

References

- Abe, T., Steigmeier, E. F., Hagleitner, W., and Pidduck, A. J.
1992. "Microroughness measurements on polished silicon wafers," *Jpn. J. Appl. Phys.* **31**, 721–728.
- ANSI/ASME
2009. Standard # B46.1-2009, *Surface Texture (Surface Roughness, Waviness, and Lay)*, Am. Soc. Mech. Eng., New York.
- Asmail, C., Hsia, J., Parr, A., and Hoeft, J.
1994. "Rayleigh scattering limits for low-level bidirectional reflectance distribution function (BRDF) measurements," *Appl. Opt.* **38**(28), 6027.
- ASTM
1991. Standard # E1392-90, *Standard Practice for Angle Resolved Optical Scatter Measurements on Specular or Diffuse Surfaces*.
- Azzam, R. M. A. and Bashara, N. M.
1977. *Ellipsometry and Polarized Light*, North Holland, New York.
- Barrick, D. E.
1970. *Radar Cross Section Handbook*, Chap. 9, Plenum, New York.
- Bawolek, E. J., Mohr, J. B., Hirleman, E. D., and Majumdar, A.
1993. "Light scatter from polysilicon and aluminum surfaces and comparison with surface-roughness statistics by atomic force microscopy," *Appl. Opt.* **32**(19), 3377.
- Beckmann, P., and Spizzichino, A.
1963. *The Scattering of Electromagnetic Waves from Rough Surfaces*, Pergamon, New York.
- Bell, B. W. and Bickel, W. S.
1981. "Single fiber light scattering matrix: an experimental determination," *Appl. Opt.* **20**(22), 3874.
- Bendat, J. S. and Piersol, A. G.
1971. *Random Data: Analysis and Measurement Procedures*, Wiley-Interscience, New York.
1986. *Engineering Applications of Correlation and Spectral Analysis*, 2nd ed., John Wiley & Sons, New York.

- Bender, J. A., Henning, T. D., and Bernt, M. L.
1992. "Near-specular measurements of integrated scatter," *Proc. SPIE* **1753**, 121–126. [doi: 10.1117/12.140696].
- Bennett, H. E. and Porteus, J. O.
1961. "Relation between surface roughness and specular reflectance at normal incidence," *JOSA* **51**, 123.
- Bennett, J. M. and Mattsson, L.
1989. *Introduction to Surface Roughness and Scattering*, OSA, Washington, D.C.
- Bickel, W. S., Davidson, J. F., Huffman, D. R., and Kilkson, R.
1976. "Application of polarization effects in light scattering: a new biophysical tool," *Proc. Nat. Acad. Sci. USA* **73**(2), 486.
- Bickel, W. S., Iafelice, V., and Videen, G.
1986. "The role of polarization in the measurement and characterization of scattering," *Proc. SPIE* **679**, 91–98.
- Bickel, W. S., Zito, R. R., and Iafelice, V.
1987. "Polarized light scattering from metal surfaces," *J. Appl. Phys.* **61**(12), 5392.
- Bobbert, P. A. and Vlieger, J.,
1986a, "Light scattering by a sphere on a substrate," *Physica* **137A**, 209–242.
- Bobbert, P. A., Vlieger, J., and Greef, R.,
1986b, "Light reflection from a substrate sparsely seeded with spheres—Comparison with an ellipsometric experiment," *Physica* **137A**, 243–257.
- Bohren, C. E. and Huffman, D. R.
1983. *Absorption and Scattering of Light by Small Particles*, John Wiley & Sons, New York.
- Breault Research Organization (2012) <http://www.breault.com/>.
- Breault, R. P.
1986. "Current technology of stray light," *Proc. SPIE* **675**, 4–13.
- Brown, N. J.
1989. "Optical fabrication," Lawrence Livermore National Laboratories, Report MISC-4476, Rev. 1.
- Bullis, W. M.
1994. "Microroughness of silicon wafers," *Proc. Electrochem. Soc.* **94**(10), 1156.
- Burnham, M.
1976. "The mechanics of micromachining," *Proc. SPIE* **93**, 38–45.
- Cady, F. M., Bjork, D. R., Rifkin, J., and Stover, J. C.
1989a. "BRDF error analysis," *Proc. SPIE* **1165**, 154–164.
1989b. "Linearity in BSDF measurements," *Proc. SPIE* **1165**, 192–201.

- Cady, F. M., Stover, J. C., Schiff, T. F., Klicker, K. A., and D. R. Bjork
1988. "Measurement of very near specular scatter," *Proc. SPIE* **967**, 264–271.
- Cheever, D. R., Cady, F. M., Klicker, K. A., and Stover, J. C.
1987. "Design review of a unique complete angle-scatter instrument (CASI)," *Proc. SPIE* **818**, 13–20.
- Chipman, R. A.
2007. "Degrees of freedom in depolarizing Mueller matrices," *Proc. SPIE* **6682**, 66820I. [doi: 10.1117/12.735892].
2009a. "Mueller Matrices" in *Handbook of Optics* (Vol. I, Chapter 14), M. Bass, Ed., McGraw-Hill.
2009b. "Polarimetry" in *Handbook of Optics* (Vol I, Chapter 15) M. Bass, Ed., McGraw-Hill.
- Church, E. L.
1977. Private communication with author.
1980. "The statistical description of optical inhomogeneities," *NBS Special Publication* **574**, 51–54.
1987. "Comments on the correlation length," *Proc. SPIE* **680**, 102–111.
1988. "Fractal surface finish," *Appl. Opt.* **27**(8), 1518–1526.
1989. Private communication: This useful relationship was first discovered serendipitously while checking Q values with a calculator and then later confirmed by derivation. 1994. Private communication with author.
- Church, E. L. and Takacs, P. Z.
1986a. "Statistical and signal processing concepts in surface metrology," *Proc. SPIE* **645**, 107–115.
1986b. "Use of an optical-profiling instrument for the measurement of the figure and finish of optical-quality surfaces," *Wear* **109**, 257.
1988. "Instrumental effects in surface finish measurement," *Proc. SPIE* **1009**, 46–55.
1989a. "Subsurface and volume scattering from smooth surfaces," *Proc. SPIE* **1165**, 31–41.
1989b. "Effects of the optical transfer function in surface profile measurements," *Proc. SPIE* **1164**, 46–59.
1993. "Specification of surface figure and finish in terms of system performance," *Appl. Opt.* **32**(19), 3344–3353.
- Church, E. L. and Zavada, J. M.
1975. "Residual surface roughness of diamond-turned optics," *Appl. Opt.* **14**, 1788.

- Church, E. L., Asmail, C. C., and Parks, R. E.
1994. "Scattering predictions based on the plateau-polishing model," unpublished.
- Church, E. L., Dainty, J. C., Gale, D. M., and Takacs, P. Z.
1988. "Comparison of optical and mechanical measurements of surface finish," *Proc. SPIE* **954**, 189–199.
- Church, E. L., Jenkinson, H. A., and Zavada, J. M.
1977. "Measurement of the finish of diamond-turned metal surfaces by differential light scattering," *Opt. Eng.* **16**(4), 360–374.
1979. "Relationship between surface scattering and microtopographic features," *Opt. Eng.* **18**(2), 125–136.
- Church, E. L., Takacs, P. Z., and Leonard, T. A.
1989. "The prediction of –RDFs from surface profile measurements," *Proc. SPIE* **1165**, 136–150.
- Collett, E.
1993. *Polarized Light: Fundamentals and Applications*, Marcel Dekker, New York.
- Dagnall, H.
1980. *Exploring Surface Texture*, Rank Taylor Hobson, Leicester, England.
- Das, K. K., Stover, J. C., Schwiegerling, J., and Karakelle, M.,
"A technique for measuring forward light scatter in intraocular lenses." To be published.
- Davies, H.
1954. "The reflection of electromagnetic waves from a rough surface," *Proc. Inst. Elec. Engrs.* **101**, 209.
- DeBoo, B., Sasian, J., and Chipman, R.
2004. "Degree of polarization surfaces and maps for analysis of depolarization," *Op. Ex.* **12**(20), 4941–4958.
2005. "Depolarization of diffusely reflecting manmade objects," *Appl. Opt.* **44**(26), 5434–5445.
- Denes, L. and Huff, H.
1992. "A Fourier analysis of silicon wafer topography," Abstract 823 RNP, 182nd Meeting of the Electrochemical Society.
- DeWitt, D. P.
1986. "Inferring temperature from optical radiation measurements," *Opt. Eng.* **25**(4), 596–601.
- DeWitt, D. P. and Nutter, G.D. (eds.)
1989. *Theory and Practice of Radiation Thermometry*, Wiley Interscience, New York.

- Doicu, A., Eremin, Y., and Wriedt, T.
2000. *Acoustic and Electromagnetic Scattering Analysis*, Academic Press, Waltham, MA.
- Elson, J. M. and Bennett, J. M.
1979. *Opt. Eng.* **18**(2), 116–124.
- Eremin, Y.-A.,
2000. “The method of discrete sources in electromagnetic scattering by axially symmetric structures,” *J. Commun. Techn. Electron.* **45**(2), S269–S280.
- Eremin, Y.-A. and Orlov, N. V.
1996. “Simulation of light scattering from a particle upon a wafer surface,” *Appl. Opt.* **35**(33), 6599–6605.
1998. “Study of scattering properties of defects of silicon wafers,” *Opt. Spectrosc.* **84**(4), 557–562.
- Eremin, Y.-A., Orlov, N. V., and Sveshnikov, A. G.
1999. “Models of electromagnetic scattering problems based on discrete sources method” in *Generalized Multipole Techniques for Electromagnetic and Light Scattering* (Vol. 4), T. Wriedt, Ed., Elsevier Science, Amsterdam.
- Eremin, Y.-A., Stover, J. C., and Orlov, N. V.
1999. “Modeling scatter from silicon wafers features based on discrete sources method,” *Opt. Eng.* **38**(8), 1296–1304. [doi: 10.1117/1.602187].
- Fossey, M. E., Stover, J. C., and Clementi, L. D.
1995. “Wafer inspection system for distinguishing pits and particles,” ADE Optical Systems Corporation, U.S. Patent No. 5712701.
- Freniere, E. R., Gregory G. G, and Chase, R. C.
1997. “Interactive software for optomechanical modeling,” *Proc. SPIE* **3130**, 128. [doi: 10.1117/12.284054].
- Gerliand, P. V., Smith, M. H., and Chipman, R. A.
1999. “Polarimetric images of a cone,” *Op. Ex.* **4**(10), 420–430.
- Germer, T. A.
1997a. “Angular dependence and polarization of out-of-plane optical scattering from particulate contamination, subsurface defects and surface microroughness,” *Appl. Opt.* **36**(33).
2000. “Measurement of roughness of two interfaces of a dielectric film by scattering ellipsometry,” *Phys Rev. Lett.* **85**, 349-352.
2001. “Polarized light scattering by microroughness and small defects in dielectric layers,” *JOSA* **18**(6), 1279.
2007a. “Effect of line and trench profile variation on specular and diffuse reflectance from a periodic structure,” *JOSA* **24**(3), 696.

- Germer, T. A. and Asmail, C. C.
1999a. "Goniometric optical scatter instrument for out-of-plane ellipsometry measurements," *Rev. Sci. Instr.* **70**(9), 3688.
1999b. "Polarization of light scattered by microrough surfaces and subsurface defects," *JOSA* **16**(6), 1326.
- Germer, T. A., Asmail, C. C., and Scheer, B. W.
1997. "Polarization of out-of-plane scattering from microrough silicon," *Opt. Lett.* **22**(17), 1284.
- Germer, T. A. and Marx, E.
2004. "Ray model of light scattering by flake pigments or rough surfaces with smooth transparent coatings," *Appl. Opt.* **43**(6), 1266.
- Germer, T. A., Wolters, C., and Brayton, D.
2008. "Calibration of wafer surface inspection systems using spherical silica nanoparticles," *Op. Ex.* **16**(7), 4698.
- Goldstein, D. H. and Chipman, R. A.
1990. "Error analysis of a Mueller matrix polarimeter," *JOSA A.* **7**(4), 693–700.
- Goodman, J. W.
1968. *Introduction to Fourier Optics*, McGraw-Hill, New York.
- Greynolds, A.
2012. Private communication with the author. See Breault Research Organization website (2012) for additional information.
- Gu, Z. H., Dummer, R. S., Maradudin, A. A., and McGurn, A. R.
1989a. "Experimental study of the opposition effect in the scattering of light from a randomly rough metal surface," *Appl. Opt.* **28**(3), 537.
1989b. "Opposition effect in the scattering of light from a random rough metal surface," *Proc. SPIE* **1165**, 42–51.
- Hancock, J. C.
1961. *Principles of Communication Theory*, McGraw-Hill, New York.
- Harvey, J. E.
1976. "Light Scattering Characteristics of Optical Surfaces," Ph.D. Dissertation, U. of Arizona.
1989. "Surface scatter phenomena: a linear, shift-invariant process," *Proc. SPIE* **1165**, 87–99.
- Harvey, J. E., Krywonos, A., and Stover, J. C.
2007. "Unified scatter model for rough surfaces at large incident and scatter angles," *Proc. SPIE* **6672**, 6620C. [doi: 10.1117/12.739139].
- Harvey, J. E., Vernold, C. L., Krywonos, A., and Thompson, P. L.
1999. "Diffracted radiance: a fundamental quantity in non-paraxial scalar diffraction theory," *Appl. Opt.* **38**, 6469–6481.

2000. "Diffracted radiance: a fundamental quantity in non-paraxial scalar diffraction theory, Errata" *Appl. Opt.* **39**, 6374–6375.
- Harvey, T. A.
2011. Cornell University; Private communication with author.
- Hill, D. P., Shoemaker, R. L., De Witt, D. P., Gaskell, D. R., Schiff, T. F., Stover, J. C., White, D., and Gaskey, K. M.
1989. "Relating surface scattering characteristics to emissivity changes during the galvanneal process," *Proc. SPIE* **1165**, 62–71.
- Hunt, A. J. and Huffman, D. R.
1973. "A new polarization-modulated light scattering instrument," *Rev. Sci. Instrum.* **44**(12), 1753.
- Hunter, R. S. and Harold, R. W.
1987. *The Measurement of Appearance*, 2nd Ed, John Wiley and Sons, New York.
- Huntley, W. H.
1980. "Grating interferometers," *Lasers* **80**, T Japan.
- Iafelice, V. J., and Bickel, W. S.
1987. "Polarized light-scattering matrix elements for select perfect and perturbed optical surfaces," *Appl. Opt.* **26**(12), 2410.
- Iizuka, K.
1985. *Engineering Optics*, Springer-Verlag, Berlin.
- Ishimaru, A.
1978. *Wave Propagation in Random Media*, Academic Press, New York.
- Ivakhnenko, V., Stover, J. C., Scheer, C. A., and Eremin, Y. A.
2001. "Effects of particle shape on particle identification and scatter predictions," *Proc. SPIE* **4449**, 140. [doi: 10.1117/12.450087].
- Izunome, K., Saito, Y., and Kubota, H.
1992. "Periodic step and terrace formation on Si(100) surface during Si epitaxial growth by atmospheric chemical vapor deposition," *Jpn. J. Appl. Phys.* **31**, L1277–L1279.
- Jenkins, F. A. and White, H. E.
1976. *Fundamentals of Optics*, McGraw-Hill, New York.
- Jenkins, G. M. and Watts, D. G.
1968. *Spectral Analysis and its Applications*, Holden-Day, San Francisco.
- Keller, J. B.
1962. "Geometrical theory of diffraction," *JOSA* **52**, 116.
- Kim, J. H., Ehrman, S. H., Mulholland, G. W., and T. A. Germer,
2002. "Polarized light scattering from metallic particles on silicon surfaces," *Appl. Opt.* **43**(3), 585.

- Klicker, K. A. and Bjork, D. R.
1988. "Model of port scatter from lasers," Final Report to U.S. Army White Sands Missile Range, Contract No. DAAD07-87-0083.
- Klicker, K. A., Fuhrman, D., and Bjork, D. R.
1990. "BSDF database," *Proc. SPIE* **1331**, 270. [doi: 10.1117/12.22663].
- Klicker, K. A., Stover, J. C., and Wilson, D. J.
1988. "Near-specular measurement techniques for curved samples," *Proc. SPIE* **967**, 255–263.
- Klicker, K. A., Stover, J. C., Cheever, D. R., and Cady, F. M.
1987. "Practical reduction of instrument signature in near specular light scatter measurements," *Proc. SPIE* **818**, 26–33.
- Krauss, H. L., Bostian, C., and Raab, F. R.
1980. *Solid State Radio Engineering*, John Wiley & Sons, New York.
- Krywonos, A.
2006. "Predicting Surface Scatter Using a Linear Systems Formulation of Nonparaxial Scalar Diffraction," Ph.D. dissertation, U. Central Florida.
- Krywonos, A., Harvey, J. E., and Choi, N.
"Linear systems formulation of surface scatter theory for rough surfaces with arbitrary incident and scattering angles," *JOSA A* **28**(6), 1121–1138 (2011).
- Lamb, L. D.
1991. "The Scattering of Infrared Light by Small Particles on Substrates," Ph.D. Thesis, Dept. of Physics, U. of Arizona.
- Leader, J. C.
1979. "Analysis and prediction of laser scattering from rough surface materials," *JOSA* **69**, 610–628.
- Lee, W. W., Scherr, L. M., and Barsh, M. K.
1986. "Stray light analysis and suppression in small angle BRDF/BTDF measurement," *Proc. SPIE* **675**, 207–216.
- Leonard, T. A. and Pantoliano, M. A.
1988. "BRDF round robin," *Proc. SPIE* **967**, 226–235. [doi: 10.1117/12.22656].
- Leonard, T. A. and Rudolph, P.
1993. "BRDF round robin test of ASTM E1392," *Proc. SPIE* **1995**, 285–293. [doi: 10.1117/12.162658].
- Leonard, T. A., Pantoliano, M. A., and Reilly, J.
1989. "Results of a CO₂ BRDF round robin," *Proc. SPIE* **1165**, 444–449.
- Lopushenko, V. V.
2000. "Applying mean-field theory in scattering from microroughness of filmed wafers," *Proc. of Fifth International Conference on Light Scattering by Nonspherical Particles*, 196–199.

- Maradudin, A. A. and Mills, D. L.
1975. "Scattering and absorption of electromagnetic radiation by a semi-finite medium in the presence of surface roughness," *Phys. Rev. B* **11**, 1392.
- Marschner, S. R., Jensen, H. W., Cammarano, M., Worley, S., and Hanrahan, H.
2003. "Light scattering from human hair fibers," *Proc. SIGGRAPH 2003* **22**, 780–791.
- Mathis, R. C.
1963. "A Lunar Echo Study at 425 mcs," Ph.D. dissertation, U. of Texas.
- Maxwell, J. R., Beard, J., Weiner, S., Ladd, D., and Ladd, S.
1973. *Bidirectional Reflectance Model Validation and Utilization*. Technical Report AFAL-TR-73-303, Wright-Patterson AFB.
- McClain, S. C., Bartlett, C. L., Pezzaniti, J. L., and Chipman, R. A.
1995. "Depolarization measurements of an integrating sphere," *Appl. Opt.* **34**(1), 152–154.
- McGary, D. E., Stover, J. C., Rifkin, J., Cady, F. M., and Cheever, D. R.
1988. "Separation and measurement of surface scatter and volume scatter from transmissive optics," *Proc. SPIE* **967**, 197–203.
- McGillem, C. D. and Cooper, G. R.
1984. *Continuous and Discrete Signal and System Analysis*, Holt, Rinehart & Winston, New York.
- Nahm, K. B. and Wolfe, W. L.
1986. "Light scattering by polystyrene spheres on a mirror," *Proc. SPIE* **675**, 295–304.
1987. "Light-scattering models for spheres on a conducting plane: comparison with experiment," *Appl. Opt.* **26**(15), 2995.
- Nicodemus, F. E., Richmond, J. C., Hsia, J. J., Ginsberg, I., and Limperis, T.
1977. *Geometric Considerations and Nomenclature for Reflectance*, U.S. Dept. of Commerce, NBS Monograph 160.
- Noll, R. J., and Glenn, P. E.
1982. "Optical surface analysis code (OSAC)," *Proc. SPIE* **362**, 78–85.
- Orazio, F. D., Stowell, W. K., and Silva, R. M.
1982. "Instrumentation of a variable angle scatterometer (VAS)," *Proc. SPIE* **362**, 165–171.
- Paumi, J. D.
1988. "Laser vs. camera inspection in the paper industry," *Tappi Journal* **71**, 129–135.
- Perilloux, B. E.
1991. "Helium neon laser optics: scattered light measurements and process control," *Proc. SPIE* **1530**, 255–262. [doi: 10.1117/12.50515].

- Pezzaniti, J. L. Chipman, R. A., and McClain, S. C.,
1994. "Polarization bidirectional reflectance distribution function (BRDF)," *Proc. SPIE* 2260, 160. [doi: 10.1117/12.189211].
- Pezzaniti, J. L. and Chipman, R. A.
1995. "Mueller matrix scatter polarimetry of a diamond-turned mirror," *Opt. Eng.* **34**(6), 1593–1598. [doi: 10.1117/12.202109].
- Rayleigh, Lord.
1907. "On the Dynamical Theory of Gratings," *Proc. R. Soc. Lond. A* **79**, 399.
- Rice, S. O.
1951. "Reflection of electromagnetic waves from slightly rough surfaces," *Commun. Pure Appl. Math.* **4**, 351.
- Rifkin, J., Stover, J. C., McGary, D. E., Kirchner, K. H., and Wilson, D. J.
1988. "Raster area scatter measurements and sample uniformity," *Proc. SPIE* **967**, 171–177.
- Salzer, D. A., Beaudry, N., Chipman, R. A., Denninghoff, K. R., Basavanthappa, S., and Park, R. I.
2008. "Diffuse spectral fundus reflectance measured using sub-retinally placed spectralon," *J. Biomed. Opt.* **13**, 044004. [doi: 10.1117/1.2966953].
- Schiff, T. F. and Stover, J. C.
1989. "Surface Statistics determined from IR scatter," *Proc. SPIE* **1165**, 52–61.
- Schiff, T. F., Knighton, M. W., Wilson, D. J., Cady, F. M., Stover, J. C., and Butler, J. J.
1993. "Design review of a high-accuracy UV to near-IR scatterometer," *Proc. SPIE* **1995**, 121–130. [doi: 10.1117/12.162643].
- Schiff, T. F., Stover, J. C., Swimley, B. D., and Bjork, D. R.
1992. "Mueller matrix measurements of scattered light," *Proc. SPIE* **1753**, 269–277. [doi: 10.1117/12.140706].
- Schiff, T. F., Stover, J. C., Cheever, D. R., and Bjork, D. R.
1988. "Maximum and minimum limitations imposed on BSDF measurements," *Proc. SPIE* **967**, 50–57.
- Schiff, T. F., Stover, J. C., Wilson, D. J., Swimley, B. D., Southwood, M. E., and Bjork, D. R.
1992a. "Mueller Matrix measurements with an out-of-plane polarimetric scatterometer," *Proc. SPIE* **1746**, 295–306. [doi: 10.1117/12.138799].
1992b. "Design review of a unique out-of-plane polarimetric scatterometer," *Proc. SPIE* **1753**, 262–268. [doi: 10.1117/12.141440].
1992c. "Retroreflections on a low-tech approach to the measurement of opposition effect," *Proc. SPIE* **1753**, 278–284. [doi: 10.1117/12.140707].

- Schröder, S., Duparre, A., Coriand, L., Tünnermann, Penalver, D. H., and Harvey, J. E.
2011. *Opt. Ex.* **19**(10), 9820.
- Shurcliff, W. A.
1962. *Polarized Light*, Harvard University Press, Cambridge, MA.
- Siegman, A. E.
1986. *Lasers*, University Science Books, Mill Valley, CA.
- Squires, G. L.
1985. *Practical Physics*, Cambridge University Press, Cambridge, UK.
- Stover, J. C.
1975. "Roughness characterization of smooth machined surfaces by light scattering," *Appl. Opt.* **14**(8), 1796.
1976b. "Surface characteristics of machined optics," *Proc. SPIE* **93**, 90–95.
1980s. Personal observation during several tours of Arizona State University labs.
2001. "Calibration of particle detection systems," in *Handbook of Silicon Semiconductor Metrology*, Diebold, A., Ed., Marcel Dekker, New York.
2007. "The art of specifying optics for scatter," *Proc. SPIE* **6291**, 62910O. [doi: 10.1117/12.693206].
2010. "Experimental confirmation of the Rayleigh–Rice obliquity factor", *Proc. SPIE* **7792**, 77920J. [doi: 10.1117/12.858799].
- Stover, J. C. and Bernt, M. L.
1992. "Very near specular measurements via incident angle scaling," *Proc. SPIE* **1753**, 115–120. [doi: 10.1117/12.140695].
1993. "Wavelength scaling investigation of several materials," *Proc. SPIE* **1995**, 256–266. [doi: 10.1117/12.162654].
- Stover, J. C. Hegstrom, E. L.,
2010. "Scatter metrology of photovoltaic textured surfaces," *Proc. SPIE* **7771**, 777109. [doi: 10.1117/12.858802].
- Stover, J. C. and Hourmand, B.
1984a. "Comparison of roughness measurements by differential scatter and total integrated scatter," *Proc. SPIE* **511**, 2–6.
1984b. "Some deviations associated with the vector perturbation theory," *Proc. SPIE* **511**, 12–17.
- Stover, J. C., Bernt, M. L., Church, E. C., and Takacs, P. Z.
1994. "Measurement and analysis of scatter from silicon wafers," *Proc. SPIE* **2260**, 182–191. [doi: 10.1117/12.189215].

- Stover, J. C., Bernt, M. L., McGary, D. E., and Rifkin, J.
1989. "Investigation of anomalous scatter from beryllium mirrors," *Proc. SPIE* **1165**, 100–109.
- Stover, J. C., Cady, F. M., and Sklar, E.
1985. "Measurement of low angle scatter," *Opt. Eng.* **24**(3), 404–407.
- Stover, J. C., Ivankhnenko, V. I., and Eremin, Y. A.
2001. "The use of light scatter signals to identify particle material," *Proc. SPIE* **4449**, 131. [doi: 10.1117/12.450086].
- Stover, J. C., Klicker, K. A., Cheever, D. R., and Cady, F. M.
1987. "Reduction of instrument signature in near angle scatter measurements," *Proc. SPIE* **749**, 46–53.
- Stover, J. C., Rifkin, J., Cheever, D. R., Kirchner, K. H., and Schiff, T. F.
1988. "Comparisons of wavelength scaling predictions to experiment," *Proc. SPIE* **967**, 44–49.
- Stover, J. C. and Scheer, C. A.,
2001a; "Accurate sizing of deposited PSL spheres from light scatter measurements;" *Proc. SPIE* **4449**, 147. [doi: 10.1117/12.450088].
- Stover, J. C., Schroeder, S., and Germer, T.,
2012a. "Upper roughness limitations on the TIS/RMS relationship;" *Proc. SPIE* **8495** (In Press).
- Stover, J. C., Schroeder, S., von Finck, A., and Duparré, A.,
2012b. "Estimating hemispherical scatter from incident plane measurements of isotropic samples;" *Proc. SPIE* **8495** (In Press).
- Stover, J. C., Serati, S. A., and Gillespie, C. H.
1984. "Calculation of surface statistics from light scatter," *Opt. Eng.* **23**(4), 406.
- Strausser, Y. E., Doris, B., Diebold, A. C., and Huff, H. R.
1994. "Measurement of silicon surface microroughness by AFM," *Proc. 185th Meeting Electrochem. Soc.*, 461.
- Sung, L., Mulholland, G. W., and Germer, T. A.
1999. "Polarized light-scattering measurements of dielectric spheres upon a silicon surface," *Opt. Lett.* **24**(13), 866.
- Swimley, B. D., Knighton, M. W., Skurdal, V. C., Pearson, L. H., and Stover, J. C.
1993. "Design review of an instrument to map low-level hydrocarbon contamination," *Proc. SPIE* **1995**, 92–100. [doi: 10.1117/12.162641].
- Tanaka, F. and DeWitt, D. P.
1989. "Theory of a new radiation thermometry method and an experimental study using galvanized steel specimens," *Trans. Soc. Inst. & Cont. Eng. (Japan)*, **25**(10), 1031.
- Thomas, T. R.
1982. *Rough Surfaces*, Longman, New York.

- van de Hulst, H. C.
1957. *Light Scattering by Small Particles*, Wiley, New York.
- Verdeyen, J. T.
1989. *Laser Electronics*, 2nd. ed., Prentice Hall, Englewood Cliffs, NJ.
- Vernold, C. L.
1989. "Application and verification of wavelength scaling for near specular scatter predictions," *Proc. SPIE* **1165**, 18–30.
- Wang, Y.
1983. "Comparison of BRDF Theories with Experiment," Ph.D. dissertation, U. of Arizona.
- Waterman, P. C.
1965. "Matrix formulation of electromagnetic scattering," *Proc. IEEE* **53**, 805–812.
- Wilson, S. R., Al-Jumaily, G. A., and McNeil, J. R.
1987. "Nonlinear characteristics of a stylus profilometer," *Proc. SPIE* **818**, 10–12.
- Wolf, E. and Marchand, E. W.
1964. "Comparison of the Kirchhoff and the Rayleigh-Sommerfield theories of diffraction at an aperture," *JOSA* **54**, 587.
- Wolfe, W. L. and Wang, Y.
1982. "Comparisons of theory and experiment for BRDF of microrough surfaces," *Proc. SPIE* **362**, 40–45.
- Yariv, A.
1976. *Introduction to Optical Electronics*, 2nd ed., Holt, Rinehart & Winston, New York.
- Young, R. P.
1975. "Mirror scatter measurement facility comparison," AEDC-TR-75-68.
1976a. "Degradation of low-scatter mirrors by particulate contamination," *Opt. Eng.* **15**(6), 516–520.
1976b. "Degradation of mirror BRDF by particulate contamination," AEDC-TR-177 [or AD-B015792].
- Zito, R. R. and Bickel, W. S.
1986. "Light scattering from twisted metal cylinders," *Appl. Opt.* **25**(11), 1833.

Works Consulted

This list includes a number of works that are related to the book but are never directly referenced. These works provide coverage of topics (such as the UV scatterometry developed at the Fraunhofer Institute) that are important contributions to scatter metrology. They are included as an additional resource.

Bamberg, J.

1983. “Stray light analysis with the HP-41C/CV calculator,” *Proc. SPIE* **384**, 109–116.

Bawolek, E.J.

1992. “Light Scattering by Spherical Particles on Semiconductor Surfaces,” Ph.D. dissertation, 82, Arizona State University, Tempe.

Baylies, W.

1994. Private communication.

Bernt, M.L. and Stover, J.C.

1990. “IR and visible BSDF measurements of several materials,” *Proc. SPIE* **1331**, 261–269. [doi: 10.1117/12.22661].

1991. “Infrared window damage measured by reflective scatter,” *Proc. SPIE* **1530**, 42–49 (1991). [doi: 10.1117/12.50495].

Bickel, W.S. and Videen, G.W.

1991. “Stokes vectors, Mueller matrices and polarized light: experimental applications to optical surfaces and all other scatterers,” *Proc. SPIE* **1530**, 2–6.

Bjork, D.R., Klicker, K.A., and Cady, F. M.

1988. “Predicting laser port scatter,” *Proc. SPIE* **967**, 58–61.

Breault, R.P., Greynolds, A.W., and Gauvin, M.A.

1986. “Stray-light analysis with APART/PADE, version 8.7,” *Proc. SPIE* **675**, 4–13.

Brown, J.L.

1991. “Light scatter variations with respect to wafer orientation in GaAs,” *Proc. SPIE* **1530**, 299–305. [doi: 10.1117/12.50519].

1993. “Preparing samples for scattering measurements—a cleaning study: part 2,” *Proc. SPIE* **1995**, 80–91. [doi: 10.1117/12.162666].

- Cady, F.M., Cheever, D.R., Klicker, K.A., and Stover, J.C.
1987. "Comparison of scatter data from various beam dumps," *Proc. SPIE* **818**, 21–25.
- Cady, F.M., Knighton, M.W., Cheever, D.R., Swimley, B.D., Huntstoff, T.L, Schiff, T.F., and Southwood, M.E.
1992. "Design review of a broadband, 3-dimensional scatterometer," *Proc. SPIE* **1753**, 148–157. [doi: 10.1117/12.141438].
- Cady, F.M., Stover, J.C., Bjork, D.R., Bernt, M.L., Knighton, M.W., Wilson, D.J., and Cheever, D.R.
1990. "Design review of a multiwavelength, three-dimensional scatterometer," *Proc. SPIE* **1331**, 201–208. [doi: 10.1117/12.22658].
- Church, E.L.
1978. "Corrections to stylus measurements of surface finish," *JOSA* **68**, 1425A–1426A.
1986. "Models for the finish of precision machined optical surfaces," *Proc. SPIE* **676**, 142–152.
1991. "Scattering from slightly rough crystal surfaces," *Proc. SPIE* **1530**, 171–184. [doi: 10.1117/12.50507].
- Church, E.L. and Berry, H.C.
1982. "Spectral analysis of the finish of polished optical surfaces," *Wear* **83**, 189–201.
- Church, E.L. and Takacs, P.Z.
1991. "Optimal estimation of finish parameters," *Proc. SPIE* **1530**, 71–85. [doi: 10.1117/12.50498].
- Church, E.L., Howells, M.R., and Vorburger, T.V.
1982. "Spectral analysis of the finish of diamond-turned mirror surfaces," *Proc. SPIE* **315**, 202–218.
- Church, E.L., Sanger, G.M., and Takacs, P.Z.
1987. "Comparison of WYKO and TIS measurements of surface finish," *Proc. SPIE* **749**, 65–73.
- Church, E.L., Takacs, P.Z., and Stover, J.C.
1990. "Scattering by anisotropic grains in beryllium mirrors," *Proc. SPIE* **1331**, 12–17. [doi: 10.1117/12.22644].
- Dolan, A.
1989. "An interactive graphical, CAD integrated tool for stray radiation analysis," *Proc. SPIE* **675**, 80–84.
- Egert, C.M.
1991. "Material characterization of beryllium mirrors exhibiting anomalous scatter," *Proc. SPIE* **1530**, 162–170. [doi: 10.1117/12.50506].

- Egert, C.M., Stover, J.C., and Bernt, M.L.
1993. "Wavelength dependence of scatter from 0–50 grade beryllium mirrors," *Proc. SPIE* **1995**, 57–65. [doi: 10.1117/12.162649].
- Elson, J.M., Bennett, J.M., and Stover, J.C.
1993. "Wavelength and angular dependence of light scattering from beryllium: comparison of theory and experiment," *Appl. Opt.* **32**(19), 3362.
- Foo, L.D.
1985. "Computer analysis of background radiation sources for a staring IRCCD camera," M.S. Thesis, U. of Arizona.
- Freniere, E.R.
1980. "Simulation of stray light in optical systems with the GUERAP III," *Proc. SPIE* **257**, 78–85.
- Freniere, E.R. and Skelton, D.L.
1986. "Use of specular black coatings in well-baffled optical systems," *Proc. SPIE* **675**, 126–132.
- Greynolds, A.
1980. "Formulas for estimating stray-radiation levels in well-baffled optical systems," *Proc. SPIE* **257**, 39–49.
- Gu, Z.H., Dummer, R.S., Maradudin, A.A., Lu, J.Q., McGurn, A.R., and Méndez, E.R.
1990. "Experimental study of enhanced transmission through rough metal surfaces," *Proc. SPIE* **1331**, 36–47. [doi: 10.1117/12.22647].
- Harvey, J.E. and Lewotsky, K.
1991. "Scattering from multilayer coatings: a linear systems model," *Proc. SPIE* **1530**, 35–44. [doi: 10.1117/12.50494].
- Kylner, C., Ingers, J.P., Mattsson, L.H., and Bjuggren, M.
1993. "Scattering signatures of isolated surface features," *Proc. SPIE* **1995**, 66–73. [doi: 10.1117/12.162657].
- Larson, T.
1993. "Particle measurement on films," ASTM/SEMATECH Symposium on Particles, Haze, and Microroughness on Silicon Wafers, Austin, TX (unpublished).
- Leonard, T.A.
1990. "Standardization of optical scatter measurements," *Proc. SPIE* **1331**, 188–194. [doi:].
- Lewis, I.T., Ledebuhr, A.G., and Bernt, M.L.
1991. "Stray-light implications of scratch/dig specifications," *Proc. SPIE* **1530**, 22–34. [doi: 10.1117/12.50493].

- Likeness, B.K.
1977. "Stray light simulation with advanced Monte Carlo techniques," *Proc. SPIE* **107**, 80–88.
- Marvin, A., Toigo, F., and Celli, V.
1975. *Phys. Rev. B* **11**, 2777.
- Matovich, T., Stover, J.C., and Rifkin, J.
1990. "Design review of a vacuum cryogenic scatterometer," *Proc. SPIE* **1331**, 135–142. [doi: 10.1117/12.22655].
- McNeil, J.R., Herrman, W.C., and Stover, J.C.
1983. "Light scattering characteristics of some metal surfaces—a smoothing effect?" *Proc. Fifteenth Annual Symposium on Optical Materials for High-Power Lasers*, 202–210.
- Neu, J.T. and Bressler, M.
1991. "Design considerations for multipurpose bidirectional reflectometers," *Proc. SPIE* **1530**, 244–254. [doi: 10.1117/12.50514].
- Noble, H., Lam, W.-S., and Chipman, R.A.,
2009. "Inferring the orientation of texture from polarization parameters," *Proc. SPIE* **7461**, 746109. [doi: 10.1117/12.828261].
- Noble, H., Smith, G.A., Lam, W.-S., McClain, S., and Chipman, R.A.
2007. "Polarization imaging light scattering facility," *Proc. SPIE* **6682**, 66820U. [doi: 10.1117/12.735013].
- Pirooz, S., Shive, L.W., Malik, I.J., and Martin, A.C.
1993. "Predicting technology advances for wafer surface inspection systems," *Microcontamination* **11**(10), 21.
- Rifkin, J., Klicker, K.A., Bjork, D.R., Cheever, D.R., Schiff, T.F., Stover, J.C., Cady, F.M., Wilson, D.J., Chausse, P.D., and Kirchner, K.H.
1988. "Design review of a complete angle scatter instrument," *Proc. SPIE* **1036**, 116–124.
- Rock, D.
1986. "ORDASCa new ray-based stray radiation analysis program," *Proc. SPIE* **675**, 85–94.
- Rönnow, D.
1993. "Sources of error in spectroscopic low-level integrated light-scattering measurements," *Proc. SPIE* **1995**, 143–151. [doi: 10.1117/12.162645].
- Rudberg, D.A., Stover, J.C., and McGary, D.E.
1991. "Mapping of imbedded contaminants in transparent material by optical scatter," *Proc. SPIE* **1530**, 232–239. [doi: 10.1117/12.50512].
- Schröder, S., Duparre, A., and Tünnerman, A.
2007. "Roughness evolution and scatter losses of multilayers for 193-nm optics," *Appl. Opt.* **47**(13), C88.

- Schröder, S., Herffurth, T., Trost, M., and Duparre, A.,
2010a “Angle-resolved scattering and reflectance of extreme-ultraviolet multilayer coatings: measurement and analysis,” *Appl. Opt.* **49**(9), 1503.
2010b. “Angle-resolved scattering: an effective method for characterizing thin-film coatings,” *Appl. Opt.* **50**(9), C164.
- St. Clair Dinger, A.
1986. “STRAY—an interactive program for the computation of stray radiation in infrared telescopes,” *Proc. SPIE* **675**, 95–104.
- Stover, J.C.
1974. “Roughness measurement by light scattering,” *Laser-Induced Damage in Optical Materials 1974* (NBS Spec. Publ. 414), 163.
1976a. “Spectral density function gives surface roughness,” *Laser Focus* **12**(2), 83.
1982. “Surface roughness measurements of curved surfaces by light scatter,” *Opt. Eng.* **21**(6), 987.
1987a. “Overview of current scatterometer measurements and the impact on optical systems,” *Proc. SPIE* **776**, 33–41.
1987b. “Near specular light scatter measurements,” *Proc. Int. Conf. on Lasers '87*.
1988. “Optical scatter measurements and specifications,” *Lasers and Optronics* **7**(8), 61.
1989. “Scatter from optical components: an overview,” *Proc. SPIE* **1165**, 2–9.
1990. *Optical Scattering: Measurement and Analysis*, McGraw-Hill, New York.
2005. “Rough surface characterization and comparison of scatter measurements and models,” *Proc. SPIE* **5878**, 58780U. [doi: 10.1117/12.613780].
- Stover, J.C. and Gillespie, C.H.
1982. “Design review of three reflectance scatterometers,” *Proc. SPIE* **362**, 172–180.
- Stover, J.C. and McGary, D.E.
1990. “Scatter from subsurface defects and contaminants,” *Proc. SPIE* **1331**, 48–52. [doi: 10.1117/12.22648].
- Stover, J.C., Bernt, M.L., and Henning, T.D.
1991. “Study of anomalous scatter characteristics,” *Proc. SPIE* **1530**, 185–195. [doi: 10.1117/12.50508].
- Stover, J.C., Bernt, M.L., Schiff, T.F., and Swimley, B.
1993. “Mueller matrix measurements of several optical components,” *Proc. SPIE* **1995**, 267–272. [doi: 10.1117/12.162655].

- Stover, J.C., Gillespie, C.H., Cady, F.M., Cheever, D.R., and Klicker, K.A.
1987a. "Wavelength scaling of BRDF scatter data," *Proc. SPIE* **818**, 62–67.
1987b. "Comparison of BRDF data from two scatterometers," *Proc. SPIE* **818**, 68–73.
- Stover, J.C., Skurdal, V., Bender, J., and Chausse, P.D.
1990. "Design review of a hand-held scatterometer," *Proc. SPIE* **1331**, 195–200. [doi: 10.1117/12.22657].
- Takacs, P.Z., Hewitt, R.C., and Church, E.L.
1987. "Correlation between the performance and metrology of glancing incidence mirrors containing millimeter wavelength shape errors," *Proc. SPIE* **749**, 119–124.
- Takacs, P.Z., Li, M.X.-O., Furenlid, K., and Church, E.L.
1993. "Step-height standard for surface-profiler calibration," *Proc. SPIE* **1995**, 235–244. [doi: 10.1117/12.164974].
- Trost, M., Schröder, S., Feigl, T., Duparre, A., and Tünnerman, A.
2010. "Influence of the substrate finish and thin film roughness on the optical performance of Mo/Si multilayers," *Appl. Opt.* **50**(9), C148.
- Videen, G.
1991. "Light scattering from a sphere on or near a surface," *JOSA A* **8**, 483–489.
- Warner, T.L., Hirleman, E.D., and Bawolek, E.J.
1993. "Characteristics of light scattering signatures of various particle types on wafer surfaces," ASTM/SEMATECH Symposium on Particles, Haze, and Microroughness on Silicon Wafers, Austin, TX, Nov. 2–3, 1993 (unpublished).
- Wolff, L.B.
1993. "Diffuse reflections from smooth dielectric surfaces," *Proc. SPIE* **1995**, 26–44. [doi: 10.1117/12.162663].
- Xie, Q.Y. and Fesko, D.G.
1993. "Characterization of curved plastic surfaces," *Proc. SPIE* **1995**, 193–201. [doi: 10.1117/12.162648].
- Young, M.
1982. "Objective measurement and characterization of scratch standards," *Proc. SPIE* **362**, 86–92.

Index

A

ABC correlation, 85
absolute method, 135
absorption losses, 176
Airy pattern, 57
aluminum, 161
American Society of Testing
Materials (ASTM), 229
angle-resolved scatter (ARS), 16
angle-resolved scatter (ARS)
standards, 230
angular collection limits, 19
aperture convolution, 121
aperture effects, 120
aperture misalignment, 150
appearance, 201
appearance monitoring, 202
application-specific specifications,
242
area profiles, 31
arithmetic average (a.a.), 25
autocorrelation function, 40
autocovariance function, 34, 40

B

bandwidth limits, 19
beryllium, 161, 162
bidirectional reflective distribution
function (BRDF), 14, 158
standard, 230
bidirectional scatter distribution
function (BSDF), 14
bidirectional transmissive distribution
function (BTDF), 14, 219

bidirectional volume distribution
function (BVDF), 14
birefringent materials, 92
black diffusers, 176
Bobbert–Vlieger calculation, 110
Brewster's law, 95
bulk defects, 192

C

calibration sample, 135
calibration wafers, 217
camera-based systems, 140
capture rate, 233
Coblentz sphere, 18, 230
color, 201
columnar defects, 164
computer disks, 74, 218
conducting medium, 263
contamination, 220
coordinate systems, 137
copper, 161
cosine-corrected BRDF (CCBRDF),
16
cosine-corrected BSDF, 16
cross-polarization technique, 186
crystal-originated particle (COP), 113
cubic spline, 173
curve fitting, 173
cusp shape, 79
cusp-shaped surface, 26

D

defect identification, 218
defect scatter, 186
depletion region, 221

depolarization, 177
deterministic profiles, 24
dielectric, 261
differential mobility analyzer (DMA), 236
differential scattering cross section (DSC), 20, 134, 230
diffraction theory, 47
diffuse integrating sphere, 146
diffuse reflectance, 170
diffuse samples, 174
dipole pattern, 111
discrete defects, 210
discrete sources method (DSM), 110
discrete surface features, 134

E

electrical noise, 150
emissivity, 224
empirical scatter specifications, 254
enhanced backscatter, 145
error analysis, 150
estimators, 31

F

false counts, 234
far field, 51, 265
field-stop aperture, 128
flat panel displays, 206
Fourier transform, 35
fractal surfaces, 86, 172
Fraunhofer approximation, 51
Fresnel approximations, 51
Fresnel–Kirchhoff, 55
Fresnel reflectance, 176
Fresnel reflection, 93
Fresnel reflection coefficients, 100
full width at half maximum (FWHM), 236

G

galvanneal process, 225
Gaussian beams, 260
Gaussian height distribution, 30, 88, 169
Gaussian PSD, 169

generic specifications, 240
glare, 219
gold, 161
 diffuse, 178
golden rule, 61
grating efficiencies, 63, 269
grating equations, 62, 159
grating interferometers, 6

H

Harvey–Shack, generalized, 168
haze, 17, 210
hemispherical scatter, 181
high-frequency limit, 19
Huygens' principle, 49

I

impedance, 259
incident-angle scaling, 162, 168
instrument calibration, 134
instrument signature, 118
integrating sphere, 230
intraocular lens (IOL), 219
isotropic, 72
isotropic samples, 160, 181
isotropic surfaces, 74

J

Jones calculus, 103

K

K-correlation, 85
Kirchhoff diffraction, 265
Kirchhoff diffraction theory, 52

L

ℓ (surface wavelength), 29
lag, 40
Lambertian samples, 175
light point defect (LPD), 211
light-scattering equivalent (LSE), 211
linear shift invariance, 70
linearly polarized, 92
Lorentzian power spectrum, 86
loss coefficient, 262
low-frequency limit, 19
low-frequency roughness, 214

M

m (surface slope), 28
machine vibration, 81
material signature, 178
mean-field theory (MFT), 168
metallic reflectance, 98
microroughness, 33
mid-IR, 178
Mie theory, 2
modeled integrated scattering tool (MIST), 113
molybdenum, 161, 163
Mueller matrix, 105, 176
multiple detector scanners, 217

N

nanotopography, 33
National Institute of Science and Technology (NIST)
“traceability,” 233
near-specular measurements, 123
near-specular scatter, 159
noise-equivalent BSDF (NEBSDF), 120, 131
noise-equivalent power (NEP), 131
nonuniformity, 179
null-field method, 110
Nyquist criteria, 31

O

obliquity factor, 55
Ohm’s law, 259
one-dimensional measurement, 179
one-dimensional samples, 165
one-dimensional surfaces, 9, 72, 77
opposition effect, 145
optical constants, 97, 264
optical profilometers, 215
optically rough surfaces, 65, 166
out-of-plane measurements, 137

P

p polarization, 95
paper flaws, 223
parallel gratings, 271

Parseval’s theorem, 35
partial data sets, 172
particle deposition, 235
particle scanners, 211, 231
particle scatter, 109
particulates, 210
phase difference, 92
photovoltaics, 220
plane waves, 258, 265
point defects, 211
polarimetry, 106
polarization concepts, 92
polarization factor Q , 61, 99
polished surfaces, 211
pollution, 220
polystyrene latex (PSL) spheres, 217, 231
power spectral density (PSD), 6, 157, 212
 accurate surface, 152
 standard, 231
Poynting vector, 257
precision-machined mirror, 78
precision-machined surface, 72
profile measurement error, 43
propagation constant, 258
PSD moments, 36
PSD spike, 77

Q

Q (polarization factor), 61

R

R_a (arithmetic average), 25
 R_q (rms roughness), 25
random profiles, 29
raster scans, 141
Rayleigh, 2
Rayleigh blue-sky factor, 61
Rayleigh–Rice equation, 158
Rayleigh–Rice perturbation theory, 69
Rayleigh–Rice prediction, 158
Rayleigh–Rice vector perturbation theory, 61
Rayleigh smooth-surface criterion, 62

Rayleigh–Sommerfeld, 55
receiver nonlinearity, 150
reciprocity, 183
reference method, 135
reference signal, 116
refractive index, 101
relative dielectric constant, 101
retardation, 92
retinal scatter, 219
retroreflection, 144
ring laser gyroscope (RLG) mirror, 144
rms roughness, 25
root mean square (rms), 25
Rowland circle, 168

S

σ (rms roughness), 25
s polarization, 95
sample mount, 116
sampled profiles, 30
scanner calibration, 235
scatter
 dipole, 13
 from small particles, 13
scatter analysis, 180
scatter function, 16
scatter prediction, 180
scatter screens, 130
scatter specifications, 239
scatter standards, 229
scatterometer components, 115
Semiconductor Equipment and Materials International (SEMI), 229
sharp-edged step, 179
signature reduction, 123
silicon, 161
silicon carbide, 161
silicon substrate, 212
silicon wafers, 73, 210
sinusoidal grating, 89, 165, 166, 265
sinusoidal surface, 3, 57, 169
SiO₂ particles, 218
skin depth, 264
slip, 40

slit aperture, 49
small particulates, 211
smooth-surface approximation, 168
smooth-surface criterion, 166
Snell's law, 93
solar energy, 220, 230
spatial bandwidth, 37, 158, 172
spatial wavelengths, 268
Spectralon[®], 176
specular reflectance, 170
speed of light, 258
spherical aberrations, 120
standard surfaces, 178
Stokes vectors, 103
stray light, 180
surface contour, 33
surface defects, 186
surface figure, 33
surface irradiance, 14
surface pits, 112, 210, 218
surface PSD, 34
surface radiance, 14
surface slope, 28
surface statistics, 158
surface step, 179
surface wavelength, 29

T

texture, 201, 218
TIS derivation, 88
topographic scatter, 158
total integrated scatter (TIS), 17, 146, 157, 215, 230, 240
 relationship, 169
total internal reflection, 95
translucent, 174
two-dimensional power spectrum, 72
two-dimensional profiles, 31
two-dimensional spectra, 38
two-dimensional surface, 9

U

UV wavelengths, 218

V

vector theory, 61

W

wave equation, 257
wavelength scale, 72

wavelength scaling, 158
white diffuser, 176
window function, 38



Photo courtesy of Ptolomey Slocum.

After receiving his Ph.D. from Purdue University, John worked on a light scatter project—a field he returned to for most of his career. On his way, he taught at two universities, worked in the defense and semiconductor industries, and was involved in a few startup ventures. He teaches a course for SPIE, holds over ten patents, and is the author of over 100 papers

and articles as well as several book chapters. He has been active in national and international standards work in ASTM and SEMI for over twenty years and is an SPIE Fellow. He resides in Tucson, Arizona, where he consults, runs a measurement service, and provides scatter instrumentation through The Scatter Works, Inc. and ScatterMaster, LLC.

John can be reached at:

John C. Stover
The Scatter Works, Inc.
Tucson, AZ
thescatterworks.com