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Semiconductors

Editors: O. Madelung · M. Schulz · H. Weiss†

Subvolume d

Technology of III–V, II–VI and
Non-Tetrahedrally Bonded Compounds

Edited by M. Schulz · H. Weiss†



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Technologie der III-V, II-VI und
nicht-tetraedrisch gebundenen Verbindungen

J. Baars · P. Glasow · R. Helbig · H. Jacob

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Vorwort

Bereits in der 6. Auflage des Landolt-Börnstein waren Tabellen über die Physik und die Technologie der Halbleiter in verschiedenen 1959, 1962 und 1965 erschienenen Bänden enthalten. In der neuen Serie bietet jetzt der Band III/17, zu dem der hier vorgelegte Teilband III/17d gehört, erstmals in dieser umfassenden Form ein detailliertes und vollständiges Daten- und Informationsmaterial über Halbleiter an. Die Daten der physikalischen Eigenschaften füllen sieben, die der Technologie zwei Teilbände. Eine Übersicht über den Inhalt aller Teilbände ist auf der Innenseite des Einbanddeckels abgedruckt.

Die technologischen Daten und Informationen erscheinen zusammengefaßt in den zwei Teilbänden III/17c und III/17d im Anschluß an die physikalischen Daten der tetraedrischen Halbleitermaterialien. Dem Gewicht der Anwendungen entsprechend ist vor allem der Siliciumtechnologie im Teilband III/17c ein großes Volumen gewidmet. Der vorliegende Teilband III/17d behandelt ausführlich die Technologie der III-V- und II-VI-Halbleiter und einiger nicht-tetraedrisch gebundener Materialien, die eine praktische Anwendung gefunden haben.

Für jedes Halbleiter-Material reicht die Information über technologische Materialdaten der Halbleiter selbst und der verwendeten Hilfsstoffe für die Technologie, über die Angabe der erreichten Materialgüte, bis hin zu technologischen Verfahren, die in der Bauelementherstellung verwendet werden.

Es war für die Herausgeber und die Autoren nicht leicht, eine einheitliche Darstellungsform und eine angemessene Schranke für den Gesamtumfang so zu finden, daß die wichtige nutzbare Information nicht in unwesentlichen Einzelheiten erstickt. Gerade die Halbleitertechnologie befindet sich derzeit noch in einer rasch fortschreitenden Entwicklung, so daß bei zu vielen technologischen Details die Gefahr des Veraltens besteht. Es wurde daher bei speziellen Verfahren und nicht allzu gebräuchlichen Variationen häufig in Übersichtstabellen auf die spezifische Fachliteratur verwiesen.

In einigen Spezialgebieten erfolgt die Weiterentwicklung der Technologie so rasch, daß schon während der Bearbeitungszeit der Buchherausgabe wesentliche Fortschritte erzielt wurden und neue Technologien entstanden sind. Kleinere Ergänzungen wurden noch während der Korrekturen in diesen Band eingearbeitet. Umfangreiche Kapitel zu neuen Gebieten sollen zu gegebener Zeit in einem Ergänzungsband dargestellt werden.

Die Texte nehmen einen etwas größeren Raum ein als in den vorhergehenden Teilbänden, da technologische Fakten der tabellarischen Darstellung nicht so gut angepaßt sind wie physikalische Zahlenwerte. Auf eine Erklärung der Funktionsprinzipien der Bauelemente wird verzichtet. In den einleitenden Kapiteln zur Bauelement-Technologie wird jedoch auf das Zusammenwirken der verschiedenen Technologieschritte und auf die möglichen Alternativen hingewiesen.

Insgesamt hoffen wir, die Darstellung so gewählt zu haben, daß ein nützliches Nachschlagewerk für die Forschungs- und Entwicklungslaboratorien von Hochschulen und Industrie entstanden ist.

Die Herausgabe von Technologie-Tabellen im Band III/17 der „Neuen Serie des Landolt-Börnstein“ wurde geplant und begonnen von Herbert Weiß, der bereits 1959 zusammen mit H. Welker die ersten Halbleiter-Daten im Landolt-Börnstein publiziert hatte. Infolge eines tragischen Unfalls hat H. Weiß die Vollendung dieser 2., wesentlich vollständigeren Bearbeitung nicht mehr erlebt. Als Erlanger Kollege des Verstorbenen hat der Mitherausgeber gerne die ehrenvolle Aufgabe übernommen, die Herausgabe der beiden Technologie-Teilbände abzuschließen.

90 Diese umfangreiche Datenzusammenstellung über Verbindungshalbleiter im 2. Technologieband III/17d war nur möglich dank der guten Kooperation der Autoren, die allen Änderungs- und Ergänzungswünschen durch die Herausgeber in ihren Manuskripten bereitwillig nachgekommen sind. Gedankt sei auch den Mitarbeitern in der Landolt-Börnstein-Redaktion, insbesondere Herrn Dr. H. Seemüller und Frau E. Hofmann für Ihre engagierte Mitarbeit, ferner meiner Sekretärin in Erlangen, Frau G. Loy, sowie dem Springer-Verlag für ein weiteres Beispiel hervorragender Buchherstellung.

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

Erlangen, im Februar 1984

Der Herausgeber

Preface

Several volumes of the 6th edition of Landolt-Börnstein which were published in 1959, 1962, and 1965 already included tables on the physics and technology of semiconductors. A detailed and complete presentation of information on semiconductors is published for the first time in this comprehensive form within the New Series in volume III/17, of which this subvolume III/17d is a part. The data on physical properties are published in seven, the technological information in two subvolumes. A survey of the contents of all subvolumes is printed on the inside of the cover.

The technological data and informations are compiled in the two subvolumes III/17c and III/17d subsequent to the subvolumes on physical data of tetrahedrally bonded semiconductors. In accordance with the importance of the applications, emphasis has been placed especially on the Si-technology which is presented in subvolume III/17c. This present subvolume III/17d compiles detailed technological information on the III-V and II-VI compounds and on several non-tetrahedrally bonded semiconductors, which have found technical applications.

For each semiconductor material, information is presented on the technological material data of the semiconductor itself and of auxiliary chemicals applied during the processing, on the material quality, and on the technological processes used in device fabrication. The editor and the authors had no easy task to find a standardized form of presentation and an appropriate limit to the total extent in such a way that the important information requested is not drowned in unnecessary details. This is especially so because semiconductor technology is still under rapid development at the moment. Too many technical details would increase the risk of obsolescence. Technological variations and special methods are therefore often surveyed in tables. References are given to specific literature where necessary.

In several areas, the progress of semiconductor technology was so rapid that even during the editing of the book important new technologies appeared and essential advances were made in processing. Minor additions and corrections could still be introduced into this book during proof reading. Major new developments, however, will be presented in a comprehensive form in a supplement volume in due time.

The technological subvolumes contain more text than the previous subvolumes. Descriptions of technology cannot as easily be presented in tabular form as physical data. The functional principles of the different devices are not explained. However, the introductory chapters to device technology discuss the mutual dependence of the different technological steps and mention alternatives.

We hope to have chosen the form of presentation in such a way that a useful reference work for research and development in laboratories, universities, and industry is possible.

The technology tables in volume III/17 were planned and commenced by Herbert Weiß, who had already edited the first semiconductor data together with H. Welker in the Landolt-Börnstein in 1959. Because of a tragic accident, H. Weiß could not see the completion of this second, more comprehensive manuscript. The editor, a colleague of H. Weiß at Erlangen university, considered it an honour to continue with the edition of the two technology subvolumes.

This comprehensive data collection on the technology of compound semiconductors in the present subvolume III/17d was only possible by the good cooperation of the authors, who readily conformed to all requests for changes and additions to their manuscripts. Thanks are also due to the members of the editorial staff of the Landolt-Börnstein, especially to Dr. H. Seemüller and Frau E. Hofmann whose competent work was of great assistance, furthermore to my secretary in Erlangen, Frau G. Loy, as well as to the Springer-Verlag for another example of excellent book production.

This volume is published without financial assistance from any other organization, as are all the other volumes of the Landolt-Börnstein.

Erlangen, February 1984

The Editor

Table of contents

Semiconductors

Subvolume d: Technology of III-V, II-VI and non-tetrahedrally bonded compounds (edited by M. SCHULZ · H. WEISS†)

A Introduction (M. SCHULZ)

1 General remarks	1
2 Frequently used symbols	2
3 Conversion of units	5
4 Abbreviations frequently used in semiconductor technology	6

B Technology of semiconductors

6 Tetrahedrally bonded semiconductors

6.1 Silicon and germanium: see subvolume III/17c

6.2 Silicon carbide: see subvolume III/17c

6.3 III-V compounds

6.3.0 Introduction

6.3.1 Technological data (H. JACOB, G. MÜLLER)

6.3.1.0 Introduction

6.3.1.1 Lattice and thermodynamic data

6.3.1.2 Phase diagrams

6.3.1.3 Vapour pressure

6.3.1.4 Thermodynamic data of impurity atoms

6.3.1.4.1 Phase diagrams $A_{III}-B_V-X$ and solubility of impurities

6.3.1.4.2 Distribution coefficients

6.3.1.4.3 Diffusion coefficients

6.3.1.5 Physical and chemical data of liquid III-V compounds

6.3.1.5.1 Density

6.3.1.5.2 Electrical conductivity and thermoelectric power

6.3.1.5.3 Kinematic viscosity and Prandtl numbers

6.3.1.5.4 Surface tension

6.3.1.5.5 Diffusion coefficient

6.3.1.5.6 Solubility of III-V compounds in liquid metals

References for 6.3.1

6.3.2 Crystal growth (H. JACOB, G. MÜLLER)

6.3.2.0 Introduction

6.3.2.1 Synthesis of III-V compounds

6.3.2.2 Crystal growth by directional solidification

6.3.2.2.1 Horizontal gradient freeze method

Data Figures

12	—
12	—
12	—
12	—
13	319ff.
17	323ff.
18	320ff.
18	—
18	333ff.
20	336ff.
24	337
26	—
27	319
27	337ff.
27	339ff.
28	339ff.
28	341
28	341ff.
29	—
34	—
34	—
34	319ff., 344ff.
37	—
37	345

	Data	Figures
6.3.2.2.2 Horizontal Bridgman method	38	—
6.3.2.2.3 Vertical gradient freeze method	38	345 ff.
6.3.2.2.4 Bridgman-Stockbarger method	38	—
6.3.2.3 Crystal growth by pulling from a crucible	38	346 ff.
6.3.2.3.1 "Normal" Czochralski technique	39	346
6.3.2.3.2 Czochralski technique for decomposing melts	39	346
6.3.2.4 Crystal growth by zone-melting	40	—
6.3.2.4.1 Zone-melting in crucibles	40	347
6.3.2.4.2 Crucible free zone-melting (floating zone technique)	41	337 ff., 347
6.3.2.5 Growth from solutions	41	324 ff., 348
6.3.2.6 Growth from the vapour phase	43	—
6.3.2.7 Wafer preparation	43	349
References for 6.3.2	46	—
6.3.3 Characterization of crystal properties (H. JACOB, G. MÜLLER)	52	—
6.3.3.1 Crystal defects	52	—
6.3.3.1.1 Point defects	52	324 ff.
6.3.3.1.2 Dislocations	52	349
6.3.3.1.3 Two-dimensional defects	53	—
6.3.3.1.4 Three-dimensional defects	54	—
6.3.3.1.5 Methods for characterization	54	349
6.3.3.2 Impurities	56	—
6.3.3.2.1 Types of impurities	56	350
6.3.3.2.2 Sources of contamination	57	—
6.3.3.2.3 Methods for the analysis of impurities and typical results	58	—
6.3.3.3 Electrical and optical properties	61	—
References for 6.3.3	63	—
6.3.4 Device technology	68	—
6.3.4.0 Basic device structures (C. WEYRICH)	68	—
6.3.4.0.1 Light emitting devices (C. WEYRICH)	68	350 ff.
6.3.4.0.2 Photodetectors (C. WEYRICH, R. TROMMER)	76	355 ff.
6.3.4.0.3 Solar cells (C. WEYRICH)	78	356
6.3.4.0.4 Photocathodes and cold cathodes (C. WEYRICH)	79	357
6.3.4.0.5 Microwave devices (C. WEYRICH, J.E. MÜLLER)	80	357 ff.
6.3.4.0.6 Integrated circuits (C. WEYRICH, J.E. MÜLLER)	83	—
6.3.4.0.7 Magnetic field devices (C. WEYRICH)	83	—
References for 6.3.4.0	84	—
6.3.4.1 Diffusion of dopants (C. WEYRICH, C. CLEMEN, P. ECKSTEIN)	88	—
6.3.4.1.1 General aspects of diffusion	88	359 ff.
6.3.4.1.2 Diffusion techniques	89	359 ff.
References for 6.3.4.1	91	—
6.3.4.2 Ion implantation (H. RUNGE)	92	—
6.3.4.2.0 Introduction	92	361
6.3.4.2.1 High resistivity layers	93	361
6.3.4.2.2 Encapsulating layers	93	361
6.3.4.2.3 Implantation of donors in GaAs	93	362
6.3.4.2.4 Implantation of acceptors in GaAs	95	362 ff.
6.3.4.2.5 Implantation ranges	96	—
6.3.4.2.6 Implantation ranges for substrates similar to GaAs	102	—
References for 6.3.4.2	102	—
6.3.4.3 Epitaxy	105	—
6.3.4.3.1 General aspects of epitaxy (C. WEYRICH, M. PLIHAL)	105	—
6.3.4.3.2 Lattice matching (C. WEYRICH, M. PLIHAL)	106	363 ff.
6.3.4.3.3 Vapour phase epitaxy (C. WEYRICH, M. DRUMINSKI, S. GISDAKIS, K. SCHWARZMICHEL)	108	363 ff.

	Data	Figures
6.3.4.3.4 Liquid phase epitaxy (C. WEYRICH, S. LEIBENZEDER, M. PLIHAL)	115	369 ff.
6.3.4.3.5 Molecular beam epitaxy (C. WEYRICH, F. RAISCH)	121	374 ff.
References for 6.3.4.3	124	—
6.3.4.4 Etching processes (C. WEYRICH, H. HUBER)	131	—
6.3.4.4.1 Methods of surface treatment	131	—
6.3.4.4.2 Wet chemical etching	131	375 ff.
6.3.4.4.3 Vapour-phase etching	132	376
6.3.4.4.4 Chemical-mechanical polishing	132	—
6.3.4.4.5 Material-selective etching	132	—
References for 6.3.4.4	134	—
6.3.4.5 Contact fabrication (C. WEYRICH, J. HEINEN)	134	376 ff.
6.3.4.5.1 Ohmic contacts (C. WEYRICH, J. HEINEN)	135	377
6.3.4.5.2 Schottky contacts (C. WEYRICH, H. ALBRECHT)	136	—
6.3.4.6 Pattern definition (C. WEYRICH)	142	—
6.3.4.7 Final device preparation (C. WEYRICH)	142	—
6.3.4.7.1 Wafer separation	142	—
6.3.4.7.2 Device mounting	142	—
6.3.4.7.3 Passivation	142	—
6.3.4.7.4 Encapsulation	143	—
References for 6.3.4.5-6.3.4.7	143	—
6.4 II-VI compounds (Wide gap semiconductors) (R. HELBIG)	145	—
6.4.1 Technological data	145	—
6.4.1.1 Heat of formation, entropy, free energy of formation and vapour pressure	145	378
6.4.1.2 Phase diagrams of binary systems	146	378 ff.
6.4.1.3 Solid intercompound solutions	147	—
6.4.2 Crystal growth	147	—
6.4.2.1 Vapour phase growth	147	—
6.4.2.2 Liquid phase growth	151	—
6.4.2.3 Solid phase growth	153	—
6.4.2.4 Other methods	154	—
6.4.3 Characterization of the crystals	154	—
6.4.4 Device technology	154	—
6.4.4.0 Basic device structures	154	—
6.4.4.0.1 Application of mechanical properties	154	379 ff.
6.4.4.0.2 Application of electrical properties	157	381
6.4.4.0.3 Gas detectors	161	382
6.4.4.0.4 Application of optical properties	161	382 ff.
6.4.4.1 Diffusion	168	385 ff.
6.4.4.2 Ion implantation	176	—
6.4.4.3 Epitaxy	181	—
6.4.4.4 Etching processes	188	—
6.4.4.5 Contact fabrication	189	—
References for 6.4	192	—
6.5 II-VI compounds (Zero gap and narrow gap semiconductors) (H. MAIER)	211	—
6.5.1 Technological data	211	—
6.5.1.1 Crystal structure and lattice parameters	211	—
6.5.1.1.1 Binary compounds	211	—
6.5.1.1.2 Pseudobinary alloys	212	—

	Data	Figures
6.5.1.2 Physical data related to material and device technology . . .	213	390
6.5.1.3 Phase diagrams: $T-x$ projections . . .	214	—
6.5.1.3.1 Binary systems . . .	214	390
6.5.1.3.2 Pseudobinary alloys . . .	215	390 ff.
6.5.1.4 Phase diagrams: $T-p$ projections . . .	215	—
6.5.1.4.1 Binary compounds . . .	215	391 ff.
6.5.1.4.2 Pseudobinary alloys . . .	215	392 ff.
6.5.1.5 Thermodynamic data of binary compounds and pseudobinary alloys . . .	216	—
6.5.1.6 Homogeneity range (solidus field) . . .	217	393
6.5.2 Crystal growth . . .	217	—
6.5.2.1 Vapour phase growth . . .	217	—
6.5.2.2 Melt and solution growth . . .	218	—
6.5.2.2.1 Bridgman growth . . .	218	—
6.5.2.2.2 Melt zone and solution zone growth . . .	218	393
6.5.2.2.3 Growth and recrystallization from slush . . .	219	—
6.5.2.2.4 Growth under microgravity conditions . . .	219	—
6.5.2.3 Solid state recrystallization . . .	220	393 ff.
6.5.2.4 Thin film deposition and epitaxy . . .	220	—
6.5.2.4.1 Vacuum evaporation, RF-sputtering, chemical deposition . . .	220	—
6.5.2.4.2 Vapour phase epitaxy . . .	222	394
6.5.2.4.3 Liquid phase epitaxy . . .	223	395 ff.
6.5.2.5 Post-growth annealing procedures . . .	224	—
6.5.3 Characterization of crystal properties . . .	224	—
6.5.3.1 Metallurgical properties . . .	224	—
6.5.3.2 Surface properties . . .	226	—
6.5.3.3 Defect and impurity doping . . .	226	—
6.5.3.4 Electrical and galvanomagnetic properties . . .	229	—
6.5.4 Device technology . . .	229	—
6.5.4.1 Basic device structures . . .	230	396 ff.
6.5.4.2 Etching and polishing processes . . .	231	—
6.5.4.3 pn-junction formation . . .	232	—
6.5.4.4 Metal contacts . . .	234	—
6.5.4.5 Passivation . . .	234	—
References for 6.5 . . .	236	—
7 Non-tetrahedrally bonded semiconductors . . .	245	—
7.1 IV-VI compounds (J. BAARS) . . .	245	—
7.1.1 Technological data . . .	245	—
7.1.1.1 Selected thermodynamic data . . .	245	—
7.1.1.2 Phase diagrams . . .	245	—
7.1.1.2.1 $T-x$ phase diagrams of binary systems . . .	245	399 ff.
7.1.1.2.2 $T-x$ phase diagrams of ternary systems . . .	248	399 ff.
7.1.1.2.3 $p-T$ phase diagrams . . .	251	400 ff., 411 ff.
7.1.1.3 Crystal structure, lattice parameters, energy gaps, and dielectric constants . . .	254	—
7.1.1.3.1 Solid solutions of monochalcogenides . . .	255	—
7.1.1.3.2 Solid solutions of heterovalent chalcogenides . . .	258	417 ff.
7.1.2 Crystal growth . . .	259	—
7.1.3 Characterization of crystal properties . . .	259	—

	Data	Figures
7.1.4 Device technology	259	—
7.1.4.0 Basic device structure	259	414
7.1.4.1 Diffusion	266	—
7.1.4.1.1 Selfdiffusion and interdiffusion of constituents		404, 410, 414ff.
7.1.4.1.2 Impurity diffusion	272	419
7.1.4.2 Epitaxy	274	419
References for 7.1	285	—
7.2 Mercury iodide (P. GLASOW, E. TOMZIG)	292	—
7.2.1 Technological data	292	—
7.2.1.1 Phase diagrams of HgI_2	292	420
7.2.1.2 Vapour pressure and rate of evaporation	292	—
7.2.2 Crystal growth	292	—
7.2.2.1 Synthesis	293	—
7.2.2.2 Purification	293	—
7.2.2.3 Setting the Hg/I_2 ratio	293	—
7.2.2.4 Doping	293	—
7.2.2.5 Growth of crystals	293	420
7.2.2.5.1 Growth from solutions	293	420ff.
7.2.2.5.2 Growth from the vapour phase	298	422
7.2.3 Characterization of crystal properties	299	—
7.2.4 Device technology	303	—
7.2.4.0 Introduction	303	423
7.2.4.1 Wafer preparation	304	—
7.2.4.2 Polishing and etching	305	—
7.2.4.3 Contact fabrication	305	—
7.2.4.4 Encapsulation	305	—
References for 7.2	305	—
7.3 Selenium (K. KASSEL)	308	—
7.3.1 Technological data	308	—
7.3.1.1 Phase diagrams	308	424
7.3.1.2 Properties of the melt	308	424
7.3.1.3 Properties of the vapour	308	—
7.3.1.3.1 Vapour pressure	308	—
7.3.1.3.2 Molecular composition of Se vapour	309	424
7.3.1.4 Amorphous Se	309	—
7.3.1.4.1 Structure	309	—
7.3.1.4.2 Glass transition temperature (T_g)	310	425
7.3.1.4.3 Viscosity	310	425
7.3.1.4.4 Microhardness	310	425
7.3.1.4.5 Structural relaxation	310	425
7.3.2 Crystal growth	310	—
7.3.2.0 Introductory remarks	310	—
7.3.2.1 Crystallization of amorphous Se	311	—
7.3.2.2 Se—Te alloys	311	426
7.3.2.3 Se—As alloys	311	—
7.3.2.4 Cl-doped Se	311	—
7.3.2.5 Recrystallization	311	—
7.3.3 Characterization of crystal properties	312	—
7.3.3.1 Amorphous Se	312	—
7.3.3.1.1 Electrical properties	312	425ff.
7.3.3.1.2 Optical properties	313	425ff.

	Data	Figures
7.3.3.2 Trigonal Se	314	—
7.3.3.2.1 Electrical properties	314	428
7.3.3.2.2 Optical properties	314	428ff.
7.3.3.3 Polycrystalline Se	314	429
7.3.4 Device technology	314	—
7.3.4.1 Photoreceptors in electrophotography	314	—
7.3.4.1.1 Substrate materials	314	—
7.3.4.1.2 Coating	314	428ff.
7.3.4.2 Selenium rectifiers	315	—
7.3.4.2.1 Rectifier plates	315	429
7.3.4.2.2 Rectifier devices	316	—
References for 7.3	316	—
7.2.2 Crystal growth	322	—
7.2.2.1 Synthesis	322	—
7.2.2.2 Purification	322	—
7.2.2.3 Setting the HgI ₂ ratio	322	—
7.2.2.4 Doping	322	—
7.2.2.5 Growth of crystals	322	—
7.2.2.5.1 Growth from solutions	322	—
7.2.2.5.2 Growth from the vapour phase	322	—
7.2.3 Characterization of crystal properties	322	—
7.2.4 Device technology	322	—
7.2.4.0 Introduction	322	—
7.2.4.1 Wafer preparation	322	—
7.2.4.2 Polishing and etching	322	—
7.2.4.3 Contact fabrication	322	—
7.2.4.4 Encapsulation	322	—
References for 7.2	322	—
7.3 Selenium (K. Kassel)	308	—
7.3.1 Technological data	308	—
7.3.1.1 Phase diagrams	308	—
7.3.1.2 Properties of the melt	308	—
7.3.1.3 Properties of the vapour	308	—
7.3.1.3.1 Vapour pressure	308	—
7.3.1.3.2 Molecular composition of Se vapour	308	—
7.3.1.4 Amorphous Se	308	—
7.3.1.4.1 Structure	308	—
7.3.1.4.2 Glass transition temperature (T _g)	310	—
7.3.1.4.3 Viscosity	310	—
7.3.1.4.4 Microhardness	310	—
7.3.1.4.5 Structural relaxation	310	—
7.3.2 Crystal growth	310	—
7.3.2.0 Introductory remarks	310	—
7.3.2.1 Crystallization of amorphous Se	311	—
7.3.2.2 Se-Te alloys	311	—
7.3.2.3 Se-As alloys	311	—
7.3.2.4 Cl-doped Se	311	—
7.3.2.5 Rectification	311	—
7.3.3 Characterization of crystal properties	312	—
7.3.3.1 Amorphous Se	312	—
7.3.3.1.1 Electrical properties	312	—
7.3.3.1.2 Optical properties	312	—

A. Introduction

1 General remarks

Contents of the technology sections

Data are listed for pure and doped semiconductors. Methods, procedures, and materials and apparatuses employed in the synthesis and purification of materials and for the growth of single crystals are described. Typical crystal properties obtained and diagnostic techniques used for the characterization are outlined. Detailed information is presented on the basic device structures and the processing involved in their fabrication. If fundamental physical semiconductor data are requested, the reader is referred to the subvolumes 17a and 17b. Only those fundamental physical semiconductor data, which are frequently used in device technology are repeated for convenience.

Form of presentation

Technological facts are summarized in the form of tables or are presented in concise statements. Where possible, relations of parameters, flow diagrams of procedures, and outlines of constructions are depicted in figures. Important technological terms or crucial facts and numbers are pointed out for easy finding by using *italic letters*.

Organization of chapters

A detailed classification scheme is used so that the information requested can be easily traced by the table of content and the headings of paragraphs. A 5-digit decimal classification is employed to organize the technological sections. Additional unnumbered headings of paragraphs guide the reader to the information requested without the need to read a whole section or paragraph.

The decimal classification continues from the sections on fundamental physical data in the subvolumes III/17a, b. The sections 6 and 7 contain the technology data of tetrahedrally and non-tetrahedrally bonded semiconductors, respectively. The order of semiconductor materials listed is the same as in the sections on fundamental physical data. The order is shown on the inside of the front cover.

For each material, subsections (3. digit in decimal classification) are presented which include the following information:¹⁾

1. Technological data:

- phase diagrams
- vapour pressures
- solubilities
- melt diffusion coefficients
- distribution coefficients
- viscosity
- surface tension
- etc.

2. Crystal growth:

- synthetization
- purification
- zone melting
- pulling techniques
- directional solidification
- sheet growth
- vapour phase growth
- gradient freeze methods
- solid state recrystallization
- wafer preparation
- etc.

3. Characterization of crystal properties:

- doping profiles
- impurities
- defects
- polytype verification
- surface properties
- diagnostic techniques
- etc.

4. Device technology:

- basic device structures
- diffusion
- ion implantation
- nuclear transmutation doping
- epitaxy
- fabrication of layers
- metallization
- lithography
- etching processes
- final device preparation
- etc.

The further classification of the topics listed is not unified because the topics vary according to the applicability of various technological steps or data for each material.

¹⁾ This survey is also shown on the fly-leaf.

2 Frequently used symbols

The symbols used are consistent throughout all the subvolumes III/17a...i of the Landolt-Börnstein volume III/17 on semiconductor data. The units given are most frequently used in the figures and tables. For the conversion of equivalent units see Tables 4 and 5.

Table 1. Alphabetical list of symbols.²⁾

Symbol	Property	Unit
<i>a</i>	thermal diffusivity ($a = \frac{\kappa}{d \cdot C}$)	$\text{cm}^2 \text{s}^{-1}$
<i>a</i>	lattice constant of wurtzite crystals	$\text{\AA} = 10^{-10} \text{m}$
<i>a</i>	radioactivity	s^{-1}
<i>A</i>	area	cm^2
<i>b</i>	line width	$\text{nm} = 10^{-9} \text{m}$
<i>b</i>	Burgers vector	$\text{\AA} = 10^{-10} \text{m}$
<i>B</i>	brightness (of ion sources)	$\text{A cm}^{-2} \text{s}^{-1}$
<i>B</i>	magnetic induction	$\text{T} = \text{Vs m}^{-2}$
<i>c_{ij}</i>	elastic stiffness coefficients	Nm^{-2}
<i>c</i>	velocity of light	cm s^{-1}
<i>c</i>	lattice constant of wurtzite crystals	$\text{\AA} = 10^{-10} \text{m}$
<i>c</i>	concentration, solubility	cm^{-3} , at %, atoms cm^{-3} , ppm
<i>C</i>	capacitance	$\text{F} = \text{As V}^{-1}$
<i>C</i>	specific heat	$\text{J mol}^{-1} \text{K}^{-1}$, $\text{cal g}^{-1} \text{K}^{-1}$
<i>CSDG</i>	critical stress of dislocation generation	g mm^{-2}
<i>CRSS</i>	critical resolved shear stress	g mm^{-2}
<i>d</i>	depth, layer thickness, diameter	μm
<i>d</i>	specific density	g cm^{-3}
<i>d</i>	lattice constant of cubic crystals	$\text{\AA} = 10^{-10} \text{m}$
<i>D</i>	diffusion coefficient	$\text{cm}^2 \text{s}^{-1}$
<i>D*</i>	detectivity of ir-detectors	$\text{cm Hz}^{-\frac{1}{2}} \text{W}^{-\frac{1}{2}}$
<i>e</i>	elementary charge	$C = \text{As}$
<i>E</i>	electrical field strength	V cm^{-1}
<i>E</i>	energy	$\text{VAs} = \text{J}$, eV
<i>f</i>	focal length	$\text{mm} = 10^{-3} \text{m}$
<i>f</i>	frequency	Hz
<i>f</i>	misfit parameter	—
<i>f</i>	factor	—
<i>F</i>	Gibbs free energy (free enthalpy)	cal mol^{-1} , J mol^{-1}
<i>FF</i>	fill factor	—
<i>g</i>	gain factor	—
<i>g</i>	generation/evaporation rate	s^{-1}
	per volume	$\text{cm}^{-3} \text{s}^{-1}$
	per area	$\text{cm}^{-2} \text{s}^{-1}$
<i>g</i>	gravitational acceleration	cm s^{-2}
<i>G</i>	Gibbs free energy (free enthalpy)	cal mol^{-1} , J mol^{-1}
<i>h</i>	Planck constant, $\hbar = h/2\pi$	Js
<i>h</i>	height	m
<i>H</i>	enthalpy	cal mol^{-1} , J mol^{-1}
<i>H</i>	hardness	$\text{Pa} = \text{Nm}^{-2}$
	empirical scale	—
<i>I</i>	flux density	$\text{cm}^{-2} \text{s}^{-1}$
<i>I</i>	electrical current	A
<i>j</i>	electrical current density	A cm^{-2}
<i>k</i>	distribution or segregation coefficient	—

²⁾ Please also consult Table 3.

Introduction: 2 Frequently used symbols

Symbol	Property	Unit
k	wave vector	cm^{-1}
k	electromechanical coupling factor	—
k	Boltzmann constant	JK^{-1}
k	reaction rate	s^{-1}
K	equilibrium constant	—
K	absorption coefficient	cm^{-1}
$K (\equiv a)$	thermal diffusivity	$\text{cm}^2 \text{s}^{-1}$
L, l	length	m
m	mass	g
M	molecular weight	—
	total mass, weight	kg
n	ideality factor	—
n	electron concentration	cm^{-3}
n	refractive index	—
N	concentration of dopant	cm^{-3}
NA	numerical aperture $NA = n \sin \alpha$	—
p	hole concentration	cm^{-3}
p	pressure	$\text{Pa} = 10^{-5} \text{ bar}$
P	power	Js^{-1}
Pr	Prandtl number	—
Q	charge	As
Q	activation energy of diffusion coefficients	eV
r	rate	s^{-1}
r	ratio	—
r	Hall scattering factor	—
r	radial distance	m
R	radius	m
R	resistance	$\Omega = \text{VA}^{-1}$
R	reflectivity	—
R_0	gas constant	$\text{Jmol}^{-1} \text{K}^{-1}$
R_H	Hall coefficient	cm^3
R_p	projected range	μm
s	solidified fraction	—
s	spacing, proximity distance	μm
S	selectivity	—
S	sensitivity	$\text{Jcm}^{-2}, \text{Ccm}^{-2}$
S	entropy	$\text{calmol}^{-1} \text{K}^{-1}, \text{Jmol}^{-1} \text{K}^{-1}$
t	time	s
T	temperature	K
u	undercutting	μm
v	velocity	cms^{-1}
V	voltage	V
V	volume	m^3
w	concentration	wt %
w	width	m
x	mole fraction, atomic fraction	—
x	variable distance	m
x	electronegativity of metals	—
X	stress	$\text{Pa} = \text{Nm}^{-2}$
Z, z	figure of merit	—
Z	atomic number	—
$\langle \rangle$ or (s)	indicates solid material	
$\{ \}$ or (l)	indicates liquid material	
$()$ or (g)	indicates gaseous material	
$[]_x$	indicates dissolved in X	
$\varnothing$	diameter	

Introduction: 2 Frequently used symbols

Table 2. Greek symbols.

Symbol	Property	Unit
α	angle	$^{\circ}$, rad
α	power coefficient	—
α	thermoelectric power	mVK^{-1}
α	linear thermal expansion coefficient	K^{-1}
β	absorption coefficient	cm^{-1}
β	angle	$^{\circ}$, rad
δ	small thickness	μm
γ	contrast	—
γ	disorder coefficient	—
γ	surface tension	Nm^{-1}
Δ	difference, change of quantity	—
ϵ	dielectric constant	—
ϵ_0	dielectric permittivity of free space	Fm^{-1}
η	efficiency, yield	—
η	viscosity	$\text{Pa s} = 10 \text{ P}$
θ	angle of incidence	$^{\circ}$, rad
κ	compressibility	Pa^{-1}
κ	thermal conductivity	$\text{Wcm}^{-1} \text{K}^{-1}$
λ	wavelength	$\text{nm} = 10^{-9} \text{ m}$
μ	mobility	$\text{cm}^2 \text{V}^{-1} \text{s}^{-1}$
$\tilde{\nu}$	wave number $\tilde{\nu} = 1/\lambda$	cm^{-1}
ν	frequency	$\text{Hz} = \text{s}^{-1}$
ν	kinematic viscosity $\nu = \eta/d$	$\text{m}^2 \text{s}^{-1} = 10^4 \text{ St}$
ρ	resistivity	Ωcm
ρ	space charge	Ccm^{-3}
σ	electrical conductivity	$\Omega^{-1} \text{cm}^{-1}$
σ	cross-section	cm^2 , barn $= 10^{-24} \text{ cm}^2$
τ	lifetime	s
φ	azimut, phase angle	$^{\circ}$, rad
Φ	barrier energy, work function	eV
χ	electron affinity	eV
χ	susceptibility	—
ω	angular frequency	rad s^{-1}

Table 3. Meaning of indices used.

The following indices are frequently used to further specify the symbols of Tables 1 and 2. Where the same letter is used, different meanings can be usually distinguished from the context in which they appear.

Index	Meaning	Index	Meaning
a	anneal	d	decay
a	acceptor	D	diffusion
abs	absolute value	D	drain
A	activation	e	electron
b	boiling	e	etch
b	bulk material value	E	emitter
B	barrier	eff	effective
B	base electrode of transistor	ex	external
c(rit)	critical value	f	forward
calc	calculated	f	formation
cw	continuous wave	f	facet
C	conduction band	F	Fermi
C	contact	FB	flatband
C	collector	g	gaseous
d	donor	g	growth
d	dopant	g	gap