Si	- Silicon	Ge	- Germanium
GaP	- Gallium Phosphide	GaAs	- Gallium Arsenide
InAs	- Indium Arsenide	C	- Diamond
GaSb	- Gallium Antimonide	InSb	- Indium Antimonide
InP	- Indium Phosphide	$GaAs_{1-x}Sb_x$	- Gallium Arsenide Antimonide
$Al_xGa_{1-x}As$	- Aluminium Gallium Arsenide		
AlN	- Aluminium Nitride	InN	- Indium Nitride
BN	- Boron Nitride	GaN	- Gallium Nitride

We are going to add new data for:

$Ga_xIn_{1-x}As_ySb_{1-y}$	- Gallium Indium Arsenide Antimonide	$Ga_xIn_{1-x}P$	- Gallium Indium Phosphide
$Ga_xIn_{1-x}As$	- Gallium Indium Arsenide	$Ga_xIn_{1-x}Sb$	- Gallium Indium Antimonide
$InAs_{1-x}Sb_x$	- Indium Arsenide Antimonide	$Ga_xIn_{1-x}As_yP_{1-y}$	- Gallium Indium Arsenide Phosphide
$Si_{1-x}Ge_x$	- Silicon Germanium	SiC	- Silicon Carbide

This section is intended to systematize parameters of semiconductor compounds and heterostructures based on them. Such a WWW-archive has a number of advantages: in particular, it enables physicists, both theoreticians and experimentalists, to rapidly retrieve the semiconducting material parameters they are interested in. In addition, physical parameters - optical, electrical, mechanical, etc. - will be presented in the framework of the electronic archive for both the known and new semiconducting compounds. As the starting point in creating the database served the voluminous reference book *"Handbook Series on Semiconductor Parameters"* vol. 1,2 edited by M. Levinstein, S. Rumyantsev and M. Shur, World Scientific, London, 1996, 1999. We express sincere gratitude to M.E. Levinstein for help and attention to this work. A great number of reference books and original papers cited at the end of this section have been used in compiling the information database.

We would like to express our warmest gratitude to all colleages presented their original data and literature references to complete these archive. If you find these archive pages helpful, and use the data retrieved through the server for your reseach, we would appreciate acknowledging it in your papers.

We would be indebted very much for any of your further suggestions and comments.

Authors


mytrix

$Ga_x In_{1-x} As$

$Ga_x In_{1-x} As$

Basic Parameters at 300 K

	$Ga_{0.47}In_{0.53}As$	**$Ga_xIn_{1-x}As$**	*Remarks*	*Referens*
Crystal structure	Zinc Blende	Zinc Blende	300 K	
Group of symmetry	T_d^2-F43m	T_d^2-F43m	300 K	
Number of atoms in 1 cm^3	$3.98 \cdot 10^{22}$	$(3.59-0.83x) \cdot 10^{22}$	300 K	
Bulk modulus	$6.62 \cdot 10^{11}$ dyn/cm^2	$(5.81+1.72x) \cdot 10^{11}$ dyn/cm^2	300 K	*Goldberg Yu.A. & N.M. Schmidt (1999)*
Debye temperature	330 K	(280+110x) K	300 K	
Density	5.50 g•cm^{-3}	(5.68-0.37x) g•cm^{-3}	300 K	
Melting point, T_m		~= 1100° C		
Specific heat	0.3 J g^{-1}°C^{-1}		300 K	
Thermal conductivity	0.05 W cm^{-1} °C^{-1}	see *Temerature dependences*		
Thermal expansion coefficient, linear	5.66×10^{-6} °C^{-1}	see *Temerature dependences*		
Dielectric constant (static)	13.9	$15.1-2.87x+0.67x^2$	300 K	
Dielectric constant (high frequency)	11.6	$12.3-1.4x$	300 K	
Infrared refractive index n	3.43 cm^2 $V^{-1}s^{-1}$	(3.51-0.16x) $V^{-1}s^{-1}$	300 K	
Radiative recombination coefficient	0.96×10^{-10} cm^2/s	see *Impact Ionization*	300 K	
Energy gaps, E_g	0.74 eV	$(0.36+0.63x+0.43x^2)$ eV $(0.4105+0.6337x+0.475x^2)$ eV	300 K 2 K	*Goetz et al.(1983)*
Effective electron mass m_e	0.041 m_o (at n= $2 \cdot 10^{17}$ cm^{-3})	$(0.023+0.037x+0.003x^2)$ m_o	300 K	*Pearsall (1982)*
Effective hole masses m_h	0.45 m_o	(0.41+0.1x) m_o	300 K	*Goldberg Yu.A. & N.M. Schmidt (1999)*
Effective hole masses m_{lp}	0.052 m_o	(0.026+0.056x) m_o	300 K	
Effective hole masses (split-off band) m_{so}		~= 0.15 m_o	300 K	
Electron affinity	4.5 eV	(4.9-0.83x) eV	300 K	
Lattice constant	5.8687 A	(6.0583-0.405x) A	300 K	
Piezoelectric constant		e_{14}= -(0.045+0.115x) C/m^2	300 K	
Optical phonon energy	34 meV	see *Raman-active phonon modes*	300 K	


mytrix

$Ga_x In_{1-x} As$

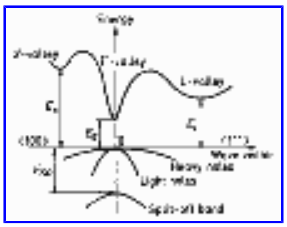
Band structure and carrier concentration

Basic Parameters for $Ga_xIn_{1-x}As_yP_{1-y}$

Zinc Blende crystal structure

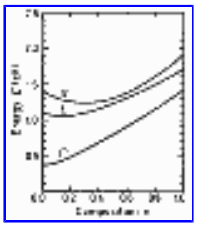
	$Ga_{0.47}In_{0.53}As$	**$Ga_xIn_{1-x}As$**	*Remarks*	*Referens*
Energy gaps, E_g	0.74 eV	$(0.36+0.63x+0.43x^2)$ eV	300 K	*Goetz et al.(1983)*
Energy gaps, E_g		$(0.4105+0.6337x+0.475x^2)$ eV	2 K	*Goetz et al.(1983)*
Electron affinity	4.5 eV	$(4.9-0.83x)$ eV	300 K	
Conduction band				
Energy separation between X valley and top of the valence band E_X	1.33 eV	$(1.37-0.63x+1.16x^2)$ eV	300 K	*Goetz et al.(1983)*
Energy separation between L valley and top of the valence band E_L	1.2 eV	$(1.08-0.02x+0.65x^2)$ eV	300 K	*Goetz et al.(1983)*
Effective conduction band density of states	$2.1 \cdot 10^{17}$ cm^{-3}	see *Temerature dependences*		
Valence band				
Energy separation of spin-orbital splitting E_{so}	***	***		
Effective valence band density of states	$7.7 \cdot 10^{18}$ cm^{-3}	see *Temerature dependences*		
Intrinsic carrier concentration	$6.3 \cdot 10^{11}$ cm^{-3}	see *Temerature dependences*		

Band structure for $Ga_xIn_{1-x}As$



$Ga_xIn_{1-x}As$ (zinc blende, cubic). Band structure
Important minima of the conduction band and maxima of the valence band..

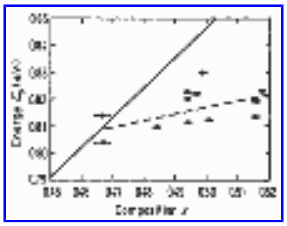
For details see *Goldberg Yu.A. & N.M. Schmidt (1999)* .



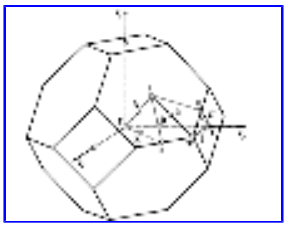
$Ga_xIn_{1-x}As$. Energy gap E_g Energy separations between •- ,X-, and L -conduction band minima and top of the valence band vs. composition parameter *x*.

Porod and Ferry (1983)

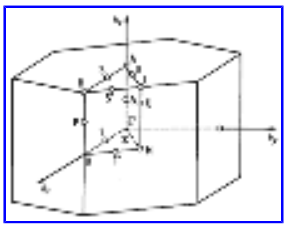
Interfacial elastic strain induced by lattice parameter mismatch between epilayer and substrate results in significant band-gap shifts:



$Ga_xIn_{1-x}As$. Energy band gap Eg of unstrained (solid line) and strained (dashed line and experimental points) vs. composition parameter *x*.
Solid line is calculated according to Eg= $(0.4105+0.6337x+0.475x^2)$ eV.
Experimental points are obtained at **4K.**
Kuo et al.(1985)



Brillouin zone of the face centered cubic lattice, the Bravais lattice of the diamond and zincblende structures.

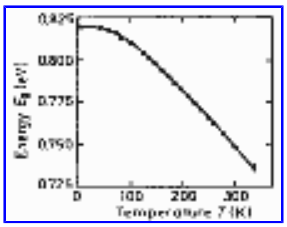


Brillouin zone of the hexagonal lattice.

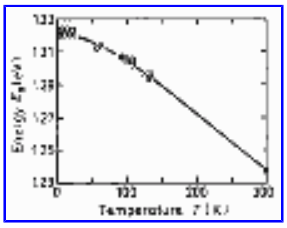
Temperature Dependences

$E_g\,(x,T)= 0.42 + 0.625x - [5.8/(T+300)-4.19/(T+271)]\cdot 10^{-4}T^2x - 4.19\cdot 10^{-4}T^2/(T+271) + 0.475x^2$ (eV)	$Ga_xIn_{1-x}As$	*Paul et al.(1991)*
$E_g\,(x,T)= E_g\,(0) + (6x^2 - 8.6x + 5.2)\cdot 10^{-4}\,T^2/(337x^2 - 455x + 196)$	$Ga_xIn_{1-x}As$ on Ga As	*Karachevtseva et al.(1994)*
$E_g\,(x,T)= 0.42 + 0.625x - [5.8/(T+300)-4.19/(T+271)]\cdot 10^{-4}T^2x - 4.19\cdot 10^{-4}T^2/(T+271) + 0.475x^2$ (eV)	$Ga_xIn_{1-x}As$	

where *T* is temperature in degrees K



$Ga_{0.47}In0.53As$. Energy gap E_g of vs. temperature
Points are experimental data.
Solid line is theoretical calculation.
$E_g(0)$=821.5 ± 0.2 meV.
Zielinski et al.(1986)

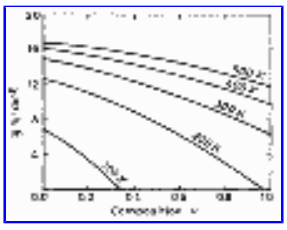


$Ga_{0.87}In0.13As$. Energy gap E_g of vs. temperature
Points are experimental data.
Solid line -- $1.321 - 4.1 \cdot 10^{-4} T^2/(T+139)$
Karachevtseva et al.(1994)

Lasing wavelength •0

Intrinsic carrier concentration:

$n_i = (N_c \cdot N_v)^{1/2} exp(-E_g/(2k_BT)) \sim= 4.82 \times 10^{15} \cdot [(0.41-0.09x)^{3/2} + (0.027+0.047x)^{3/2}]1^{/2} \times$
$x(0.025+0.043x)^{3/4}[\ T^{3/2} \exp(-\bullet/2)(1+3.75/\bullet +3.28/\bullet^2 -2.46/\bullet^3)^{1/2}\ ]\ (cm^{-3})$,
where $\bullet = E(x,T)/2kT$
Paul et al.(1991).



$Ga_xIn_{1-x}As$. Intrinsic carrier concentration vs. temperature for $Ga_xIn_{1-x}As$.
T = 100K; 200K; 300K; 400K; 500K;
Paul et al.(1991)

n_i = 6.3x1011 cm-3 for **$Ga_{0.47}In_{0.53}As$** at **300K**

Effective density of states in the conduction band: N_c

$N_c \sim= 4.82 \times 10^{15} \cdot (m_\bullet /m_0)^{3/2} T^{3/2}\ (cm^{-3}) \sim= 4.82 \times 10^{15} \cdot (0.023+0.037x+0.003x^2)^{3/2} T^{3/2}\ (cm^{-3})$:

Effective density of states in the valence band: N_v

$N_v \sim= 4.82 \times 10^{15} \cdot (m_h/m_0)^{3/2} T^{3/2}\ (cm^{-3}) = 4.82 \times 10^{15} \cdot (0.41-0.1x)^{3/2} T^{3/2}\ (cm^{-3})$:

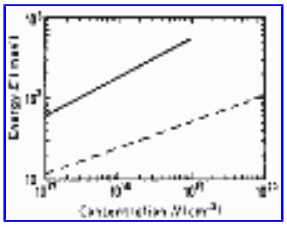
Dependence on Hydrostatic Pressure

$E_g\ (0.47,P) \sim= (0.796+10.9 \times 10^{-3} \cdot P -30 \times 10^{-6} \cdot P^2)$ eV	80K, **$Ga_{0.47}In_{0.53}As$**	x=0.47	*Lambkin and Dunstan (1988)*
$E_g\ (0.47,P) \sim= (0.733+11.0 \times 10^{-3} \cdot P -27 \times 10^{-6} \cdot P^2)$ eV	300K, **$Ga_{0.47}In_{0.53}As$**	x=0.47	

E_g (0.0, P)~= (E_g (0)+4.8x 10^{-3} • P) eV	300K, **InAs**	x=0.
E_g (1.0, P)~= (E_g (0)+12.6x 10^{-3} • P -37.7x10^{-6} • P^2) eV	300K, **GaAs**	x=1.

where P is pressure in kbar.

Energy gap narrowing at high doping levels



$Ga_{0.47}In0.53As$. Energy gap narrowing E_g vs. donor (solid line) **and acceptor** (dashed line) **doping density**
solid line -- donor doping density;
dashed line -- acceptor doping density
Jain et al. (1990)

• E_g ~= (A • $N^{1/3}$ 10^{-9} +B • $N^{1/4}$ 10^{-7} +C • $N^{1/2}$ 10^{-12}) meV	300K, **$Ga_{0.47}In_{0.53}As$**	x=0.47

where

n : A=15.5; B=1.95; C=159	300K, **$Ga_{0.47}In_{0.53}As$**	x=0.47
p : A= 9.2; B=3.57; C=3.65	300K, **$Ga_{0.47}In_{0.53}As$**	x=0.47

N -- carrier concentration in cm^{-3}

Band Discontinuities at Heterointerfaces

Band discontinuities at **$Ga_xIn_{1-x}As/Al_yGa_{1-y}As$** heterointerface *Shur (1990)*.

			Referens
Conduction band discontinuity	• E_v =(• E_g - • E_v) eV		*Shur (1990)*
Valence band discontinuity	• E_c = (0.44 •E_{gg}) eV		*Shur (1990)*

where •E_{gg} (eV) = [1.247y + 1.5(1-x) - 0.4(1-x)^2] (eV) is the difference between •-valleys in $Ga_xIn_{1-x}As$ and $Al_yGA1-yAs$.

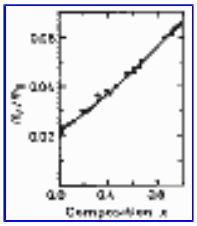
Energy gap E_g discontinuity :	• E_g = • E_{gg}	for y<0.45	
Energy gap E_g discontinuity :	• E_g = 0.476 +0.125y + 0.143y^2 +1.5(1-x) - 0.4(1-x)^2	for y>0.45	
Band discontinuities	• E_v ~= 0.38 eV • E_c ~= 0.22 eV	at **$Ga_{0.47}In_{0.53}As/InP$** heterointerface	*Adachi (1992); Hybertsen (1991)*
Band discontinuities	• E_v ~= 0.2 eV • E_c ~= 0.52 eV	at **$Ga_{0.47}In_{0.53}As/Al_{0.48}In_{0.52}As$** heterointerface	*Adachi (1992); Hybertsen (1991)*
	• E_c /• E_g = [0.653 + 0.1(1-x)] eV	at **$Ga_xIn_{1-x}As/Al_xIn_{1-x}As$** heterointerface	*Wolak et al.(1991)*

Effective Masses and Density of States:

Electrons

For wurtzite crystal structure the surfaces of equal energy in • valley should be ellipsoids, but effective masses in z direction and perpendicular directions are estimated to be approximately the same:

Effective Electron Masses		*Remarks*	*Referens*
Effective electron mass $m_e = m_•$	$0.023 -0.037x +0.003x^2$ m_o	$Ga_xIn_{1-x}As$; 300K; for • - valley	*Goldberg Yu.A. & N.M. Schmidt (1999)*
Effective electron mass m_e	$m_• = 0.041\ m_o$ at n= $2x•10^{17}$ cm^{-3} $m_• = 0.074\ m_o$ at n= $6x•10^{18}$ cm^{-3}	$Ga_{0.47}In_{0.53}As$; x=0.47	*Pearsall (1982)*
	$m_L = 0.29\ m_o$; (L - valley)	$Ga_{0.47}In_{0.53}As$; x=0.47	*Pearsall (1982)*
	$m_X = 0.68\ m_o$; (X - valley)		



$Ga_xIn_{1-x}As$. Electron effective mass vs. concentration x for $Ga_xIn_{1-x}As$; **300K**
Adachi (1992))

Holes

Effective Masses for Zinc Blende GaN		*Remarks*	*Referens*
Effective hole masses (heavy) m_h	m_h ~= (0.41 -0.1x) m_o	$Ga_xIn_{1-x}As$; 300K;	*Goldberg Yu.A. & N.M. Schmidt (1999)*
Effective hole masses (light) m_{lp}	m_{lp} ~= (0.026 -0.056x) m_o	$Ga_xIn_{1-x}As$; 300K;	
Effective hole masses (split-off band) m_s	m_{so} ~= 0.15 m_o	$Ga_xIn_{1-x}As$; 300K;	

Donors and Acceptors

Ionization energies of Shallow Donors		*Remarks*	
Sn, Ge, Si, C	~ 5 meV	$Ga_{0.47}In_{0.53}As$; x=0.47	*Goldberg Yu.A. & N.M. Schmidt (1999)*
Sn, Ge, Si, S, Se, Te	> 1 meV	InAs; x=0	
Sn, Ge, Si, S, Se, Te	~ 6 meV	GaAs; x=1	

Ionization energies of Shallow Acceptor

Mg	~ 25 meV	$Ga_{0.47}In_{0.53}As$; x=0.47	*Goldberg Yu.A. & N.M. Schmidt (1999)*
Zn	~ 20 meV	$Ga_{0.47}In_{0.53}As$; x=0.47	
Cd	~ 30 meV	$Ga_{0.47}In_{0.53}As$; x=0.47	
Mn	~ 50 meV	$Ga_{0.47}In_{0.53}As$; x=0.47	
Fe	~ 150 meV	$Ga_{0.47}In_{0.53}As$; x=0.47	

(above valence band), 280, 370, and 440 below conduction band

Mg	~ 25 meV	$Ga_xIn_{1-x}As$; $0<x<1$
Be	~ 25 meV	$Ga_xIn_{1-x}As$; $0<x<1$
Cd	~ 8-20 meV	$Ga_xIn_{1-x}As$; $0<x<1$

(above valence band), 280, 370, and 440 below conduction band

Sn-10; Ge-14; Si-20; Cd-15; Zn-10 meV	InAs; x=0
C - 20, Si - three acceptor levels ~ 30, 100, and 220, Ge - 30, Zn - 25, Sn - 20.	GaAs; x=1

$Ga_x In_{1-x} As$

Electrical properties

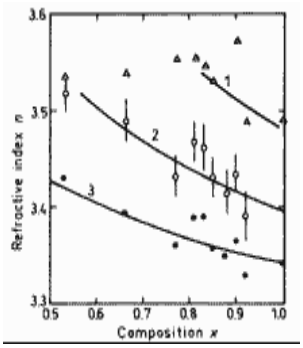
Basic Parameters

	$Ga_{0.47}In_{0.53}As$	**$Ga_xIn_{1-x}As$**	*Remarks*	*Referens*
Breakdown field	• $2 \cdot 10^5$ V/cm	$\cdot(2 \div 4) \cdot 10^5$ V/cm	300 K	*Goldberg Yu.A. & N.M. Schmidt (1999)*
Mobility electrons	$<12 \cdot 10^3$ cm^2 V^{-1}s^{-1}	$(40\text{-}80.7x\text{+}49.2x^2) \cdot 10^3$ cm^2 V^{-1}s^{-1}	300 K	
Mobility holes	<300 cm^2 V^{-1}s^{-1}	~300÷400 cm^2 V^{-1}s^{-1}	300 K	
Diffusion coefficient electrons	<300 cm^2/s	$(10\text{-}20.2x\text{+}12.3x^2) \cdot 10^2$ cm^2/s	300 K	
Diffusion coefficient holes	<7.5 cm^2/s	~7÷12 cm^2/s	300 K	
Electron thermal velocity	$5.5 \cdot 10^5$ m/s	$(7.7\text{-}5.9x\text{+}2.6x^2) \cdot 10^5$ m/s	300 K	
Hole thermal velocity	$2 \cdot 10^5$m/s	$(1.8 \div 2) \cdot 10^5$m/s	300 K	
Surface recombination velocity		$<10^6$ cm/s	300 K	
Radiative recombination coefficient	$0.96 \cdot 10^{-10}$ cm^3/s		300 K	
Auger coefficient	$7 \cdot 10^{-29}$ cm^6/s		300 K	

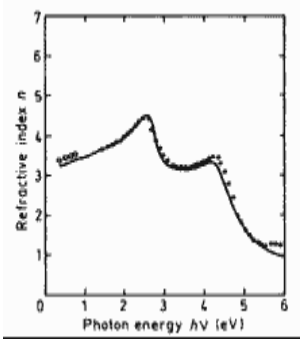
$Ga_x In_{1-x} As$

Optical properties

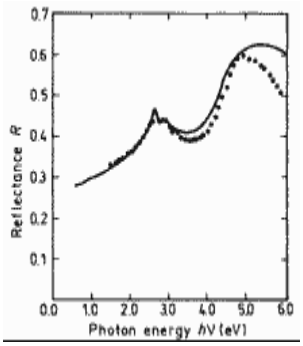
	$Ga_{0.47}In_{0.53}As$	$Ga_xIn_{1-x}As$	*Remarks*	*Referens*
Dielectric constant (static)	13.9	$15.1-2.87x+0.67x^2$	300 K	
Dielectric constant (high frequency)	11.6	$12.3-1.4x$	300 K	
Infrared refractive index *n*	3.43 $cm^2 V^{-1}s^{-1}$	$(3.51-0.16x) V^{-1}s^{-1}$	300 K	*Goldberg Yu.A. & N.M. Schmidt (1999)*
Radiative recombination coefficient	0.96 x 10^{-10} cm^2/s	see *Impact Ionization*	300 K	
Optical phonon energy	34 meV	see *Raman-active phonon modes*	300 K	



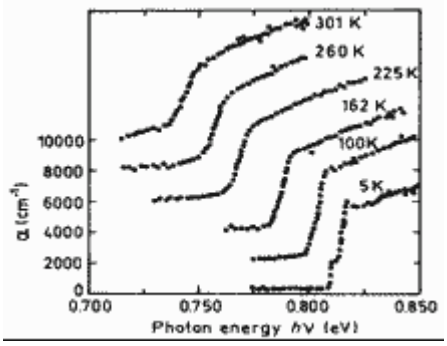
Refractive index *n* versus alloy composition *x* at different photon energies
1 1.2 eV
2 0.9 eV
3 0.6 eV.
Takagi (1978)



Refractive index *n* versus photon energy for *x*=0.47. 300 K.
Adachi (1992)

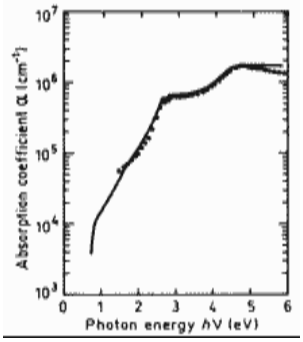


Normal incidence reflectivityversus photon energy for *x*=0.47. 300 K.
Adachi (1992)

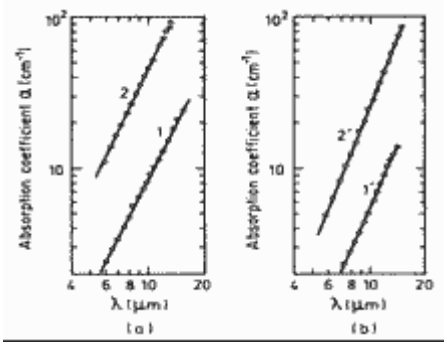


The absorption coefficient versus photon energy at different temperatures for *x*=0.47.

Electron concentration n_o=8•10^{14} cm^{-3}.
Curves are shifted vertically for clarity.
Zielinski et al. (1986)



The absorption coefficient versus photon energy for *x*=0.47, 300 K.
Adachi (1992)



Free carrier absorption coefficient versus wavelength.
a - T=300 K, b - T=92 K.
1 *x*=0.08, N_d=1.4•10^{17} cm^{-3}
2 *x*=0.1 N_d=5.4•10^{17} cm^{-3}.
Aliev et al. (1987)

A ground state Rydberg energy R_{X1}=2.5 meV (for *x*=0.47).

$Ga_x In_{1-x} As$

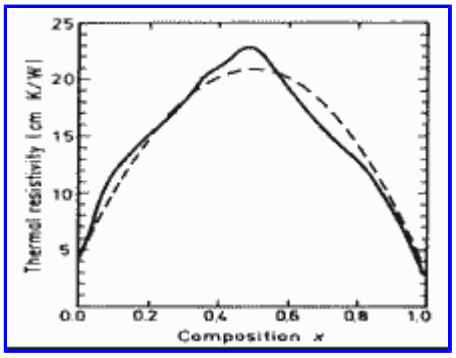
Thermal properties

Basic parameters

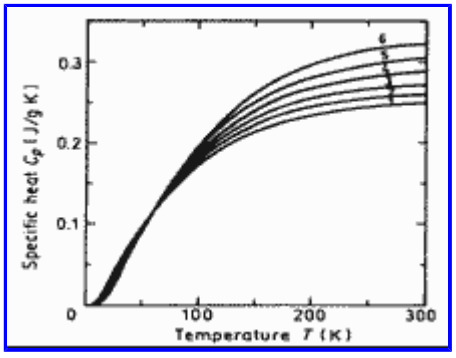
	$Ga_{0.47}In_{0.53}As$	$Ga_xIn_{1-x}As$	*Remarks*	*Referens*
Bulk modulus	$6.62 \cdot 10^{11}$ dyn/cm^2	$(5.81+1.72x) \cdot 10^{11}$ dyn/cm^2	300 K	*Goldberg Yu.A. & N.M. Schmidt (1999)*
Debye temperature	330 K	(280+110*x*) K		
Density	5.50 g/cm^3	5.68-0.37x g/cm^3	300 K	*Goldberg Yu.A. & N.M. Schmidt (1999)*
Melting point, T_m		~= 1100° C		
Specific heat	0.3 J g^{-1}°C^{-1}			
Thermal conductivity	0.05 W cm^{-1} °C^{-1}	see *Temerature dependences*		
Thermal expansion coefficient, linear	5.66×10^{-6} °C^{-1}	see *Temerature dependences*		
Lattice constant	5.8687 A	(6.0583-0.405*x*) A		

Thermal conductivity

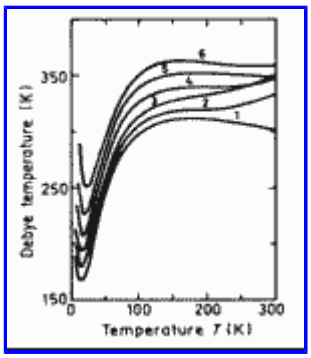
Thermal conductivity 0.05 W cm^{-1} °C^{-1}



$Ga_xIn_{1-x}As$. Thermal resistivity vs. composition parameter *x* 300K
Solid lines shows the experimental data.
Dashed lines are the results theoretical calculation.
Adachi (1983)



$Ga_xIn_{1-x}As$. Specific heat at constant pressure vs. temperature for different concentrations *x*.
1 - x=0.0;
2 - x=0.2;
3 - x=0.4;
4 - x=0.6;
5 - x=0.8.
6 - x=1.0.
Sirota et al. (1982)



$Ga_xIn_{1-x}As$. Debye temperature vs. temperature for different concentrations *x*.
1 - x=0.0;
2 - x=0.2;
3 - x=0.4;
4 - x=0.6;
5 - x=0.8.
6 - x=1.0.
Sirota et al. (1982)

Lattice properties

Lattice parameters

	Remarks	*Referens*
Lattice constant, *a* (6.0583-0.405*x*) A	$Ga_xIn_{1-x}As$; 300K	*Adachi (1982)*
5.8687 A	$Ga_{0.47}In_{0.53}As$; 300K, *x*=0.47	

Linear thermal expansion coefficient

$Ga_x In_{1-x} As$

Mechanical properties, elastic constants, lattice vibrations

Basic Parameter

	$Ga_{0.47}In_{0.53}As$	$Ga_xIn_{1-x}As$	*Remarks*	*Referens*
Bulk modulus	$6.62 \cdot 10^{11}$ dyn/cm^2	$(5.81+1.72x) \cdot 10^{11}$ dyn/cm^2	300 K	*Goldberg Yu.A. & N.M. Schmidt (1999)*
Debye temperature	330 K	(280+110*x*) K		
Density	5.50 g/cm^3	5.68-0.37x g/cm^3	300 K	*Goldberg Yu.A. & N.M. Schmidt (1999)*
Melting point, T_m		~= 1100° C		
Specific heat	0.3 J g^{-1}°C^{-1}			
Thermal conductivity	0.05 W cm^{-1} °C^{-1}	see *Temerature dependences*		
Thermal expansion coefficient, linear	5.66×10^{-6} °C^{-1}	see *Temerature dependences*		
Hardness on the Mohs scale		***		
Surface microhardness (using Knoop's pyramid test)		see *Micro Hardness*		
Piezoelectric constant		e_{14}= -(0.045+0.115*x*) C/m^2		
Cleavage plane	{110}	{110}		
Lattice constant	5.8687 A	(6.0583-0.405*x*) A		

Elastic constants at 300K

$C_{11} = (8.34 + 3.56x) \cdot 10^{11}$ dyn/cm^2
$C_{12} = (4.54 + 0.8x) \cdot 10^{11}$ dyn/cm^2
$C_{44} = (3.95 + 2.01) \cdot 10^{11}$ dyn/cm^2

Cleavage plane	{110}
Bulk modulus (compressibility^{-1})	
$B_s=(C_{11}+2C_{12})/3$	$B_s = (5.81+1.72x) \cdot 10^{11}$ dyn/cm^2
Anisotropy factor	

$C'=(C_{11}-C_{12})/2$ A = (0.48+0.07x)

Shear modulus

$C'=(C_{11}-C_{12})/2$ C' = (1.9+1.38x)•10^{11} dyn/cm^2

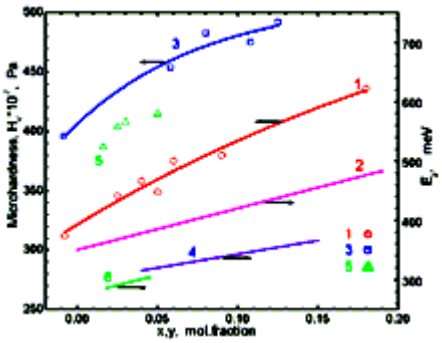
[100] Young's modulus

$Y_o=(C_{11}+2C_{12})$• $(C_{11}-C_{12})/(C_{11}+C_{12})$ Y_o= (5.14+3.39x)•10^{11} dyn/cm^2

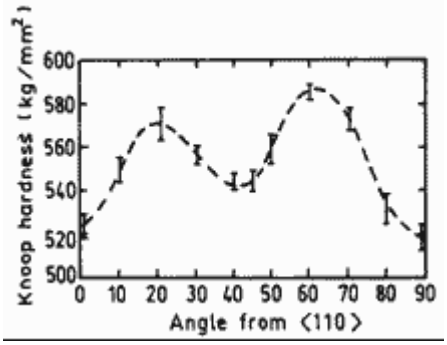
[100] Poisson ratio

• $_o=C_{12}/(C_{11}+C_{12})$ • $_o$ = (0.35-0.04x)

Micro Hardness



Micro hardness (Hv) and **energy gap values E_g vs composition** of three alloy systems:
$In_{1-x}Ga_xAs$ (1, 2),
$In_{1-x}Ga_xAs_{0.9}Sb_{0.1}$ (3, 4) and
$InAs_{1-x-0.1}Sb_{0.1}P_y$ (5, 6).
Measured using (111) oriented epilayers at 50 g weight (stress) on Vikkers pyramid
*B.A.Matveev et al. Izv.Akad.Nauk SSSR, Neorg.Mater, **26** (1990), 639*
Contact authors: *B.A.Matveev*

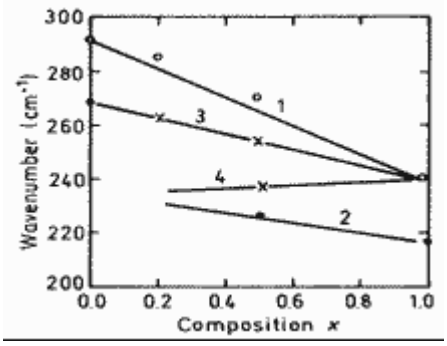


Knoop microhardness anisotropy on the {100} plane for $Ga_{0.47}In_{0.53}As$.
Adachi (1992)

Acoustic Wave Speeds

Wave propagation Direction	Wave character	Expression for wave speed	Wave speed (in units of 10^5 cm/s)
[100]	V_L (longitudinal)	$(C_{11}/\bullet\ )^{1/2}$	3.83+0.90x
	V_T (transverse)	$(C_{44}/\bullet\ )^{1/2}$	2.64+0.71x
[100]	V_l	$[(C_{11}+C_{12}+2C_{44})/2\bullet\ ]^{1/2}$	4.28+0.96x
	$V_{t\|\|}$	$V_{t\|\|}=V_T=(C_{44}/\bullet\ ;)^{1/2}$	2.64+0.71x
	$V_t\perp$	$[(C_{11}-C_{12})/2\bullet\ ]^{1/2}$	1.83+0.65x
[111]	V_l'	$[(C_{11}+2C_{12}+4C_{44})/3\bullet\ ]^{1/2}$	4.41+0.99x
	V_t'	$[(C_{11}-C_{12}+C_{44})/3\bullet\ ]^{1/2}$	2.13+0.67x

Phonon frequencies



Raman-active phonon modes in $Ga_xIn_{1-x}As$.
The symbols show experimental results.
1 - LO phonon behavior,
2 - TO phonon behavior,
3,4 - mixed mode behavior.
Pearsall et al. (1983)

$Ga_x In_{1-x} As$

Piezoelectric, Thermoelectic and Magnetic Properties

Piezoelectric constant

			Remarks	*Referens*
Piezoelectric constant	e_{14}= -(0.045+0.115x) C/m^2	300 K		*Goldberg Yu.A. & N.M. Schmidt (1999)*

$Ga_x In_{1-x} As$

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mytrix

InP - Indium Phosphide

InP - Indium Phosphide

Basic Parameters at 300 K

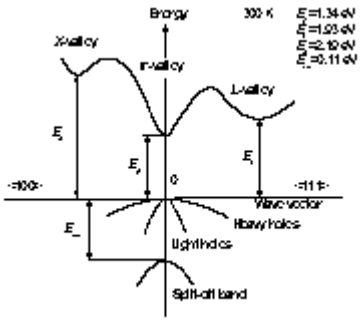
Crystal structure	Zinc Blende
Group of symmetry	T_d^2-F43m
Number of atoms in 1 cm^3	$3.96 \cdot 10^{22}$
Debye temperature	425 K
Density	4.81 g/cm^3
Dielectric constant (static)	12.5
Dielectric constant (high frequency)	9.61
Effective electron mass	$0.08m_o$
Effective hole masses m_h	$0.6m_o$
Effective hole masses m_{lp}	$0.089m_o$
Electron affinity	4.38 eV
Lattice constant	5.8687 A
Optical phonon energy	0.043 eV

InP - Indium Phosphide

Band structure and carrier concentration

Basic Parameters

Energy gap	1.344 eV
Energy separation ($E_{\Gamma L}$) between Γ and L valleys	0.59 eV
Energy separation ($E_{\Gamma X}$) between Γ and X valleys	0.85 eV
Energy spin-orbital splitting	0.11 eV
Intrinsic carrier concentration	$1.3 \cdot 10^{7}$ cm^{-3}
Intrinsic resistivity	$8.6 \cdot 10^{7}$ • • c m
Effective conduction band density of states	$5.7 \cdot 10^{17}$ cm^{-3}
Effective valence band density of states	$1.1 \cdot 10^{19}$ cm^{-3}



Band structure and carrier concentration of InP.
Important minima of the conduction band and maxima of the valence band. 300 K.
E_g = 1.34eV;
E_L = 1.93 eV;
E_X = 2.19 eV;
E_{so} = 0.11 eV

Temperature Dependences

Temperature Dependences Temperature dependence of the energy gap

$E_g = 1.421 - 4.9 \cdot 10^{-4} \cdot T^2/(T+327)$ (eV),
where T is temperature in degrees K (0 < T < 800).

Temperature dependence of the energy separation between Γ and X valleys

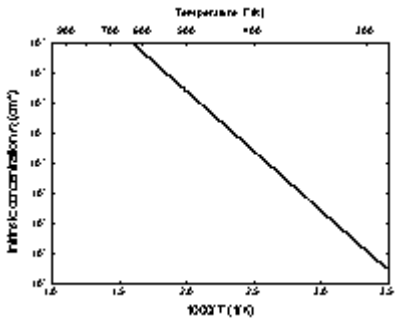
$E_{\Gamma X} = 0.96 - 3.7 \cdot 10^{-4} \cdot T$ (eV),
where T is temperature in degrees K (0 < T < 300).

Effective density of states in the conduction band

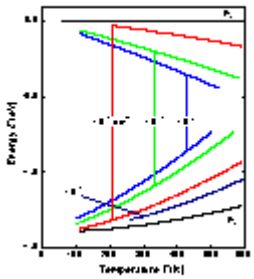
$N_c \cdot 1.1 \cdot 10^{14} \cdot T^{3/2}$ (cm^{-3}).

Effective density of states in the valence band

$N_v \cdot 2.2 \cdot 10^{15} \cdot T^{3/2}$ (cm^{-3}).



The temperature dependence of the intrinsic carrier concentration.

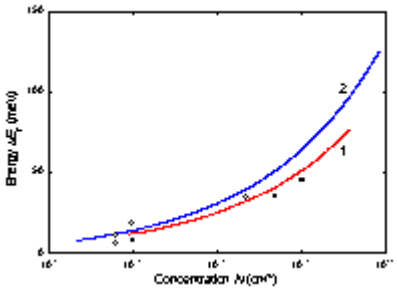


Fermi level versus temperature for different concentrations of shallow donors and acceptors.

Dependences on Hydrostatic Pressure

$E_g = E_g(0) + 8.4 \cdot 10^{-3}P - 1.8 \cdot 10^{-5}P^2$ (eV)
$E_L = E_L(0) + 4.6 \cdot 10^{-3}P$ (eV),
$E_X = E_X(0) + 2 \cdot 10^{-3}P$ (eV),
where P is pressure in kbar.

Energy Gap Narrowing at High Doping Levels



Energy gap narrowing versus donor (curve 1 and experimental points) and acceptor (curve 2) doping density, T = 300 K.
Curve 1 and experimental points *(Bugajski and Lewandowski [1985])*;
Curve 2 *(Jain et al. [1990])*.

For *n*-type InP:

$\cdot E_g \cdot 22.5 \cdot 10^{-9} \cdot N_d^{1/3}$ (eV)
(Bugajski and Lewandowski [1985])

For *p*-type InP

$\bullet E_g \bullet 10.3 \bullet 10^{-9} \bullet N_a^{1/3} + 4.43 \bullet 10^{-7} \bullet N_a^{1/4} + 3.38 \bullet 10^{-12} \bullet N_a^{1/2}$ (eV)
(Jain et al. [1990]).

Effective Masses

Electrons:	
For •-valley	$m_\bullet = 0.08m_o$
The are 4 equivalent L-valleys in the conduction band:	
in one L-valley	$m_L = 0.25m_o$
for all L-valley	$m_{Ld} = 0.63m_o$
The are 3 equivalent X-valleys in the conduction band:	
in one X-valley	$m_X = 0.32m_o$
for all X-valley	$m_{Xd} = 0.66m_o$
Holes:	
Heavy	$m_h = 0.6m_o$
Light	$m_{lp} = 0.089m_o$
Split-off band	$m_{so} = 0.17m_o$
Effective mass of density of states	$m_v = 0.6m_o$

Donors and Acceptors

Ionization energies of shallow donors (eV) ~0.0057:

S, **Si**, **Sn**, **Ge**

Ionization energies of shallow acceptors (eV):

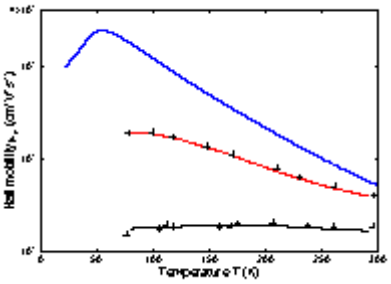
C	**Hg**	**Zn**	**Cd**	**Si**	**Cu**	**Be**	**Mg**	**Ge**	**Mn**
0.04	0.098	0.035	0.057	0.03	0.06	0.03(MBE)	0.03(MBE)	0.021	0.27

InP - Indium Phosphide

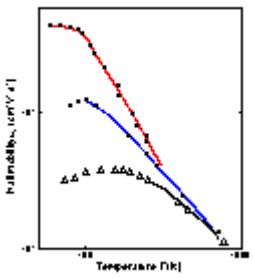
Electrical properties

Basic Parameters

Breakdown field	$\bullet 5 \bullet 10^5$ V cm^{-1}
Mobility electrons	$\bullet 5400$ cm^{2}V^{-1}s^{-1}
Mobility holes	$\bullet 200$ cm^2 V^{-1}s^{-1}
Diffusion coefficient electrons	$\bullet 130$ cm^2 s^{-1}
Diffusion coefficient holes	$\bullet 5$ cm^2 s^{-1}
Electron thermal velocity	$3.9 \bullet 10^5$ m s^{-1}
Hole thermal velocity	$1.7 \bullet 10^5$ m s^{-1}



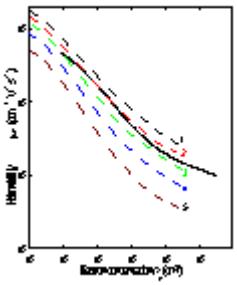
Electron Hall mobility versus temperature for different doping levels.
Bottom curve - $n_o=N_d-N_a=8 \bullet 10^{17}$ cm^{-3};
Middle curve - $n_o=2 \bullet 10^{15}$ cm^{-3};
Top curve - $n_o=3 \bullet 10^{13}$ cm^{-3}.
(Razeghi et al. [1988]) and *(Walukiewicz et al [1980])*.



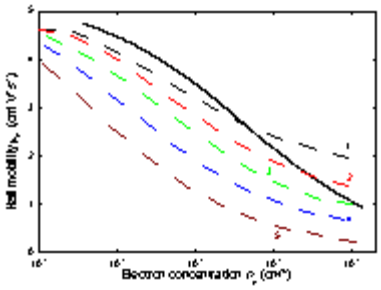
Electron Hall mobility versus temperature (high temperatures):
Bottom curve - $n_o=N_d-N_a \sim 3 \bullet 10^{17}$ cm^{-3};
Middle curve - $n_o \sim 1.5 \bullet 10^{16}$ cm^{-3};
Top curve - $n_o \sim 3 \bullet 10^{15}$ cm^{-3}.
(Galavanov and Siukaev[1970]).

For weakly doped *n*-InP at temperatures close to 300 K electron drift mobility:

$\mu_n = (4.2 \div 5.4) \bullet 10^3 \bullet (300/T)$ (cm^{2}V^{-1} s^{-1})



Hall mobility versus electron concentration for different compensation ratios.
• = N_a/N_d, 77 K.
Dashed curves are theoretical calculations: **1**. • = 0; **2**. • = 0.2; **3**. • = 0.4; **4**. • = 0.6; **5**. • = 0.8;
(Walukiewicz et al. [1980]).
Solid line is mean observed values *(Anderson et al. [1985])*.

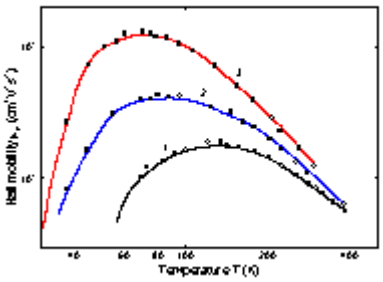


Hall mobility versus electron concentration for different compensation ratios
• =N_a/N_d, 300 K.
Dashed curves are theoretical calculations: **1**. • = 0; **2**. • = 0.2; **3**. • = 0.4; **4**. • = 0.6; **5**. • = 0.8;
(Walukiewicz et al. [1980]).
Solid line is mean observed values *(Anderson et al. [1985])*.

Approximate formula for electron Hall mobility

$\mu=\mu_{OH}/[1+(N_d/10^7)^{1/2}]$,
where μ_{OH}=5000 cm^2V^{-1} s^{-1},
N_d- in cm^{-3} *(Hilsum [1974])*

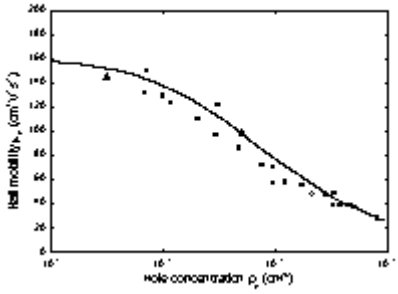
At 300 K, the electron Hall factor $\mathbf{r_n}$• **1** in *n*-InP.
for $N_d > 10^{15}$ cm^{-3}.



Hole Hall mobility versus temperature for different doping (Zn) levels.
Hole concentration at 300 K: **1**. $1.75•10^{18}$ cm^{-3}; **2**. $3.6•10^{17}$ cm^{-3}; **3**. $4.4•10^{16}$ cm^{-3}.
•=N_a/N_d~0.1.
(Kohanyuk et al. [1988]).

For weakly doped *p*-InP at temperature close to 300 K the Hall mobility

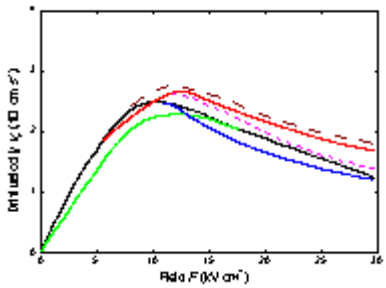
μ_{pH}~$150•(300/T)^{2.2}$ (cm^2V^{-1} s^{-1}).



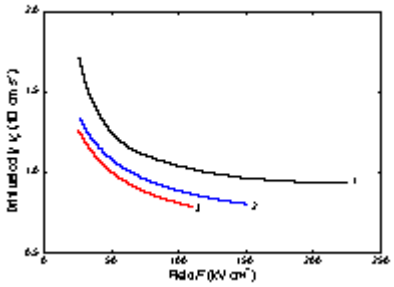
Hole Hall mobility versus hole density, 300 K (Wiley [1975]).
The approximate formula for hole Hall mobility:
$\mu_p=\mu_{po}/[1 + (N_a/2•10^{17})^{1/2}]$, where μ_{po}~150 cm^2V^{-1} s^{-1}, N_a- in cm^{-3}

At 300 K, the hole factor in pure *p*-InP: $\mathbf{r_p \sim 1}$

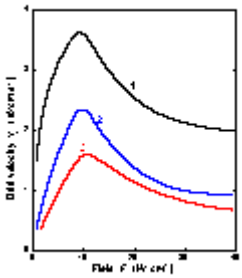
Transport Properties in High Electric Fields



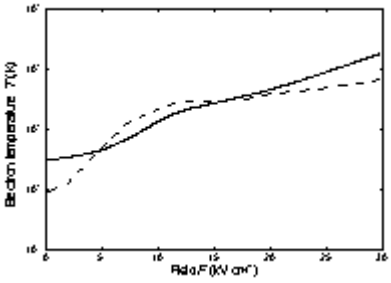
Field dependences of the electron drift velocity in InP, 300 K.
Solid curve are theoretical calculation.
Dashed and dotted curve are measured data.
(Maloney and Frey [1977]) and *(Gonzalez Sanchez et al. [1992])*.



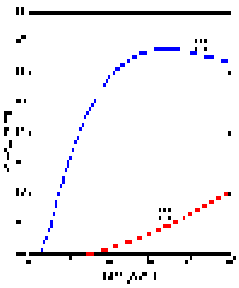
The field dependences of the electron drift velocity for high electric fields.
T(K): **1**. 95; **2**. 300; **3**. 400.
(Windhorn et al. [1983]).



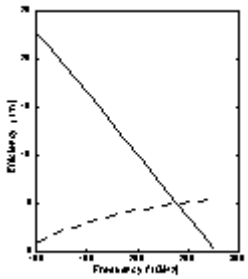
Field dependences of the electron drift velocity at different temperatures.
Curve 1 -77 K *(Gonzalez Sanchez et al. [1992])*.
Curve 2 - 300 K, Curve 3 - 500 K *(Fawcett and Hill [1975])*.



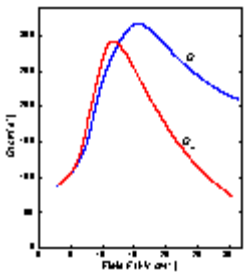
Electron temperature versus electric field for 77 K and 300 K.
(Maloney and Frey [1977])



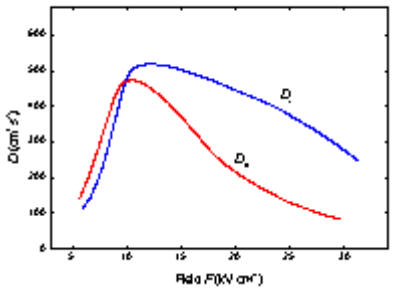
Fraction of electrons in L and X valleys n_L/n_0 and n_X/n_0 as a function of electric field, 300 K.
(Borodovskii and Osadchii [1987]).



Frequency dependence of the efficiency • at first (solid line) and at the second (dashed line) harmonic in LSA mode.
Monte Carlo simulation.
$F = F_o + F_1 \bullet \sin(2 \bullet\bullet ft) + F_2 \bullet [\sin(4 \bullet\bullet ft) + 3 \bullet /2]$,
$F_o = F_1 = 35$ kV cm^{-1},
$F_2 = 10.5$ kV cm^{-1}
(Borodovskii and Osadchii [1987]).

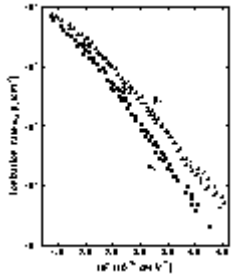


Longitudinal (D || F) and transverse (D ⊥ F) electron diffusion coefficients at 300 K.
Ensemble Monte Carlo simulation.
(Aishima and Fukushima [1983]).

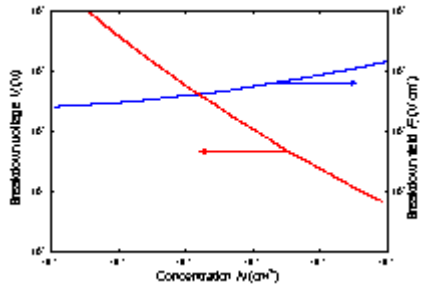


Longitudinal (D || F) and transverse (D ⊥ F) electron diffusion coefficients at 77K.
Ensemble Monte Carlo simulation.
(Aishima and Fukushima [1983]).

Impact Ionization



The dependence of ionization rates for electrons •¡ and holes •¡ versus 1/F, 300 K.
(Cook et al. [1982]).



Breakdown voltage and breakdown field versus doping density for an abrupt *p-n* junction, 300 K
(Kyuregyan and Yurkov [1989]).

Recombination Parameters

Pure *n*-type material ($n_o \sim 10^{-14} cm^{-3}$)

The longest lifetime of holes	• $_p \sim 3 \cdot 10^{-6}$ s
Diffusion length $L_p = (D_p \cdot \cdot _p)^{1/2}$	$L_p \sim 40$ μm.

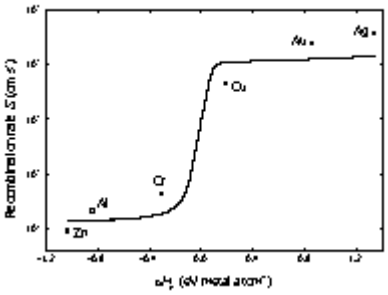
Pure *p*-type material($p_o \sim 10^{15} cm^{-3}$)

(a)Low injection level

The longest lifetime of electrons	• $_n \sim 2 \cdot 10^{-9}$ s
Diffusion length $L_n = (D_n \cdot \cdot _n)^{1/2}$	$L_n \sim 8$ μm

(b) High injection level (filled traps)

The longest lifetime of electrons	• $\sim 10^{-8}$ s
Diffusion length L_n	$L_n \sim 25$ μm



Surface recombination velocity versus the heat of reaction per atom of each metal phosphide $\cdot H_R$
(Rosenwaks et al. [1990]).

If the surface Fermi level E_{FS} is pinned close to midgap ($E_{FS} \sim E_g/2$) the surface recombination velocity increases from $\sim 5 \cdot 10^{-3}$cm/s for doping level $n_o \sim 3 \cdot 10^{15}$ cm^{-3} to $\sim 10^6$ cm/s for doping level $n_o \sim 3 \cdot 10^{18} cm^{-3}$ *(Bothra et al. [1991])*.

Radiative recombination coefficient (300 K)	$1.2 \cdot 10^{-10}$ cm^3/s
Auger coefficient (300 K)	$\sim 9 \cdot 10^{-31}$ cm^6/s

InP - Indium Phosphide

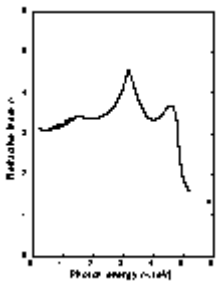
Optical properties

Infrared refractive index	3.1
Radiative recombination coefficient	$1.2 \cdot 10^{-10}$ cm^3/s

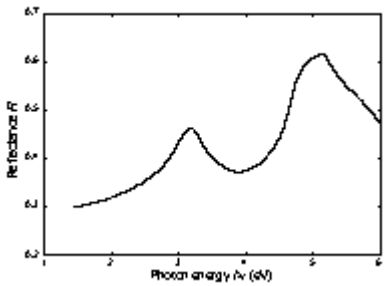
Infrared refractive index

$n = k^{1/2} = 3.075 \cdot (1+2.7 \cdot 10^{-5}T)$

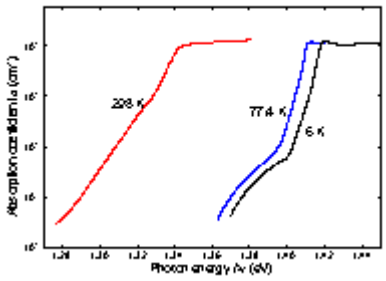
Long-wave TO phonon energy at 300 K $h\nu_{TO}$ = 38.1 meV
Long-wave LO phonon energy at 300 K $h\nu_{LO}$ = 42.6 meV



Refractive index n versus photon energy.
Solid curve is theoretical calculation.
Points represent experimental data, 300 K
(Adachi [1989]).

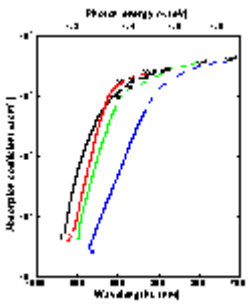


Normal incidence reflectivity versus photon energy, 300 K
(Aspnes and Studna [1983]).



Intrinsic absorption coefficient near the intrinsic absorption edge for different temperatures.
n-InP. $n_o = 5 \cdot 10^{15}$ cm^{-3}
(Turner et al. [1964]).

A ground state Rydberg energy R_{X1} = 5.0 meV.



Intrinsic absorption edge at 296 K at different doping levels

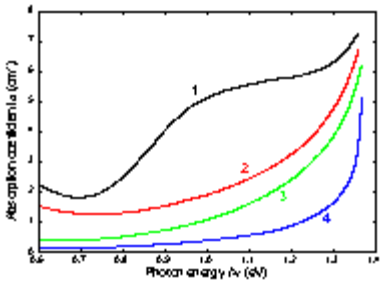
1. *p*-type sample, $p_o = 1.1 \cdot 10^{18}$ cm^{-3}

3. *n*-type sample, $n_o = 1.9 \cdot 10^{18}$ cm^{-3}

2. *n*-type sample, $n_o = 7.4 \cdot 10^{16}$ cm^{-3}

4. *n*-type sample, $n_o = 7 \cdot 10^{18}$ cm^{-3}

(Burkhard et al. 1982]).



Intrinsic absorption edge at 77 K for *n*-InP at different doping levels

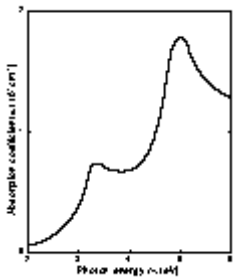
1. $n_o = 10^{19}$ cm^{-3};

2. $n_o = 5 \cdot 10^{18}$ cm^{-3};

3. $n_o = 2 \cdot 10^{18}$ cm^{-3};

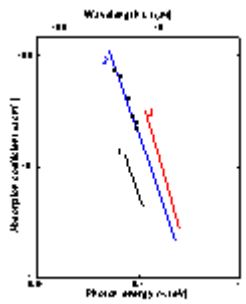
4. $n_o = 9.6 \cdot 10^{16}$ cm^{-3}

(Bugajski and Lewandowski [1985]).



The absorption coefficient versus photon energy, 300 K

(Aspnes and Studna [1983]).



Free carrier absorption versus photon energy ai different doping levels, 300 K.

Electron concentration n_o (cm^{-3}): **1**. $4 \cdot 10^{16}$; **2**. $2 \cdot 10^{17}$; **3**. $4 \cdot 10^{17}$

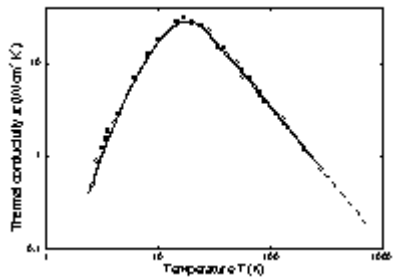
(Newman [1958]).

InP - Indium Phosphide

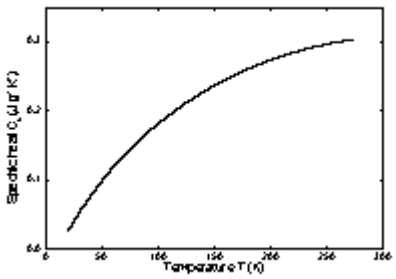
Thermal properties

Bulk modulus	$7.1 \cdot 10^{11}$ dyn cm^{-2}
Melting point	1060 °C
Specific heat	0.31 J g^{-1} $°C^{-1}$
Thermal conductivity	0.68 W cm^{-1} $°C^{-1}$
Thermal diffusivity	0.372 cm^2 s^{-1}
Thermal expansion, linear	$4.60 \cdot 10^{-6}$ $°C^{-1}$

Melting point T_m = 1333 K
For 0 < P < 40 kbar
$T_m = 1333 - 2.0 \cdot P$ (P in kbar)
(Glasov et al. [1977]).

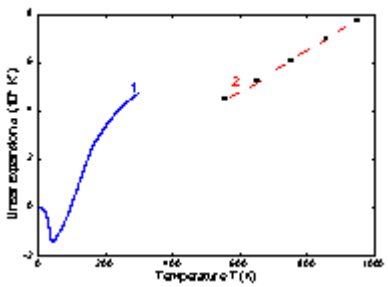


Temperature dependence of thermal conductivity.
n-type samples, $n_o = 2 \cdot 10^{16}$ cm^{-3}
(Aliev et al [1965]).

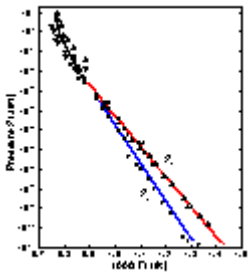


Temperature dependence of specific heat at constant pressure
(Piesbergen [1963]).

For 298< T < 910 K
$C_p = 0.28 + 10^{-4} \cdot T$ (J g^{-1} K^{-1})
(Barin et al. [1977]).



Temperature dependence of linear expansion coefficient •.
1. *(Soma et al. [1982])*,
2. *(Glazov et al. [1977])*.



Temperature dependence of saturation vapor pressure.
(Panish and Arthur[1970]).

InP - Indium Phosphide

Mechanical properties, elastic constants, lattice vibrations

Basic Parameter

Bulk modulus	$7.1 \cdot 10^{11}$ dyn cm^{-2}
Density	4.81 g cm^{-3}
Surface microhardness (using Knoop's pyramid test)	~460 kg mm^{-2}
Cleavage plane	{100}
Piezoelectric constant	e_{14}= $-3.5 \cdot 10^{-2}$ C m^{-2}

Elastic constants at 300 K

$C_{11} = 10.11 \cdot 10^{11}$ dyn/cm^2
$C_{12} = 5.61 \cdot 10^{11}$ dyn/cm^2
$C_{44} = 4.56 \cdot 10^{11}$ dyn/cm^2
(Nichols et al. [1980]).

Bulk modulus (compressibility^{-1})	B_s= $7.11 \cdot 10^{11}$ dyn/cm^2
Shear modulus	C'= $2.25 \cdot 10^{11}$ dyn/cm^2
[100] Young's modulus	Y_o= $6.11 \cdot 10^{11}$ dyn/cm^2
[100] Poisson ratio	• $_o$ = 0.36

Acoustic Wave Speeds

Wave propagation Direction	Wave character	Expression for wave speed	Wave speed (in units of 10^5 cm/s)
[100]	V_L	$(C_{11}/\bullet)^{1/2}$	4.58
	V_T	$(C_{44}/\bullet)^{1/2}$	3.08
[100]	V_l	$[(C_{11}+C_{l2}+2C_{44})/2\bullet]^{1/2}$	5.08
	V_{tll}	$V_{tll}=V_T=(C_{44}/\bullet)^{1/2}$	3.08
	$V_{t\perp}$	$[(C_{11}-C_{12})/2\bullet]^{1/2}$	2.16
[111]	V_l'	$[(C_{11}+2C_{12}+4C_{44})/3\bullet]^{1/2}$	5.23
	V_t'	$[(C_{11}-C_{12}+C_{44})/3\bullet]^{1/2}$	2.51

Phonon frequencies (in units of 10^{12} Hz)

- TO(•) 9.2
- LO(•) 10.3
- TA(X) 2.05
- LA(X) 5.8
- TO(X) 9.7
- LO(X) 9.95
- TA(L) 1.65
- LA(L) 5.0
- TO(L) 9.5
- LO(L) 10.2

(Suto and Nashizawa [1990]).

InP - Indium Phosphide

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