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CONTRACT AF 33(616)-8438
PROJECT 7381; TASK 738103

INDIUM PHOSPHIDE

Data Sheets

M. Neuberger

DS-102
June 1962

EPIC

HUGHES
HUGHES AIRCRAFT COMPANY
CULVER CITY CALIFORNIA

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FOREWORD

This report was prepared by Hughes Aircraft Company under Contract No. AF 33(616)-8438. The contract was initiated under Project No. 7381, Task No. 738103. The work was administered under the direction of the Directorate of Materials and Processes, Aeronautical Systems Division, with Mr. R.F. Klinger acting as Project Engineer.

Many persons have contributed to the program which this report represents. The author wishes especially to acknowledge the contributions of the following: J.J. Anders, J.W. Atwood, C.L. Blocher, D.L. Grigsby, J.J. Grossman, F.S. Harter, D.H. Johnson, H.T. Johnson, J.T. Milek, G.S. Picus, and E. Schafer.

ABSTRACT

The Electronic Properties Information Center has been established to collect, index and abstract the literature on the electrical and electronic properties of materials and to evaluate and compile the experimental data from that literature. A modified coordinate index to the literature is machine stored and printed for manual use. The Center publishes data sheets, summary reports, thesauri, glossaries, and similar publications as sufficient information is evaluated and compiled. This report consists of the compiled data sheets on Indium Phosphide.

This report has been reviewed and is approved for publication.

H. Thayne Johnson, Supervisor
Electronic Properties Information Center

John W. Atwood
Project Manager

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INTRODUCTION

In June 1961, a program was initiated under the direction of the Air Force to collect, index and abstract the literature on the electrical and electronic properties of materials and to evaluate and compile the experimental data from that literature. Placed at Hughes Aircraft Company in Culver City, California, the program, now called the Electronic Properties Information Center, was originally intended to cover ten major categories of materials: Semiconductors, Insulators, Ceramics, Ferroelectrics, Metals, Ferrites, Ferromagnetics, Electroluminescent Materials, Thermionic Emitters, and Superconductors.

During the first year, studies were completed on the Semiconductor and Insulator categories; and Ceramics was discontinued as a separate category and subsumed under the other nine. Vocabulary studies have now been completed on all categories, and retrospective documentation is virtually complete for Semiconductors and Insulators. A full index to the literature is maintained; and publications such as data sheets, summary reviews, glossaries, and thesauri are periodically issued. The use of the Center and these publications are available to anyone wishing information within the scope of the Center's objectives. A full list of publications to date appears at the end of this report.

This report contains data sheets on Indium Phosphide. The data sheets have been compiled direct from the literature. Articles are allowed to accumulate in the system until it is judged that a sufficient number are available on one material for adequate evaluation. The manual modified coordinate index is then used to retrieve all literature on the material to be compiled. Bibliographies are checked to make sure that valuable and relevant literature is not overlooked. Then the assembled literature is given to the specialist doing the evaluation and compilation.

Evaluation is confined to primary source data except when only secondary citations are available. If equally valid data are available from several sources, all are given. Data are rejected when judged questionable because of faulty or dubious measurements, unknown sample composition, or if more reliable data are available from another source. Selection of data is based upon that which is judged most representative, precise, reliable, and covers the widest range of variables. The addition of new data to a previously evaluated property requires a reappraisal of the reported values. Older data may be deleted if the new data are judged more accurate or representative.

After a thorough analysis and evaluation, the data is compiled into data sheets which present it in its most optimum form. This will be, primarily, but not limited to, curves or tabular form. Where possible, graphs are adapted directly from the original sources. If this is not possible, they are drawn from data compiled from the articles. Where thought important, notes are entered with each graph to help the user.

The references, from which the data are drawn, are shown by reference number below each graph with the full bibliographic information at the end of the data sheets. The bibliography is referred to and listed in the order of entry into the Center (accession number). This provides a quick cross reference into the index used with the literature.

These data sheets were originally issued in loose leaf form in June 1962. In response to numerous additional requests for copies, they are being reissued at this time.

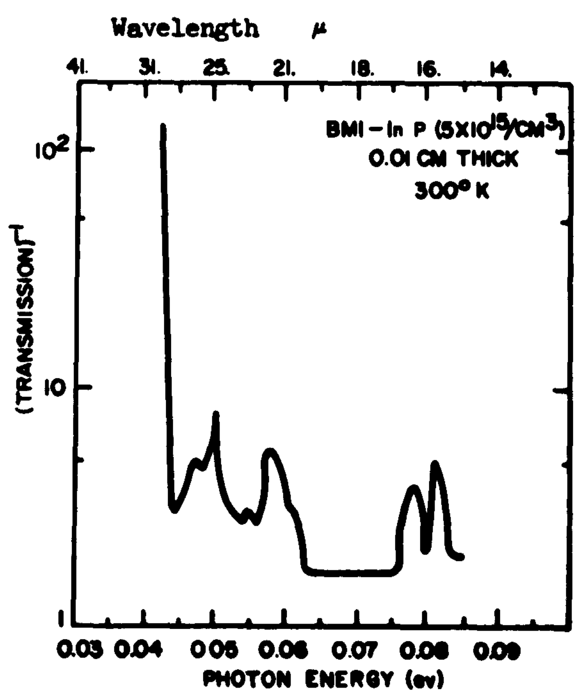
This compilation deals only with Indium Phosphide as a Semiconductor. Non-semiconductor data will be included in a future revision.

SEMICONDUCTOR MATERIALS

June 1962

INDIUM PHOSPHIDE

Absorption



Absorption spectrum (300°K) of an InP sample in the reststrahlen region. (n-type single crystal) [Ref. 13]

SEMICONDUCTOR MATERIALS

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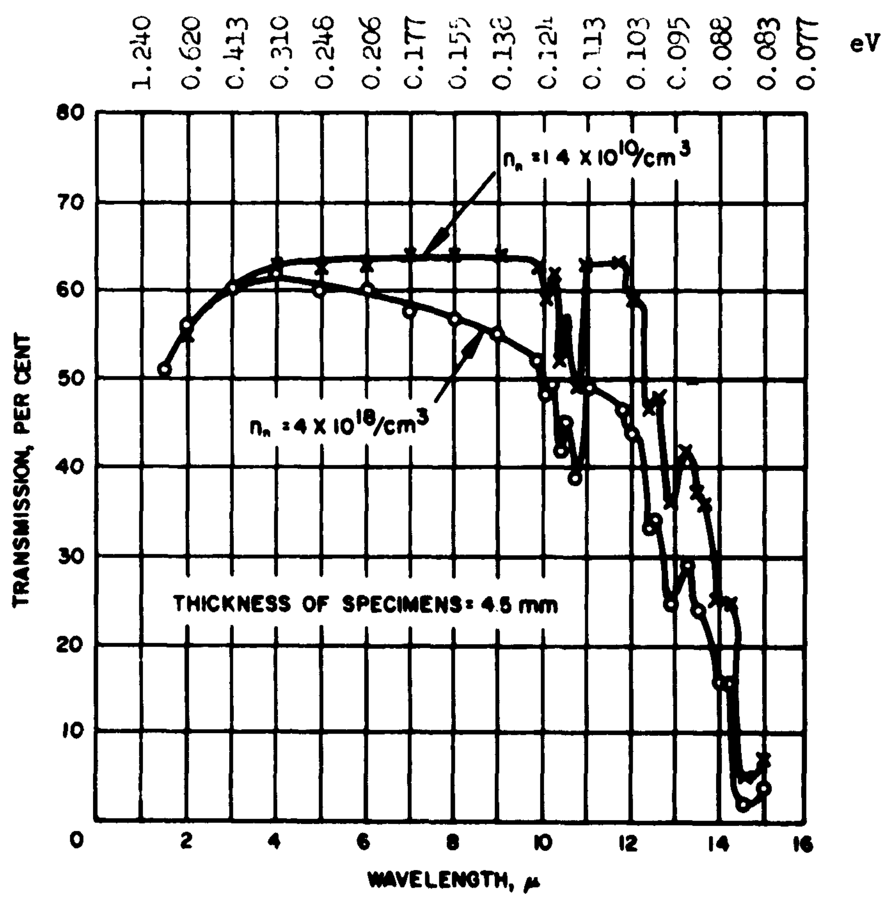
INDIUM PHOSPHIDE

Absorption

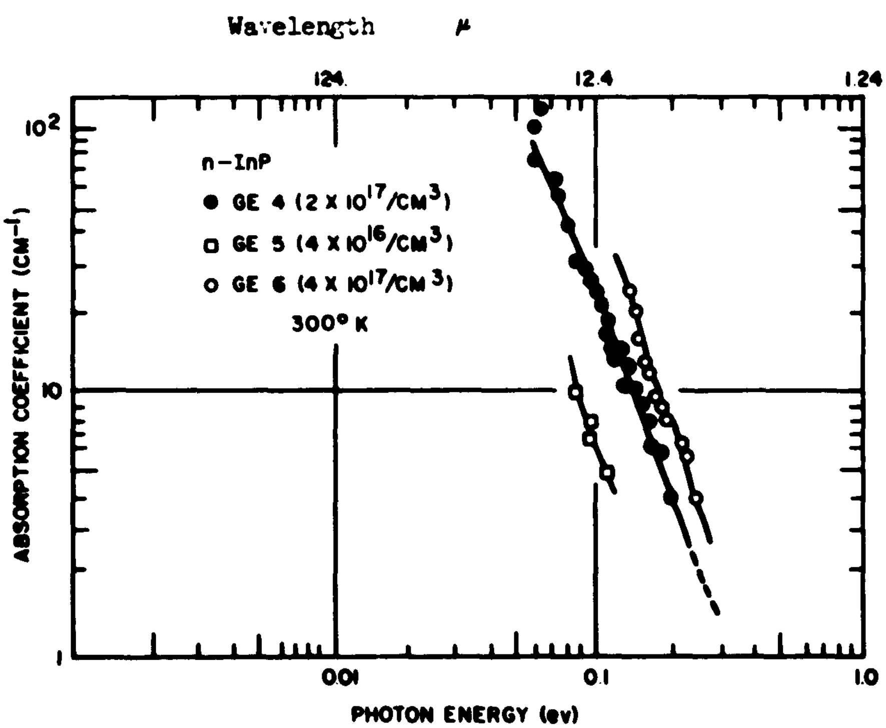


Transmission characteristics of two n-type single-crystal specimens of InP at 300°K.

[Ref. 9]

INDIUM PHOSPHIDE

Absorption



Free-carrier absorption (300°K) in various InP samples. (single crystal) [Ref. 13]

SEMICONDUCTOR MATERIALS

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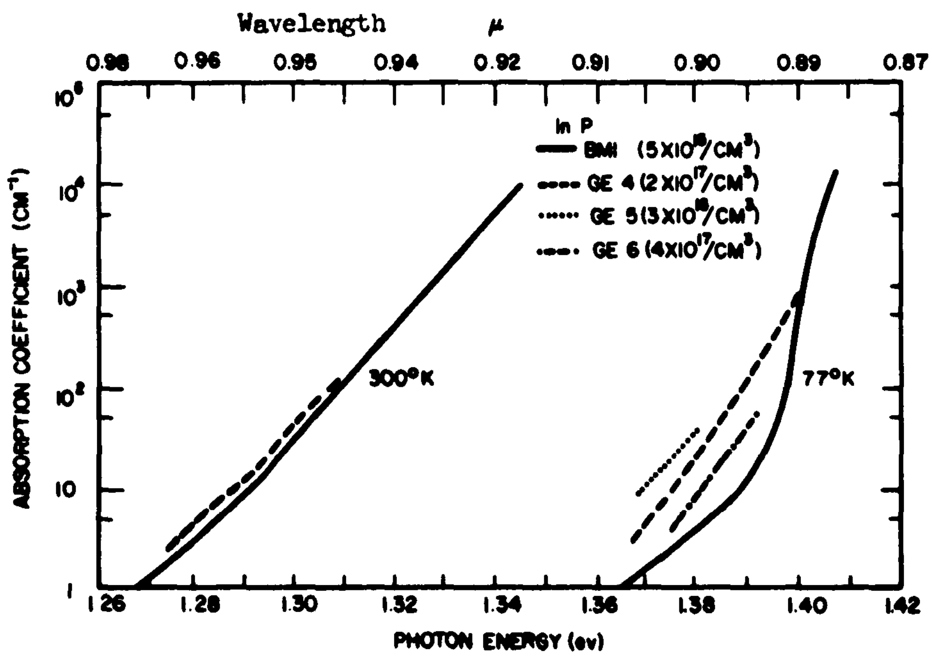
INDIUM PHOSPHIDE

Absorption



Intrinsic absorption edge of InP at 77°K and 300°K. The different curves refer to different ingots. [Ref. 13]
n-type, single crystal.

SEMICONDUCTOR MATERIALS

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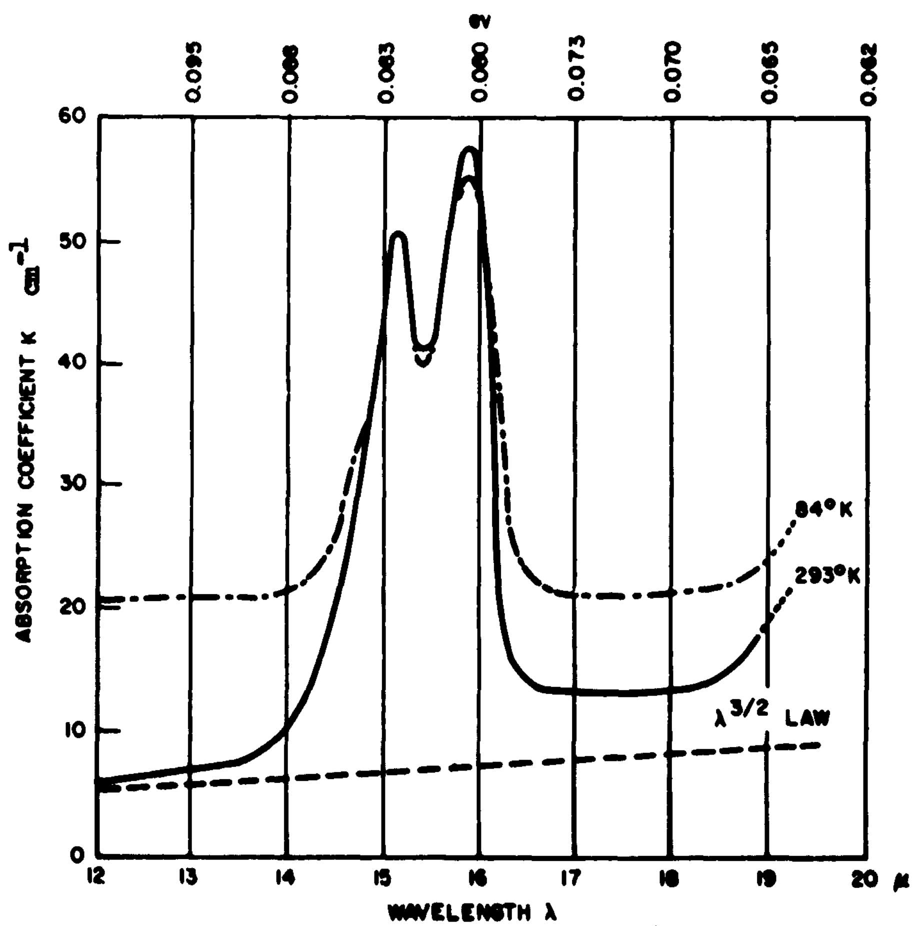
INDIUM PHOSPHIDE

Absorption



Infra-red absorption curves for n-type indium phosphide at 293°K and 84°K. The broken line corresponds to $K \propto \lambda^{1.5}$.
(probably single-crystal)

[Ref. 18]

DATA SHEET

ELECTRICAL AND ELECTRONIC PROPERTIES

MATERIALS CENTRAL
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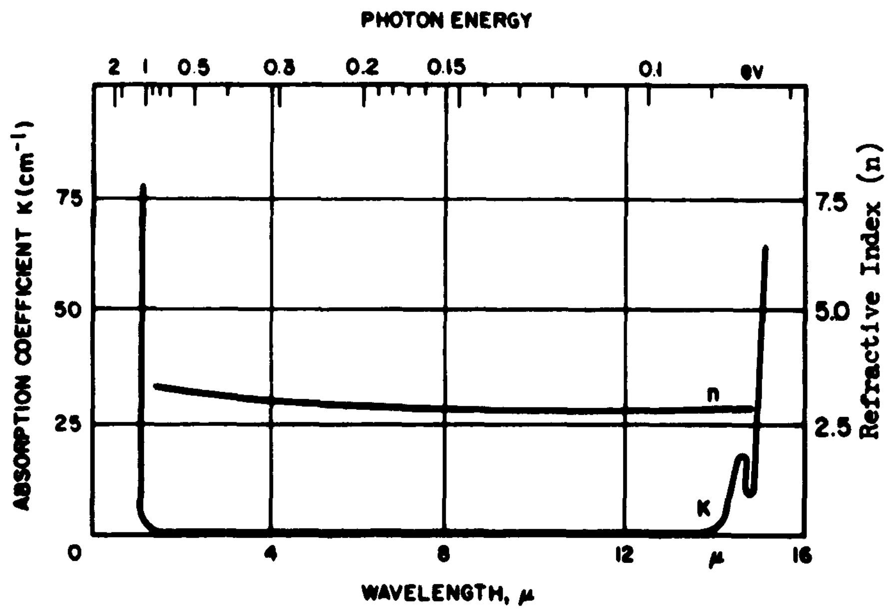
SEMICONDUCTOR MATERIALS

June 1962

INDIUM PHOSPHIDE

Absorption



Indium Phosphide; ρ = 0,1 Ωcm, n-type, poly-crystal. [Ref. 15]
n = 3.1 in infra-red.

Dielectric Constant

Symbol	Value	Type	Test Conditions	Ref.
ϵ	15	n-single	300°K photon freq. = 0.040eV	13
	10.6		300°K photon freq. = 0.060eV to band edge	13

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INDIUM PHOSPHIDE

Effective Mass

Symbol	Value	Type	Test Conditions	Ref.
m_p^*	$0.69\ m_o$	n-Poly		12
m_n^*	→ $0.077\ m_o \pm 0.005$		$n_n = 6.1 \times 10^{15}/cm^3$ $\mu = 18,600\ cm^2/V\ sec$	17
	→ $0.073\ m_o \pm 0.007$	n-Poly	Faraday effect data	12
	$0.02\ m_o$	n-Poly	84^oK, optical data	18
m^*	$0.2\ m_o$	n-Single Intrinsic	$n_n = 5 \times 10^{18}/cm^3$, optical data	13
	$0.2\text{-}0.8\ m_o$	p	Cd-doped, mobility data	5
	$0.23\ m_o$	p-Poly Intrinsic	Conductivity measurements	4
	$0.10\ m_o$		Faraday rotation, $\lambda = 2\text{-}17\mu$ room temperature $n_n = 1.1\text{-}1.17 \times 10^{17}/cm^3$	1

→ Best values

SEMICONDUCTOR MATERIALS

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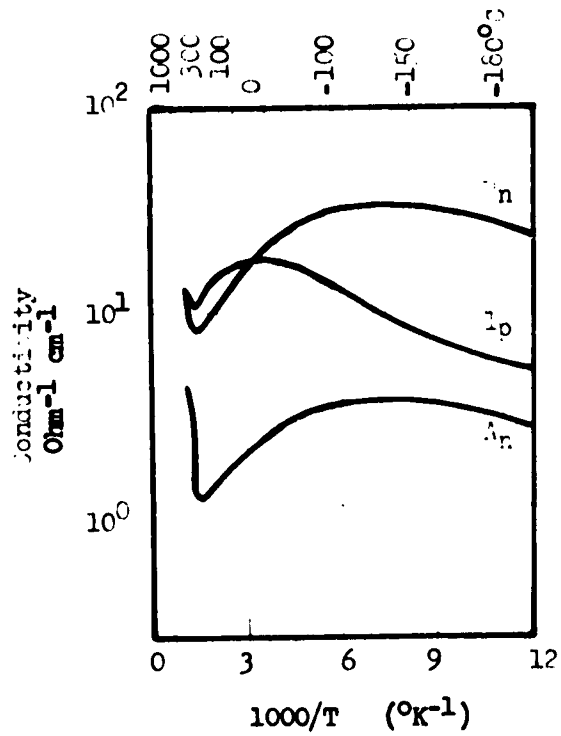
INDIUM PHOSPHIDE

Electrical Conductivity



A_n = n-type, 4×10^{15} electrons/cm^3, 300°C
B_n = n-type
1_p = p-type, prepared by diffusion of zinc into A_n
T = -180° to 960°C

[Ref. 4]

SEMICONDUCTOR MATERIALS

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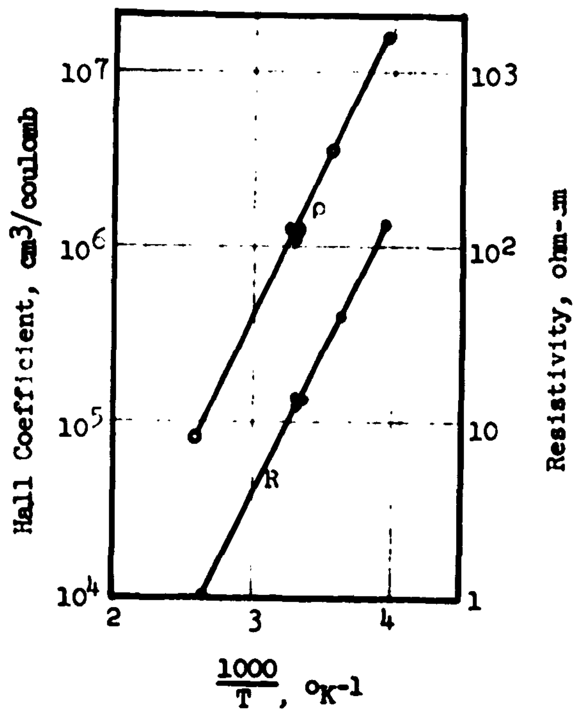
INDIUM PHOSPHIDE

Electrical Conductivity



Before irradiation R = -59 cm^3/coulomb
ρ = 0.0179 Ω cm and
μ_H = 3300 cm^2/volt sec.
n-type, single crystal, 250-360°K.

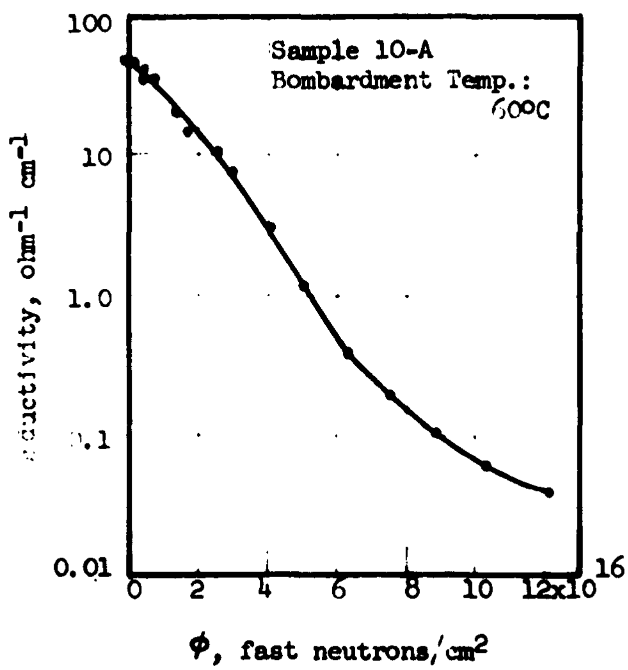
Temperature dependence of Hall coefficient, R, and resistivity, ρ, of InP sample after fast neutron irradiation. [Ref. 2]

SEMICONDUCTOR MATERIALS

June 1962

INDIUM PHOSPHIDE

Electrical Conductivity

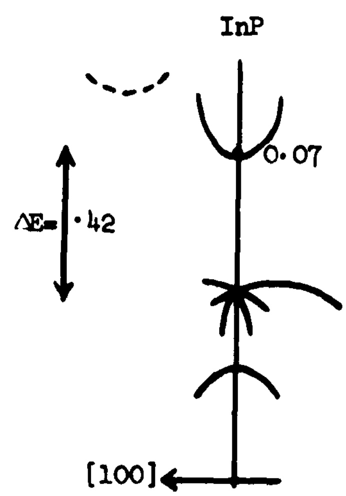


Irradiation of n-type InP; variation in conductivity with total neutron irradiation.

[Ref. 2]

INDIUM PHOSPHIDE

Energy Band Structure



Probable band structure of Indium phosphide. Effective conduction band mass and 0°K band gap are indicated. [Ref. 10]

Energy Gap

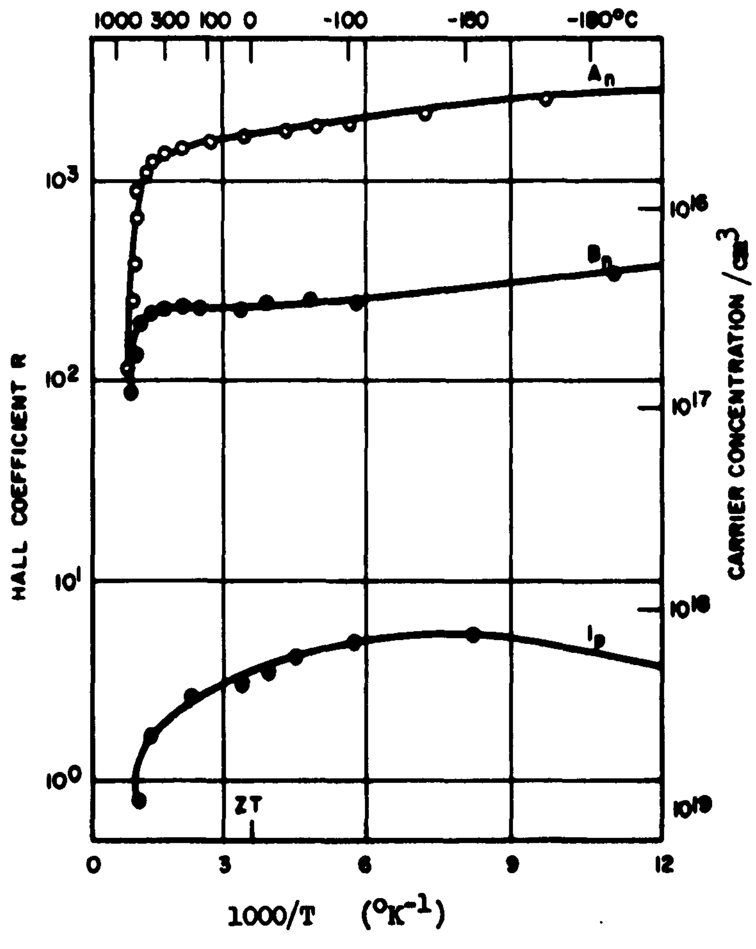
	Value	Sample	Temperature	Ref.
E_g	1.34 eV	Polycrystalline (n or p-type)	0°K	4
	$1.41 -- 4.6 \times 10^{-4}$	Polycrystalline (ρ = 0.23 ohm cm) (μ_n = 29 cm^2/V sec)	0°K	14
	1.36		109°K	18
	1.27 ± 0.01		293°K	18
	1.25		300°K	11

Energy Level

	Value	Sample	Temperature	Ref.
E_1	0.026 eV	Single Crystalline, p-type $n = 8.5 \times 10^{17}/cm^3$	77-290°K	5
	0.047 eV	$n = 3 \times 10^{16}/cm^3$ cadmium impurity		

INDIUM PHOSPHIDE

Hall Coefficient



Hall coefficient and carrier concentration of two n- and one p-conducting indium phosphide compounds.

[Ref. 4]

INDIUM PHOSPHIDE

Irradiation Effects

See Electrical Conductivity

Lifetime--Diffusion Length

Symbol	Value	Type	Test Conditions	Ref.
L_n	130 mu = 0.13 mm	p-n junction, single		6
τ_i	2×10^{-6} sec.			6
L	0.2 mm (est.)		From photoconductive threshold	18
τ	5×10^{-6} sec. (est.)			18

SEMICONDUCTOR MATERIALS

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INDIUM PHOSPHIDE

Magnetoelectric Properties

Crystal	Hall mobility (cm^2/V-sec)	Electron concentration (cm^{-3})	Temperature (°K)	Magnetoresistance $\Delta\rho/\rho_0 H^2$ (10^6 cm^4/v^2-sec^2) I [110] H [110]	I [110] H [001]	I [110] H [110]
192†	4600	6×10^{15}	292	0·02	1·11	1·09††
192	4200	6×10^{15}	294	0·05	1·3	1·5
54	2800	6×10^{15}	290	0·37	1·15	1·22
T43	4300	$4{\cdot}3 \times 10^{16}$	293	0·20	0·66	0·25
T43†	4000	5×10^{16}	292	0·02	0·28	0·21††
51	3150	$1{\cdot}2 \times 10^{17}$	290	0·03	0·13	0·10
1	3150	$1{\cdot}4 \times 10^{17}$	289	0·31	0·55	0·26
T5†	2750	$4{\cdot}6 \times 10^{17}$	293	0·02	0·14	0·10††
T43	8700	$4{\cdot}3 \times 10^{16}$	77	0·6	8·2	6·6
T43†	6900	5×10^{16}	77	0·09	6·2	5·8 ††

† The side contacts were 0·002 in. diameter gold wires welded to the crystal.

†† Purest

Magnetoresistance of n-type InP. In the conventional notation three coefficients b, c, and d may be defined by

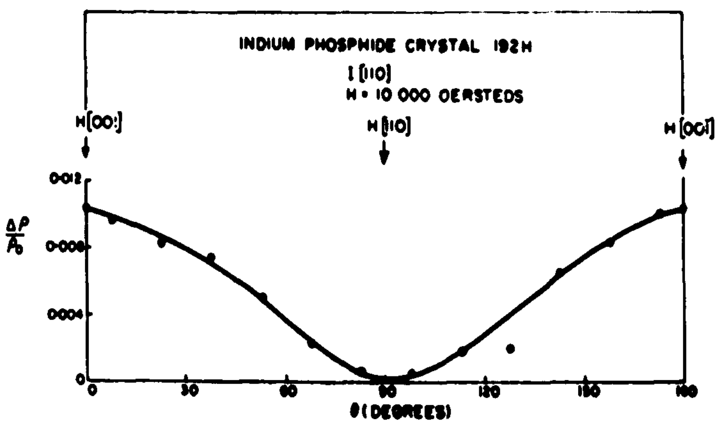
$$\frac{\Delta\rho}{\rho_0 H^2} = b + \frac{(I \cdot H)^2}{I^2 H^2} c + \frac{\sum_i I_i^2 H_i^2}{I^2 H^2} d.$$

The last three columns of Table refer respectively to measurements of b + c + 1/2d, b, and b + 1/2d.

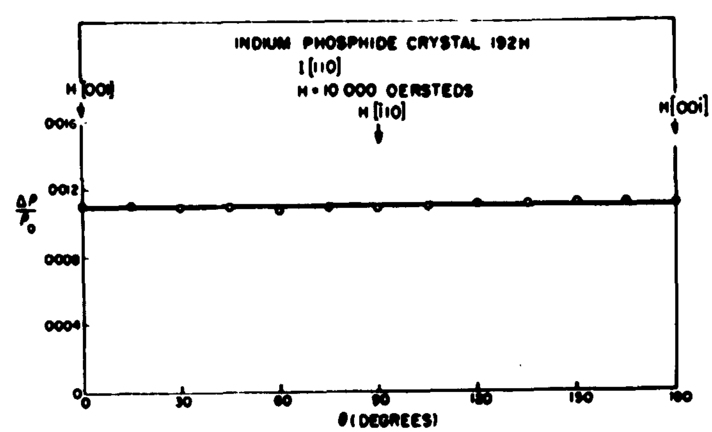
[Ref. 7]

INDIUM PHOSPHIDE

Magnetoelectric Properties



The magnetoresistance of n-type InP crystal 192 as a function of the angle the magnetic field makes with the [001] direction in the ($\bar{1}10$) plane. The temperature was 292°K. [Ref. 7]



The magnetoresistance of n-type InP crystal 192 as a function of the angle the magnetic field makes with the [001] direction in the (110) plane. The temperature was 292°K. [Ref. 7]

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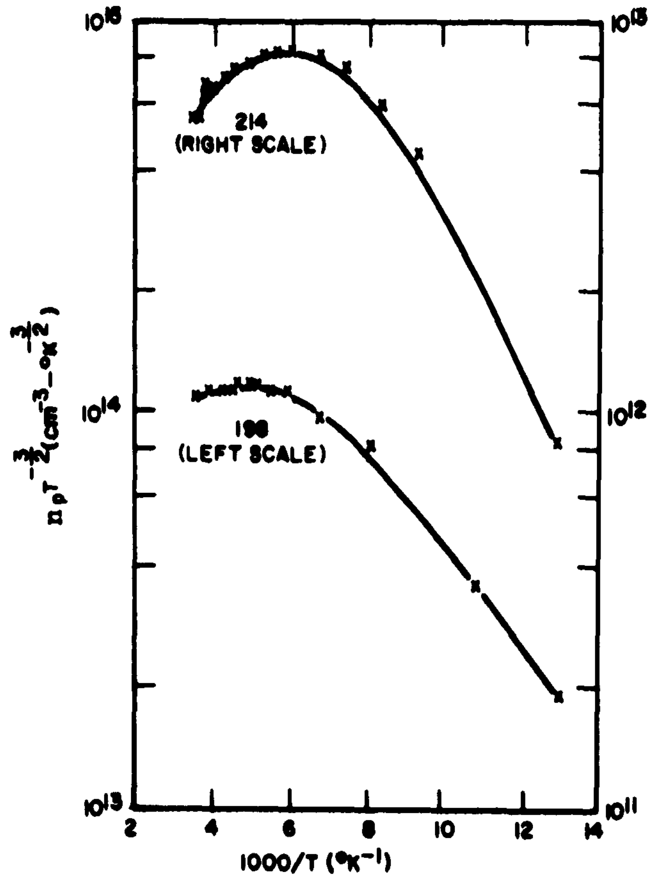
INDIUM PHOSPHIDE

Mobility



The product of hole concentration and (temperature)-1.5 as a function of 1/T. The slope at low temperatures was used to estimate the ionization energy. [Ref. 5]

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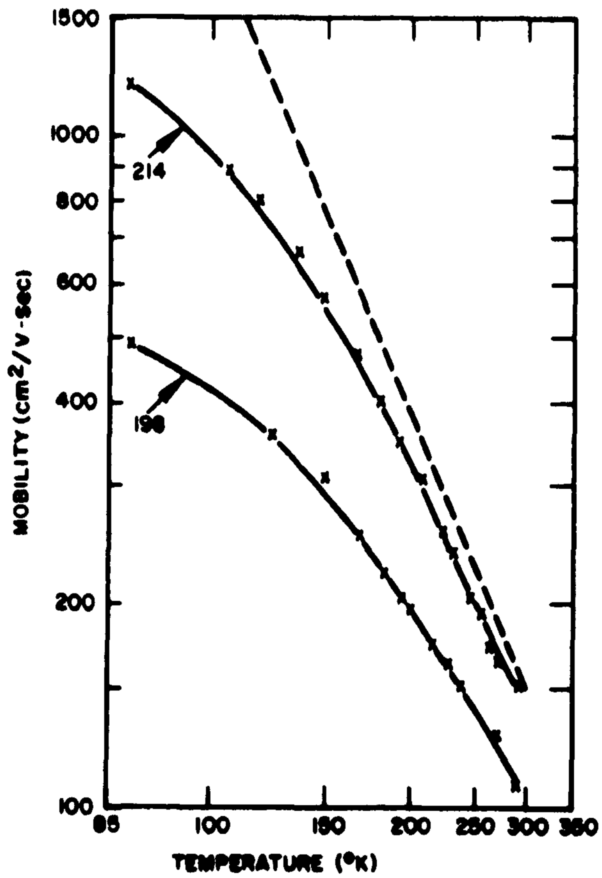
INDIUM PHOSPHIDE

Mobility



The Hall mobility of p-type InP crystals as a function of temperature. The dashed curve is the lattice mobility calculated from the 214 curve, assuming $m^*=0.2m_0$. [Ref. 5]

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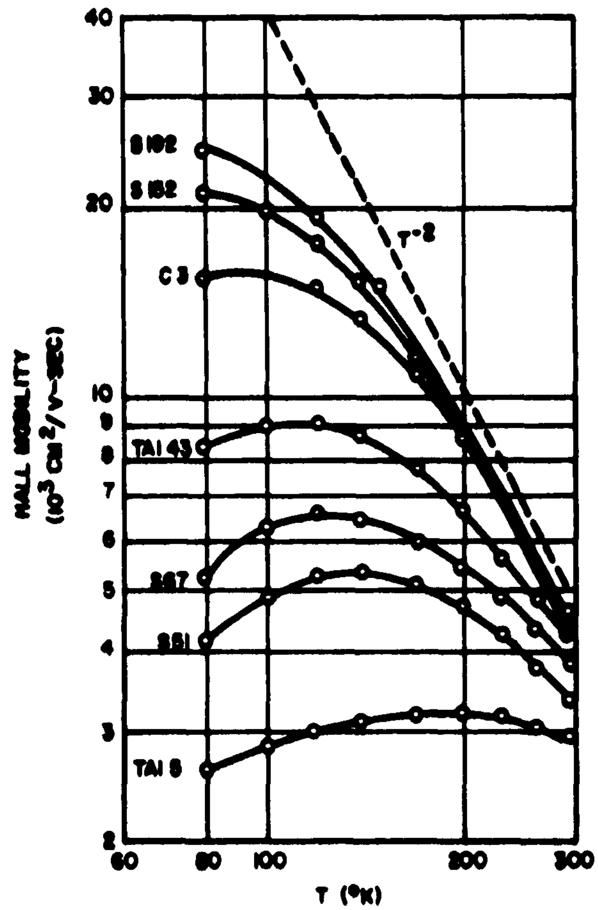
Mobility



Measured Hall mobilities μ_H as a function of temperature for n-type indium phosphide. Values for C3 have been adjusted to give 4300 cm^2/v-sec at 290°K. single crystal. [Ref. 8]

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INDIUM PHOSPHIDE

Mobility

Symbol	Value	Type	Temp.	Test Conditions	Ref.
μ_n	4600		300°K	$n=5 \times 10^{16}/cm^3$	20
μ_p	100		300°K	$n=3 \times 10^{17}/cm^3$	20
μ	190	p-single	300°K	$n=5 \times 10^{16}/cm^3$ for	3
μ	1200	p-single	77°K	cadmium doping	3
μ_n	4500	n-single	300°K	$n=6 \times 10^{15}/cm^3$	3
μ_n	23400	n-single	77°K	pure	3

n-type Crystal	Concentration of electrons at 290°K, $10^{16} cm^{-3}$	Mobility at 290°K, $cm^2/v\text{-}sec$	Mobility at 77°K, $cm^2/v\text{-}sec$
TA15	54	2910	2600
S51	7.4	3400	4170
S67	0.37	3800	4170
TAI43	4.3	4200	8300
C3	2.6	3800	13,500
S152	0.83	4300	21,000
S192†	0.63	4500	23,400

† These values represent the results for a number of samples.

[Ref. 8]

SEMICONDUCTOR MATERIALS

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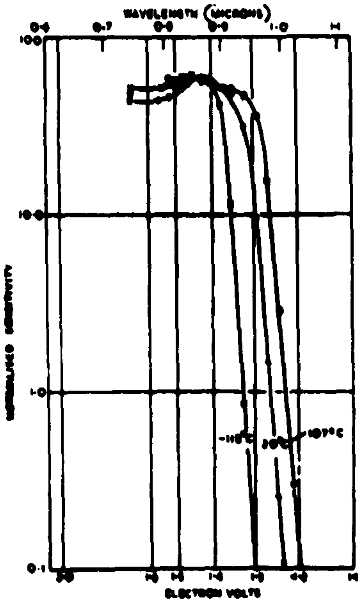
INDIUM PHOSPHIDE

__Photoelectronic Properties__



Response curves for a p-type indium phosphide photodiode.

Polycrystal
Diode was a point contact on p-type polycrystalline material. The photovoltaic threshold (where response is 1/2 peak value) is given as a function of temperature by [Ref. 18]

$E_z = 1.44 - 4.5 \times 10^{-4}$ TeV

__Piezoelectric Properties__

Piezoresistance

π	n-single	300°K	$n = 2.5 \times 10^{16}$ isotropic compression	[Ref. 19]

$-1/P \cdot \delta R/R = (\pi_{11} + 2\pi_{12}) = -(8.2 \pm 0.3) \times 10^{-12}$ cm²/dyne

Current and stress along (110) direction:

$1/X \cdot \delta R/R = 1/2(\pi_{1} + \pi_{12} + \pi_{44}) = -(1.3 \pm 0.5) \times 10^{-12}$ cm²/dyne

SEMICONDUCTOR MATERIALS

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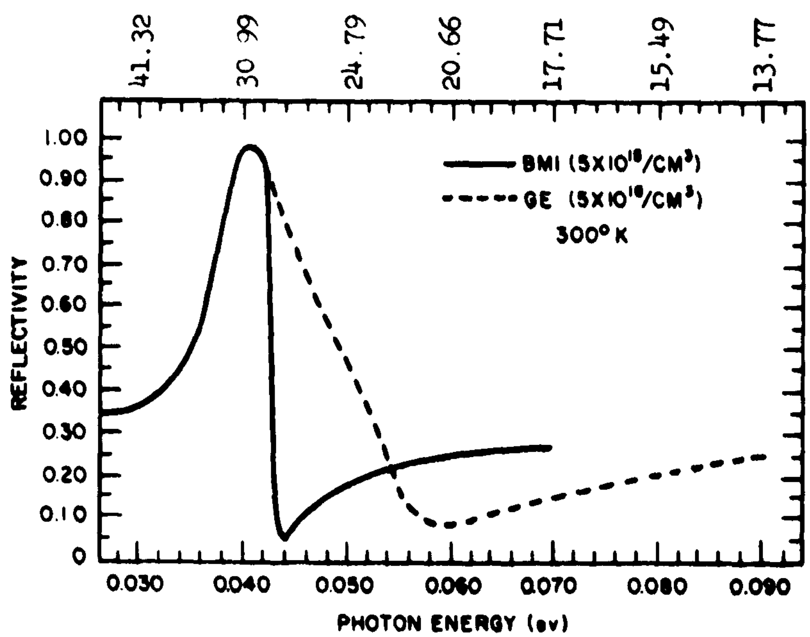
INDIUM PHOSPHIDE

Reflectivity

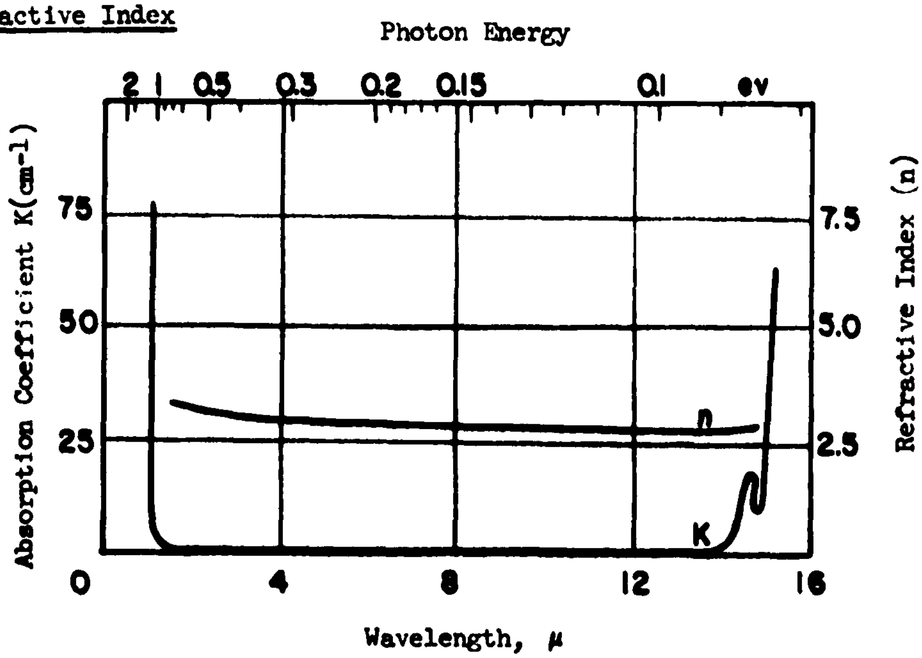


Reflectance spectra (300°K) of InP for two samples having different free electron densities as noted. Low concentration sample exhibits clear reststrahl peak from which longitudinal and transverse optical phonon energies are found to be $h\omega_l$ = 0.043eV and $h\omega_t$ = 0.036eV. Sample are n-type, polycrystal. [Ref. 13]

Symbol	Value	Type	Test Conditions	Ref.
R	0.25	n-poly	λ = 4-15 μ ρ = 0.1 ohm cm	16

INDIUM PHOSPHIDE

Refractive Index



Indium Phosphide; $\rho = 0.1$ Ωcm, n-type, single crystal. [Ref. 15]
n = 3.1 in infra-red.

Symbol	Value	Type	Test Conditions	Ref.
n	3.26		Room Temperature	10

Thermoelectric Properties

Seebeck Effect

S	-400 μ V/°C	n-single	300°K n=5 x 10^{15}	13
S	-100 μ V/°C	n-single	300°K n=5 x 10^{18}	13

SEMICONDUCTOR MATERIALS

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INDIUM PHOSPHIDE

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DATA SHEET

ELECTRICAL AND ELECTRONIC PROPERTIES

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INDIUM PHOSPHIDE

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PUBLICATIONS OF THE ELECTRONIC PROPERTIES INFORMATION CENTER

Summary Reviews and Data Sheets

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