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Otfried Madelung

Semiconductors: Data Handbook

3rd edition



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Preface

"The frequent use of well known critical data handbooks like Beilstein, Gmelin and Landolt-Börnstein is impeded by the fact that only larger libraries - often far away from the scientist's working place - can afford such precious collections. To satisfy an urgent need of many scientists working in the field of semiconductor physics for having at their working place a comprehensive, high quality, but inexpensive collection of at least the basic data of their field of interest this volume contains the most important data of semiconductors. All data were compiled from information on semiconductors presented on more than 6 000 pages in various volumes of the New Series of Landolt-Börnstein."

With these words the aim of the volume "Semiconductors – Basic Data", published by the present author – was defined in the preface to its first Edition. This edition – published in two volumes in the Series "Data in Science and Technology" – appeared in 1991/92. The 2nd Edition was published in one volume five years later.

While preparing the third edition, it became clear that a complete revision was necessary for several reasons:

- To the eleven subvolumes of volumes III/17 and III/22 of the New Series of Landolt-Börnstein – published between 1982 and 1988 – eight new supplementary subvolumes (III/41) appeared in the meantime. The 19 volumes now available comprise about 10 000 pages with more than 13 000 figures. Thus, much new data had to be included in this collection of basic data.
- The Landolt-Börnstein series is now available on the Internet. So easy access to the data via Internet had to be considered in the structure of this volume.
- Last but not least the possibility *to combine a printed medium with an enclosed CD-ROM* gives the opportunity to improve the value of a data collection by shifting parts of the information onto the CD-ROM, thereby increasing the amount of information substantially without an undue increase of the number of pages.

By this opportunity, a drawback of earlier editions could be eliminated: To limit the number of pages, a comprehensive presentation of the most important data was only possible for the group IV and III-V semiconductors. All other groups of semiconductors could only be handled very briefly in tabular form with a restricted number of figures and without references. This drawback is now eliminated. The (printed) volume contains the basic data for all known groups of semiconductors in suitable length. Figures on crystal structures and band structures supplement the tables.

Further information was shifted to the CD-ROM:

- *Figures*. A user of this book usually first looks for *data collected in tables*. Figures can supply deeper information by presenting functional dependences, such as temperature dependence, pressure dependence, and by presenting dispersion curves, optical spectra etc. Such additional information is now provided in about 1000 additional figures on the CD-ROM. Presenting these figures in the printed version had required several hundred pages.
- *References*. The knowledge of the origin of data is necessary for the user to find the context in which the data were measured. Thus, data presented in this volume should also contain more than 100 pages of references. These references were shifted to the enclosed CD-ROM.
- *Additional information useful for the reader but too spacious to be presented in the printed version*. There are a large number of substances (e.g. boron compounds, transition metal and rare earths compounds) exhibiting "semiconducting properties". A presentation of data referring to such substances in the printed text seemed to be too extensive and was therefore left to the CD-ROM

Thus, the present edition differs substantially from the former editions in the amount of information and the manner of presentation (and unavoidable also in the number of pages). To emphasize this change the title of the third edition has been changed from "*Semiconductors: Basic Data*" to "*Semiconductors: Data Handbook*".

I do hope the users of the volume will profit from these innovations.

Marburg, August 2003

Otfried Madelung

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25.10	Bismuth selenide (Bi_2Se_3)	628
25.11	Bismuth telluride (Bi_2Te_3)	630
25.12	Realgar (As_4S_4)	633

26 V-VII₃ compounds

26.0	Crystal structure and electronic structure ...	634
26.1	Arsenic triiodide (AsI_3)	635
26.2	Antimony triiodide (SbI_3)	636
26.3	Bismuth triiodide (BiI_3)	637

E Further ternary compounds

27 I_x-IV_y-VI_z compounds

27.0	Crystal structure	640
27.1	Ag_8GeS_6 (argyrodite)	641
27.2	Ag_8SnS_6 (canfieldite)	641
27.3	Ag_8SiSe_6	642
27.4	Ag_8GeSe_6	642

27.5	Ag_8SnSe_6	643
27.6	Ag_8GeTe_6	643
27.7	Cu_8GeS_6	644
27.8	Cu_8GeSe_6	644
27.9	$\text{Cu}_4\text{Ge}_3\text{S}_5$, $\text{Cu}_4\text{Ge}_3\text{Se}_5$ and $\text{Cu}_4\text{Sn}_3\text{Se}_5$	644
27.10	Cu_4SnS_4	644

28 I_x-V_y-VI_z compounds

28.0	Crystal structure and electronic structure ..	645
28.1	AgAsS_2	646
28.2	AgAsSe_2	646
28.3	AgAsTe_2	647
28.4	AgSbS_2	647
28.5	AgSbSe_2	647
28.6	AgSbTe_2	648
28.7	AgBiS_2	648
28.8	AgBiSe_2	649
28.9	AgBiTe_2	649
28.10	CuSbSe_2	650
28.11	CuSbTe_2	650
28.12	CuBiSe_2	651
28.13	CuBiTe_2	651
28.14	Ag_3AsS_3	651
28.15	Ag_3SbS_3	652

29 II_x-III_y-VI_z compounds

29.0	Crystal structure of II-III-VI ₂ compounds .	653
29.1	CdInS_2	653
29.2	CdInSe_2	654
29.3	CdInTe_2	654
29.4	CdTlS_2	655
29.5	CdTlSe_2	655
29.6	CdTlTe_2	656
29.7	HgTlS_2	656

30 III_x-V_y-VI_z compounds

30.0	Crystal structure of III-V-VI ₂ compounds	657
30.1	TlAsS_2	657
30.2	TlSbS_2	657
30.3	TlBiS_2	658
30.4	TlBiSe_2	658
30.5	TlBiTe_2	659
30.6	$\text{Ga}_6\text{Sb}_5\text{Te}$	659

30.7	In ₆ Sb ₅ Te	659
30.8	In ₇ SbTe ₆	660

31 IV_x-V_y-VI_z compounds

31.0	Crystal structure.....	661
31.1	Bi ₁₂ SiO ₂₀	661
31.2	Bi ₁₂ GeO ₂₀	662
31.3	PbSb ₂ S ₄ , GeSb ₂ Te ₄ , GeBi ₂ Te ₄ , SnBi ₂ Te ₄ ..	662
31.4	GeBi ₄ Te ₇ , GeSb ₄ Te ₇ , PbBi ₄ Te ₇	663

32 V-VI-VII compounds

32.0	Crystal structure and electronic structure ..	665
32.1	AsSBr	666
32.2	SbSI	666
32.3	SbSBr	669
32.4	SbSeBr	669
32.5	SbSeI	669
32.6	SbTeI	670
32.7	BiOCl	670
32.8	BiOBr	670
32.9	BiOI	671
32.10	BiSCl	671
32.11	BiSBr	671
32.12	BiSI	671
32.13	BiSeBr	672
32.14	BiSeI	672
32.15	BiTeBr	672
32.16	BiTeI	673

33 Further ternary compounds

33.1	Cu ₃ In ₅ Se ₉	674
33.2	Cu ₃ Ga ₅ Se ₉	674
33.3	Ag ₃ In ₅ Se ₉	675
33.4	Ag ₃ Ga ₅ Se ₉	675
33.5	Cu ₂ Ga ₄ Te ₇	675
33.6	Cu ₂ In ₄ Te ₇	676
33.7	CuIn ₃ Te ₅	676
33.8	AgIn ₃ Te ₅	677
33.9	AgIn ₅ S ₈	677
33.10	AgIn ₉ Te ₁₄	677
33.11	Cd ₂ SnO ₄	677
33.12	CdSnO ₃	678
33.13	Li ₃ CuO ₃	678

33.14	Hg ₃ PS ₃ , Hg ₃ PS ₄	678
33.15	Cd ₄ (P,As) ₂ (Cl,Br,I) ₃	678

F Boron, transition metal and rare earth compounds with semiconducting properties (data only on the enclosed CD-ROM)

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35 Binary transition metal compounds

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37 Ternary transition metal compounds

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