

UNIVERSITAT POLITÈCNICA DE CATALUNYA

*Laboratory of Photonics
Electromagnetics and Photonics Engineering group
Dept. of Signal Theory and Communications*

**OPTICAL SOLITONS IN QUADRATIC
NONLINEAR MEDIA AND
APPLICATIONS TO ALL-OPTICAL
SWITCHING AND ROUTING DEVICES**

Autor: María Concepción Santos Blanco
Director: Lluís Torner

Barcelona, january 1998

Bibliography

- [1] J. L. Baird, British Patent Specification No.20,969/27 (1927).
- [2] C. W. Hansell, U.S. Patent 1,751,584 (1930).
- [3] H. Lamm, *Z. Instrumentenk.* **50**, 579 (1930).
- [4] A. Blanc-Lapierre, M. Perrot, G. Péri, *Optica Acta* **2**, 1 (1955).
- [5] *Proceedings of the IEEE*, Special Issue on Optical Communications, vol **58**, 10 (1970).
- [6] K. C. Kao and G. A. Hockam, *Proc. IEE* **113**, 1151 (1966).
- [7] H. A. Haus, *Proc. IEEE* **81**, 969 (1993).
- [8] T. Morioka, H. Takara, S. Kawanishi, O. Katamani, K. Takiguchi, U. Uchiyama, M. Saruwatari, H. Takahashi, M. Yamada, T. Kanamori and H. Ono, *Electron. Lett.* **32**, 906 (1996).
- [9] K. Habara, *IEEE Comm. Mag.*, 25 (Nov-1988).
- [10] W. Stephens and K. Young, *IEEE LCS*, 20 (1990).
- [11] D. Delisle and L. Pelamourgues, *IEEE Spectrum*, 39 (Aug-1991).
- [12] W. Stephens and K. Young, *IEEE LCS*, 20 (1990).
- [13] S. J. Hinterlong, H. M. Hall Jr., *AT&T Tech J.* (1994).
- [14] H. S. Hinton, *IEEE J. Sel. Areas Com.* **6**, 1209 (1988).

- [15] *8th European Conference on Integrated Optics (ECIO'97)*, Stockholm, Sweden, Plenary Session, April 1997.
- [16] J. E. Midwinter ed., *Photonics in Switching I & II*, Quantum Electronics Principles and Applications, Academic Press, inc. (1993).
- [17] R. O'B. Carpenter, *J. Opt. Soc. Am.* **25**, 1145 (1953).
- [18] J. A. Armstrong, N. Bloembergen, J. Ducuing and P. S. Pershan, *Phys. Rev.* **127**, 1918 (1962).
- [19] Y. R. Shen, *Principles of Nonlinear Optics*, Wiley, New York (1984).
- [20] R. W. Boyd, *Nonlinear Optics*, Academic Press, Boston 1992.
- [21] G. P. Agrawal, *Nonlinear Fiber Optics*, Quantum Electronics. Principles and Applications, Paul F. Liao and Paul L. Kelley eds., Academic Press, Inc. (1989).
- [22] G. I. Stegeman and E. M. Wright, review paper for *J. Optical and Quant. Electron.* **22**, 95 (1990).
- [23] G. I. Stegeman and A. Miller, book chapter in *Photonic Switching, Vol I*, ed. J. Midwinter, Academic Press, Orlando 1992, 81.
- [24] R. DeSalvo, D. J. Hagan, M. Sheik-Bahae, G. Stegeman and E. W. Van Stryland, *Opt. Lett.* **17**, 28 (1992).
- [25] G. I. Stegeman, M. Sheik-Bahae, E. W. Van Stryland and G. Assanto, *Opt. Lett.* **18**, 13 (1993).
- [26] R. Schiek, *B J. Opt. Soc. Am. B* **10**, 1848 (1993).
- [27] N. R. Belashenkov, S. V. Gagarskii and M. V. Inochkin, *Opt. Spectrosc.* **66**, 806 (1989).
- [28] T. K. Gustafson, J.-P. E. Taran, P.L. Kelley and R. Y. Chiao, *Optics Communications* **2**, 17 (1970).
- [29] J.-M. R. Thomas and J.-P. E. Taran, *Optics Communications* **4**, 329 (1972).

- [30] D. N. Klyshko, B. F. Polkovnikov, *Sov. J. Quant. Electron.* **3**, 324 (1972).
- [31] K. Jain and G. W. Pratt Jr., *Appl. Phys. Lett.* **28**, 719 (1976).
- [32] R. Nakach and H. Wilhelmsson, *Phys. Rev. A* **14**, 451 (1976).
- [33] N. B. Baranova and B. Ya. Zeldovich, *Sov. Phys. Dokl.* **27**, 222 (1982).
- [34] G. R. Meredith, *Phys. Rev. E* **24**, 5522 (1981).
- [35] R. C. Eckardt and J. Reintjes, *IEEE Journal of Quantum Electronics* **QE-20**, 1178-1187 (1984).
- [36] J. T. Manassah and O. R. Cockings **12**, 1005 (1987).
- [37] J. T. Manassah, *J. Opt. Soc. Am. B* **4**, 1235 (1987).
- [38] A. A. Kanashov and A. M. Rubenchik, *Opt. Comm.* **24**, 121 (1978).
- [39] A. A. Kanashov, and A. M. Rubenchik, *Physica D* **4**, 122 (1981).
- [40] E. A. Kutnetsov, A. M. Rubenchik and V. E. Zakharov, *Phys. Rep.* **142**, 103 (1986).
- [41] J. P. Coffinet and F. De Martini, *Phys. Rev. Lett.* **22**, 60 (1969).
- [42] E. Yablonovitch, C. Flytzanis, N. Bloembergen, *Phys. Rev. Lett.* **29**, 865 (1972).
- [43] S. A. Akhmanov, A. N. Dubovik, S. M. Saltiel, I. V. Tomov and V. G. Tunkin, *JETP Lett.* **20**, 117 (1974).
- [44] S. A. Akhmanov, L. B. Meisner, S. T. Parinov, S. M. Saltiel, I. V. Tomov and V. G. Tunkin, *Sov. Phys. JETP Lett.* **46**, 898 (1977).
- [45] M. Zgonik and P. Gunter, *Ferroelectrics* **126**, 33 (1992).
- [46] H. J. Bakker, P. C. M. Planken, L. Kuipers and A. Lagendijk, *Phys. Rev. A* **42**, 4085 (1990).
- [47] L. A. Ostrovskii, *JETP Lett.* **5**, 272 (1967).

- [48] M. L. Sundheimer, Ch. Bossard, E. W. Van Stryland, G. I. Stegeman and J. D. Bierlein, *Opt. Lett.* **18**, 1397 (1993).
- [49] M. L. Sundheimer, A. Villeneuve, G. I. Stegeman and J. D. Bierlein, *Electr. Lett.* **30**, 1401 (1994).
- [50] R. Schiek, M. L. Sundheimer, D. Y. Kim, Y. Baek, G. I. Stegeman, H. Suche and W. Sohler, *Opt. Lett.* **19**, 1949 (1994).
- [51] I. Ledoux, C. Lepers, A. Perigaud, J. Badan and J. Zyss, *Opt. Commun.* **80**, 149 (1990).
- [52] H. Tan, G. P. Banfi and A. Tomaselli, *Appl. Phys. Lett.* **63**, 2472 (1993).
- [53] F. Hache, A. Zéboulon, G. Gallot and G. M. Gale, *Opt. Lett.* **20**, 1995 (1995).
- [54] S. Nitti, H. M. Tan, G. P. Banfi and V. Degiorgio, *Opt. Commun.* **106**, 263 (1994).
- [55] D. Y. Kim, W. E. Torruellas, J. Kang, C. Bosshard, G. I. Stegeman, P. Vidakovic, J. Zyss, W. E. Moerner, R. Twieg, G. Bjorklund, *Opt. Lett.* **19**, 868 (1994).
- [56] G. J. M. Krijnen, W. E. Torruellas, G. I. Stegeman, P. V. Lambeck and H. J. W. M. Hoekstra, *IEEE J. Quant. Electron.* **32**, 729 (1996).
- [57] C. Bosshard, G. Knöpfle, P. Prête, S. Follonier, C. Serbutoviez and P. Günter, *Opt. Eng.* **34**, 1951 (1995).
- [58] I. Ledoux, C. Lepers, A. Périgaud, J. Badan and J. Zyss, *Opt. Comm.* **80**, 149 (1990).
- [59] S. R. Marder, J. W. Perry and C.R. Yakymyshyn, *Chem. Mater.* **6**, 1137 (1994).
- [60] C. Bosshard, K. Sutter, R. Schlessler and P. Günter, *J. Opt. Soc. Am. B* **10**, 867 (1993).
- [61] G. Assanto, G. Stegeman, M. Sheik-Bahae and E. Van Stryland, *Appl. Phys. Lett.* **62**, 1323 (1993).
- [62] R. Schiek, *Optical and Quantum Electronics* **26**, 415 (1994).
- [63] G. Assanto, A. Lauretti-Palma, C. Sibilìa and M. Bertolotti, *Opt. Comm.* **110**, 599 (1994).
- [64] M. Picciau, G. Leo and G. Assanto, *J. Opt. Soc. Am. B* **13**, 661 (1996).

- [65] C. N. Ironside, J. S. Aitchinson and J. M. Arnold, *IEEE Journal of Quantum Electronics* **29**, 2650 (1993).
- [66] G. Assanto, Z. Wang, D. J. Hagan and E. W. VanStryland, *Appl. Phys. Lett.* **67**, 2120 (1995).
- [67] Y. Baek, R. Schiek and G. I. Stegeman, *Appl. Phys. Lett.* **68**, 2055 (1996).
- [68] G. I. Stegeman, R. Schiek, L. Torner, W. Torruellas, Y. Baek, D. Baboiu, Z. Wang, E. VanStryland, D. Hagan and G. Assanto, book chapter in *Novel Optical Materials and Applications* edited by I. C. Khoo and F. Simoni, Wiley Interscience, New York (1995).
- [69] A. Hasegawa and F. Tappert, *Appl. Phys. Lett.* **23**, 142 (1973).
- [70] N. A. Akhmediev and A. Ankiewicz, *Solitons. Nonlinear pulses and beams*, Optical and Quantum Electronics Series 5, Chapman & Hall, (1997).
- [71] N. J. Zabusky and M. D. Kruskal, *Phys. Rev. Lett.* **15**, 240 (1965).
- [72] C. S. Gardner, J. M. Greene, M. D. Kruskal and M.D. Miura, *Phys. Rev. Lett.* **19**, 1095 (1967).
- [73] V. E. Zakharov and A. B. Shabat, *Sov. Phys. JETP* **34**, 62 (1972).
- [74] L. F. Mollenauer, R. H. Stolen and J. P. Gordon, *Phys. Rev. Lett.* **45**, 1095 (1980).
- [75] M. N. Islam, *Ultrafast Fiber Switching Devices and Systems*, Cambridge Studies in Modern Optics 12, P. L. Knight and W. J. Firth eds., Cambridge University Press (1992).
- [76] A. Barthelemy, S. Maneuf, C. Froehly, *Opt. Commun.* **55**, 201 (1985).
- [77] J. S. Aitchinson, A. M. Weiner, Y. Silberberg, M. K. Oliver, M., J. L. Jackel, D. E. Leaird, E. M. Vogel and P. W. E. Smith, *Opt. Lett.* **15**, 471 (1990).
- [78] Yu. N. Karamzin, and A. P. Sukhorukov, *JETP Lett.* **20**, 339 (1974).
- [79] Yu. N. Karamzin, and A. P. Sukhorukov, *Sov. Phys. JETP* **41**, 414 (1976)..
- [80] Q. Guo, *Quantum. Opt.* **5**, 133 (1993).

- [81] A. G. Kalocsai and J. W. Haus, *Phys. Rev. A* **49**, 574 (1994).
- [82] K. Hayata and M. Koshihara, *Phys. Rev. Lett.* **71**, 3275 (1993).
- [83] M. J. Werner and P. D. Drummond, *J. Opt. Soc. Am. B* **10**, 2390 (1993).
- [84] M. A. Karpiez and M. Sypek, *Opt. Comm.* **110**, 75- (1994).
- [85] C. R. Menyuk, R. Schiek and L. Torner, *J. Opt. Soc. Am. B* **11**, 2434 (1994).
- [86] L. Torner, C. R. Menyuk and G. I. Stegeman, *Opt. Lett.* **19**, 1615 (1994); *J. Opt. Soc. Am. B* **12**, 889 (1995).
- [87] L. Torner, and E. M. Wright, *J. Opt. Soc. Am. B* **13**, 864 (1996).
- [88] L. Torner, C. R. Menyuk, W. E. Torruellas and G. I. Stegeman, *Opt. Lett.* **20**, 13 (1995).
- [89] A. V. Buryak, and Y. S. Kivshar, *Opt. Lett.* **19**, 1612 (1994); erratum **20**, 1080 (1995).
- [90] A. V. Buryak, Y. S. Kivshar, and V. V. Steblina, *Phys. Rev. A* **52**, 1670 (1995).
- [91] A. V. Buryak, and Y. S. Kivshar, *Phys. Lett. A* **197**, 407 (1995).
- [92] L. Torner, *Opt. Comm.* **114**, 136 (1995).
- [93] L. Torner, D. Mihalache, D. Mazilu, E. M. Wright W. E. Torruellas and G. I. Stegeman, *Opt. Commun.* **121**, 149-155 (1995).
- [94] L. Bergé, V. K. Mezentsev, J. J. Rasmussen and J. Wyller, *Phys. Rev. A* **52**, 28 (1995).
- [95] S. K. Turysin, *JETP Lett.* **61**, 469 (1995).
- [96] D. E. Pelinovsky, A. V. Buryak and Y. S. Kivshar, *Phys. Rev. Lett.* **75**, 591 (1995).
- [97] L. Torner, D. Mihalache, D. Mazilu and N. N. Akhmediev, *Opt. Lett.* **20**, 2183 (1995).
- [98] A. D. Boardman K. Xie and A. Sangarpaul, *Phys. Rev. A* **52**, 4099 (1995).
- [99] K. Hayata and M. Koshihara, *J. Opt. Soc. Am. B* **12**, 2288 (1995).
- [100] B. A. Malomed, D. Anderson, A. Berntson, M. Florjanczyk and M. Lisak, *Pure and Appl. Opt.* **5**, 941-946 (1996).

- [101] R. Schiek, Y. Baek, and G.I. Stegeman, *Phys. Rev. E* **53**, 1138 (1996).
- [102] W. E. Torruellas, Z. Wang, D. J. Hagan, E. W. VanStryland, G. I. Stegeman, L. Torner, and C. R. Menyuk, *Phys. Rev. Lett.* **74**, 5036 (1995).
- [103] D. Hutchings, J. S. Aitchinson and C. N. Ironside, *Opt. Lett.* **18**, 793-795 (1993).
- [104] G. Assanto, I. Torelli and S. Trillo, *Opt. Lett.* **19**, 170 (1994).
- [105] A. L. Belostotsky, A. S. Leonov and A. V. Meleshko, *Opt. Lett.* **19**, 856 (1994).
- [106] G. Assanto, *Opt. Lett.* **20**, 1595 (1995).
- [107] G. Assanto and I. Torelli, *Opt. Commun.* **119**, 143 (1995).
- [108] A. Kobayakov, U. Peschel, R. Muschall, G. Assanto, V. P. Torchigin and F. Lederer, *Opt. Lett.* **20**, 1686 (1995).
- [109] A. Kobayakov, U. Peschel and F. Lederer, *Opt. Comm.* **124**, 184 (1996).
- [110] D. Mihalache, F. Lederer, D. Mazilu and L.-C. Crasovan, *Opt. Eng.* **35**, 1616 (1996).
- [111] H. He, M. J. Werner and P. D. Drummond, *Phys. Rev. E* **54**, 896 (1996).
- [112] A. V. Buryak, *Phys. Rev. E* **52**, 1156 (1995).
- [113] S. Trillo and P. Ferro, *Opt. Lett.* **20**, 438 (1995).
- [114] S. Trillo and P. Ferro, *Phys. Rev. E* **51**, 4994 (1995).
- [115] S. Trillo, A. V. Buryak and Y. S. Kivshar, *Opt. Commun.* **122**, 200 (1996).
- [116] A. V. Buryak, Y. S. Kivshar and S. Trillo, *Opt. Lett.* **20**, 1677 (1995).
- [117] M. A. Karpierz, *Opt. Lett.* **12**, 614 (1995).
- [118] W. E. Torruellas, Z. Wang, L. Torner and G. I. Stegeman, *Opt. Lett.* **20**, 19, 1949 (1995).
- [119] W. E. Torruellas, G. Assanto, B. L. Lawrence, R. A. Fuerts, and G. I. Stegeman, *Appl. Phys. Lett.* **68**, 1449 (1996).

- [120] L. Torner, W. E. Torruellas and G. I. Stegeman, *Opt. Lett.* **20**, 19, 1951 (1995).
- [121] L. Torner, W. E. Torruellas, G. I. Stegeman, and C. R. Menyuk, *Opt. Lett.* **20**, 1952 (1995)
- [122] L. Torner, J. P. Torres, and C. R. Menyuk, *Opt. Lett.* **21**, 462 (1996).
- [123] G. Leo and G. Assanto, *Optics Comm.* 223 (1996).
- [124] M. C. Santos, A. Aceves and L. Torner, *Proceedings of the 8th European Conference on Integrated Optics (ECIO'97)*, 366, Stockholm, Sweden, April 1997.
- [125] M. C. Santos, A. Aceves and L. Torner, *Quantum Electronics and Laser Science Technical Digest*, 171, May 1997.
- [126] L. Torner, D. Mazilu and D. Mihalache, *Phys. Rev. Lett.* **77**, 2455 (1996).
- [127] D. Mihalache, D. Mazilu, L.-C. Crasovan and L. Torner, *Opt. Comm.* **137**, 113 (1997).
- [128] C. Etrich, U. Peschel, F. Lederer and B.A. Malomed, *Phys. Rev. E* **55**, 4321 (1996).
- [129] L. Torner, D. Mihalache, D. Mazilu, C. Santos and N. Akhmediev, *J. Opt. Soc. Am. B*, in press.
- [130] L. Torner, D. Mazilu, D. Mihalache, C. Santos, *Optics & Imaging in the Information Age / OSA Annual Meeting*, paper TuQ2, Rochester New York, October 1996.
- [131] L. Torner and M. C. Santos, *Optics in 1997*, Special issue of OSA's *Optics and Photonics News*, 45 (1997)
- [132] G. I. Stegeman, D. J. Hagan, and L. Torner, *Opt. Quantum Electron.* **28**, 1691 (1996).
- [133] P. N. Butcher and C. Cotter, *The Elements of Nonlinear Optics*, Cambridge Studies in Modern Optics 9, P. L. Knight and W. J. Firth eds., Cambridge University Press (1990).
Lett. **30**, 1401 (1994).
- [134] A. C. Newell, J. M. Moloney, *Nonlinear Optics*, Addison-Wesley Publishing Company (1992).

- [135] M. M. Fejer, G. A. Magel, D. H. Jundt, R. L. Byer, *IEEE Journal of Quantum Electronics* **28**, 2631 (1992).
- [136] A. E. Kaplan, *Opt. Lett.* **18**, 1223 (1993).
- [137] W. H. Press, S. A. Teukolsky, W. T. Vetterling, B. T. Flannery, *Numerical Recipes in Fortran*, Second Edition, Cambridge University Press, 1992.
- [138] N. Akhmediev, A. Buryak and J. M. Soto-Crespo, *Opt. Commun.* **112**, 278 (1994).
- [139] V. E. Zakharov and E.A. Kuznetsov, *Sov. Phys. JETP* **39**, 285 (1975).
- [140] J. S. Aitchinson, Y. Silberberg, A. M. Weiner, D. E. Leaird, M. K. Oliver, J. L. Jackel, E. M. Vogel and P.W. E. Smith, *J. Opt. Soc. Am. B* **8**, 1290 (1991).
- [141] F. Reynaud and A. Barthelemy, in *Guided-Wave Nonlinear Optics*, D. B. Ostrowsky and R. Reinisch, eds. (Kluwer, Dordrecht, The Netherlands, 1992), 319.
- [142] M. Shalaby, F. Reynaud and A. Barthelemy, *Opt. Lett.* **17**, 778 (1992).
- [143] R. de la Fuente and A. Barthelemy, *IEEE J. Quantum Electron.* **28**, 547 (1992).
- [144] B. Luther-Davies and Y. Xiaoping, *Opt. Lett.* **17**, 496 (1992).
- [145] H. T. Tran, R. A. Sammut and W. Samir, *Opt. Lett.* **19**, 945 (1994).
- [146] B. Luther-Davies and Y. Xiaoping, *Opt. Lett.* **17**, 1775 (1992).
- [147] A. T. Ryan and G. P. Agrawal, *Opt. Lett.* **18**, 1795 (1993).
- [148] X. D. Cao, D. D. Meyerhofer and G. P. Agrawal, *J. Opt. Soc. Am. B* **11**, 2224 (1994).
- [149] A. B. Aceves, C. De Angelis, T. Peschel, R. Muschall, F. Lederer, S. Trillo and S. Wabnitz, *Phys Rev. E* **53**, 1172 (1996).
- [150] C. R. Menyuk, *Opt. Lett.* **12**, 614 (1987).
- [151] C. R. Menyuk, *J. Opt. Soc. Am. B* **5**, 392 (1995).

- [152] R. G. Hunsperger, *Integrated Optics: Theory and Technology*, Springer Series in Optical Sciences, Springer-Verlag (1982).
- [153] R. Syms, J. Cozens, *Optical Guided Waves and Devices*, Mc Graw-Hill (1992).
- [154] C. Yeh, *Applied Photonics*, Academic Press (1994).
- [155] L. Allen, M. W. Beijersbergen, R. J. Spreeuw, and J. P. Woerdman, *Phys. Rev. A* **45**, 8185 (1992).
- [156] G. A. Swartzlander, and C. T. Law, *Phys. Rev. Lett.* **69**, 2503 (1992).
- [157] J. F. Nye, and M. V. Berry, *Proc. R. Soc. London A* **336**, 165 (1974).
- [158] G. Indebetouw, *J. Mod. Opt.* **40**, 73 (1993).
- [159] F. S. Roux, *J. Opt. Soc. Am. B* **12**, 1215 (1995).
- [160] V. I. Kruglov, Yu. A. Logvin, and V. M. Volkov, *J. Mod. Opt.* **39**, 2277 (1992).
- [161] G. S. McDonald, K. S. Syed, and W. J. Firth, *Opt. Commun.* **94**, 469 (1992).
- [162] I. V. Basistiy, V. Yu. Bazhenov, M. S. Soskin, and M. V. Vasnetsov, *Opt. Commun.* **103**, 422 (1993).
- [163] N. N. Rosanov, V. A. Smirnov, and N. V. Vyssotina, *Chaos Solitons Fractals* **4**, 1767 (1994).
- [164] B. Luther-Davies, R. Powles, and V. Tikhonenko, *Opt. Lett.* **19**, 1816 (1994).
- [165] V. Tikhonenko, J. Christou, and B. Luther-Davies, *J. Opt. Soc. Am. B* **12**, 2046 (1995).
- [166] V. Tikhonenko, and N. N. Akhmediev, *Opt. Commun.* **126**, 108 (1996).
- [167] N. R. Heckenberg, R. McDuff, C. D. Smith, and A. G. White, *Opt. Lett.* **17**, 221 (1992).
- [168] M. W. Beijersbergen, R. P. C. Coewinkel, M. Kristensen, and J. P. Woerdman, *Opt. Commun.* **96**, 123 (1993).
- [169] M. Padjett, J. Arlt, N. Simpson, and L. Allen, *Am. J. Phys.* **64**, 77 (1996).

[170] J. M. Soto-Crespo, D. R. Heatley, E. M. Wright, and N. N. Akhmediev, *Phys. Rev. A* **44**, 636 (1991).

[171] J. M. Soto-Crespo, E. M. Wright, and N. N. Akhmediev, *Phys. Rev. A* **45**, 3168 (1992).



BIBLIOTECA RECTOR GABRIEL FERRATÉ
Campus Nord