0.4250	2.511	2.514
0.4300	2.502	2.505
0.4400	2.486	2.488
0.4500	2.473	2.477
0.4600	2.459	2.463
0.4700	2.448	2.453
0.4750	2.445	2.449
0.4800	2.438	2.443
0.4900	2.428	2.433
0.5000	2.421	2.425
0.5250	2.402	2.407
0.5500	2.386	2.392
0.5750	2.375	2.378
0.6000	2.363	2.368
0.6250	2.354	2.358
0.6500	2.346	2.350
0.6750	2.339	2.343
0.7000	2.332	2.337
0.8000	2.324	2.328
0.9000	2.310	2.315
1.000	2.301	2.303
1.200	2.290	2.294
1.400	2.285	2.288

ZINC SULFIDE (ZnS)

ZINC SULFIDE (ZnS) Refractive Index of ZnS versus Wavelength at Room Temperature⁵.

Wavelength (μm)	n
0.45	2.4709
0.50	2.4208
0.60	2.3640
0.70	2.3333
0.80	2.3146
0.90	2.3026
1.00	2.2932
1.10	
1.20	2.2822
1.40	2.2762
1.60	2.2716
1.80	2.2680
2.00	2.2653
2.20	2.2637
2.40	2.2604

ZINC SULFIDE (ZnS) Refractive Index of CVD ZnS Specimen #1 at Discrete Wavelengths (T = 21.6° C)⁶.

λ_{μ}	n	λ_{μ}	n	λ_{μ}	n
0.55	2.38579	1.50	2.27209	6.50	2.23583
0.60	2.36237	2.00	2.26453	7.00	2.23183
0.65	2.34509	2.50	2.26030	7.50	2.22749
0.70	2.33189	3.00	2.25719	8.00	2.22280
0.75	2.32155	3.50	2.25445	8.50	2.21775
0.80	2.31327	4.00	2.25178	9.00	2.21231
0.85	2.30652	4.50	2.24903	9.50	2.20645
0.90	2.30093	5.00	2.24610	10.00	2.20016
0.95	2.29626	5.50	2.24294	10.50	2.19340
1.00	2.29230	6.00	2.23953		

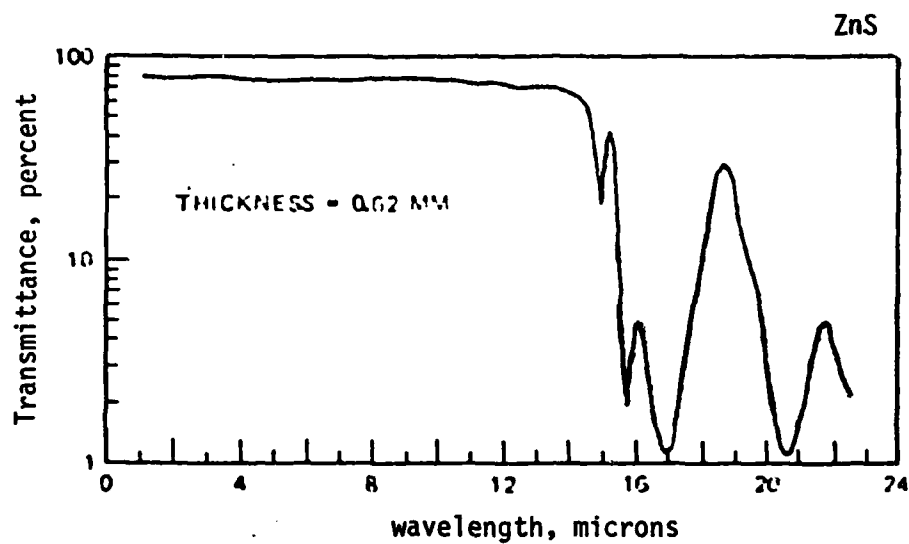
ZINC SULFIDE (ZnS)

ZINC SULFIDE (ZnS)
 dn/dT of CVD ZnS (10^{-5} K^{-1})⁶.

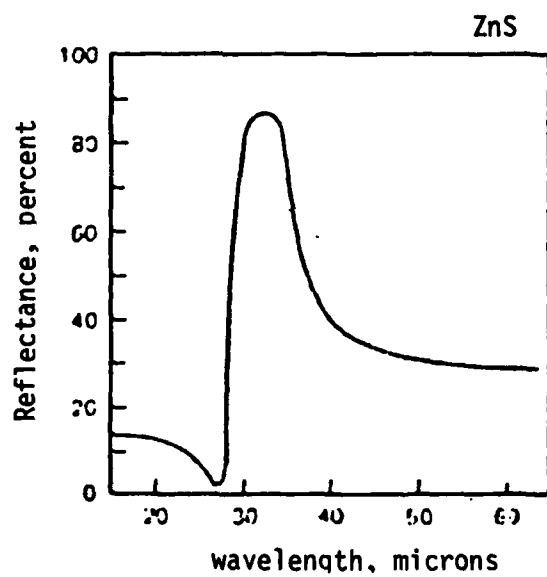
Temperature (°C)	Wavelength (μm)		
	1.15	3.39	10.6
-180	3.5	2.8	2.7
-160	3.7	3.1	3.0
-140	3.8	3.3	3.3
-120	4.0	3.5	3.5
-100	4.1	3.7	3.7
- 80	4.2	3.9	3.8
- 60	4.3	4.0	3.9
- 40	4.4	4.1	4.0
- 20	4.5	4.1	4.0
0	4.5	4.2	4.1
20	4.6	4.2	4.1
40	4.6	4.3	4.1
60	4.7	4.3	4.1
80	4.7	4.3	4.1
100	4.7	4.3	4.2
120	4.8	4.4	4.2
140	4.8	4.4	4.3
160	4.9	4.4	4.4
180	4.9	4.5	4.5
200	5.0	4.6	4.7
σ^a	0.2	0.2	0.2

^aStandard deviation from a third degree polynomial fit.

ZINC SULFIDE (ZnS)



Transmittance of 0.62 mm thick ZnS versus wavelength⁷.



Reflectance of ZnS versus wavelength⁸.

ZnGeP₂

STRUCTURE

CRYSTALLINE

SYMMETRY	=	Tetragonal, $\bar{4}2m$ (chalcopyrite)
LATTICE CONSTANTS (Å)	=	$a = 5.466 \pm 0.001$ $c = 10.722 \pm 0.002$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	199.2
DENSITY (g/cm ³)	=	4.17
SOLUBILITY IN WATER (g/100g of H ₂ O)	=	Not available

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	1295
LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	--
THERMAL CONDUCTIVITY (W/cm°K)	=	0.18
SPECIFIC HEAT (cal/g)/°K	=	--

MECHANICAL PROPERTIES

YOUNGS MODULUS	=	--
HARDNESS (kg/mm ²)	=	660

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT	=	--
RESISTIVITY (Ohm-cm)	=	6.5×10^6
BAND GAP ENERGY (eV)	=	2.25
EFFECTIVE MASS	=	--
MOBILITY	=	--

ZnGeP₂

SECOND HARMONIC COEFFICIENTS¹ (10¹² m/v)

$$d_{36} = d_{14} = 111 \pm 30 \quad \text{at} \quad 10.6 \mu\text{m}$$

References:

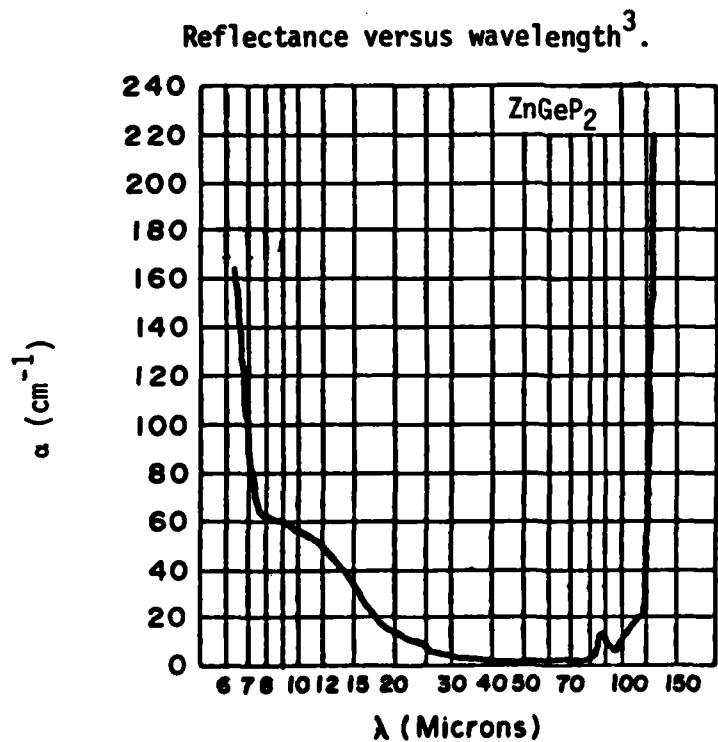
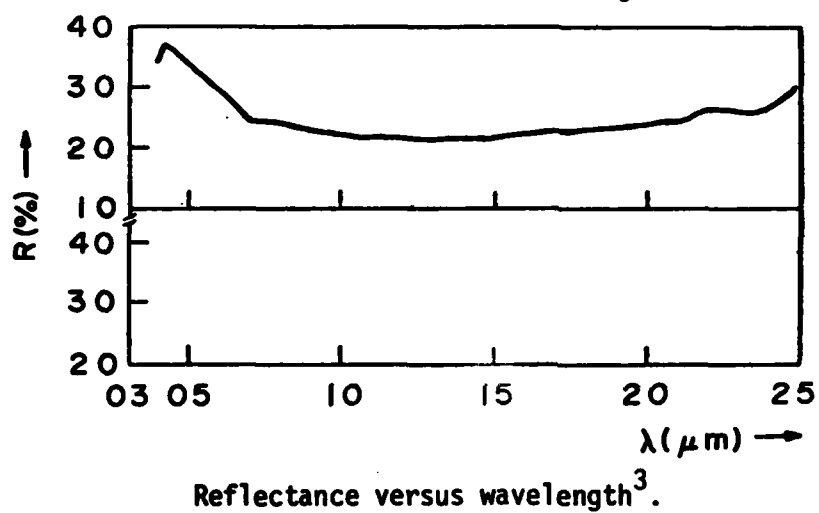
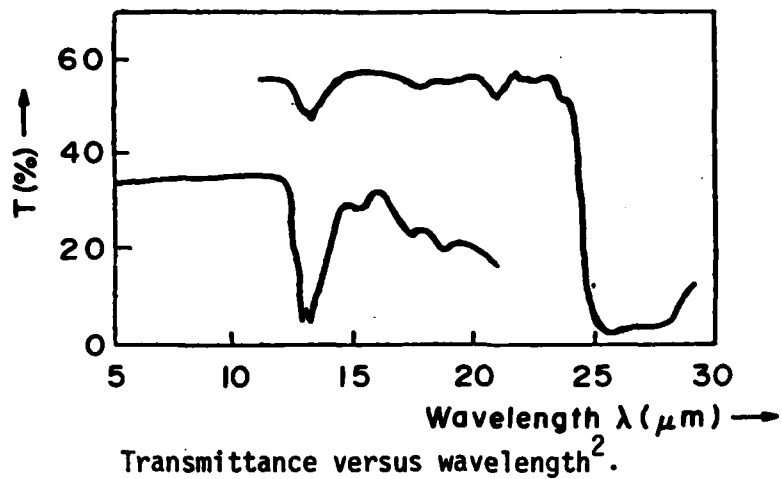
1. G.D. Boyd, E. Buehler and F.G. Storg, Appl. Phys. Lett. 18, 301 (1971).
2. S. Isomura and K. Masumoto, Phys. Stat. Sol. A6, K139 (1971).
3. S. Isomura and K. Masumoto, Phys. Stat. Sol. A13, 223 (1972).
4. G.D. Boyd, E. Buehler, F.G. Storg and J.H. Wernik, IEEE J. Quant. El. QE8, 419 (1972).

ZnGeP₂

ZnGeP₂
Wavelength dependence of Refractive Indices¹.

λ (μ)	n^o	n^e
0.64	3.5052	3.5802
0.66	3.4756	3.5467
0.68	3.4477	3.5160
0.70	3.4233	3.4885
0.75	3.3730	3.4324
0.80	3.3357	3.3915
0.85	3.3063	3.3593
0.90	3.2830	3.3336
0.95	3.2638	3.3124
1.00	3.2478	3.2954
1.10	3.2232	3.2688
1.20	3.2054	3.2493
1.30	3.1924	3.2316
1.40	3.1820	3.2244
1.60	3.1666	3.2077
1.80	3.1562	3.1965
2.00	3.1490	3.1889
2.20	3.1433	3.1820
2.40	3.1388	3.1780
2.60	3.1357	3.1745
2.80	3.1327	3.1717
3.00	3.1304	3.1693
3.20	3.1284	3.1671
3.40	3.1263	3.1647
3.60	3.1257	3.1632
3.80	3.1237	3.1616
4.00	3.1223	3.1608
4.20	3.1209	3.1595
4.50	3.1186	3.1561
4.70	3.1174	3.1549
5.00	3.1149	3.1533
5.50	3.1131	3.1518
6.00	3.1101	3.1480
6.50	3.1057	3.1445
7.00	3.1010	3.1420
7.50	3.0991	3.1378
8.00	3.0961	3.1350
8.50	3.0919	3.1311
9.00	3.0880	3.1272
9.50	3.0836	3.1231
10.00	3.0788	3.1183
10.50	3.0738	3.1137
11.00	3.0689	3.1087
11.50	3.0623	3.1008
12.00	3.0552	3.0919

ZnGeP₂



ZnSiAs₂

STRUCTURE

CRYSTALLINE

SYMMETRY	=	Tetragonal, $\bar{4}2m$ (chalcopyrite)
LATTICE CONSTANTS (Å)	=	$a = 5.61$ $c = 10.88$

PHYSICAL PROPERTIES

MOLECULAR WEIGHT	=	239.3
DENSITY (g/cm ³)	=	4.7
SOLUBILITY IN WATER (g/100g of H ₂ O)	=	Not available

THERMAL PROPERTIES

MELTING/SOFTENING TEMPERATURE (°K)	=	1369
LINEAR EXPANSION COEFFICIENT (°K ⁻¹)	=	--
THERMAL CONDUCTIVITY (W/cm°K)	=	0.11
SPECIFIC HEAT (cal/g)/°K	=	--

MECHANICAL PROPERTIES

YOUNGS MODULUS	=	--
HARDNESS (kg/mm ²)	=	480

ELECTRICAL PROPERTIES

DIELECTRIC CONSTANT	=	--
RESISTIVITY (Ohm-cm)	=	$1.8 - 4.5 \times 10^2$
BAND GAP ENERGY (eV)	=	1.76
EFFECTIVE MASS	=	--
MOBILITY μ_e (cm ² /v-sec)	=	25

ZnSiAs₂

OPTICAL PROPERTIES

TRANSMISSION RANGE: .8 - 20 μ m

SECOND HARMONIC COEFFICIENT¹ (10^{12} m/v)

$d_{36} = 109 \pm 33$ at 10.6 μ m

References:

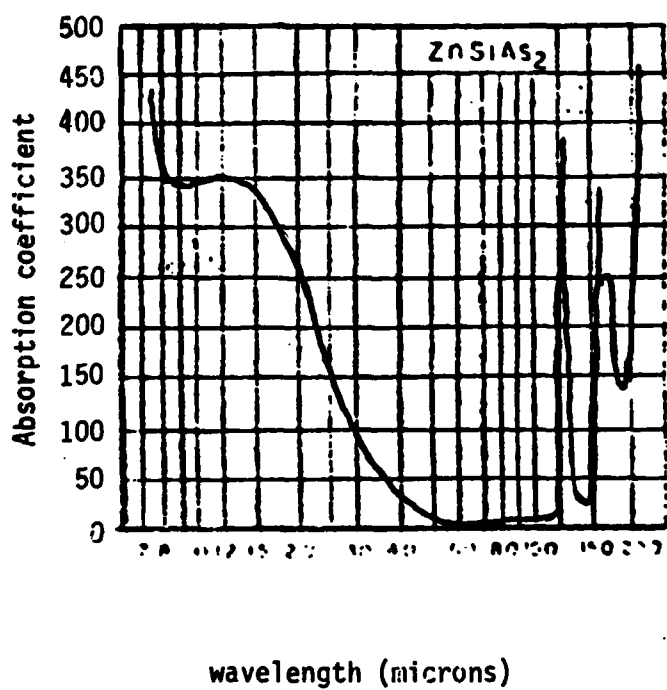
1. G.D. Boyd, E. Buehler, F. Storz and J.H. Wernick, IEEE J. Quant. El. QE8, 419 (1972).

ZnSiAs₂

ZnSiAs₂
Refractive Index ZnSiAs₂ (Prism Angle A = 20.0667°)¹

λ	$\nu = \lambda^{-1}$			
μ	μ^{-1}	n^o	n^e	$n^e - n^o$
.70	1.4286	3.5579	3.6201	.0621
.75	1.3333	3.5002	3.5539	.0537
.80	1.2500	3.4570	3.5050	.0480
.85	1.1765	3.4210	3.4655	.0445
.90	1.1111	3.3946	3.4362	.0416
.95	1.0526	3.3722	3.4116	.0393
1.00	1.0000	3.3551	3.3928	.0377
1.10	.9091	3.3266	3.3618	.0352
1.20	.8333	3.3061	3.3394	.0333
1.30	.7692	3.2901	3.3221	.0320
1.40	.7143	3.2782	3.3093	.0311
1.60	.6250	3.2593	3.2889	.0296
1.80	.5556	3.2485	3.2771	.0286
2.00	.5000	3.2405	3.2692	.0287
2.20	.4545	3.2346	3.2620	.0274
2.40	.4167	3.2296	3.2572	.0276
2.60	.3846	3.2268	3.2539	.0272
2.80	.3571	3.2233	3.2506	.0272
3.00	.3333	3.2210	3.2481	.0271
3.20	.3125	3.2197	3.2464	.0267
3.40	.2941	3.2178	3.2447	.0269
3.60	.2778	3.2162	3.2426	.0264
3.80	.2632	3.2146	3.2413	.0268
4.00	.2500	3.2133	3.2402	.0268
4.50	.2222	3.2106	3.2372	.0266
5.00	.2000	3.2081	3.2345	.0265
5.50	.1818	3.2053	3.2317	.0264
6.00	.1667	3.2025	3.2287	.0262
6.50	.1538	3.2002	3.2263	.0261
7.00	.1429	3.1979	3.2241	.0263
7.50	.1333	3.1956	3.2220	.0264
8.00	.1250	3.1930	3.2195	.0265
8.50	.1176	3.1905	3.2168	.0264
9.00	.1111	3.1874	3.2138	.0263
9.50	.1053	3.1842	3.2106	.0264
10.00	.1000	3.1810	3.2074	.0264
10.50	.0952	3.1772	3.2037	.0264
11.00	.0909	3.1733	3.1996	.0263
11.50	.0870	3.1685	3.1953	.0268
12.00	.0833	3.1626		

Note: All index values are actual data points.



Absorption coefficient in ZnSiAs_2 versus wavelength¹.

THE TACTICAL WEAPON GUIDANCE AND CONTROL INFORMATION ANALYSIS CENTER (GACIAC)

GACIAC is a DoD Information Analysis Center operated by IIT Research Institute under the technical sponsorship of the Joint Service Guidance and Control Committee with members for OUSDRE, Army, Navy, Air Force, and DARPA. The U.S. Army Missile Command provides the Contracting Officer's Technical Representative. Its mission is to assist the tactical weapon guidance and control community by encouraging and facilitating the exchange and dissemination of technical data and information for the purpose of effecting coordination of research, exploratory development, and advanced technology demonstrations. To accomplish this, GACIAC's functions are to:

- 1. Develop a machine-readable bibliographic data base - currently containing over 30,000 entries;*
- 2. Collect, review, and store pertinent documents in its field of interest - the library contains over 9,000 reports;*
- 3. Analyze, appraise and summarize information and data on selected subjects;*
- 4. Disseminate information through the GACIAC Bulletin, bibliographies, state-of-the-art summaries, technology assessments, handbooks, special reports, and conferences;*
- 5. Respond to technical inquiries related to tactical weapon guidance and control; and*
- 6. Provide technical and administrative support to the Joint Service Guidance and Control Committee (JSGCC).*

The products and services of GACIAC are available to qualified industrial users through a subscription plan or individual sales. Government personnel are eligible for products and services under block funding provided by the Army, Navy, Air Force and DARPA. A written request on government stationery is required to receive all the products as a government subscriber.

Further information regarding GACIAC services, products, participation plan, or additional copies of this Handbook may be obtained by writing or calling: GACIAC, IIT Research Institute, 10 West 35th Street, Chicago, Illinois 60616, Area Code 312, 567-4519 or 567-4544.