

Vol. 0.0 (V.1)

 $\Delta(\epsilon) \propto \Delta \text{ bas } \Delta \propto V(\lambda) = \Delta (V)$ $\Delta(\epsilon) \propto (V) \text{ const}$

as a basis for the development of optical materials

and applications in the field of photonics

and quantum optics.

The following sections will introduce the basic concepts of optical properties and their applications in various fields.

The first section will focus on the basic principles of optics, including reflection, refraction, dispersion, and interference.

The second section will discuss the properties of different types of materials, such as metals, semiconductors, and insulators.

The third section will cover the applications of optical properties in various industries, such as telecommunications, medicine, and energy.

The fourth section will provide an overview of the future trends in optical materials research.

The fifth section will conclude with a summary of the key findings and implications of the research presented in this chapter.

Bibliography

Chapter 1: Introduction

Bach, H. and Neuroth, N. (1995). *The properties of optical glass*. Springer-Verlag, Berlin.

Bleaney, B.I. and Bleaney, B. (1976). *Electricity and magnetism* (3rd edn). Clarendon Press, Oxford. Reissued in two volumes in 1989.

Born, M. and Wolf, E. (1999). *Principles of optics* (7th edn). Cambridge University Press, Cambridge.

Buckley, A.R., Rahn, M.D., Hill, J., Cabanillas-Gonzalez, J., Fox, A.M., and Bradley, D.D.C. (2001). Energy transfer dynamics in polyfluorene-based polymer blends. *Chem. Phys. Lett.*, **339**, 331–6.

Driscoll, W.G. and Vaughan, W. (1978). *Handbook of optics*. McGraw-Hill, New York.

Hecht, Eugene (2001). *Optics* (4th edn). Addison-Wesley, Reading, MA.

Kaye, G.W.C. and Laby, T.H. (1986). *Tables of physical and chemical constants* (15th edn).

Longman Scientific, Harlow, UK.

Krause, D. (2005). Glasses. In *Springer handbook of condensed matter and materials data* (eds W. Martienssen and H. Warlimont). Springer-Verlag, Berlin, pp. 523–72.

Lide, D.R. (1996). *CRC handbook of chemistry and physics* (77th edn). CRC Press, Boca Raton, FL.

Lorrain P., Corson D.R., and Lorrain F. (2000). *Fundamentals of electromagnetic phenomena*. W.H. Freeman, Basingstoke.

McCarthy, D.E. (1967). Transmittance of optical materials from 0.17μ to 3.0μ . *Applied Optics*, **6**, 1896–8.

Madelung, O. (1996). *Semiconductors, basic data* (2nd edn). Springer-Verlag, Berlin.

Nye, J.F. (1985). *Physical properties of crystals*. Clarendon Press, Oxford.

Chapter 2: Classical propagation

Bleaney, B.I. and Bleaney, B. (1976). *Electricity and magnetism* (3rd edn). Clarendon Press, Oxford. Reissued in two volumes in 1989.

Born, M. and Wolf, E. (1999). *Principles of optics* (7th edn). Cambridge University Press, Cambridge.

Dressel, M. and Grüner, G. (2002). *Electrodynamics of solids*. Cambridge University Press, Cambridge.

Driscoll, W.G. and Vaughan, W. (1978). *Handbook of optics*. McGraw-Hill, New York.

Hecht, Eugene (2001). *Optics* (4th edn). Addison-Wesley, Reading, MA.

Hoffmann, H.-J. (1995). Differential changes of the refractive index. In *The properties of optical glass* (eds H. Bach and N. Neuroth). Springer-Verlag, Berlin, pp. 96–123.

Kaye, G.W.C. and Laby, T.H. (1986). *Tables of physical and chemical constants* (15th edn). Longman Scientific, Harlow, UK.

Klein, M.V. and Furtak, T.E. (1986). *Optics* (2nd edn). Wiley, New York.

Nye, J.F. (1985). *Physical properties of crystals*. Clarendon Press, Oxford.

Palik, E.D. (1985). *Handbook of the optical constants of solids*. Academic Press, San Diego.

Smith, D.Y., Shiles, E., and Inokuti, M. (2004). Refraction and dispersion in optical glass. *Nuclear instruments and methods in physics research B: beam interactions with materials and atoms*, **218**, 170–5.

Chapter 3: Interband absorption

- Aspnes, D.E. (1980). Modulation spectroscopy/electric field effects on the dielectric function of semiconductors. In *Handbook on Semiconductors*, vol. 2 (ed. M. Balkanski). North Holland, Amsterdam, pp. 109–54.
- Aspnes, D.E. and Studna, A.A. (1983). Dielectric functions and optical parameters of Si, Ge, GaP, GaAs, GaSb, InP, InAs, and InSb from 1.5 to 6.0 eV. *Phys. Rev. B*, **27**, 985–1009.
- Bhattacharya, P. (1997). *Semiconductor optoelectronic devices* (2nd edn). Prentice Hall, New Jersey.
- Burns, G. (1985). *Solid state physics*. Academic Press, San Diego.
- Chelikowsky J.R. and Cohen, M.L. (1976). Nonlocal pseudopotential calculations for the electronic structure of eleven diamond and zinc-blende semiconductors. *Phys. Rev. B*, **14**, 556–82.
- Chuang, S.L. (1995). *Physics of optoelectronic devices*. Wiley, New York.
- Cohen, M.L. and Chelikowsky, J. (1988). *Electronic structure and optical properties of semiconductors*. Springer-Verlag, Berlin.
- Corney, Alan (1977). *Atomic and laser spectroscopy*. Clarendon Press, Oxford.
- Dash, W.C. and Newman, R. (1955). Intrinsic optical absorption in single-crystal germanium and silicon at 77°K and 300°K. *Phys. Rev.*, **99**, 1151–5.
- Hamaguchi, C. (2001). *Basic semiconductor physics*. Springer-Verlag, Berlin.
- Harrison, W. (1999). *Elementary electronic structure*. World Scientific, Singapore.
- Hecht, Eugene (2001). *Optics* (4th edn). Addison-Wesley, Reading, MA.
- Ibach, H. and Luth, H. (2003). *Solid-state physics* (3rd edn). Springer-Verlag, Berlin.
- Kane, E.O. (1957). Band structure of indium antimonide. *J. Phys. Chem. Solids*, **1**, 249–61.
- Kittel, Charles (2005). *Introduction to solid state physics* (8th edn). Wiley, New York.
- Klingshirn, C.F. (1995). *Semiconductor optics*. Springer-Verlag, Berlin.
- MacFarlane, G.G. and Roberts, V. (1955). Infrared absorption of germanium near the lattice edge. *Phys. Rev.*, **97**, 1714–6.
- Madelung, O. (1996). *Semiconductors, basic data* (2nd edn). Springer-Verlag, Berlin.
- Palik, E.D. (1985). *Handbook of the optical constants of solids*. Academic Press, San Diego.
- Pankove, J.I. (1971). *Optical processes in semiconductors*. Dover, New York.
- Seeger, K. (1997). *Semiconductor physics* (6th edn). Springer-Verlag, Berlin.
- Singleton, J. (2001). *Band structure and electrical properties of solids*. Clarendon Press, Oxford.
- Sze, S.M. (1985). *Semiconductor devices*. Wiley, New York.
- Wilson, J. and Hawkes, J. (1998). *Optoelectronics* (3rd edn). Prentice Hall Europe, London.
- Woodgate, G.K. (1980). *Elementary atomic structure* (2nd edn). Clarendon Press, Oxford.
- Yariv, Amnon (1997). *Optical electronics in modern communications* (5th edn). Oxford University Press, New York.
- Yu, P.Y. and Cardona, M. (1996). *Fundamentals of semiconductors*. Springer-Verlag, Berlin.
- Zwerdling, S., Lax, B., and Roth, L.M. (1957). Oscillatory magneto-absorption in semiconductors. *Phys. Rev.*, **108**, 1402–8.

Chapter 4: Excitons

- Burns, G. (1985). *Solid state physics*. Academic Press, San Diego.
- Butov, L.V. (2007). Cold exciton gases in coupled quantum well structures. *J. Phys.: Condens. Matter*, **19**, 295202.
- Dexter, D.L. and Knox, R.S. (1965). *Excitons*. Wiley, New York.
- Fehrenbach, G.W., Schäfer, W., and Ulbrich, R.G. (1985). Excitonic versus plasma screening in highly excited gallium arsenide. *J. Luminescence*, **30**, 154–61.
- Griffin, A., Snoke, D.W., and Stringari, S. (1995). *Bose-Einstein condensation*. Cambridge University Press, Cambridge.
- Kavokin, A.V., Baumberg, J.J., Malpuech, G., and Laussy, F.P. (2007). *Microcavities*. Oxford University Press, Oxford.
- Kasprzak, J., Richard, M., Kundermann, S., Baas, A., Jeambrun, P., Keeling, J.M.J., et al. (2006). Bose-Einstein condensation of exciton polaritons. *Nature*, **443**, 409–14.
- Kittel, Charles (2005). *Introduction to solid state physics* (8th edn). Wiley, New York.
- Klingshirn, C.F. (1995). *Semiconductor optics*. Springer-Verlag, Berlin.
- Mandl, F. (1988). *Statistical physics* (2nd edn). Wiley, Chichester.
- Matsui, A. and Nishimura, H. (1980). Luminescence of free and self trapped excitons in pyrene. *J. Phys. Soc. Jap.*, **49**, 657–63.
- Moskalenko, S.A. and Snoke, D.W. (2000). *Bose-Einstein condensation of excitons and biexcitons*. Cambridge University Press, Cambridge.
- Palik, E.D. (1985). *Handbook of the optical constants of solids*. Academic Press, San Diego.
- Pankove, J.I. (1971). *Optical processes in semiconductors*. Dover, New York.
- Rashba E.I. and Sturge, M.D. (1982). *Excitons*. North Holland, Amsterdam.
- Reynolds, D.C. and Collins, T.C. (1981). *Excitons: their properties and uses*. Academic Press, New York.
- Seeger, K. (1997). *Semiconductor physics* (6th edn). Springer-Verlag, Berlin.
- Song, K.S. and Williams, R.T. (1993). *Self-trapped excitons*. Springer-Verlag, Berlin.
- Sturge, M.D. (1962). Optical absorption of gallium arsenide between 0.6 and 2.75 eV. *Phys. Rev.*, **127**, 768–73.
- Yu, P.Y. and Cardona, M. (1996). *Fundamentals of semiconductors*. Springer-Verlag, Berlin.
- Macmillan, New York.

Chapter 5: Luminescence

- Awschalom, D.D., Loss, D., and Samarth, N. (2002). *Semiconductor spintronics and quantum computation*. Springer-Verlag, Berlin.
- Bhattacharya, P. (1997). *Semiconductor optoelectronic devices* (2nd edn). Prentice Hall, New Jersey.
- Chuang, S.L. (1995). *Physics of optoelectronic devices*. Wiley, New York.
- Dyakonov, M.I. (2008). *Spin physics in semiconductors*. Springer-Verlag, Berlin.
- Elliott, R.J. and Gibson, A.F. (1974). *An introduction to solid state physics and its applications*.
- Gustafsson, A., Pistol, M.-E., Montelius, L., and Samuelson, L. (1998). Local probe techniques for luminescence studies of low-dimensional semiconductor structures. *J. Appl. Phys.*, **84**, 1715–75.
- Kash K. and Shah J. (1984). Carrier energy relaxation in $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ determined from picosecond luminescence studies. *Appl. Phys. Lett.*, **45**, 401–3.
- Kusrayev, Y. and Landwehr, G. (2008). Special issue on optical orientation. *Semicond. Sci. Technol.*,

- 23**, 110301–114018.
- Landsberg, P.T. (1991). *Recombination in semiconductors*. Cambridge University Press, Cambridge.
- Madelung, O. (1996). *Semiconductors, basic data* (2nd edn). Springer-Verlag, Berlin.
- Meier, F. and Zakharchenya, B.P. (1984). *Optical orientation*. North Holland, Amsterdam.
- Nakamura, F., Pearton S., and Fasol, G. (2000). *The blue laser diode* (2nd edn). Springer-Verlag, Berlin.
- Pankove, J.I. (1971). *Optical processes in semiconductors*. Dover, New York.
- Schubert, E.F. (2006). *Light-emitting diodes* (2nd edn). Cambridge University Press, Cambridge.
- Shah, J. (1999). *Ultrafast spectroscopy of semiconductors and semiconductor nanostructures* (2nd edn). Springer-Verlag, Berlin.
- Silfvast, W.T. (2004). *Laser fundamentals* (2nd edn). Cambridge University Press, Cambridge.
- Svelto, O. (1998). *Principles of lasers* (4th edn). Plenum Press, New York.
- Sze, S.M. (1981). *Physics of semiconductor devices* (2nd edn). Wiley, New York.
- Sze, S.M. (1985). *Semiconductor devices*. Wiley, New York.
- Voos, M., Leheney, R.F., and Shah, J. (1980). Radiative recombination. In *Handbook on semiconductors*, vol. 2 (ed. M. Balkanski). North Holland, Amsterdam, pp. 329–416.
- Wilson, J. and Hawkes, J. (1998). *Optoelectronics* (3rd edn). Prentice Hall Europe, London.
- Yacobi, B.G. and Holt, D.B. (1990). *Cathodoluminescence microscopy of inorganic solids*. Plenum, New York.
- Yariv, Amnon (1997). *Optical electronics in modern communications* (5th edn). Oxford University Press, New York.
- Yu, P.Y. and Cardona, M. (1996). *Fundamentals of semiconductors*. Springer-Verlag, Berlin.

Chapter 6: Quantum confinement

- Awschalom, D.D., Loss, D., and Samarth, N. (2002). *Semiconductor spintronics and quantum computation*. Springer-Verlag, Berlin.
- Bastard, G. (1990). *Wave mechanics applied to semiconductor heterostructures*. Wiley, New York.
- Bimberg, D., Grundmann M., and Ledentsov, N.N. (1999). *Quantum dot heterostructures*. Wiley, Chichester.
- Blood, P. (1999). Visible-emitting quantum well lasers. In *Semiconductor quantum electronics* (eds A. Miller, M. Ebrahimzadeh, and D.M. Finlayson). Institute of Physics, Bristol, pp. 193–211.
- Burns, G. (1985). *Solid state physics*. Academic Press, San Diego.
- Chuang, S.L. (1995). *Physics of optoelectronic devices*. Wiley, New York.
- Davies, A.G., Linfield, E.H., and Pepper, M. (2004). Proceedings of the Discussion Meeting on ‘The terahertz gap: the generation of far-infrared radiation and its applications’. *Phil. Trans. R. Soc. Lond. A*, **362**, pp. 197–414.
- De Giorgi, M., Tari, Manna, L., Krahne, R., and Cingolani, R. (2005). Optical properties of colloidal nanocrystal spheres and tetrapods. *Microelectronics Journal*, **36**, 552–4.
- Dyakonov, M.I. (2008). *Spin physics in semiconductors*. Springer-Verlag, Berlin.
- Esaki, L. and Tsu, R. (1970). Superlattice and negative differential conductivity in semiconductors. *IBM Journal of Research and Development*, **14**, 61–5.
- Fox A.M. (1996). Optoelectronics in quantum well structures. *Contemporary Physics*, **37**, 111–25.
- Fry, P.W., Itskevich, I.E., Mowbray, D.J., Skolnick, M.S., Finley, J.J., Barker, J.A., et al. (2000). Inverted electron-hole alignment in InAs-GaAs self-assembled quantum dots. *Phys. Rev. Lett.*, **84**, 733–6.
- Gasiorowicz, Stephen (1996). *Quantum physics* (2nd edn). Wiley, New York.

- Harrison, P. (2005). *Quantum wells, wires and dots* (2nd edn). Wiley, Chichester.
- Helm, M. (2000). *Long wavelength infrared emitters based on quantum wells and superlattices*. Gordon and Breach, Amsterdam.
- Jaros, M. (1989). *Physics and applications of semiconductor microstructures*. Clarendon Press, Oxford.
- Kagan, C.R., Murray, C.B., and Bawendi, M.G. (1996). Long-range resonance transfer of electronic excitations in close-packed CdSe quantum-dot solids. *Phys. Rev. B*, **54**, 8633–43.
- Kelly, M.J. (1995). *Low-dimensional semiconductors*. Clarendon Press, Oxford.
- Liu, H.C. and Capasso, F. (2000a). *Intersubband transitions in quantum wells: physics and device applications I, Semiconductors and Semimetals*, vol. 62 (series eds R.K. Willardson and E.R. Weber). Academic Press, San Diego.
- Liu, H.C. and Capasso, F. (2000b). *Intersubband transitions in quantum wells: physics and device applications II, Semiconductors and Semimetals*, vol. 66 (series eds R.K. Willardson and E.R. Weber). Academic Press, San Diego.
- Michler, P. (2003). *Single quantum dots*. Springer-Verlag, Berlin.
- Miller, D.A.B., Chemla, D.S., Eilenberger, D.J., Smith, P.W., Gossard, A.C. and Tsang, W.T. (1982). Large room-temperature optical nonlinearity in GaAs/Ga_{1-x}Al_xAs multiple quantum well structures. *Appl. Phys. Lett.*, **41**, 679–81.
- Miller, D.A.B. (2008). *Quantum mechanics for scientists and engineers*. Cambridge University Press, New York.
- Murray, C.B., Kagan, C.R., and Bawendi, M.G. (2000). Synthesis and characterization of monodisperse nanocrystals and close-packed nanocrystal assemblies. *Annu. Rev. Mater. Sci.*, **30**, 545–610.
- Oulton R., Finley J.J., Ashmore A.D., Gregory I.S., Mowbray D.J., Skolnick M.S., et al. (2002). Manipulation of the homogeneous linewidth of an individual In(Ga)As quantum dot. *Phys. Rev. B*, **66**, 045313.
- Schiff, L.I. (1969). *Quantum mechanics*. McGraw-Hill, New York.
- Singh, J. (1993). *Physics of semiconductors and their heterostructures*. McGraw-Hill, New York.
- Singleton, J. (2001). *Band structure and electrical properties of solids*. Clarendon Press, Oxford.
- Viña, L. (1999). Spin relaxation in low-dimensional systems. *J. Phys.: Condens. Matter*, **11**, 5929–52.
- Weisbuch, C. and Vinter, B. (1991). *Quantum semiconductor structures*. Harcourt, San Diego.
- Williams, B.S. (2007). Terahertz quantum-cascade lasers. *Nature Photonics*, **1**, 517.
- Woggon, U. (1997). *Optical properties of semiconductor quantum dots*. Springer-Verlag, Berlin.
- Woodgate, G.K. (1980). *Elementary atomic structure* (2nd edn). Clarendon Press, Oxford.
- Yu, P.Y. and Cardona, M. (1996). *Fundamentals of semiconductors*. Springer-Verlag, Berlin.

Chapter 7: Free electrons

- Ashcroft, N.W. and Mermin, N.D. (1976). *Solid state physics*. Saunders College Publishing, Philadelphia.
- Barnes, W.L., Dereux, A., and Ebbeson, T.W. (2003). Surface plasmon subwavelength optics. *Nature*, **424**, 824–30.
- Bleaney, B.I. and Bleaney, B. (1976). *Electricity and magnetism* (3rd edn). Clarendon Press, Oxford. Reissued in two volumes in 1989.
- Born, M. and Wolf, E. (1999). *Principles of optics* (7th edn). Cambridge University Press, Cambridge.
- Burns, G. (1985). *Solid state physics*. Academic Press, San Diego.
- Ebbeson, T.W., Genet, C., and Bozhevolnyi, S.I. (2008). Surface-plasmon circuitry. *Physics Today*, **61**(5), 44–50.
- Ehrenreich, H., Philipp, H.R., and Segall, B. (1963). Optical properties of aluminium. *Phys. Rev.*, **132**, 1918–28.

- Givens, M.P. (1958). Optical properties of metals. In *Solid state physics*, vol. 6 (eds F. Seitz and D. Turnbull). Academic Press, New York, pp. 313–52.
- Hecht, Eugene (2001). *Optics* (4th edn). Addison-Wesley, Reading, MA.
- Jagannath, C., Grabowski, Z.W., and Ramdas, A.K. (1981). Linewidths of the electronic excitation spectra of donors in silicon. *Phys. Rev. B*, **23**, 2023–98.
- Kittel, Charles (2005). *Introduction to solid state physics* (8th edn). Wiley, New York.
- Lal, S., Link, S., and Halas, N.J. (2007). Nano-optics from sensing to waveguiding. *Nature Photonics*, **1**, 641–8.
- Lide D.R. (1996). *CRC handbook of chemistry and physics* (77th edn), CRC Press, Boca Raton.
- Maier, Stefan A. (2007). *Plasmonics: fundamentals and applications*. Springer-Verlag, Berlin.
- Maier, S.A., and Atwater, H.A. (2005). Plasmonics: localization and guiding of electromagnetic energy in metal/dielectric structures. *J. Appl. Phys.*, **98**, 011101.
- Mooradian, A. (1972). Raman spectroscopy of solids. In *Laser handbook* vol. II (eds F.T. Arecchi and E.O. Schulz-duBois). North Holland, Amsterdam, pp. 1409–56.
- Moruzzi, V.L., Janak, J.F., and Williams, A.R. (1978). *Calculated electronic properties of metals*. Pergamon Press, New York.
- Murray, W.A. and Barnes, W.L. (2007). Plasmonic materials. *Adv. Mater.*, **19**, 3771–82.
- Pendry, J.B. (2004). Negative refraction. *Contemp. Phys.*, **45**, 191–202.
- Pendry, J.B. and Smith, D.R. (2004). Reversing light with negative refraction. *Physics Today*, **57**(6), 37–43.
- Pidgeon, C.R. (1980). Free carrier optical properties of semiconductors. In *Handbook on Semiconductors*, vol. 2 (ed. M. Balkanski). North Holland, Amsterdam, pp. 223–328.
- Raether, Heinz (1988). *Surface plasmons*. Springer-Verlag, Berlin.
- Ramakrishna, S.A. (2005). Physics of negative refractive index materials. *Rep. Prog. Phys.*, **68**, 449–521.
- Segall, B. (1961). Energy bands of aluminium. *Phys. Rev.*, **124**, 1797–806.
- Shalaev, V.M. (2007). Optical negative-index metamaterials. *Nature Photonics*, **1**, 41–8.
- Singleton, J. (2001). *Band structure and electrical properties of solids*. Clarendon Press, Oxford.
- Spitzer, W.G. and Fan, H.Y. (1957). Determination of optical constants and carrier effective mass of semiconductors. *Phys. Rev.*, **106**, 882–90.
- Veselago, V.G. (1968). The electrodynamics of substances with simultaneously negative values of ϵ and μ . *Soviet Physics USPEKHI*, **10**, 509–14.
- Wyckoff, R.W.G. (1963). *Crystal structures* (2nd edn). Wiley Interscience, New York.
- Yu, P.Y. and Cardona, M. (1996). *Fundamentals of semiconductors*. Springer-Verlag, Berlin.

Chapter 8: Molecular materials

- Avouris, P. (2009). Carbon nanotube electronics and photonics. *Physics Today*, **62**(1), 34–40.
- Banwell, C.N. and McCash, E.M. (1994). *Fundamentals of molecular spectroscopy* (4th edn). McGraw-Hill, London.
- Brabec, C., Dyakonov, V., and Scherf, U. (2008). *Organic photovoltaics*. Wiley–VCH, Weinheim.
- Castro Neto, A.H., Guinea, F., Peres, N.M.R., Novoselov, K.S., and Geim, A.K. (2009). The electronic properties of graphene. *Rev. Mod. Phys.*, **81**, 109–62.
- Dresselhaus, M.S., Dresselhaus, G., and Eklund, P.C. (1996). *Science of fullerenes and carbon nanotubes*. Academic Press, San Diego.
- Dresselhaus, M.S., Dresselhaus, G., Saito, R., and Jorio, A. (2007). Exciton photophysics of carbon nanotubes. *Annu. Rev. Phys. Chem.*, **58**, 719–47.
- Farchioni, R. and Grosso, G. (2001). *Organic electronic materials*. Springer-Verlag, Berlin.

- Forrest, S.R. and Thompson, M.E. (2007). Special issue on organic electronics and optoelectronics. *Chemical Reviews*, **107**, 923–1386.
- Friend, R.H., Gymer, R.W., Holmes, A.B., Burroughes, J.H., Marks, R.N., Taliani, C., et al. (1999). Electroluminescence in conjugated polymers. *Nature*, **397**, 121–8.
- Garbuзов, D.Z., Bulović, V., Burrows, P.E., and Forrest, S.R. (1996). Photoluminescence efficiency and absorption of aluminium-tris-quinolate (Alq_3) thin films. *Chem. Phys. Lett.*, **249**, 433–7.
- Gasiorowicz, Stephen (1996). *Quantum physics* (2nd edn). Wiley, New York.
- Geim, A.K. and MacDonald, A.H. (2007). Graphene: exploring carbon flatland. *Physics Today*, **60**(8), 35–41.
- Geim, A.K. and Novoselov, K.S. (2007). The rise of graphene. *Nature Materials*, **6**, 183–91.
- Gorman, A.A., Hamblett, I., King, T.A., and Rahn, M.D. (2000). A pulse radiolysis and laser study of the pyrromethene 567 triplet state. *J. Photochem. Photobiol. A: Chemistry*, **130**, 127–132.
- Haken, H. and Wolf, H.C. (1995). *Molecular physics and elements of quantum chemistry*. Springer-Verlag, Berlin.
- Hartschuh, A., Pedrosa, H.N., Novotny, L., and Krauss, T.D. (2003). Simultaneous fluorescence and Raman scattering from single carbon nanotubes. *Science*, **301**, 1354–6.
- Hertel, D., Bässler, H., Scherf, U., and Hörrhold, H.H. (1999). Charge carrier transport in conjugated polymers. *J. Chem. Phys.*, **110**, 9214–22.
- Kataura, H., Kumazawa, Y., Maniwa, Y., Umezu, I., Suzuki, S., Ohtsuka, Y., and Achiba, Y. (1999). Optical Properties of single-wall carbon nanotubes. *Synthetic Metals*, **103**, 2555–8.
- Klessinger, M. and Michl, J. (1995). *Excited states and photochemistry of organic molecules*. VCH Publishers, New York.
- Kravets, V.G., Grigorenko, A.N., Nair, R.R., Blake, P., Anissimova, S., Novoselov, K.S., and Geim, A.K. (2010). Spectroscopic ellipsometry of graphene and an exciton-shifted van Hove peak in absorption. *Phys. Rev. B*, **81**, 155413.
- Machón, M., Reich, S., Thomsen, C., Sánchez-Portal, D., and Ordejón, P. (2002). *Ab initio* calculations of the optical properties of 4-Å-diameter single-walled nanotubes. *Phys. Rev. B*, **66**, 155410.
- Mak, K.F., Shan, J., and Heinz, T.F. (2011). Seeing many-body effects in single- and few-layer graphene: observation of two-dimensional saddle-point excitons. *Phys. Rev. Lett.*, **106**, 046401.
- Möller, S. and Weiser, G. (1999). Photoconductivity of polydiacetylene chains in polymer and monomer single crystals. *Chem. Phys.*, **246**, 483–94.
- Mueller, G. (2000). *Electroluminescence I & II, Semiconductors and Semimetals*, vols 64 & 65 (series eds R.K. Willardson and E.R. Weber). Academic Press, San Diego.
- Nair, R.R., Blake, P., Grigorenko, A.N., Novoselov, K.S., Booth, T.J., Stauber, T., et al. (2008). Fine structure constant defines visual transparency of graphene. *Science*, **320**, 1308.
- Pope, M. and Swenberg, C.E. (1999). *Electronic processes in organic crystals and polymers* (2nd edn). Oxford University Press, New York.
- Reich, S., Thomsen, C., and Maultzsch, J. (2004). *Carbon nanotubes*. Wiley–VCH, Weinheim.
- Ren, S.L., Wang, Y., Rao, A.M., McRae, E., Holden, J.M., Hager, T., et al. (1991). Ellipsometric determination of the optical properties of C_{60} (Buckminsterfullerene) films. *Appl. Phys. Lett.*, **59**, 2678–80.
- Saito, S. and Zettl, A. (2008). *Carbon nanotubes: quantum cylinders of graphene*. Elsevier, Amsterdam.
- Schlaich, H., Muccini, M., Feldmann, J., Bässler, H., Göbel, E.O., Zamboni, R., et al. (1995). Absorption at the dipole-forbidden optical gap of C_{60} . *Chem. Phys. Lett.*, **236**, 135–40.
- Scholes, G.D. and Rumbles, G. (2006). Excitons in nanoscale systems. *Nature Materials*, **5**, 683–96.
- Slepkov, A.D., Hegmann, F.A., Eisler, S., Elliott, E., and Tykwiński, R.R. (2004). The surprising nonlinear optical properties of conjugated

- polyyne oligomers. *J. Chem. Phys.*, **120**, 6807–10.
- Tang, C.W. and VanSlyke S.A. (1987). Organic electroluminescent diodes. *Appl. Phys. Lett.*, **51**, 913–5.
- Watanabe, K. (1954). Photoionization and total cross section of gases. I. Potentials of several molecules. Cross sections of NH₃ and NO. *J. Chem. Phys.*, **22**, 1564–70.
- Wolf, von H.C. (1958). Die niedersten elektronischen Anregungszustände des Anthracen-Kristalls. *Z. Naturforsch.*, **A13**, 414–9.
- Wright, J.B. (1995). *Molecular crystals* (2nd edn). Cambridge University Press, Cambridge.

Chapter 9: Luminescence centres

- Acosta, V.M., Bauch, E., Ledbetter, M.P., Santori, C., Fu, K.-M.C., Barclay, P.E., et al. (2009). Diamonds with a high density of nitrogen-vacancy centers for magnetometry applications. *Phys. Rev. B*, **80**, 115202.
- Ashcroft, N.W. and Mermin, N.D. (1976). *Solid state physics*. Saunders College Publishing, Philadelphia.
- Balasubramanian, G., Neumann, P., Twitchen, D., Markham, M., Kolesov, R., Mizuuchi, N., et al. (2009). Ultralong spin coherence time in isotopically engineered diamond. *Nature Materials*, **8**, 383–7
- Baldacchini G. (1992). Relaxed excited states of color centers. In *Optical properties of excited states in solids* (ed. B. Di Bartolo), NATO ASI Series B, vol. 301. Plenum Press, New York, pp. 255–303.
- Blundell, S. (2001). *Magnetism in condensed matter physics*. Clarendon Press, Oxford.
- Burns, G. (1985). *Solid state physics*. Academic Press, San Diego.
- Di Bartolo, B. (1992). *Optical properties of excited states in solids*, NATO ASI Series B, vol. 301. Plenum Press, New York.
- Elliott, R.J. and Gibson, A.F. (1974). *An introduction to solid state physics and its applications*. Macmillan, New York.
- Gaebel, T., Popa, I., Gruber, A., Domhan, M., Jelezko, F., and Wrachtrup, J. (2004). Stable single-photon source in the near infrared. *New Journal of Physics*, **6**, 98.
- Hayes, W. and Stoneham, A.M. (1985). *Defect and defect processes in nonmetallic solids*. Wiley, New York.
- Henderson, B. and Bartram, R.H. (2000). *Crystal-field engineering of solid-state laser materials*. Cambridge University Press, Cambridge.
- Henderson, B. and Imbusch, G.F. (1989). *Optical spectroscopy of inorganic solids*. Clarendon Press, Oxford.
- Jelezko, F., Popa, I., Gruber, A., Tietz, C., Wrachtrup, J., Nizivtsev, A., and Kilin, S. (2002). Single spin states in a defect center resolved by optical spectroscopy. *Appl. Phys. Lett.*, **81**, 2160–2.
- Jelezko, F. and Wrachtrup, J. (2004). Read-out of single spins by optical spectroscopy. *J. Phys.: Condens. Matter*, **16**, R1089–104.
- Jelezko, F. and Wrachtrup, J. (2006). Single defect centres in diamond: a review. *Physica Stat. Sol.(a)*, **203**, 3207–25.
- Kittel, Charles (2005). *Introduction to solid state physics* (8th edn). Wiley, New York.
- Koningstein, J.A. and Geusic, J.E. (1964). Energy levels and crystal-field calculations of neodymium in yttrium aluminium garnet. *Phys. Rev.*, **136**, A711–6.
- Manson, N.B., Harrison, J.P., and Sellars, M.J. (2006). Nitrogen-vacancy center in diamond: Model of the electronic structure and associated dynamics. *Phys. Rev. B*, **74**, 104303.
- Mita, Y. (1996). Change of absorption spectra in type-Ib diamond with heavy neutron bombardment. *Phys. Rev. B*, **53**, 11360–4.
- Mollenauer, L.F. (1985). Color center lasers. In *Laser handbook*, vol. 4., (eds M.L. Stich and M. Bass). Elsevier Science Publishers, North Holland, pp. 143–228.

- Moulton P.F. (1986). Spectroscopic and laser characteristics of Ti:Al₂O₃. *J. Opt. Soc. Am. B*, **3**, 125–33.
- Mueller-Mach, R., Mueller, G., Krames, M.R., Höppe, H.A., Stadler, F., Schnick, W., et al. (2005). Highly efficient all-nitride phosphor-converted white light emitting diode. *Physica Stat. Sol. (a)*, **202**, 1727–32.
- Narukawa Y. (2004). White-light LEDs. *Optics & Photonics News*, **15**(4), 24–9.
- Schubert, E.F., Kim, J.K., Luo, H., and Xi, J.-Q. (2006). Solid-state lighting—a benevolent technology. *Rep. Prog. Phys.*, **69**, 3069–99.
- Shur, M.S. and Žukauskas A. (2005). Solid-state lighting; toward superior illumination. *Proc. IEEE*, **93**, 1691–703.
- Silfvast, W.T. (2004). *Laser fundamentals* (2nd edn). Cambridge University Press, Cambridge.
- Smets, B. (1992). Advances in sensitization of phosphors. In *Optical properties of excited states in solids* (ed. B. Di Bartolo), NATO ASI Series B, vol. 301. Plenum Press, New York, pp. 349–98.
- Svelto, O. (1998). *Principles of lasers* (4th edn). Plenum Press, New York.

Chapter 10: Phonons

- Ashcroft, N.W. and Mermin, N.D. (1976). *Solid state physics*. Saunders College Publishing, Philadelphia.
- Burns, G. (1985). *Solid state physics*. Academic Press, San Diego.
- Hass, M. (1967). Lattice reflection. In *Semiconductors and Semimetals, vol. 3: Optical properties of III-V compounds* (eds R.K. Willardson and A.C. Beer). Academic Press, New York, pp. 3–16.
- Henry, C.H. and Hopfield, J.J. (1965). Raman scattering by polaritons. *Phys. Rev. Lett.*, **15**, 964–6.
- Houghton, J.T. and Smith, S.D. (1966). *Infra-red physics*. Clarendon Press, Oxford.
- Ibach, H. and Luth, H. (2003). *Solid-state physics* (3rd edn). Springer-Verlag, Berlin.
- Kittel, Charles (2005). *Introduction to solid state physics* (8th edn). Wiley, New York.
- Madelung, O. (1978). *Introduction to solid-state theory*. Springer-Verlag, Berlin.
- Madelung, O. (1996). *Semiconductors, basic data* (2nd edn). Springer-Verlag, Berlin.
- Maier, Stefan A. (2007). *Plasmonics: fundamentals and applications*. Springer-Verlag, Berlin.
- Mooradian, A. (1972). Raman spectroscopy of solids. In *Laser Handbook*, vol. II (eds F.T. Arecchi and E.O. Schulz-duBois). North Holland, Amsterdam, pp. 1409–56.
- Pidgeon, C.R. (1980). Free carrier optical properties of semiconductors. In *Handbook on Semiconductors*, vol. 2 (ed. M. Balkanski). North Holland, Amsterdam, pp. 223–328.
- Pope, M. and Swenberg, C.E. (1999). *Electronic processes in organic crystals and polymers* (2nd edn). Oxford University Press, New York.
- Seeger, K. (1997). *Semiconductor physics* (6th edn). Springer-Verlag, Berlin.
- Shah, J. (1999). *Ultrafast spectroscopy of semiconductors and semiconductor nanostructures* (2nd edn). Springer-Verlag, Berlin.
- Song, K.S. and Williams, R.T. (1993). *Self-trapped excitons*. Springer-Verlag, Berlin.
- Turner, W.J. and Reese, W.E. (1962). Infrared lattice bands of AlSb. *Phys. Rev.*, **127**, 126–31.
- Yu, P.Y. and Cardona, M. (1996). *Fundamentals of semiconductors*. Springer-Verlag, Berlin.

Chapter 11: Nonlinear optics

- Born, M. and Wolf, E. (1999). *Principles of optics* (7th edn). Cambridge University Press, Cambridge.
- Butcher, P.N. and Cotter, D. (1990). *The elements of nonlinear optics*. Cambridge University Press, Cambridge.
- Chemla, D.S. (1985). Excitonic optical nonlinearities. *J. Opt. Soc. Am. B*, **2**, 1135–1243.
- DeSalvo, R., Said, A.A., Hagan, D.J., Van Stryland, E.W., and Sheik-Bahae, M. (1996). Infrared to ultraviolet measurements of two-photon absorption and n_2 in wide bandgap solids. *IEEE J. Quantum Electron.*, **32**, 1324–33.
- Fox, A.M., Maciel, A.C., Shorthose, M.G., Ryan, J.F., Scott, M.D., Davies, J.I., and Riffat, J.R. (1987). Nonlinear excitonic optical absorption in GaInAs/InP quantum wells. *Appl. Phys. Lett.*, **51**, 30–2.
- Klein, R.S., Kugel, G.E., Maillard, A., Sifi, A., and Polgár, K. (2003). Absolute non-linear optical coefficients measurements of BBO single crystal and determination of angular acceptance by second harmonic generation. *Optical Materials*, **22**, 163–9.
- Kroner, M., Rémi, S., Högele, A., Seidl, S., Holleitner, A.W., Warburton, R.J., et al. (2008). Resonant saturation laser spectroscopy of a single self-assembled quantum dot. *Physica E*, **40**, 1994–6.
- Mollenauer, L.F. and Gordon, J.P. (1994). In *Nonlinear spectroscopy of solids* (ed. B. Di Bartolo), NATO ASI Series B, vol. 339. Plenum Press, New York, pp. 451–80.
- Nye, J.F. (1957). *Physical properties of crystals*. Clarendon Press, Oxford.
- Schmitt-Rink, S., Chemla, D.S., and Miller, D.A.B. (1989). Linear and nonlinear optical properties of semiconductor quantum wells. *Adv. Phys.*, **38**, 89–188.
- Sheik-Bahae, M., Hutchings, D.C., Hagan, D.J., and Van Stryland, E.W. (1991). Dispersion of bound electronic nonlinear refraction in solids. *IEEE J. Quantum Electron.*, **27**, 1296–309.
- Tang, C.L. (1995). Nonlinear optics. In *Handbook of optics*, vol. II (ed. M. Bass). McGraw-Hill, New York, chapter 38.
- Westland, D.J., Fox, A.M., Maciel, A.C., Ryan, J.F., Scott, M.D., Davies, J.I., and Riffat, J.R. (1987). Optical studies of excitons in $\text{Ga}_{0.47}\text{In}_{0.53}\text{As}/\text{InP}$ multiple quantum wells. *Appl. Phys. Lett.*, **50**, 839–41.
- Yariv, Amnon (1997). *Optical electronics in modern communications* (5th edn). Oxford University Press, New York.

Appendices

- Ashcroft, N.W. and Mermin, N.D. (1976). *Solid state physics*. Saunders College Publishing, Philadelphia.
- Bleaney, B.I. and Bleaney, B. (1976). *Electricity and magnetism* (3rd edn). Clarendon Press, Oxford. Reissued in two volumes in 1989.
- Born, M. and Wolf, E. (1999). *Principles of optics* (7th edn). Cambridge University Press, Cambridge.
- Burns, G. (1985). *Solid state physics*. Academic Press, San Diego.
- Corney, Alan (1977). *Atomic and laser spectroscopy*.

- Clarendon Press, Oxford.
- Duffin W.J. (1990). *Electricity and magnetism* (4th edn). McGraw-Hill, London.
- Fox, M. (2006). *Quantum optics: an introduction*. Clarendon Press, Oxford.
- Gasiorowicz, Stephen (1996). *Quantum physics* (2nd edn). Wiley, New York.
- Good R.H. (1999). *Classical electromagnetism*. Saunders College Publishing, Fort Worth.
- Grant, I.S. and Phillips, W.R. (1990). *Electromagnetism* (2nd edn). Wiley, New York.

- Hecht, Eugene (2001). *Optics* (4th edn). Addison-Wesley, Reading, MA.
- Ibach, H. and Luth, H. (2003). *Solid-state physics* (3rd edn). Springer-Verlag, Berlin.
- Kittel, Charles (2005). *Introduction to solid state physics* (8th edn). Wiley, New York.
- Lorrain P., Corson D.R., and Lorrain F. (2000). *Fundamentals of electromagnetic phenomena*. W.H. Freeman, Basingstoke.
- Madelung, O. (1996). *Semiconductors, basic data* (2nd edn). Springer-Verlag, Berlin.
- Madelung, O. (1982). *Semiconductors: physics of group IV elements and III-V compounds*, Landolt-Börnstein New Series, vol. III/17a. Springer-Verlag, Berlin.
- Miller, D.A.B. (2008). *Quantum mechanics for scientists and engineers*. Cambridge University Press, Cambridge.
- Singleton, J. (2001). *Band structure and electrical properties of solids*. Clarendon Press, Oxford.
- Smith, F.G., King, T.A., and Wilkins, D. (2007). *Optics and photonics* (2nd edn). Wiley, Chichester.
- Sze, S.M. (1981). *Physics of semiconductor devices* (2nd edn). Wiley, New York.
- Sze, S.M. (1985). *Semiconductor devices*. Wiley, New York.
- Woodgate, G.K. (1980). *Elementary atomic structure* (2nd edn). Clarendon Press, Oxford.