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国外物理名著系列 5

(影印版)

Semiconductor Optics  
(3rd Edition)

半导体光学  
(第三版)

C. F. Klingshirn



科学出版社

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## 国外物理名著(影印版)系列序言

对于国内的物理学工作者和青年学生来讲,研读国外优秀的物理学著作是系统掌握物理学知识的一个重要手段。但是,在国内并不能及时、方便地买到国外的图书,且国外图书不菲的价格往往令国内的读者却步,因此,把国外的优秀物理原著引进到国内,让国内的读者能够方便地以较低的价格购买是一项意义深远的工作,将有助于国内物理学工作者和青年学生掌握国际物理学的前沿知识,进而推动我国物理学科研究和教学的发展。

为了满足国内读者对国外优秀物理学著作的需求,科学出版社启动了引进国外优秀著作的工作,出版社的这一举措得到了国内物理学界的积极响应和支持,很快成立了专家委员会,开展了选题的推荐和筛选工作,在出版社初选的书单基础上确定了第一批引进的项目,这些图书几乎涉及了近代物理学的所有领域,既有阐述学科基本理论的经典名著,也有反映某一学科专题前沿的专著。在选择图书时,专家委员会遵循了以下原则:基础理论方面的图书强调“经典”,选择了那些经得起时间检验、对物理学的发展产生重要影响、现在还不“过时”的著作(如:狄拉克的《量子力学原理》)。反映物理学某一领域进展的著作强调“前沿”和“热点”,根据国内物理学研究发展的实际情况,选择了能够体现相关学科最新进展,对有关方向的科研人员和研究生有重要参考价值的图书。这些图书都是最新版的,多数图书都是2000年以后出版的,还有相当一部分是2006年出版的新书。因此,这套丛书具有权威性、前瞻性和应用性强的特点。由于国外出版社的要求,科学出版社对部分图书进行了少量的翻译和注释(主要是目录标题和练习题),但这并不会影响图书“原汁原味”的感觉,可能还会方便国内读者的阅读和理解。

“他山之石,可以攻玉”,希望这套丛书的出版能够为国内物理学工作者和青年学生的工作和学习提供参考,也希望国内更多专家参与到这一工作中来,推荐更多的好书。

杨国桢

中国科学院院士  
中国物理学会理事长  
2007年3月20日

To my parents, my wife and my children

Wahrheit und Klarheit sind komplementär.

E. MOLLWO

This aphorism was coined in the nineteen-fifties by E. MOLLWO, Professor of Physics at the Institut für Angewandte Physik of the Universität Erlangen during a discussion with W. HEISENBERG. The author hopes that, with respect to his book, the deviations from exact scientific truth (Wahrheit) and perfect understandability (Klarheit) are in a reasonable balance.

Just as an illustration of the above statement, the attention of the author has been drawn to the fact, that the same statement has been reported even in German language also from NIELS BOHR. See Steven Weinberg, *Dreams of a Final Theory*, Vintage Books, New York (1994) p. 74.

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## Preface to the Third Edition

The second edition, which appeared in 2005 and contains substantial updates and amendments compared to the first one and its corrected reprints, was again favourably received by the students and the scientific community worldwide.

As a consequence, the present third edition became necessary. The changes introduced are, compared to the second edition, more limited, among others because the time elapsed between second and third edition is much shorter than the time between first and second one.

The main changes concern the following points: The discussion about the density, at which an electron-hole plasma is formed, has been up-dated, in the section about photonic crystals a few comments on meta-materials have been added, several new and timely references have been included and some of the misprints have been removed.

Karlsruhe,  
August 2006

*C.F. Klingshirn*

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## Preface to the Second Edition

The book on Semiconductor Optics has been favourably received by the students and the scientific community worldwide. After the first edition, which appeared in 1995 several reprints became necessary starting from 1997, one of them for the Chinese market. They contained only rather limited updates of the material and corrections.

In the meantime scientific progress brought a lot of new results, which necessitate a new, seriously revised edition. This progress includes bulk semiconductors, but especially structures of reduced dimensionality. These new trends and results are partly included in existing chapters e.g. for phonons or for time-resolved spectroscopy, partly new chapters have been introduced like the ones on cavity polaritons and photonic structures.

We based the description of the optical properties again on the simple and intuitively clear model of the Lorentz-oscillators and the concept of polaritons as the quanta of light in matter. But since there is presently a trend to describe at least the optical properties of the electronic system of semiconductors by the optical or the semiconductor Bloch equations, a chapter has been added on this topic written by Prof. Dr. R. v. Baltz (Karlsruhe) to familiarize the reader with this concept, too, which needs a bit more quantum mechanics compared the approach used here. The chapter on group theory has been revised by Prof. Dr. K. Hümmer (Karlsruhe/Forchheim)

Karlsruhe,  
September 2004

*C.F. Klingshirn*



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## Preface to the First Edition

One of the most prominent senses of many animals and, of course, of human beings is sight or vision. As a consequence, all phenomena which are connected with light and color, or with the optical properties of matter, have been focal points of interest throughout the history of mankind. Natural light sources such as the Sun, the Moon and stars, or fire, were worshipped as gods or goddesses in many ancient religions. Fire, which gives light and heat, was for many centuries thought to be one of the four elements – together with earth, water, and air. In alchemy, which marks the dawn of our modern science, the Sun and the Moon appeared as symbols of gold and silver, respectively, and many people tried to produce these metals artificially. Some time later, Johann Wolfgang von Goethe (1749–1832) considered his “Farbenlehre” as more important than his poetry. In the last two centuries a considerable fraction of modern science has been devoted to the investigation and understanding of light and the optical properties of matter. Many scientists all over the world have added to our understanding of this topic. As representatives of the many we should like to mention here only a few of them: I. Newton (1643–1727), J.C. Maxwell (1831–1879), M. Planck (1858–1947), A. Einstein (1879–1955), N. Bohr (1885–1962), and W. Heisenberg (1901–1976).

The aim of this book is more modest. It seeks to elucidate one of the numerous aspects in the field of light and the optical properties of matter, namely the interaction of light with semiconductors, i.e., semiconductor optics. The investigation of the properties of semiconductors has, in turn, its own history, which has been summarized recently by H.J. Queisser [85Q1]. In Queisser’s book one can find early examples of semiconductor optics, namely the observation of artificially created luminescence by V. Cascariolo in Bologna at the beginning of the 17th century, or by K.F. Braun (1850–1918), inventor of the “Braun’sche Röhre” (Braun’s tube) now usually called CRT (cathode ray tube), at the beginning of this century.

Another root of semiconductor optics comes from the investigation of the optical properties of insulators, especially of the color (Farb- or F-) centers in alkali halides. This story has been written down recently by J. Teich-

- i. 20th ICPS, Thessaloniki (1990), ed. by E.M. Anastassakis, J.D. Joannopoulos (World Scientific, Singapore 1990)
  - j. 21st ICPS, Beijing (1992), ed. by Ping Jiang, Hou-Zhi Zheng (World Scientific, Singapore 1993)
  - k. 22nd ICPS, Vancouver (1994) D.J. Looockwood ed. (World Scientific, Singapore, 1995)
  - l. 23rd ICPS, Berlin (1996), M. Scheffler and R. Zimmermann (eds.), World Scientific, Singapore (1996)
  - m. 24th ICPS, Jerusalem (1998), D. Gershoni (ed.), World Scientific, Singapore (1999)
  - n. 25th ICPS, Osaka (2000), N. Miura and T. Ando (eds.), Springer Proc. In Physics **87**, Springer, Berlin (2001)
  - o. 26th ICPS, Edinburgh (2002), A.R. Long and J.H. Davies (eds.), Institute of Physics Conf. Series **171**, (2003)
  - p. 27th ICPS, Flagstaff (2004), J. Menéndez and Ch. Van de Walle eds., American Institute of Physics Conf. Proc. **772** (2005)
  - q. 28th ICPS, Vienna (2006) in press
- [77B1] A.D. Beyerchen: *Scientists under Hitler*, (Yale Univ. Press, New Haven 1977)
- [84M1] E. Mollwo: *Physik in unserer Zeit* **15**, 110 (1984)
- [85Q1] H.-J. Queisser: *Kristallene Krisen* (Piper, München 1985)
- [88H1] F. Hund, H. Maier-Leibnitz, E. Mollwo: *Eur. J. Phys.* **9**, 188 (1988)
- [88T1] J. Teichmann: *Zur Geschichte der Festkörperphysik-Farbzentrenforschung bis 1940* (Steiner, Wiesbaden 1988)
- [81I1] The proceedings of the Series of Int'l Conferences of Luminescence (ICL) are published in *J. Lumin.* The more recent ones were
- a. ICL, Berlin (1981), ed. by I. Broser, H.-E. Gumlich, R. Broser: *J. Lumi.* **24/25** (1981)
  - b. ICL, Madison (1984), ed. by W.M. Yen, J.C. Wright: *J. Lumin.* **31/32** (1984)
  - c. ICL, Beijing (1987), ed. by Xu Xurong: *J. Lumin.* **40/41** (1987)
  - d. ICL, Lisbon (1990), ed. by S.J. Formosinho, M.D. Sturge: *J. Lumin.* **48/49** (1990)
  - e. ICL, Storrs (1993) ed. by D.S. Hamilton, R.S. Meltzer and M.D. Sturge: *J. Lumi.* **60/61** (1995)
  - f. ICL, Prague (1996) ed. J. Hala, P. Reinecker, *J. Lumin.* **72-74** (1997)
  - g. ICL, Osaka (1999) ed by K. Cho, *J. Lumin* **87-89** (2000)
  - h. ICL Budapest (2002), ed by S. Speiser, *J. Lumin* **102-103** (2003)
  - i. ICL Beijing (2005) in press
- [87N1] The Series of International conferences/workshops on Nonlinear Optics and Excitation Kinetics (NOEKS) has been started in the former German Democratic Republic (DDR) and continued successfully after the reunification of Germany. The proceedings have so far been published in
- a. NOEKS I Nov. 1987, Bad Stuer phys. stat. sol. (b) **146** and **147** (1988)
  - b. NOEKS II Dez. 1989, Bad Stuer phys. stat. sol. (b) **159** (1) (1990)
  - c. NOEKS III Mai 1992, Bad Honnef phys. stat. sol. (b) **173** (1) (1992)
  - d. NOEKS IV Nov. 1994, Gosen phys. stat. sol. (b) **188** (1) (1995)
  - e. NOEKS V Sept. 1997, Graal-Müritz phys. stat. sol. (b) **206** (1) (1998)
  - f. NOEKS VI April 2000, Marburg phys. stat. sol. (b) **221** (1) (2000)
  - g. NOEKS VII Feb. 2003, Karlsruhe phys. stat. sol. (c) **0** (5) (2003)
  - h. NOEKS VIII Feb. 2006, Münster, phys. stat. sol. (c) **3** (7) (2006)

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The sources of the scientific information presented here are partly the references given. Of equal importance, however, is the physics, which I learned from my academic teachers during my studies and PhD work at the University of Erlangen, my post-doc time at the Laboratoire de Spéctroscopie et d'Optique du Corps Solide in Strasbourg and my Habilitation at the University of Karlsruhe, and later on from fruitful discussions with many colleagues and co-workers at the places where I was or still am as Professor (Frankfurt am Main, Kaiserslautern and Karlsruhe) and abroad including guest scientists in my group. Without trying to be complete, I should like to mention my academic teachers Profs. Drs. R. Fleischmann (†), H. Volz (†), E. Mollwo (†), R. Helbig and K. Hümmer (Erlangen) and F. Stöckmann (†), W. Ruppel and W. Stöbel (Karlsruhe).

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My special thanks are due to all my former and present students and co-workers, who produced their Diplom, PhD or Habilitation thesis in my research group and many of the fine results presented in this book and who partly hold in the meantime professorships or equivalent positions of their own (H. Kalt (Karlsruhe), M. Wegener (Karlsruhe), U. Woggon (Dortmund), H. Giessen (Stuttgart), M. Kuball (Bristol) and W. Langbein (Cardiff)). Beyond that I do not want to give names here, because they are too many and I am afraid to forget somebody.

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A lot of thanks also to all, who tried to solve “the final problem” on p782 of the second edition. Without trying to be complete, I should like to mention my colleague Prof. Dr. R. v. Baltz and my diplom student M. Hauser in Karlsruhe.

Last but not least, I should like to thank the Publishing House Springer and there especially Dr. Th. Schneider for the excellent cooperation in the production of this new edition.

Karlsruhe,  
August 2006

*Claus F. Klingshirn*

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