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Numerical Data and Functional Relationships
in Science and Technology

Zahlenwerte und Funktionen
aus Naturwissenschaften und Technik

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## Semiconductors

Subvolume b

Physics of II–VI and I–VII Compounds,
Semimagnetic Semiconductors

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# LANDOLT-BÖRNSTEIN

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semimagnetische Halbleiter

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A. Hoffmann · J. Kossut · E. Mollwo · H. Nelkowski · G. Nimtz
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# Vorwort

Im Anschluß an die Behandlung der tetraedrisch gebundenen Elemente der IV. Gruppe und der III-V-Verbindungen in Teilband III/17a bringt der vorliegende Band III/17b die physikalischen Eigenschaften der II–VI- und I–VII-Verbindungen. Behandelt werden ferner die semimagnetischen Halbleiter, d.h. Legierungen aus normalen halbleitenden Verbindungen und magnetischen Halbleitern. Weitere Teilbände über Halbleitertechnologie und die physikalischen Eigenschaften anderer Halbleiterfamilien werden folgen.

Der Umfang eines Manuskriptes wächst beim Schreiben. Diese Erfahrung haben alle Autoren gemacht, und so sind ihre Beiträge um das Doppelte bis Zehnfache (!) umfangreicher geworden als bei einer ersten Planung abgeschätzt worden war. Dies hat zur Folge, daß mehr Teilbände erscheinen werden als in der Übersicht in Band 17a angegeben wurde. Der Überblick über den Gesamtinhalt auf der Deckelinnenseite des vorliegendenen Teilbandes gibt die neue (und hoffentlich endgültige) Aufteilung des Stoffes auf die Teilbände 17a···17i.

Einige Worte zum Gebrauch dieses Bandes mögen nützlich sein. Für die Organisation des Datenmaterials in den Abschnitten über die einzelnen Substanzen sind verschiedene Wege möglich, wie bei jeder linearen Darstellung eines vielfach-verknüpften Problems. Das hier eingehaltene Schema ist ein Kompromiß zwischen einer nach theoretischen Gesichtspunkten geordneten Einteilung (elektronische Eigenschaften, Gittereigenschaften usw.) und einer nach experimentellen Gebieten geordneten Gliederung (Transporteigenschaften, optische Eigenschaften usw.). Dies mag zur Folge haben, daß der Leser Daten in einem anderen Abschnitt findet als er zunächst erwartet. Ein Gliederungsschema auf der Innenseite des Buchdeckels soll zum schnelleren Auffinden helfen.

Bei der Auswahl der Daten war die Richtschnur, sich nicht nur auf die Halbleitereigenschaften eines Materials zu beschränken, sondern alle die Daten zu bringen, die ein Halbleiterphysiker sucht. Struktureigenschaften oder Information über Phasenübergänge u.dgl. wurden nicht ausgelassen, obwohl sie in anderen Landolt-Börnstein-Bänden ausführlicher dargestellt werden. Sie wurden in einem Rahmen gebracht, wie er von einem Benutzer dieser Bände erwartet werden mag. Für eine Resonanz der Leser zu dieser Frage, ebenso wie für Hinweise und ergänzendes Material wäre ich dankbar.

Ich möchte allen denjenigen meinen Dank ausdrücken, die geholfen haben die Herausgabe dieses Bandes zu einem glücklichen Ende zu führen, den Autoren, die alle Änderungen in ihren Manuskripten hingenommen haben, die für eine einheitliche Darstellung der Daten notwendig waren, den Mitarbeitern der Landolt-Börnstein-Redaktion, insbesondere Herrn Dr. W. Polzin und Frau D. Dolle, deren präzise und engagierte Mitarbeit mir ganz wesentlich geholfen hat und nicht zuletzt dem Springer-Verlag für ein weiteres Beispiel hervorragender Buchherstellung.

Dieser Band wurde wie alle anderen Bände des Landolt-Börnstein ohne finanzielle Hilfe von anderer Seite veröffentlicht.

Marburg, im August 1982 **Der Herausgeber**

# Preface

In continuation of the treatment of the tetrahedrally bonded elements of the IVth group and the III–V compounds in subvolume 17a this subvolume presents the physical properties of the II–VI and I–VII compounds. The volume also contains a chapter on semimagnetic semiconductors, i.e. on the solid solutions between ordinary semiconducting compounds and magnetic semiconductors. Further subvolumes on semiconductor technology and on the physical properties of other semiconductor families will follow.

The scope of a manuscript grows during the writing. This experience has been made by all authors: their contributions became twice to ten times (!) as large as estimated in an earlier stage of preparation. Consequently, more subvolumes will be published than announced in the list of contents of subvolume 17a. A new – and hopefully final – subdivision of the material on subvolumes 17a···17i is presented on the inside of the front cover of this volume.

A few words about the use of this book may be helpful. The data in the sections for the various substances can be organized in different ways – as can each linear presentation of a multi-connected problem. The organization used here is a compromise between a theoretical one (electronic properties, lattice properties etc.) and a phenomenological one (transport properties, optical properties etc.). Thus the reader may find an item in a section in which he does not expect it at first. The organization scheme printed on the inside of the front cover should help to find the way more easily.

The policy for the selection of the data was not to compile only the semiconductor properties of materials but to present all data a semiconductor physicist is looking for. Thus structural data and information about phase transitions etc. – which can be found more completely in other Landolt-Börnstein volumes – have not been omitted but are presented to such extent as may be expected by a user. A resonance by the users to these questions as well as remarks, hints and additions would be helpful to the editor.

I would like to express my gratitude to all who helped to bring the edition of this volume to a successful end – to the authors, who accepted all changes in their manuscripts necessary to reach a uniform presentation of the material, to the editorial staff of the Landolt-Börnstein office, especially Dr. W. Polzin and Frau D. Dolle whose precise and engaged cooperation was extremely helpful to me, and last but not least to Springer-Verlag for another demonstration of their excellent standard of book production.

As all previous volumes of Landolt-Börnstein, this new one is published without any financial support from other sources.

Marburg, August 1982 **The Editor**

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## Semiconductors

## Subvolume b: Physics of II–VI and I–VII compounds, semimagnetic semiconductors

(edited by O. MADELUNG)

# Volume III/17: Semiconductors

## Contents of Subvolumes 17a···i

# A. Introduction

## 1. List of symbols

In the following list all symbols frequently used in this volume are specified. The references in the last column refer to the introductory part A in subvolume 17a (cited as 17a/followed by the number of the respective section) or to that section of part B of this subvolume where the quantity is defined or introduced the first time (cited as 17b/ followed by the number of the respective section). The units listed in the second-last column are the most frequently used units. In the tables of part B data are generally given in units of the original paper. To facilitate a conversion from CGS units to SI units or vice versa conversion tables are presented in section 3 below.

| Symbol | Property | Unit | Introduced in section |
|---|---|---|---|
| $a$ | thermal diffusivity | $cm^2 s^{-1}$ | 17b/3.6 |
| $a, b, c$ | lattice parameters | Å | |
| $A, B, C$ | anisotropy parameter of warped energy surfaces | – | 17a/2.1.1, eq.(A.6) |
| $b$ | mobility ratio $\mu_n/\mu_p$ | – | |
| $B(B_S, B_T)$ | bulk modulus (adiabatic, isothermal) | $dyn\,cm^{-2}$ | 17a/2.1.2, eq.(A.17) |
| $B$ | Nernst coefficient | $cm^2 K^{-1} s^{-1}$ | 17a/2.2.1 |
| $\boldsymbol{B}$ | magnetic induction | T, G | |
| $B_{n(p)}$ | capture coefficient for electrons (holes) $(=\sigma_{n(p)} v_{th})$ | $cm^3 s^{-1}$ | |
| $c_{lm}$ | elastic moduli (stiffnesses) | $dyn\,cm^{-2}$ | 17a/2.1.2, eq.(A.19) |
| $c_{lm}^{D(E)}$ | elastic moduli at constant electric displacement (electric field) | $dyn\,cm^{-2}$ | |
| $c_{ikl}$ | third order elastic moduli | $dyn\,cm^{-2}$ | 17a/2.1.2 |
| $C$ | capacity | F | |
| $C_i$ | deformation potentials | eV | 17b/3.7, 3.10 |
| $C_p$, $C_v$ | heat capacities | $J\,mol^{-1} K^{-1}$ | |
| $d$ | density | $g\,cm^{-3}$ | |
| $d$ | thickness (of samples) | cm | |
| $d_{opt}$ | optical density | – | |
| $d_{ik}$ | piezoelectric strain coefficients | $cm\,V^{-1}$ | 17a/2.2.1 |
| $D_{u(u')}$ | deformation potentials for [100] and [111] stress, respectively | eV | 17a/2.4.1, eq.(A.86/7) |
| $D_{n(p)}$ | diffusion coefficient for electrons (holes) | $cm^2 s^{-1}$ | |
| $Dq$ | crystal field splitting parameter | $cm^{-1}$ | 17b/3.7 |
| $e$ | elementary charge | C | |
| $e^*_{(T)}$ | (transverse) effective ion charge | $e$ | 17a/2.1.2, 17b/3.1 |
| $\boldsymbol{e}$ | polarization vector | – | 17a/2.1.2 |
| $e_{ik}$ | strain tensor ($6 \times 6$) (in literature frequently labeled $S_{ij}$) | – | 17a/2.1.2 |
| $e_{ik}$ | piezoelectric stress coefficients | $C\,cm^{-2}$ | 17a/2.2.1, eq.(A.33) |
| $e_k$ | strain vector (6-component) | – | 17a/2.1.2 |
| $\boldsymbol{E}$ | electric field strength | $V\,cm^{-1}$ | |
| $E$ | energy | eV | |
| $E_{0,1,2\ldots}$ | energies of critical points in optical spectra | eV | 17a/2.1.1 |
| $E(\Gamma_6)\ldots$ | energy of band edge of type $\Gamma_6\ldots$ | eV | 17a/2.4.1 |
| $E_{[hkl]}$ | Young's modulus (measured in [hkl] direction) | $dyn\,cm^{-2}$ | 17a/2.4.2, eq.(A.100) |
| $E_{a(d)}$ | energy of acceptor (donor) state measured from the respective band edge | eV | 17a/2.3.1 |
| $E_A$ | activation energy (of conductivity or other temperature or pressure dependent properties) | eV | |
| $E_b$ | binding energy (mostly of exciton) | eV | 17a/2.1.1 |
| $E_{bx}$ | binding energy of an exciton to an impurity, localization energy of bound exciton | eV | |
| $E_b^{e-h}$ | binding energy of electron-hole liquid (relative to free exciton binding energy) | eV | 17b/3.6 |

| Symbol | Property | Unit | Introduced in section |
|---|---|---|---|
| $E_b^{biex}$ | biexciton binding energy (relative to free exciton binding energy) | eV | 17b/3.6 |
| $E_{c(v)}$ | band edge of conduction (valence) band | eV | 17a/2.1.1, eq.(A.1) |
| $E_{el}$ | electron energy | eV | |
| $E_{ex,\,ion}$ | bound exciton ionization energy | eV | 17b/4.5 |
| $E_F$ | Fermi energy | eV | |
| $E_g$ | energy gap | eV | 17a/2.1.1 |
| $E_{g,\,th}$ | energy gap at 0 K (thermal energy gap) | eV | 17a/2.2.1 |
| $E_{g,\,dir(ind)}$ | direct (indirect) energy gap | eV | 17a/2.1.1 |
| $E_{gx}$ | excitonic energy gap ($E_g - E_b$) | eV | 17a/2.1.1 |
| $E_{gx}^{thr}$ | exciton absorption threshold energy | eV | 17b/4.5 |
| $E_n(k)$ | band structure function | eV | 17a/2.1.1 |
| $E_p$ | characteristic energy in Kane's theory ($=(2m_0/\hbar^2)P^2$) | eV | 17a/2.4.1, eq.(A.79) |
| $E_{pl}$ | plasmon energy | eV | 17b/3.1 |
| $E_t$, $E_{trap}$ | energy of trap level | eV | |
| $E_{vac}$ | vacuum energy level | eV | |
| $E_{ZP}$ | zero phonon transition energy (bound exciton) | eV | 17b/4.5 |
| $f$ | frequency | Hz | |
| $f_i$ | ionicity, electronegativity | – | |
| $f_{ex}$ | oscillator strength of free exciton | – | 17b/3.7 |
| $F$ | parameter of Kane's theory | – | 17b/5 |
| $g^*$, $g_{eff}$ | effective $g$-factor | – | 17a/2.1.1, eq.(A.15) |
| $g_c$, $g_n$ | $g$-factor of conduction electrons | – | |
| $g_v$, $g_p$ | $g$-factor of holes (valence band) | – | |
| $g_{so}$ | $g$-factor in spin-orbit split valence band | – | |
| $g_{ik}$ | piezoelectric strain coefficients | $cm^2C^{-1}$ | 17a/2.2.1, eq.(A.35) |
| $G_{[hkl]}$ | torsional (shear) modulus in [hkl] direction | $dyn\,cm^{-2}$ | |
| $\Delta G_f^0$ | standard free energy of formation | $kcal\,mol^{-1}$ | |
| $h_{ik}$ | piezoelectric stress coefficients | $V\,cm^{-1}$ | 17a/2.2.1, eq.(A.35) |
| $H(H_{B,K})$ | hardness (Brinell, Knoop) | $kg\,mm^{-2}$ | |
| $H$ | magnetic field strength | $A\,cm^{-1}$, Oe | |
| $\Delta H_{at}^0$ | standard heat of atomization | $kcal\,mol^{-1}$ | |
| $\Delta H_f^0$ | standard heat of formation | $kcal\,mol^{-1}$ | |
| $\Delta H_m$ | heat of fusion | $kcal\,mol^{-1}$ | |
| $\Delta H_v$ | heat of vaporization | $kcal\,mol^{-1}$ | |
| $\Delta H_c$ | heat of conversion | $kcal\,mol^{-1}$ | |
| $\Delta H_s$ | heat of sublimation | $kcal\,mol^{-1}$ | |
| $\Delta H_{tr}$ | (phase) transformation heat | $kcal\,mol^{-1}$ | |
| $i$ | current density | $A\,cm^{-2}$ | |
| $I$ | current | A | |
| $I_{ph}$ | photocurrent | A | |
| $I$ | intensity | $cm^{-2}s^{-1}$ | |
| $I_{r,\,t}$ | intensity (reflected, transmitted) | $cm^{-2}s^{-1}$ | 17a/2.2.2, eq.(A.41) |
| $I_R$ | Raman intensity | $cm^{-2}s^{-1}$ | |
| j | index designating the branches of the phonon dispersion curves | – | 17a/2.1.2 |
| $k$ | extinction coefficient (absorption index) | – | 17a/2.2.2, eq.(A.41) |
| k | Boltzmann constant | $JK^{-1}$ | |
| $k$ | wave vector of electrons | $cm^{-1}$ | 17a/2.1.1 |
| $k_0$ | location of band edge in $k$-space | $cm^{-1}$ | 17a/2.1.1 |
| $k_{c(v)}$ | location of conduction (valence) band edge | $cm^{-1}$ | 17a/2.1.1 |
| $k_{lm}$ | electromechanical coupling factor | – | 17b/3.5 |
| $k_t$ | thickness coupling factor | – | 17b/3.5 |
| $K$ | absorption coefficient | $cm^{-1}$ | 17a/2.2.2, eq.(A.38) |
| $K$ | anisotropy constant of ellipsoidal energy surfaces | – | 17a/2.4.2, eq.(A.95) |
| $K$ | exciton wave vector | $cm^{-1}$ | 17a/2.1.1, eq.(A.14) |

| Symbol | Property | Unit | Introduced in section |
|---|---|---|---|
| L | symmetry point in the Brillouin zone | – | 17a/2.4, Fig. A.4 |
| $L, M, N$ | valence band anisotropy parameters | – | 17a/2.4.1, eq.(A.71) |
| $\Delta l/l$ | linear thermal elongation | – | |
| $m_0$ | electron mass | g | |
| $m^*$ | effective mass | $m_0$ | 17a/2.1.1 |
| $m^{**}$ | polaronic mass | $m_0$ | 17a/2.1.1, eq.(A.10) |
| $m_{n(p)}$ | effective mass of electrons (holes) | $m_0$ | 17a/2.1.1, eq.(A.1) |
| $m_{ex,\,h(l)}$ | effective mass of heavy (light) excitons (sometimes $M$ is also used) | $m_0$ | |
| $m_{p,\,h(l)}$ | effective mass of heavy (light) holes | $m_0$ | |
| $m_{\parallel}(m_{\perp})$ | longitudinal (transverse) effective mass | $m_0$ | 17a/2.4.1, eq.(A.75) |
| $m(\Gamma_6)\ldots$ | effective mass at band edge of type $\Gamma_6\ldots$ | $m_0$ | 17a/2.4.1 |
| $m_{ds}$ | density of states mass | $m_0$ | 17a/2.1.1, eq.(A.9) |
| $m_{so}$ | effective mass in the spin-orbit split valence band | $m_0$ | |
| $m_{\omega_c}$ | effective "cyclotron resonance mass" | $m_0$ | 17a/2.2.2, eq.(A.57) |
| $m_{ik}$ | elastoresistance coefficients | – | 17a/2.2.1, eq.(A.32) |
| $n$ | refractive index (real refractive index) | – | 17a/2.2.2, eq.(A.37) |
| $n_0\ (=n_\omega)$ | refractive index for ordinary ray | – | |
| $n_e\ (=n_\varepsilon)$ | refractive index for extraordinary ray | – | |
| $n_{a,\,b,\,c}$ | refractive index in $a$, $b$, $c$ direction | – | |
| $\Delta n$ | birefringence $(=n_{\parallel}-n_{\perp})$ | – | |
| $n$ | electron concentration (also carrier concentration in general) | $cm^{-3}$ | |
| $n_i$ | intrinsic carrier concentration | $cm^{-3}$ | 17a/2.1.3, eq.(A.20) |
| $n_{a(d)}$ | acceptor (donor) concentration | $cm^{-3}$ | |
| $n_{ion}$ | concentration of ionized impurities | $cm^{-3}$ | |
| $n_{l(h)}$ | concentration of light (heavy) electrons | $cm^{-3}$ | |
| $p$ | pressure | bar | |
| $p$ | hole concentration | $cm^{-3}$ | |
| $p_i$ | pyroelectric constants | $A\,s\,cm^{-2}\,K^{-1}$ | 17b/3.5 |
| $p_{l(h)}$ | concentration of light (heavy) holes | $cm^{-3}$ | |
| $p_{ijkl}$ | elastooptic tensor components | – | 17a/2.2.2 |
| $p_{ij}$ | elastooptic constants of cubic crystals | – | 17a/2.4.2 |
| $P$ | Ettinghausen coefficient | $K\,cm^3\,J^{-1}$ | 17a/2.2.1 |
| $P$ | Kane's matrix elements (see $E_p$) | $eV\,cm$ | |
| $P_i$ | dielectric polarization vector | $C\,cm^{-2}$ | |
| $q$ | valence band parameter | – | 17a/2.4.1, eq.(A.73) |
| $\boldsymbol{q}$ | wave vector of phonons | $cm^{-1}$ | |
| $q_{ijkl}$ | piezooptic tensor components | – | 17a/2.2.2 |
| $q_{ij}$ | piezooptic constants in cubic crystals | – | |
| $r$ | radius (ionic, covalent, of exciton ...) | cm | |
| $r_{ij}^{X(e)}$ | linear electrooptic constant at constant stress (strain) | $cm\,V^{-1}$ | 17b/3.5 |
| $R$ | resistance | Ω | |
| $R$ | reflectance | – | 17a/2.2.2, eq.(A.42) |
| $R$ | volume recombination coefficient | $cm^{-3}\,s^{-1}$ | |
| $R_H$ | Hall coefficient | $cm^3\,C^{-1}$ | 17a/2.2.1 |
| $S$ | spin quantum number | – | |
| $S_{(A)}$ | Seebeck coefficient, thermoelectric power (of material A) | $V\,K^{-1}$ | 17a/2.2.1, eq.(A.42) |
| $S_R$ | Righi-Leduc coefficient | $cm^2\,V^{-1}\,s^{-1}$ | 17a/2.2.1 |
| $s_{ml}$ | elastic compliances | $cm^2\,dyn^{-1}$ | 17a/2.1.2, eq.(A.19) |
| $S^0$ | standard entropy (at 298.15 K) | $cal\,mol^{-1}\,K^{-1}$ | |
| $\Delta S_f^0$ | standard entropy (change) of formation | $cal\,mol^{-1}\,K^{-1}$ | |
| $\Delta S_{at}^0$ | standard entropy (change) of atomization | $cal\,mol^{-1}\,K^{-1}$ | |
| $\Delta S_m$ | entropy (change) of fusion | $cal\,mol^{-1}\,K^{-1}$ | |
| $t$ | time | s | |

| Symbol | Property | Unit | Introduced in section |
|---|---|---|---|
| $T$ | temperature | K, °C | |
| $T$ | transmission coefficient | – | |
| $T_b$ | boiling temperature | K | |
| $T_m$ | melting temperature | K | |
| $T_{tr}$ | transition temperature | K | |
| $T_q$ | quenching temperature | K | |
| $T_p$ | temperature of glow peak | K | |
| $T_C$ | Curie temperature | K | 17b/5 |
| $T_G$ | transition temperature paramagnet – spin glass | K | 17b/5 |
| $T_N$ | Néel temperature | K | 17b/5 |
| $u$ | atomic position parameter (defined in figures for the respective lattice) | – | |
| $U$ | voltage | V | |
| $U_{th}$ | thermoelectric voltage | V | |
| $v_{th}$ | thermal velocity | $cm\,s^{-1}$ | |
| $v_{LA(TA)}$ $(v_{L(T)})$ | velocity of longitudinal (transverse) acoustic (sound) waves | $cm\,s^{-1}$ | 17a/2.1.2 |
| $v_{dr}$ | drift velocity | $cm\,s^{-1}$ | |
| $V$ | Verdet coefficient | $deg\,T^{-1}\,cm^{-1}$ | 17a/2.2.2 |
| $V_{(m)}$ | (molar) volume | $cm^3(mol^{-1})$ | |
| X | symmetry point in the Brillouin zone | – | 17a/2.4.1, Fig. A4 |
| $X_i$ | deformation potentials | eV | 17b/3.5 |
| $X_k$ | stress vector (6-component) | $dyn\,cm^{-2}$ | 17a/2.1.2 |
| $X_{ik}$ | stress tensor ($6 \times 6$) (in literature often labeled $T_{ij}$) | $dyn\,cm^{-2}$ | 17a/2.1.2 |
| $X_{[hkl]}$ | stress in [hkl] direction | $dyn\,cm^{-2}$ | |
| $\alpha$ | polarizability | $cm^3$ | |
| $\alpha(\alpha_F)$ | (Fröhlich) polaron coupling constant | – | 17a/2.1.1, eq.(A.11) |
| $\alpha(\alpha_\perp, \alpha_\parallel)$ | linear thermal expansion coefficient (perpendicular and parallel to the crystallographic axis) | $K^{-1}$ | 17a/2.1.2, eq.(A.17) |
| $\alpha_{a,b,c}$ | linear thermal expansion coefficient in $a$, $b$, $c$ direction | $K^{-1}$ | |
| $\alpha_i$ | direction cosines | – | |
| $\alpha, \beta$ | exchange constants | eV | 17b/5 |
| $\beta(\beta_2)$ | two-photon absorption coefficient | $cm\,W^{-1}$ | 17a/2.2.2 |
| $\beta$ | volume thermal expansion coefficient ($=3\alpha$) | $K^{-1}$ | 17a/2.1.2, eq.(A.17) |
| $\beta_{2\omega}$ | absorption coefficient associated with second harmonic generation | $cm\,W^{-1}$ | 17b/3.10 |
| $\beta_n$ | absorption coefficient for two-photon excited non-equilibrium free carriers | $cm\,W^{-1}$ | 17b/3.10 |
| $\beta_\Sigma$ | total non-linear absorption coefficient ($=\beta_2+\beta_{2\omega}+\beta_n$) | $cm\,W^{-1}$ | 17b/3.10 |
| $\beta_3$ | three photon absorption coefficient | $cm^3\,W^{-2}$ | 17b/3.10 |
| $\gamma_i$ | Luttinger coefficients | – | 17a/2.4.1, eq.(A.73) |
| $\gamma$ | Grüneisen constant | – | 17a/2.1.2, eq.(A.18) |
| $\gamma_{jq}$ | mode Grüneisen parameter | – | 17a/2.1.1, eq.(A.18) |
| $\Gamma$ | center of Brillouin zone | – | 17a/2.4.1, Fig. A4 |
| $\Gamma$ | sound absorption coefficient | $db\,cm^{-1}$ | |
| $\delta$ | Anderson-Grüneisen constant | – | 17b/3.1 |
| $\Delta$ | [100]-axis in $k$-space | – | 17a/2.4.1, Fig. A4 |
| $\Delta_{(0)}, \Delta_{so}$ | spin-orbit splitting energy at $\Gamma$ | eV | |
| $\Delta_{1(2)}$ | spin-orbit splitting energy at L(X) | eV | |
| $\Delta_{cf}, \Delta_{cr}$ | crystal field splitting energy | eV | 17b/3.10 |
| $\Delta_1$ | short range electron-hole interaction | eV | 17b/3.7 |
| $\Delta_{dip}, \Delta_{ex}$ | exciton exchange interaction energies | eV | 17b/4.1 |
| $\Delta_{ex}^{L-T}$ | longitudinal-transverse exciton splitting energy | eV | 17b/4.1 |
| $\Delta_{ex}^{magn}$ | splitting of free exciton line in magnetic field | eV | 17b/5 |
| $\Delta_L, \Delta_T$ | exchange energy of longitudinal (transverse) exciton | eV | 17b/4.1 |
| $\varepsilon_0$ | permittivity of free space | $F\,cm^{-1}$ | |
| $\varepsilon$ | dielectric constant | – | |

| Symbol | Property | Unit | Introduced in section |
|---|---|---|---|
| $\varepsilon_{1(2)}$ | real (imaginary) part of dielectric constant | – | 17a/2.2.2, eq.(A.39) |
| $\varepsilon(0)$ | low frequency dielectric constant | – | 17a/2.2.2, eq.(A.53) |
| $\varepsilon(\infty)$ | high frequency dielectric constant | – | 17a/2.2.2, eq.(A.53) |
| $\varepsilon_L$ | lattice part of dielectric constant | – | 17a/2.2.2, eq.(A.48) |
| $\zeta$ | reduced wave vector coordinate | – | |
| $\theta$ | Faraday angle | deg | 17a/2.2.2 |
| $\Theta_p$ | paramagnetic Curie temperature | K | |
| $\Theta_D$ | Debye temperature | K | 17a/2.1.2 |
| $\kappa(\kappa_{L,el})$ | thermal conductivity (lattice, electronic contribution) | $W cm^{-1} K^{-1}$ | 17a/2.2.1, eq.(A.36) |
| $\kappa$ | compressibility (=1/bulk modulus) | $cm^2 dyn^{-1}$ | |
| $\kappa_{S(T)}$ | adiabatic (isothermal) compressibility | $cm^2 dyn^{-1}$ | |
| $\kappa_{v(l)}$ | volume (linear) compressibility | $cm^2 dyn^{-1}$ | |
| $\kappa$ | valence band parameter | – | 17a/2.4.1, eq.(A.73) |
| $\lambda$ | wavelength | cm | |
| $\mu(\mu_{ex})$ | reduced mass (of excitons) | $m_0$ | |
| $\mu_{n(p)}$ | electron (hole) mobility | $cm^2 V^{-1} s^{-1}$ | 17a/2.2.1, eq.(A.25) |
| $\mu_{dr}$ | drift mobility | $cm^2 V^{-1} s^{-1}$ | 17a/2.2.1 |
| $\mu_H$ | Hall mobility | $cm^2 V^{-1} s^{-1}$ | 17a/2.2.1, eq.(A.27) |
| $\nu$ | number of equivalent ellipsoidal band edges | – | 17a/2.1.1, eq.(A.9) |
| $\nu$ | Poisson's ratio | – | 17a/2.4.2, eq.(A.100) |
| $\nu$ | frequency | $s^{-1}$ | |
| $\bar{\nu}$ | wavenumber | $cm^{-1}$ | |
| $\bar{\nu}_R$ | Raman wavenumber | $cm^{-1}$ | |
| $\Xi_u$ | deformation potential for pure shear | eV | 17a/2.1.1, eq.(A.13) |
| $\Xi_d$ | diagonal component of deformation potential tensor | eV | 17a/2.1.1, eq.(A.13) |
| $\pi_{ik}$ | piezoresistance coefficients | $cm^2 dyn^{-1}$ | 17a/2.2.1, eq.(A.32) |
| $\pi_{ik}$ | piezooptic constants (coefficients of the piezooptic tensor in cubic crystals) | $cm^2 dyn^{-1}$ | |
| $\varrho$ | resistivity | $\Omega$cm | |
| $\varrho_{ik}^{(2)}$ | magnetoresistance tensor ($6 \times 6$) | $G^{-2}, T^{-2}$ | 17a/2.2.1, eq.(A.30) |
| $\varrho_{ijkl}, \varrho_{ijkl}^{(2)}$ | fourth-rank tensor components in a power expansion of the resistivity in a magnetic field | $\Omega cm G^{-2}$ | 17a/2.2.1, eq.(A.29) |
| $\Delta\varrho/\varrho_0$ | magnetoresistance | – | 17a/2.2.1, eq.(A.30) |
| $\sigma$ | cross section | $cm^2$ | |
| $\sigma_{(i)}$ | (intrinsic) conductivity | $\Omega^{-1} cm^{-1}$ | 17a/2.2.1 |
| $\sigma_{n(p)}$ | contribution of electrons (holes) to the conductivity | $\Omega^{-1} cm^{-1}$ | 17a/2.2.1, eq.(A.25) |
| $\sigma_{n(p)}$ | capture cross section of electrons (holes) at impurities | $cm^2$ | |
| $\sigma_{ph}$ | photoconductivity | $\Omega^{-1} cm^{-1}$ | |
| $\sigma_s$ | surface conductivity | $\Omega^{-1}$ | |
| $\sigma_d$ | dark conductivity | $\Omega^{-1} cm^{-1}$ | |
| $\sigma_R$ | Raman cross section | $cm^2$ | |
| $\tau$ | relaxation time, decay time, delay time, rise time | s | |
| $\varphi$ | photoelectric threshold | eV | 17b/3.6 |
| $\Phi$ | work function | eV | 17b/3.6 |
| $\Phi_{ph(th)}$ | photoelectric (thermoelectric) work function | eV | |
| $\chi$ | electron affinity | eV | 17b/3.6 |
| $\chi_v$ | magnetic volume susceptibility | – | |
| $\chi_g, \chi$ | magnetic mass susceptibility | $cm^3 g^{-1}$ | |
| $\chi_m$ | magnetic molar susceptibility | $cm^3 mol^{-1}$ | |
| $\omega$ | circular frequency | $rad\, s^{-1}$ | |
| $\omega_j(q)$ | phonon dispersion relation | $s^{-1}$ | 17a/2.1.2, eq.(A.16) |
| $\hbar\omega$ | photon energy | eV | |
| $\omega_c$ | cyclotron resonance frequency | $s^{-1}$ | 17a/2.2.2, eq.(A.56) |
| $\omega_p$ | plasma resonance frequency | $s^{-1}$ | 17a/2.2.2, eq.(A.49) |
| $\omega_q$ | phonon frequency | $s^{-1}$ | |
| $\omega_{TO(LO)}$ | frequency of transverse (longitudinal) optical phonon | $s^{-1}$ | 17a/2.1.2 |
| $\omega_D$ | Debye frequency | $s^{-1}$ | 17a/2.1.2 |

## 2. List of abbreviations

| | |
|---|---|
| a, A($A^0$, $A^+$) | acceptor (neutral, positively charged) |
| a | amorphous |
| AAS | atom absorption spectroscopy |
| ac | acoustic |
| ac | alternating current |
| AKCR | Azbel-Kaner cyclotron resonance |
| APW | augmented plane wave (method) |
| $A^0X$($D^0X$) | neutral acceptor (donor) bound exciton |
| bcc | body centered cubic |
| BE | bound exciton |
| BIN, BIS, TRIG | binary, bisectrix, trigonal axis |
| c | crystalline |
| calc | calculated |
| CB | conduction band |
| COL | complex orange luminescence |
| cov | covalent |
| CPM | circular polarization modulation |
| cub | cubic |
| CVD | chemical vapor deposition |
| cw | constant wave |
| D, d | donor |
| DAP | donor acceptor pair |
| dc | direct current |
| DDLTS | double correlated DLTS |
| dir | direct |
| DLTS | deep level transient spectroscopy |
| DPS | deformation potential scattering |
| DTA | differential thermal analysis |
| e | electron |
| EELS, ELS | electron energy loss spectrum |
| eff | effective |
| EHL | electron hole liquid |
| EHP | electron hole plasma |
| EM | exciton molecule |
| emf | electromotive force |
| endor | electron nuclear double resonance |
| ENP(NENP) | ellipsoidal non-parabolic (non ellipsoidal non-parabolic) |
| EPM | empirical pseudopotential method |
| ER-OPW | extended relativistic orthogonalized plane wave (method) |
| ESCA | electron spectroscopy for chemical analysis |
| esr, ESR | electron spin resonance |
| epr, EPR | electron paramagnetic resonance |
| ex | exciton |
| exc | excitation |
| exp | experimental |
| fcc | face centered cubic |
| FE | free exciton |
| fir, FIR | far infrared |
| g | gaseous |
| h | hole |
| hex | hexagonal |
| $I_{1, 2, 3, ...}$ | excitons bound to neutral or ionized impurities (see corresponding section for special meaning) |
| IIS | ionized impurity scattering |
| ind | indirect |
| INDO | intermediate neglect of differential overlap |
| ion | ionic |

(continued)