

Preface

The unification of the asymmetry of the wave vector space of charge carriers in semiconductors with modern techniques of fabricating nanostructured materials such as MBE, MOCVD, and FLL in one, two, and three dimensions (such as quantum wells (QWs), NIPI structures, inversion and accumulation layers, quantum well superlattices, carbon nanotubes, quantum wires, quantum wire superlattices, magnetic quantization, magneto size quantization, quantum dots, magneto inversion and accumulation layers, magneto NIPIs, magneto quantum well superlattices, quantum dot superlattices, and other field aided low-dimensional systems spawn not only useful quantum effect devices but also unearth new concepts in the realm of low-dimensional solid-state science and related disciplines. It is worth remarking that these semiconductor nanostructures occupy a central position in the entire arena of nanoscience and technology by their own right and find extensive applications in quantum registers, quantum switches, quantum sensors, quantum logic gates, heterojunction field effect devices, quantum well and quantum wire transistors, quantum cascade lasers, high-speed digital networks, high-frequency microwave circuits, high-resolution terahertz spectroscopy, superlattice photo-oscillator, advanced integrated circuits, superlattice photocathodes, resonant tunneling diodes and transistors, thermoelectric devices, super-lattice coolers, thin film transistors, intermediate-band solar cells, micro-optical systems, high performance infrared imaging systems, bandpass filters, thermal sensors, optical modulators, optical switching systems, single electron/molecule electronics, nanotube-based diodes, and other nanoelectronic devices. Knowledge regarding these quantized structures may be gained from original research contributions in scientific journals, various patents, proceedings of conferences, review articles, and different research monographs [1–5] respectively. In this context, it may be noted that the available reports on the said areas cannot afford to cover even an entire chapter excluding a few pages on the Debye screening length (DSL) for nanostructured materials.

It is well known that the DSL of the carriers in semiconductors is a very important quantity characterizing the screening of the Coulomb field of the ionized impurity centers by the free carriers [6]. It affects many of the special features of modern nanodevices, the carrier mobilities under different mechanisms of scattering, and the carrier plasmas in semiconductors [7–9]. The DSL is a good approximation for the accurate self-consistent screening in presence of band tails

and is also used to illustrate the interaction between the colliding carriers in Auger effect in solids [6]. The classical value of the DSL is equal to $[\epsilon_{sc} k_B T / (e^2 n_0)]^{1/2}$ (ϵ_{sc} , k_B , T , e , and n_0 are the semiconductor permittivity, the Boltzmann's constant, the temperature, the magnitude of the carrier charge, and the electron concentration, respectively, which is valid for both the carriers. In this conventional form, the DSL decreases with increasing carrier concentration at a constant temperature and this relation holds only under the condition of carrier non-degeneracy. On the other hand, under the condition of extreme degeneracy, the expression of DSL for materials having parabolic energy bands can be written as $L_D = (\pi^{2/3} \hbar \sqrt{\epsilon_{sc}}) (e g_v^{1/3} 3^{1/6} n_0^{1/6} \sqrt{m_c})^{-1}$ (\hbar , m_c and g_v are Dirac constant, effective electron mass at the edge of the conduction band and valley degeneracy respectively). Thus we observed that in this case the result is independent of temperature, but depends on n_0 , g_v and m_c . Besides, the indices of inverse electron variation changes from half in the former case to one-sixth in the latter case. Since the performance of the electron devices at the device terminals and the speed of operation of modern switching transistors are significantly influenced by the degree of carrier degeneracy present in these devices, the simplest way of analyzing such devices taking into account the degeneracy of the band is to use the appropriate DSL to express the performance at the device terminal and switching speed in terms of the carrier concentration [10].

The DSL depends on the density-of-states function which, in turn, is significantly affected by the different carrier energy spectra of different semiconductors having various band structures. In recent years, various energy wave vector dispersion relations of the carriers of different materials have been proposed [11–28] which have created the interest in studying the DSL in such quantized structures under external conditions. It is well known, from the fundamental study of Landsberg [6], that the DSL for electronic materials having degenerate electron concentration is essentially determined by their respective energy band structures. It has, therefore, different values in different materials and varies with the electron concentration, with the magnitude of the reciprocal quantizing magnetic field under magnetic quantization, with the quantizing electric field as in inversion layers, with the nano-thickness as in quantum wells, with superlattice period as in the quantum confined superlattices of small gap compounds with graded interfaces having various carrier energy spectra. The nature of these variations has been investigated in the literature by [29–49] and some of the significant features, which have emerged from these studies, are:

- (a) The DSL in bulk semiconductors decreases with increasing carrier concentration and such variations are significantly influenced by constants of the energy band spectra;
- (b) The DSL decreases with the increasing magnitude of the quantizing electric field as in inversion layers;
- (c) The DSL oscillates with the inverse quantizing magnetic field under magnetic quantization due to the SdH effect;

- (d) The DSL exhibits composite oscillations with the various controlled quantities as in superlattices of non-parabolic compounds with graded interfaces.

This book, divided into four parts, contains fifteen chapters, is partially based on our ongoing researches on the DSL from 1980 and an attempt has been made to present a cross section of the DSL for wide range of non-parabolic semiconductors and their nanostructures with varying carrier energy spectra under various physical conditions. The first part deals with the influence of quantum confinement on the DSL in non-parabolic semiconductors. [Chapter 1](#) investigates the DSL in quantum wells of non-parabolic semiconductors and at first we study the DSL in QWs of nonlinear optical materials on the basis of a generalized electron dispersion law introducing the anisotropies of the effective masses and the spin-orbit splitting constants, respectively, together with the inclusion of the crystal field splitting within the framework of the $k.p$ formalism. The results of III–V (e.g., InAs, InSb, GaAs etc.), ternary (e.g., $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$), quaternary (e.g., $\text{In}_{1-x}\text{Ga}_x\text{As}_{1-y}\text{P}_y$ lattice matched to InP) compounds form a special case of our generalized analysis under certain limiting conditions. The DSL in QWs of II–VI, Bi, IV–VI, stressed Kane-type semiconductors, Te, GaP, PtSb_2 , Bi_2Te_3 , Ge, and GaSb materials have also been investigated by using the respective appropriate energy band structure. The importance of the aforementioned semiconductors has also been described in the same chapter. With the advent of modern experimental techniques of fabricating nanomaterials, it is possible to grow semiconductor superlattices (SLs) composed of alternative layers of two different degenerate layers with controlled thickness [50]. These structures have found wide applications in many new devices such as photodiodes [51], photoresistors [52], transistors [53], light emitters [54], tunneling devices [55], etc [56–69]. The investigations of the physical properties of narrow gap SLs have increased extensively, since they are important for optoelectronic devices and also since the quality of heterostructures involving narrow gap materials has been greatly improved. It may be noted that the NIPI structures, also called the doping superlattices, are crystals with a periodic sequence of ultrathin film layers [70, 71] of the same semiconductor with the intrinsic layer in-between together with the opposite sign of doping. All the donors will be positively charged and all the acceptors negatively. This periodic space charge causes a periodic space charge potential which quantizes the motions of the carriers in the z -direction together with the formation of the subband energies. The electronic structures of the NIPIs differ radically from the corresponding bulk semiconductors as stated below:

- a. Each band is split into mini-bands;
- b. The magnitude and the spacing of these mini-bands may be designed by the choice of the superlattices parameters; and
- c. The electron energy spectrum of the NIPI crystal becomes two-dimensional leading to the step functional dependence of the density-of-states function.

In [Chap. 2](#) the DSL in NIPI structures of nonlinear optical, III–V, II–VI, IV–VI, and stressed Kane-type semiconductors has been studied. In recent years, there has

been considerable interest in the study of the inversion layers which are formed at the surfaces of semiconductors in metal-oxide-semiconductor field-effect transistors (MOSFET) under the influence of a sufficiently strong electric field applied perpendicular to the surface by means of a large gate bias. In such layers, the carriers form a two-dimensional gas and are free to move parallel to the surface while their motion is quantized in the direction perpendicular to it leading to the formation of electric subbands [72–84]. In [Chap. 3](#) the DSL in n-channel inversion layers of nonlinear optical, III–V, II–VI, IV–VI, stressed Kane-type semiconductors, Ge and GaSb has been investigated. It is worth remarking that under conditions of extreme degeneracy, electric quantum limit, and parabolic electron dispersion law of the corresponding bulk materials, the 2D DSL for 2D systems of inversion layers, ultrathin films and NIPI structures, assumes the common form as $L_{2D} = [(2\varepsilon_{sc}\pi\hbar^2)/(e^2m_cg_v)]$. Thus, the result is independent of carrier concentration, temperature, and the signature of the nature of the specific 2D system is totally absent, although for non-parabolic energy bands both the result and conclusion differ widely. Under condition of non-degeneracy, screening length for all the three aforesaid 2D systems can be written as $L_{2D} = [(2\varepsilon_{sc}k_BT)/(e^2n_s)]$ (n_s is the surface electron concentration per unit area). Thus, we infer that in the previous case, the result is independent of electron statistics and temperature whereas in the latter case L_{2D} varies inversely as n_s at constant temperature exhibiting rectangular hyperbolic variation.

With the advent of nanophotonics, there has been considerable interest in studying the optical processes in semiconductors and their nanostructures in the presence of intense light waves [85]. It appears from the literature that the investigations have been carried out on the assumption that the carrier energy spectra are invariant quantities in the presence of strong external photo excitation, which is not fundamentally true. The physical properties of semiconductors in the presence of strong light waves which alter the basic dispersion relations have relatively been much less investigated in [86, 87] as compared with the cases of other external fields needed for the characterization of the low-dimensional semiconductors. The second part of this book studies the influence of light waves on the DSL in optoelectronic semiconductors and [Chap. 4](#) investigates the influence of light waves on the DSL in III–V, ternary and quaternary semiconductors by formulating new electron dispersion relation within the framework of **k,p** formalism. [Chapter 5](#) explores the effect of light waves on the DSL for ultra-thin films of III–V, ternary, and quaternary semiconductors. [Chapters 6](#) and [7](#) investigate the opto-DSL under magnetic quantization and also under cross-field configurations of the said materials respectively.

With the advent of nanodevices, the built-in electric field becomes so large that the electron energy spectrum changes fundamentally and the solo [Chap. 8](#) in the third part investigates the DSL under intense electric field in bulk specimens of III–V, ternary and quaternary semiconductors. This chapter also explores the influence of electric field on the DSL on the basis of new dispersion law under magnetic quantization, size quantization, NIPI structures, inversion layers,

effective mass superlattices, and also superlattices with graded interfaces under magnetic quantization respectively. Chapter 9 suggests the experimental determinations of 2D and 3D DSLs and few related applications of the content of this book. Our suggestion for the experimental determination of 3D DSL and the theoretical formula for Cd_3As_2 based on our generalized analysis incorporating all types of anisotropies of the energy band structure agree well with each other and are discussed in this chapter.

Chapter 10 contains the conclusion and the scope for future research. The fourth part of the book has been named as appendices and contains Chaps. 11 to 15. The Chap. 11 studies the DSL in bulk specimens of nonlinear optical and tetragonal materials, III–V, II–VI, Bi, IV–VI, stressed compounds, n-Te, n-GaP, PtSb_2 , n-Ge, and n-GaSb respectively. It may be noted that the effects of quantizing magnetic field (B) on the band structures of compound semiconductors are most striking than that of the parabolic one and are easily observed in experiments. A number of interesting physical features originate from the significant changes in the basic energy wave vector relation of the carriers caused by the magnetic field. The valuable information could also be obtained from experiments under magnetic quantization regarding the important physical properties such as Fermi energy and effective masses of the carriers, which affect almost all the transport properties of electron devices [88–100] of various materials having different carrier dispersion relations [101–112]. The DSL in the presence of magnetic quantization is a tensor quantity and we take that particular element of the DSL which is in the direction of magnetic field only ($L_{D_{zz}}$). The $L_{D_{zz}}$ for isotropic parabolic energy bands under conditions of extreme degeneracy and magnetic quantum limit can be expressed as $L_{D_{zz}} = (\hbar^2 \pi^2 \sqrt{2\epsilon_{sc}} / e^2 B) \sqrt{n_0}$). Thus we observe that in the presence of quantizing magnetic field, the DSL increases with increasing n_0 , whereas in the absence of magnetic quantization for bulk materials, the DSL decreases with increasing carrier degeneracy. This diametrically opposite behavior manifests the signature of the singularity of the density-of-states function in the respective cases. Chapter 12 studies the influence of magnetic quantization on the DSL for the aforementioned materials. It is worth remarking that the influence of crossed electric and quantizing magnetic fields on the transport properties of semiconductors having various band structures are relatively less investigated as compared with the corresponding magnetic quantization, although, the cross-fields are fundamental with respect to the addition of new physics and the related experimental findings. It is well known that in the presence of electric field (E_0) along x-axis and the quantizing magnetic field (B) along z-axis, the dispersion relations of the conduction electrons in semiconductors become modified and for which the electron moves in both z and y directions. The motion along y direction is purely due to the presence of E_0 along x-axis and in the absence of electric field, the effective electron mass along y-axis tends to infinity which indicates the fact that the electron motion along y-axis is forbidden. The effective electron mass of the isotropic, bulk semiconductors having parabolic energy bands exhibits mass anisotropy in the presence of cross fields and this anisotropy depends on the electron energy, the magnetic quantum

number, the electric and the magnetic fields, respectively, although the effective electron mass along z -axis is a constant quantity. In 1966, Zawadzki and Lax [113] formulated the electron dispersion law for III–V semiconductors in accordance with the two-band model of Kane under cross fields configuration which generates the interest to study this particular topic of solid-state science in general [114–126]. Chapter 13 investigates the DSL under cross field configuration in nonlinear optical, III–V, II–VI, IV–VI, stressed Kane-type semiconductors and their nanostructures. Chapter 14 studies the DSL for heavily doped semiconductors (HDS) in a nutshell. It is an amazing fact that though HDS have been studied in the literature [127–130], the study of the carrier transport in such materials through proper formulation of the Boltzmann transport equation which needs in turn, the corresponding heavily doped carrier energy spectra, is still one of the open research problems. The last Chap. 15 presents a simplified analysis of the DSL in superlattices of heavily doped non-parabolic semiconductors under magnetic quantization, which is a big topic of research by its own right. In Chap. 11 to Chap. 15 no graphs, together with results and discussions, are presented since we feel that the readers will enjoy the complex computer algorithm to investigate the DSL in the respective case generating new physics and thereby transforming each chapter of part 4 into a short monograph by considering various materials having different dispersion relations.

It is needless to say that this monograph is based on the iceberg principle [131], the rest of which will be explored by researchers from different appropriate fields. Since there is no existing report devoted solely to the study of DSL for nano-structured materials to the best of our knowledge, we hope that the present book will be a useful reference source for the present and the next generation of readers and researchers of solid-state and allied sciences in general. In spite of our joint efforts, the production of an error-free first edition of any book from every point of view enjoys permanently the domain of impossibility theorems and the same stands true for this monograph also. Various expressions and a few chapters of this book have been appearing for the first time in printed form. Suggestions from the readers for the development of the book will be highly appreciated for the purpose of inclusion in a future edition, if any. In this book, from Chap. 1 till the end, we have presented *200 open research problems* in this particular topic. The problems presented here are the integral part of this book and will be useful for the readers to initiate their own contributions on the DSL. This aspect is also important for Ph.D. aspirants and researchers.

In this monograph, we have investigated various dispersion relations of different quantized structures and the corresponding carrier statistics to study the concentration dependence of the DSL. Thus, in this book, the readers will get much information regarding quantum confined low-dimensional materials having different band structures. For the enhancement of the materials aspect we have considered various materials having the same dispersion relation to study the influence of energy band constants of the different materials on DSL. Although the name of the book is extreme specific, from the content, one can infer that it should be useful in graduate courses on materials physics and devices in many universities

and institutions. Last but not the least, we do hope that our humble effort will kindle the desire to delve deeper into this fascinating topic by anyone engaged in materials research and device development either in academics or in industries.

References

1. S. Bhattacharya, K.P. Ghatak, *Fowler-Nordheim Field Emission: Effects in Semiconductor Nanostructures*, Springer Series in Solid State Sciences **170** (Springer, Heidelberg, 2012)
2. S. Bhattacharya, K.P. Ghatak, *Effective Electron Mass in Low Dimensional Semiconductors*, Springer Series in Materials Sciences **167** (Springer, Heidelberg, 2013)
3. K.P. Ghatak, S. Bhattacharya, *Thermo Electric Power in Nano structured Materials Strong Magnetic Fields*, Springer Series in Materials Science **137** (Springer, Heidelberg, 2010)
4. K.P. Ghatak, S. Bhattacharya, D. De, *Photoemission from Optoelectronic Materials and their Nanostructures*, Springer Series in Nanostructure Science and Technology, (Springer, New York, 2009)
5. K.P. Ghatak, S. Bhattacharya, D. De, *Einstein Relation in Compound Semiconductors and their Nanostructures*, Springer Series in Materials Science **116** (Springer, Heidelberg, 2009)
6. P.T. Landsberg, Eur. J. Phys. **2**, (213) (1981)
7. R.B. Dingle, Philos. Mag. **46**, (813) (1955)
8. D. Redfield, M.A. Afromowitz, Ibid. **19**, (831) (1969)
9. H.C. Casey, F. Stern, J. Appl. Phys. **47**, (631) (1976)
10. S.N. Mohammad, J. Phys. C **13**, (2685) (1980)
11. K.P. Ghatak, S. Bhattacharya, S. Pahari, S.N. Mitra, P.K. Bose, D. De, J. Phys. Chem. Sol. **70**, (122) (2009)
12. K.P. Ghatak, J.Y. Siddiqui, B. Nag, Phys. Lett. A: Gen. At. solid. state. Phys. **282**, (428) (2001)
13. B. Nag, K.P. Ghatak, J. Phys. Chem. Sol. **58**, (427) (1997)
14. K.P. Ghatak, J.P. Banerjee, B. Nag, J. Appl. Phys. **83**, (1420) (1998)
15. K.P. Ghatak, B. Nag, Nanostruc. Mat. **10**, (923) (1998)
16. K.P. Ghatak, J.P. Banerjee, D. Bhattacharyya, B. Nag, Nanotechnology **7**, (110) (1996)
17. B. Nag, K.P. Ghatak, Phys. Scr. **54**, (657) (1996)
18. A.K. Sreedhar, S.C. Gupta, Phys. Rev. B **5**, (3160) (1972)
19. R.W. Keyes, IBM. J. Res. Dev. **5**, (266) (1961)
20. R.W. Keyes, Solid State Phys. **20**, (37) (1967)
21. S. Bhattacharya, S. Chowdhury, S. Ghoshal, S.K. Biswas, D. De, K.P. Ghatak, J. Comput. Theor. Nanosci. **3**, (423) (2006)
22. S. Chowdhury, L.J. Singh, K.P. Ghatak, Phys. B: Condens. Matter **365**, (5) (2005)
23. L.J. Singh, S. Choudhary, A. Mallik, K.P. Ghatak, J. Comput. Theor. Nanosci. **2**, (287) (2005)
24. B. Nag, K.P. Ghatak, Mol. Cryst. Liq. Cryst. Sci. Technol., Sect. B: Nonlinear Opt. **19**, (1) (1998)
25. K.P. Ghatak, D.K. Basu, B. Nag, J. Phys. Chem. Solids **58**, (133) (1997)
26. K.P. Ghatak, J.P. Banerjee, B. Goswami, B. Nag, Mol. Cryst. Liq. Cryst. Sci. Technol., Sect. B: Nonlinear Opt. **16**, (241) (1996)
27. K.P. Ghatak, J.P. Banerjee, M. Mitra, B. Nag, Mol. Cryst. Liq. Cryst. Sci. Technol., Sect. B: Nonlinear Opt. **17**, (193) (1996)
28. K.P. Ghatak, B. Mitra, Phys. Scr. **46**, (182) (1992)
29. K.P. Ghatak, S. Bhattacharya, J. Appl. Phys. **102**, 073704 (2007)
30. M. Mondal, K.P. Ghatak, Phys. Lett. **102A**, (54) (1984)
31. S. Bhattacharya, N.C. Paul, K.P. Ghatak, Phys. B **403**, (4139) (2008)

32. K.P. Ghatak, S. Bhattacharya, H. Saikia, D. Baruah, A. Saikia, K.M. Singh, A. Ali, S.N. Mitra, P.K. Bose, A. Sinha, J. Comput. Theor. Nanosci. **3**, (727) (2006)
33. P.K. Chakraborty, G.C. Datta, K.P. Ghatak, Phys. Scr. **68**, (368) (2003)
34. E.O. Kane, Solid-State Electron **28**, 3 (1985)
35. W. Zawadzki, in *Handbook on Semiconductors*, vol. 1, ed. by W. Paul, (North Holland, New York, 1982), p. 715
36. A.N. Chakravarti, D. Mukherjee, Phys. Lett. **53A**, (403) (1975)
37. B. Mitra, D.K. Basu, B. Nag, K.P. Ghatak, Nonlinear Opt. **17**, (171) (1997)
38. M. Mondal, K.P. Ghatak, Phys. Status Solidi B **135**, (239) (1986)
39. A.N. Chakravarti, S. Swaminathan, Phys. Status Solidi A **23**, (K191) (1974)
40. A.N. Chakravarti, Ibid. **25**, (K105) (1974)
41. A.N. Chakravarti, K.P. Ghatak, K.K. Ghosh, A. Dhar, Phys. Status Solidi B **103**, (K55) (1981)
42. T. Ando, A.H. Fowler, F. Stern, Rev. Mod. Phys. **54**, (437) (1982)
43. P.K. Basu, *Optical Processes in Semiconductors* (Oxford University Press, New York, 2001)
44. N. Kampf, D. Ben-Yaakov, D. Andelman, S.A. Safran, J. Klein, Phys. Rev. Lett. **103**, (118304) (2009)
45. P. Arnold, L.G. Yaffe, Phys. Rev. D **52**, (7208) (1995)
46. G.S. Kulkarni, Z. Zhong, Nano Lett. **12**, (719) (2012)
47. E. Stern, R. Wagner, F.J. Sigworth, R. Breaker, T.M. Fahmy, M.A. Reed, Nano Lett. **7**, (3405) (2007)
48. A.N. Chakravarti, D. Mukherji, Phys. Lett. A **53**, (57) (1975)
49. W. Zawadzki, Adv. Phys. **23**, (435) (1974)
50. N.G. Anderson, W.D. Laidig, R.M. Kolbas, Y.C. Lo, J. Appl. Phys. **60**, (2361) (1986)
51. F. Capasso, Semiconductors and Semimetals **22**, (2) (1985)
52. F. Capasso, K. Mohammed, A.Y. Cho, R. Hull, A.L. Hutchinson, Appl. Phys. Letts. **47**, (420) (1985)
53. F. Capasso, R.A. Kiehl, J. Appl. Phys. **58**, (1366) (1985)
54. K. Ploog, G.H. Doheler, Adv. Phys. **32**, (285) (1983)
55. F. Capasso, K. Mohammed, A.Y. Cho, Appl. Phys. Lett. **48**, (478) (1986)
56. R. Grill, C. Metzner, G.H. Döhler, Phys. Rev. B **63**, (235316) (2001)
57. J.Z. Wang, Z.G. Wang, Z.M. Wang, S.L. Feng, Z. Yang, Phys. Rev. B **62**, (6956) (2000)
58. J.Z. Wang, Z.G. Wang, Z.M. Wang, S.L. Feng, Z. Yang, Phys. Rev. B **61**, (15614) (2000)
59. A.R. Kost, M.H. Jupina, T.C. Hasenberg, E.M. Garmire, J. Appl. Phys. **99**, (023501) (2006)
60. A.G. Smirnov, D.V. Ushakov, V.K. Kononenko, Proc. SPIE **4706**, (70) (2002)
61. D.V. Ushakov, V.K. Kononenko, I.S. Manak, Proc. SPIE **4358**, (171) (2001)
62. J.Z. Wang, Z.G. Wang, Z.M. Wang, S.L. Feng, Z. Yang, Phys. Rev. B **62**, (6956) (2000)
63. A.R. Kost, L. West, T.C. Hasenberg, J.O. White, M. Matloubian, G.C. Valley, Appl. Phys. Lett. **63**, (3494) (1993)
64. S. Bastola, S.J. Chua, S.J. Xu, J. Appl. Phys. **83**, (1476) (1998)
65. Z.J. Yang, E.M. Garmire, D. Doctor, J. Appl. Phys. **82**, (3874) (1997)
66. G.H. Avetisyan, V.B. Kulikov, I.D. Zalevsky, P.V. Bulaev, Proc. SPIE **2694**, (216) (1996)
67. U. Pfeiffer, M. Kneissl, B. Knüpfer, N. Müller, P. Kiesel, G.H. Döhler, J.S. Smith, Appl. Phys. Lett. **68**, (1838) (1996)
68. H.L. Vaghjiani, E.A. Johnson, M.J. Kane, R. Grey, C.C. Phillips, J. Appl. Phys. **76**, (4407) (1994)
69. P. Kiesel, K.H. Gulden, A. Hoeffler, M. Kneissl, B. Knuepfer, S.U. Dankowski, P. Riel, X. Wu, J. S. Smith, G. H. Doehler, Proc. SPIE **1985**, (278) (1993)
70. G.H. Doheler, Phys. Sc. **24**, (430) (1981)
71. S. Mukherjee, S.N. Mitra, P.K. Bose, A.R. Ghatak, A. Neoigi, J.P. Banerjee, A. Sinha, M. Pal, S. Bhattacharya, K.P. Ghatak, J. Comput. Theor. Nanosci. **4**, (550) (2007)

72. J.J. Quinn, P.J. Styles, (ed.) *Electronic Properties of Quasi Two Dimensional Systems*, (North Holland, Amsterdam, 1976)
73. G.A. Antcliffe, R.T. Bate, R.A. Reynolds, *Proceedings of the International Conference, Physics of Semi-metals and Narrow-Gap Semiconductors* ed. D.L. Carter, R.T. Bate, (Pergamon Press, Oxford, 1971), p. 499
74. G. Paasch, T. Fiedler, M. Kolar, I. Bartos, *Phys. Stat. Sol. (b)* **118**, (641) (1983)
75. Th. Lindner, G. Paasch, *J. Appl. Phys.* **102**, (054514) (2007)
76. S. Lamari, *J. Appl. Phys.* **91**, (1698) (2002)
77. K.P. Ghatak, M. Mondal, *J. Appl. Phys.* **70**, (299) (1991)
78. K.P. Ghatak, S.N. Biswas, *J. Vac. Sc. and Tech.* **7B**, (104) (1989)
79. B. Mitra, K.P. Ghatak, *Sol. State Electron.* **32**, (177) (1989)
80. K.P. Ghatak, M. Mondal, *J. Appl. Phys.* **62**, (922) (1987)
81. M. Mondal, K.P. Ghatak, *J. Magn. Magn. Mater.* **62**, (115) (1986)
82. M. Mondal, K.P. Ghatak, *Phys. Sc.* **31**, (613) (1985)
83. K.P. Ghatak, M. Mondal, *Z. fur, Physik B* **64**, (223) (1986)
84. K.P. Ghatak, S.N. Biswas, *Sol. State Electron.* **37**, (1437) (1994)
85. K.P. Ghatak, S. Bhattacharya, S. Bhowmik, R. Benedictus, S. Chowdhury, *J. Appl. Phys.* **103**, (094314) (2008)
86. K.P. Ghatak, S. Bhattacharya, S.K. Biswas, A. De, A.K. Dasgupta, *Phys. Scr.* **75**, (820) (2007)
87. K.P. Ghatak, S. Bhattacharya, S. Pahari, D. De, S. Ghosh, M. Mitra, *Ann. Phys.* **17**, (195) (2008)
88. B.R. Nag, *Electron Transport in Compound Semiconductors*, (Springer Heidelberg, 1980)
89. B.K. Ridley, *Quantum Processes in Semiconductors*, 4th edn. (Oxford publications, Oxford 1999)
90. J.H. Davis, *Physics of Low Dimensional Semiconductors*, (Cambridge University Press, Cambridge 1998)
91. M. Schaden, K.F. Zhao, Z. Wu, *Phys. Rev. A* **76**, (062502) (2007)
92. T. Kawarabayashi, T. Ohtsuki, *Phys. Rev. B* **51**, (10897) (1995)
93. B. Laikhtman, *Phys. Rev. Lett.* **72**, (1060) (1994)
94. A. Houghton, J.R. Senna, S.C. Ying, *Phys. Rev. B* **25**, (6468) (1982)
95. I.M. Tsidilkovski, *Band Structures of Semiconductors* (Pergamon Press, London, 1982)
96. B. Mitra, K.P. Ghatak, *Phys. Sc.* **40**, (776) (1989)
97. S.K. Biswas, A.R. Ghatak, A. Neogi, A. Sharma, S. Bhattacharya, K.P. Ghatak, *Phys. E* **36**, (163) (2007)
98. A.N. Chakravarti, A.K. Choudhury, K.P. Ghatak, S. Ghosh, A. Dhar, *Appl. Phys.* **25**, (105) (1981)
99. K.P. Ghatak, M. Mondal, *Z.F. Physik B* **B69**, (471) (1988)
100. M. Mondal, K.P. Ghatak, *Phys. Lett.* **131 A**, (529) (1988)
101. K.P. Ghatak, A. Ghoshal, B. Mitra, *Nuovo Cimento* **14D**, (903) (1992)
102. B. Mitra, A. Ghoshal, K.P. Ghatak, *Nuovo Cimento D* **12D**, (891) (1990)
103. K.P. Ghatak, S.N. Biswas, *Nonlin. Opt. Quant. Opts.* **12**, (83) (1995)
104. B. Mitra, K.P. Ghatak, *Solid State Electron.* **32**, (177) (1989)
105. K.P. Ghatak, S.N. Biswas, *Proc. SPIE* **1484**, (149) (1991)
106. M. Mondal, K.P. Ghatak, *Graphite Intercalation Compounds: Science and Applications*, MRS Proceedings, ed. By M. Endo, M.S. Dresselhaus, G. Dresselhaus, MRS Fall Meeting, EA **16**, (173) (1988)
107. M. Mondal, N. Chattopadhyay, K.P. Ghatak, *J. Low Temp. Phys.* **66**, (131) (1987)
108. A.N. Chakravarti, K.P. Ghatak, K.K. Ghosh, S. Ghosh, A. Dhar, *Z. Physik B.* **47**, (149) (1982)
109. K.P. Ghatak, M. Mondal, *Z. fur Nature A* **41A**, (881) (1986)
110. A.N. Chakravarti, B.R. Nag, *Int. J. Elect.* **37**, (281) (1974)
111. C.C. Wu, C.J. Lin, *J. Low Temp. Phys.* **57**, (469) (1984)

112. M.H. Chen, C.C. Wu, C.J. Lin, J. Low Temp. Phys. **55**, (127) (1984)
113. W. Zawadzki, B. Lax, Phys. Rev. Lett. **16**, (1001) (1966)
114. K.P. Ghatak, J.P. Banerjee, B. Goswami, B. Nag, Nonlinear Opt. and Quantum Opt. **16**, (241) (1996)
115. M. Mondal, K.P. Ghatak, Phys. Status Solidi B **133**, K67 (1986)
116. M. Mondal, K.P. Ghatak, Phys. Status Solidi B **147**, K179 (1988)
117. B. Mitra, A. Ghoshal, K.P. Ghatak, Phys. Status Solidi B **154**, K147 (1989)
118. B. Mitra, K.P. Ghatak, Phys. Status Solidi B **164**, K13 (1991)
119. K.P. Ghatak, B. Mitra, Int. J. Electron. **70**, (345) (1991)
120. K.P. Ghatak, B. Goswami, M. Mitra, B. Nag, Nonlinear Opt. and Quantum Opt. **16**, (9) (1996)
121. K.P. Ghatak, M. Mondal, Zeit. Fur, Phys. B **69**, (471) (1988)
122. S. Pahari, S. Bhattacharya, D. De, A. Niyogi, A. de, N. Paitya, P.C. Saha, P.K. Bose, K.P. Ghatak, Phys. B, **405**, (4064) (2010)
123. S. Bhattacharya, S. Choudhary, S. Ghoshal, S.K. Bishwas, D. De, K.P. Ghatak, J. Comput. Theor. Nanosci. **3**, (423) (2006)
124. M. Mondal, K.P. Ghatak, Ann. der Phys. **46**, (502) (1989)
125. K.P. Ghatak, B. Mitra, Phys. Lett. A **141A**, (81) (1989)
126. K.P. Ghatak, B. Mitra, Phys. Lett. A **137A**, (413) (1989)
127. P.K. Chakraborty, A. Sinha, S. Bhattacharya, K.P. Ghatak, Phys. B **390**, (325) (2007)
128. P.K. Chakraborty, K.P. Ghatak, J. Phys. Chem. Solids **62**, (1061) (2001)
129. P.K. Chakraborty, K.P. Ghatak, Phys. Letts. A **288**, (335) (2001)
130. P.K. Chakraborty, K.P. Ghatak, Phys. D, Appl. Phys. **32**, (2438) (1999)
131. A. Pais, J. Robert Oppenheimer (Oxford University Press, U.K, 2006 (p.xviii))

Debye Screening Length

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2014, XXXIII, 385 p. 123 illus., Hardcover

ISBN: 978-3-319-01338-1