Synthesis, surface profile, nonlinear reflective index and photophysical properties of curcumin compound

Journal of Materials Science: Materials in Electronics

July 2018, Volume 29, Issue 13, pp 10890–10903 | Cite as

- Hussain Ali Badran (1) Email author (badran_hussein@yahoo.com)
- Ahmed Al-Maliki (1)
- R. K. Fakher Alfahed (2)
- Bahjat Ali Saeed (3)
- A. Y. Al-Ahmad (1) (4)
- F. A. Al-Saymari (1) (5)
- Rita S. Elias (6)

1. Physics Department, College of Education for Pure Sciences, University of Basrah, , Basrah, Iraq
2. Al-Nahrain Nano-renewable Energy Research Center, Al-Nahrain University, , Baghdad, Iraq
3. Chemistry Department, College of Education for Pure Sciences, University of Basrah, , Basrah, Iraq
4. School of Mathematical and Physical Sciences, University of Newcastle, , Newcastle, Australia
5. Department of Physics, Lancaster University, Lancaster, , Lancaster, UK
6. Department of Pharmaceutical Chemistry, College Pharmacy, University of Basrah, , Basrah, Iraq

Article
First Online: 28 April 2018

Abstract

Curcumin and other three curcuminoids (bisdemethoxycurcumin, α-chlorocurcumin and α-methylcurcumin) were synthesized. Fourier transform infrared spectroscopy, Fluorescence quantum yields, AFM analysis and image surface profiles were characterized. All compounds possessed electron donor moieties at both ends of the conjugated π-system and an electron acceptor moiety in the middle of the molecules (D-A-D system) and should exhibit different optical properties depending on substituents on the benzene rings. The third order nonlinear optical properties of the curcuminoids have been investigated by z-scan technique. The optical response was characterized by measuring the refractive index (n_2) of the derivatives of curcumin using the Z-scan technique. The compounds showed negative and large nonlinear refractive index values of the order of 10^{-7} cm^2/W and reverse saturable absorption

with high values of the nonlinear absorption coefficient of the order of 10^{-4} cm/W. The nonlinear refractive index was found to vary with the different compound. The optical constants of the different compound films were studied and the dispersion of the refractive index was discussed in terms of the Wemple-DiDomenico single oscillator model. The photo-physical properties of these compounds are compared to those of native curcumin, in order to provide a rationale to the design of samples with molecular structures optimized for a photosensitizer. These types of materials may be considering new photonic applications.

References

1. M. Tomasulo, M.F. Raymo, Org. Lett. **7**, 4633 (2005)
CrossRef (https://doi.org/10.1021/ol051750m)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=M.%20Tomasulo&author=MF.%20Raymo&journal=Org.%20Lett.&volume=7&pages=4633&publication_year=2005)

2. V.S. Govindarajan, H.S. William, Crit. Rev. Food Sci. Nutr. **29**, 199 (2009)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=VS.%20Govindarajan&author=HS.%20William&journal=Crit.%20Rev.%20Food%20Sci.%20Nutr.&volume=29&pages=199&publication_year=2009)

3. S.Y. Han, Y.Q. Yang, Dyes Pigm. **64**, 157 (2005)
CrossRef (https://doi.org/10.1016/j.dyepig.2004.05.008)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=SY.%20Han&author=YQ.%20Yang&journal=Dyes%20Pigm.&volume=64&pages=157&publication_year=2005)

4. O.P. Sharma, Biochem. Pharmacol. **25**, 1811 (1976)
CrossRef (https://doi.org/10.1016/0006-2952(76)90421-4)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=OP.%20Sharma&journal=Biochem.%20Pharmacol.&volume=25&pages=1811&publication_year=1976)

5. K.I. Priyadarsini, Free Rad. Biol. Med. **23**, 838 (1977)
CrossRef (https://doi.org/10.1016/S0891-5849(97)00026-9)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=KI.%20Priyadarsini&journal=Free%20Rad.%20Biol.%20Med.&volume=23&pages=838&publication_year=1977)

6. S.M. Khopde, K.I. Priyadarsini, P. Venkatesan, M.N.A. Rao, Biophys. Chem. **80**, 85 (1999)
CrossRef (https://doi.org/10.1016/S0301-4622(99)00070-8)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=SM.%20Khopde&author=KI.%20Priyadarsini&author=P.%20Venkatesan&author=MNA.%20Rao&journal=Biophys.%20Chem.&volume=80&pages=85&publication_year=1999)

7. C.F. Chignell, P. Bilskj, K.J. Reszka, A.G. Motten, R.H. Sik, T.A. Dahl, Photochem. Photobiol. **59**, 295 (1994)
CrossRef (https://doi.org/10.1111/j.1751-1097.1994.tb05037.x)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=CF.%20Chignell&author=P.%20Bilskj&author=KJ.%20Reszka&autho

r=AG.%20Motten&author=RH.%20Sik&author=TA.%20Dahl&journal=Photochem.%20Photobiol.&volume=59&pages=295&publication_year=1994)

8. D. Patra, C. Barakat, Spectrochim. Acta A **79**, 1034 (2011)
CrossRef (https://doi.org/10.1016/j.saa.2011.04.016)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=D.%20Patra&author=C.%20Barakat&journal=Spectrochim.%20Acta%20A&volume=79&pages=1034&publication_year=2011)

9. T.A. Dahl, P. Bilski, K. Reszka, C.F. Chignell, Photochem. Photobiol. **59**, 290 (1994)
CrossRef (https://doi.org/10.1111/j.1751-1097.1994.tb05036.x)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=TA.%20Dahl&author=P.%20Bilski&author=K.%20Reszka&author=CF.%20Chignell&journal=Photochem.%20Photobiol.&volume=59&pages=290&publication_year=1994)

10. S.M. Khopde, K.I. Priyadarsini, D.K. Palit, T. Mukherjee, Photochem. Photobiol. **72**, 625 (2000)
CrossRef (https://doi.org/10.1562/0031-8655(2000)072<0625%3AEOSOTE>2.0.CO%3B2)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=SM.%20Khopde&author=KI.%20Priyadarsini&author=DK.%20Palit&author=T.%20Mukherjee&journal=Photochem.%20Photobiol.&volume=72&pages=625&publication_year=2000)

11. P.H. Bong, Bull. Korean Chem. Soc. **21**, 81 (2000)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=PH.%20Bong&journal=Bull.%20Korean%20Chem.%20Soc.&volume=21&pages=81&publication_year=2000)

12. M.G. Alloza, L.A. Borrelli, A.B. Rozkalne, T.B. Hyman, J.J. Bacskai, Neurochemistry **102**, 1095 (2007)
CrossRef (https://doi.org/10.1111/j.1471-4159.2007.04613.x)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=MG.%20Alloza&author=LA.%20Borrelli&author=AB.%20Rozkalne&author=TB.%20Hyman&author=JJ.%20Bacskai&journal=Neurochemistry&volume=102&pages=1095&publication_year=2007)

13. F. Yang, G.P. Lim, A.N. Begum, O.J. Ubeda, M.R. Simmons, S.S. Ambegaokar, P.P. Chen, R. Kayed, C.G. Glabe, S.A. Frautschy, G.M. Cole, Biol. Chem. **280**, 5892 (2005)
CrossRef (https://doi.org/10.1074/jbc.M404751200)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=F.%20Yang&author=GP.%20Lim&author=AN.%20Begum&author=OJ.%20Ubeda&author=MR.%20Simmons&author=SS.%20Ambegaokar&author=PP.%20Chen&author=R.%20Kayed&author=CG.%20Glabe&author=SA.%20Frautschy&author=GM.%20Cole&journal=Biol.%20Chem.&volume=280&pages=5892&publication_year=2005)

14. E.K. Ryu, Y.S. Choe, K.H. Lee, Y. Choi, B.T. Kim, J. Med. Chem. **49**, 6111 (2006)
CrossRef (https://doi.org/10.1021/jm0607193)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=EK.%20Ryu&author=YS.%20Choe&author=KH.%20Lee&author=Y.%20Choi&author=BT.%20Kim&journal=J.%20Med.%20Chem.&volume=49&pages=6111&publication_year=2006)

15. A. Chaicham, S. Kulchat, G. Tumcharern, T. Tuntulani, B. Tomapatanaget, Tetrahedron **66**, 6217 (2010)
CrossRef (https://doi.org/10.1016/j.tet.2010.05.088)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=A.%20Chaicham&author=S.%20Kulchat&author=G.%20Tumcharern&author=T.%20Tuntulani&author=B.%20Tomapatanaget&journal=Tetrahedron&volume=66&pages=6217&publication_year=2010)

16. S. Senthilarasu, R. Sathyamoorthy, Cryst. Res. Technol. **41**, 1136 (2006)
CrossRef (https://doi.org/10.1002/crat.200610734)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=S.%20Senthilarasu&author=R.%20Sathyamoorthy&journal=Cryst.%20Res.%20Technol.&volume=41&pages=1136&publication_year=2006)

17. M.J. Scotter, LWT Food Sci. Technol. **42**, 1345 (2009)
CrossRef (https://doi.org/10.1016/j.lwt.2009.03.014)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=MJ.%20Scotter&journal=LWT%20Food%20Sci.%20Technol.&volume=42&pages=1345&publication_year=2009)

18. S.K. Par, O. Sangtae, H.K. Shin, S.H. Kim, H. Jungyeob, J.S. Song, L. Seokjoon, Bioorg. Med. Chem. Lett. **21**, 3573 (2011)
CrossRef (https://doi.org/10.1016/j.bmcl.2011.04.106)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=SK.%20Par&author=O.%20Sangtae&author=HK.%20Shin&author=SH.%20Kim&author=H.%20Jungyeob&author=JS.%20Song&author=L.%20Seokjoon&journal=Bioorg.%20Med.%20Chem.%20Lett.&volume=21&pages=3573&publication_year=2011)

19. L. Nardo, R. Paderno, A. Andreoni, T. Haukvik, M. Masson, H.H. Tannesen, Spectroscopy **22**, 187 (2008)
CrossRef (https://doi.org/10.1155/2008/928407)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=L.%20Nardo&author=R.%20Paderno&author=A.%20Andreoni&author=T.%20Haukvik&author=M.%20Masson&author=HH.%20Tannesen&journal=Spectroscopy&volume=22&pages=187&publication_year=2008)

20. J. Karlsen, A. Mostad, H.H. Tannesen, Acta Chem. Scand. B **42**, 23 (1988)
CrossRef (https://doi.org/10.3891/acta.chem.scand.42b-0023)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=J.%20Karlsen&author=A.%20Mostad&author=HH.%20Tannesen&journal=Acta%20Chem.%20Scand.%20B&volume=42&pages=23&publication_year=1988)

21. L. Nardo, A. Andreoni, M. Bondani, M. Masson, H. Hjorth Tonnesen, J. Photochem. Photobiol. B **97**, 77 (2009)
CrossRef (https://doi.org/10.1016/j.jphotobiol.2009.08.004)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=L.%20Nardo&author=A.%20Andreoni&author=M.%20Bondani&author=M.%20Masson&author=H.%20Hjorth%20Tonnesen&journal=J.%20Photochem.%20Photobiol.%20B&volume=97&pages=77&publication_year=2009)

22. E.R. Shaaban, N. A_fy, A. El-Taher, J. Alloys Compd. **482**, 400 (2009)
CrossRef (https://doi.org/10.1016/j.jallcom.2009.04.033)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=ER.%20Shaaban&author=N.%20A_fy&author=A.%20El-Taher&journal=J.%20Alloys%20Compd.&volume=482&pages=400&publication_year=2009)

23. E.R. Shaaban, I.S. Yahia, E.G. El-Metwally, Acta Phys. Pol. A **121**, 628 (2012)
CrossRef (https://doi.org/10.12693/APhysPolA.121.628)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=ER.%20Shaaban&author=IS.%20Yahia&author=EG.%20El-Metwally&journal=Acta%20Phys.%20Pol.%20A&volume=121&pages=628&publication_year=2012)

24. A.T. Davidson, J. Chem. Phys. **77**, 162 (1982)
CrossRef (https://doi.org/10.1063/1.443636)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=AT.%20Davidson&journal=J.%20Chem.%20Phys.&volume=77&pages=162&publication_year=1982)

25. T. Fujii, H. Nishikiori, T. Tamura, Chem. Phys. Lett. **233**, 424 (1995)
CrossRef (https://doi.org/10.1016/0009-2614(94)01477-D)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=T.%20Fujii&author=H.%20Nishikiori&author=T.%20Tamura&journal=Chem.%20Phys.%20Lett.&volume=233&pages=424&publication_year=1995)

26. A.A.M. Farag, I.S. Yahia, Opt. Commun. **238**, 4310 (2010)
CrossRef (https://doi.org/10.1016/j.optcom.2010.06.081)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=AAM.%20Farag&author=IS.%20Yahia&journal=Opt.%20Commun.&volume=238&pages=4310&publication_year=2010)

27. H. Gazy Lazim, K.I. Ajeel, A. Hussain, Badran, Spectrochim. Acta A **145**, 598 (2015)
CrossRef (https://doi.org/10.1016/j.saa.2015.02.096)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=H.%20Gazy%20Lazim&author=KI.%20Ajeel&author=A.%20Hussain&author=.%20Badran&journal=Spectrochim.%20Acta%20A&volume=145&pages=598&publication_year=2015)

28. F. Dkhilalli, S. Megdiche Borchani, M. Rasheed, R. Barille, K. Guidara, M. Megdiche, J. Mater. Sci. Mate. Electron. **29**, 6297 (2018)
CrossRef (https://doi.org/10.1007/s10854-018-8609-z)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=F.%20Dkhilalli&author=S.%20Megdiche%20Borchani&author=M.%20Rasheed&author=R.%20Barille&author=K.%20Guidara&author=M.%20Megdiche&journal=J.%20Mater.%20Sci.%20Mate.%20Electron.&volume=29&pages=6297&publication_year=2018)

29. T. Namitha Asokan, K.S. Urmila, B. Pradeep, J. Mater. Sci. Mater. Electron. **27**, 5646 (2016)
CrossRef (https://doi.org/10.1007/s10854-016-4473-x)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=T.%20Namitha%20Asokan&author=KS.%20Urmila&author=B.%20Pradeep&journal=J.%20Mater.%20Sci.%20Mater.%20Electron.&volume=27&pages=5646&publication_year=2016)

30. M. Shkir, V. Ganesh, S. Al Faify, I.S. Yahia, H.Y. Zahran, J. Mater. Sci. Mater. Electron. **29**, 6446 (2018)
CrossRef (https://doi.org/10.1007/s10854-018-8626-y)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=M.%20Shkir&author=V.%20Ganesh&author=S.%20Al%20Faify&author=IS.%20Yahia&author=HY.%20Zahran&journal=J.%20Mater.%20Sci.%20Mater.%20Electron.&volume=29&pages=6446&publication_year=2018)

31. H. Neumann, W. Horig, E. Reccius, H. Sobotta, B. Schumann, G. Kuhn, Thin Solid Films **61**, 13 (1979)
CrossRef (https://doi.org/10.1016/0040-6090(79)90494-2)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=H.%20Neumann&author=W.%20Horig&author=E.%20Reccius&author=H.%20Sobotta&author=B.%20Schumann&author=G.%20Kuhn&journal=Thin%20Solid%20Films&volume=61&pages=13&publication_year=1979)

32. H.A. Badran, M.F. AL-Mudhaffer, Q.M.A. Hassan, A.Y. AL-Ahmad, Chalcogenide Lett. **9** 483 (2012)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&author=MF.%20AL-Mudhaffer&author=QMA.%20Hassan&author=AY.%20AL-Ahmad&journal=Chalcogenide%20Lett.&volume=9&pages=483&publication_year=2012)

33. S.H. Wimple, M. Didomenico, Phys. Rev. Lett. **23**, 1156 (1969)
CrossRef (https://doi.org/10.1103/PhysRevLett.23.1156)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=SH.%20Wimple&author=M.%20Didomenico&journal=Phys.%20Rev.%20Lett.&volume=23&pages=1156&publication_year=1969)

34. H.S. Shaaker, W.A. Hussain, H.A. Badran, Adv. Appl. Sci. Res. **3**, 2940 (2012)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HS.%20Shaaker&author=WA.%20Hussain&author=HA.%20Badran&journal=Adv.%20Appl.%20Sci.%20Res.&volume=3&pages=2940&publication_year=2012)

35. H.A. Badran, A.Y. AL-Ahmad, Q.M.A. Hassan, C.A. Emshary, Pramana J Phys. **86**, 135 (2016)
CrossRef (https://doi.org/10.1007/s12043-015-0960-5)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&author=AY.%20AL-Ahmad&author=QMA.%20Hassan&author=CA.%20Emshary&journal=Pramana%20J%20Phys.&volume=86&pages=135&publication_year=2016)

36. H.A. Badran, Am. J. Appl. Sci. **9**, 250 (2012)
CrossRef (https://doi.org/10.3844/ajassp.2012.250.253)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&journal=Am.%20J.%20Appl.%20Sci.&volume=9&pages=250&publication_year=2012)

37. H. Ticha, J.Schwarz,L. Tichy, R. Mertens, J. Optoelectron. Adv. Mater. **6**, 747 (2004)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=H.%20Ticha&author=JSchwarz%2CL.%20Tichy&author=R.%20Mertens&journal=J.%20Optoelectron.%20Adv.%20Mater.&volume=6&pages=747&publication_year=2004)

38. Z. Sofiani, B. Sahraoui, M. Addou, R. Adhiri, M. Alauoui Lamrani, L. Dghoughi, N. Fellahi, B. Derkowska, W. Bala, J. Appl. Phys. **101**, 063104 (2007)
CrossRef (https://doi.org/10.1063/1.2711143)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=Z.%20Sofiani&author=B.%20Sahraoui&author=M.%20Addou&author=R.%20Adhiri&author=M.%20Alauoui%20Lamrani&author=L.%20Dghoughi&author=N.%20Fellahi&author=B.%20Derkowska&author=W.%20Bala&journal=J.%20Appl.%20Phys.&volume=101&pages=063104&publication_year=2007)

39. S.H. Wemple, M. DiDomenico, Phys. Rev. B **3**, 1338 (1971)
CrossRef (https://doi.org/10.1103/PhysRevB.3.1338)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=SH.%20Wemple&author=M.%20DiDomenico&journal=Phys.%20Rev.%20B&volume=3&pages=1338&publication_year=1971)

40. H.A. Badran, A.Y. Taha, A.F. Abdulkader, C.A. Emshary, J. Ovon. Res. **8**, 161 (2012)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&author=AY.%20Taha&author=AF.%20Abdulkader&author=CA.%20Emshary&journal=J.%20Ovon.%20Res.&volume=8&pages=161&publication_year=2012)

41. M.A. Lamrani, M. Addou, Z. Sofiani, B. Sahraoui, J. Ebothe, A. El Hichou, N. Fellahi, J.C. Bernede, R. Dounia, Opt. Commun. **277**, 196 (2007)
CrossRef (https://doi.org/10.1016/j.optcom.2007.04.033)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=MA.%20Lamrani&author=M.%20Addou&author=Z.%20Sofiani&author=B.%20Sahraoui&author=J.%20Ebothe&author=A.%20Hichou&author=N.%20Fellahi&author=JC.%20Bernede&author=R.%20Dounia&journal=Opt.%20Commun.&volume=277&pages=196&publication_year=2007)

42. R. Adair, L.L. Chase, S.A. Payne, Phys. Rev. B **39**, 3337 (1989)
CrossRef (https://doi.org/10.1103/PhysRevB.39.3337)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=R.%20Adair&author=LL.%20Chase&author=SA.%20Payne&journal=Phys.%20Rev.%20B&volume=39&pages=3337&publication_year=1989)

43. V. Narayanan, R.K. Thareja, Opt. Commun. **260**, 170 (2006)
CrossRef (https://doi.org/10.1016/j.optcom.2005.09.073)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=V.%20Narayanan&author=RK.%20Thareja&journal=Opt.%20Commun.&volume=260&pages=170&publication_year=2006)

44. A. Abdolahzadeh Ziabari, F.E. Ghodsi, J. Mater. Sci. Mater. Electron. **23**, 1628 (2012)
CrossRef (https://doi.org/10.1007/s10854-012-0640-x)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=A.%20Abdolahzadeh%20Ziabari&author=FE.%20Ghodsi&journal=J.%20Mater.%20Sci.%20Mater.%20Electron.&volume=23&pages=1628&publication_year=2012)

45. H.A. Badran, H.F. Hussain, K.I. Ajeel, Optik **127**, 5301 (2016)
CrossRef (https://doi.org/10.1016/j.ijleo.2016.03.030)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&author=HF.%20Hussain&author=KI.%20Ajeel&journal=Optik&volume=127&pages=5301&publication_year=2016)

46. H.A. Badran, Q.M. Ali Hassan, A. Imran, J. Mater. Sci. Mater. Electron. **26**, 5958 (2015)
CrossRef (https://doi.org/10.1007/s10854-015-3169-y)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&author=QM.%20Ali%20Hassan&author=A.%20Imran&journal=J.%20Mater.%20Sci.%20Mater.%20Electron.&volume=26&pages=5958&publication_year=2015)

47. H.A. Badran, Appl. Phys. B **119**, 319 (2015)
CrossRef (https://doi.org/10.1007/s00340-015-6068-2)

Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&journal=Appl.%20Phys.%20B&volume=119&pages=319&publication_year=2015)

48. M. Saravanan, T.C. Sabari Girisun, G. Vinitha, J. Mater. Sci. **51**, 3289 (2016)
CrossRef (https://doi.org/10.1007/s10853-015-9642-4)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=M.%20Saravanan&author=TC.%20Sabari%20Girisun&author=G.%20Vinitha&journal=J.%20Mater.%20Sci.&volume=51&pages=3289&publication_year=2016)

49. A. John Kiran, K. Chandrasekharan, S. Rai Nooji, H.D. Shashikala, G. Umesh, B. Kalluraya, Chem. Phys. **324**, 699 (2006)
CrossRef (https://doi.org/10.1016/j.chemphys.2005.12.006)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=A.%20John%20Kiran&author=K.%20Chandrasekharan&author=S.%20Rai%20Nooji&author=HD.%20Shashikala&author=G.%20Umesh&author=B.%20Kalluraya&journal=Chem.%20Phys.&volume=324&pages=699&publication_year=2006)

50. H.A. Badran, A.Y. AL-Ahmad, M.F.A.L. Mudhaffer, C.A. Emshary, Opt. Quant. Electron. **47**, 1859 (2015)
CrossRef (https://doi.org/10.1007/s11082-014-0051-8)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&author=AY.%20AL-Ahmad&author=MFAL.%20Mudhaffer&author=CA.%20Emshary&journal=Opt.%20Quant.%20Electron.&volume=47&pages=1859&publication_year=2015)

51. A. Sundari, S. Manikandan, J. Mater. Sci. Mater. Electron. **29**, 558 (2018)
CrossRef (https://doi.org/10.1007/s10854-017-7947-6)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=A.%20Sundari&author=S.%20Manikandan&journal=J.%20Mater.%20Sci.%20Mater.%20Electron.&volume=29&pages=558&publication_year=2018)

52. H.A. Badran, Q.M. A.Hassan, A.Y. Al-Ahmad, C.A. Emshary, Can. J. Phys. **89**, 1219 (2011)
CrossRef (https://doi.org/10.1139/p11-118)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&author=QM.%20A.Hassan&author=AY.%20Al-Ahmad&author=CA.%20Emshary&journal=Can.%20J.%20Phys.&volume=89&pages=1219&publication_year=2011)

53. H.A. Badran, H.A. Sultan, Q.M. Ali Hassan, J. Mater. Sci. Mater. Electron. **27**, 6735 (2016)
CrossRef (https://doi.org/10.1007/s10854-016-4622-2)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&author=HA.%20Sultan&author=QM.%20Ali%20Hassan&journal=J.%20Mater.%20Sci.%20Mater.%20Electron.&volume=27&pages=6735&publication_year=2016)

54. H.A. Badran, Adv. Phys. Theor. Appl. **26**, 36 (2013)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&journal=Adv.%20Phys.%20Theor.%20Appl.&volume=26&pages=36&publication_year=2013)

55. C.A. Emshary, H.A. Badran, A.Y. AL-Ahmad, Q.M.A. Hassan, J. Mater. Environ. Sci. **4**, 319 (2013)

Google Scholar (http://scholar.google.com/scholar_lookup?&author=CA.%20Emshary&author=HA.%20Badran&author=AY.%20AL-Ahmad&author=QMA.%20Hassan&journal=J.%20Mater.%20Environ.%20Sci.&volume=4&pages=319&publication_year=2013)

56. Q.M.A. Hassan, H.A. Badran, A.Y. AL-Ahmad, C.A. Emshary, Chin. Phys. B **22**, 114209 (2013)
CrossRef (https://doi.org/10.1088/1674-1056/22/11/114209)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=QMA.%20Hassan&author=HA.%20Badran&author=AY.%20AL-Ahmad&author=CA.%20Emshary&journal=Chin.%20Phys.%20B&volume=22&pages=114209&publication_year=2013)

57. A.Y. Al-Ahmad, Q.M.A. Hassan, H.A. Badran, K.A. Hussain, Opt. Laser Technol. **44**, 1450 (2012)
CrossRef (https://doi.org/10.1016/j.optlastec.2011.12.019)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=AY.%20Al-Ahmad&author=QMA.%20Hassan&author=HA.%20Badran&author=KA.%20Hussain&journal=Opt.%20Laser%20Technol.&volume=44&pages=1450&publication_year=2012)

58. H.A. Badran, K.I. Ajeel, H. Gazy Lazim, Mater. Res. Bull. **76**, 422 (2016)
CrossRef (https://doi.org/10.1016/j.materresbull.2016.01.005)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&author=KI.%20Ajeel&author=H.%20Gazy%20Lazim&journal=Mater.%20Res.%20Bull.&volume=76&pages=422&publication_year=2016)

59. H.A. Badran, R.C. Abul-Hail, H.S. Shaker, A.I. Musa, Q.M.A. Hassan, Appl. Phys. B **123**, 31 (2017)
CrossRef (https://doi.org/10.1007/s00340-016-6607-5)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&author=RC.%20Abul-Hail&author=HS.%20Shaker&author=AI.%20Musa&author=QMA.%20Hassan&journal=Appl.%20Phys.%20B&volume=123&pages=31&publication_year=2017)

60. M.R. Rashidian Vaziri. Appl. Opt. **52**, 4843 (2013)
CrossRef (https://doi.org/10.1364/AO.52.004843)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=MR.%20Rashidian%20Vaziri&journal=Appl.%20Opt.&volume=52&pages=4843&publication_year=2013)

61. P. Fakhri, M.R. Rashidian Vaziri, B. Jaleh, N. Partovi Shabestari, J. Opt. **18**, 015502 (7pp) (2016)
CrossRef (https://doi.org/10.1088/2040-8978/18/1/015502)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=P.%20Fakhri&author=MR.%20Rashidian%20Vaziri&author=B.%20Jaleh&author=N.%20Partovi%20Shabestari&journal=J.%20Opt.&volume=18&pages=015502%20%287pp%29&publication_year=2016)

62. H.A. Badran, A.A. Al-Fregi, R.K. Fakher Alfahed, A.S. Al-Asadi, J. Mater. Sci. Mater. Electron. **28**, 17288 (2017)
CrossRef (https://doi.org/10.1007/s10854-017-7661-4)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&author=AA.%20Al-Fregi&author=RK.%20Fakher%20Alfahed&author=AS.%20Al-

Asadi&journal=J.%20Mater.%20Sci.%20Mater.%20Electron.&volume=28&pages=17288&publication_year=2017)

63. H.A. Badran, A.A. Jari, Int. Res. J. Nat. Appl. Sci. **4**, 29 (2017)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&author=AA.%20Jari&journal=Int.%20Res.%20J.%20Nat.%20Appl.%20Sci.&volume=4&pages=29&publication_year=2017)

64. H.A. Badran, A. Imran, Q.M. Ali Hassan, Optik **127**, 2659 (2016)
CrossRef (https://doi.org/10.1016/j.ijleo.2015.12.040)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=HA.%20Badran&author=A.%20Imran&author=QM.%20Ali%20Hassan&journal=Optik&volume=127&pages=2659&publication_year=2016)

65. M. Thangaraj, G. Vinitha, T.C. Sabari Girisun, P. Anandan, G. Ravi, Opt. Laser Technol. **73**, 130 (2015)
CrossRef (https://doi.org/10.1016/j.optlastec.2015.04.023)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=M.%20Thangaraj&author=G.%20Vinitha&author=TC.%20Sabari%20Girisun&author=P.%20Anandan&author=G.%20Ravi&journal=Opt.%20Laser%20Technol.&volume=73&pages=130&publication_year=2015)

66. R.K. Choubey, S. Medhekar, R. Kumar, S. Mukherjee, S. Kumar, J. Mater. Sci. Mater. Electron. **25**, 1410 (2014)
CrossRef (https://doi.org/10.1007/s10854-014-1743-3)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=RK.%20Choubey&author=S.%20Medhekar&author=R.%20Kumar&author=S.%20Mukherjee&author=S.%20Kumar&journal=J.%20Mater.%20Sci.%20Mater.%20Electron.&volume=25&pages=1410&publication_year=2014)

67. C. Gayathri, A. Ramalingam, Spectrochim. Acta A **69**, 980 (2008)
CrossRef (https://doi.org/10.1016/j.saa.2007.05.060)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=C.%20Gayathri&author=A.%20Ramalingam&journal=Spectrochim.%20Acta%20A&volume=69&pages=980&publication_year=2008)

68. I.A.H.A. Al-Saidi, S.A. Abdul-kareem, Opt Laser Technol. **82**, 150 (2016)
CrossRef (https://doi.org/10.1016/j.optlastec.2016.03.013)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=IAHA.%20Al-Saidi&author=SA.%20Abdul-kareem&journal=Opt%20Laser%20Technol.&volume=82&pages=150&publication_year=2016)

69. S.J. Mathews, S. Chaitanya Kumar, L. Giribabu, S. Venugopal Rao, Mater. Lett. **61**, 4426 (2007)
CrossRef (https://doi.org/10.1016/j.matlet.2007.02.034)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=SJ.%20Mathews&author=S.%20Chaitanya%20Kumar&author=L.%20Giribabu&author=S.%20Venugopal%20Rao&journal=Mater.%20Lett.&volume=61&pages=4426&publication_year=2007)

70. D. Prabha, R. Karunathan, V. Sathyanarayanamoorthi, J. Mater. Sci. Mater. Electron. **28**, 9675 (2017)
CrossRef (https://doi.org/10.1007/s10854-017-6718-8)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=D.%20Prabha&author=R.%20Karunathan&author=V.%20Sathyanarayanamoorthi&journal=J.%20Mater.%20Sci.%20Mater.%20Electron.&volume=28&pages=9675&publication_year=2017)

71. S. Aithal, P.S. Aithal, G.K. Bhat, Int. J. Appl. Eng. Manag. Lett (IJAEML) **1**, 19 (2017)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=S.%20Aithal&author=PS.%20Aithal&author=GK.%20Bhat&journal=Int.%20J.%20Appl.%20Eng.%20Manag.%20Lett%20%28IJAEML%29&volume=1&pages=19&publication_year=2017)

72. S. Jeyaram, T. Geethakrishnan, J. Mater. Sci. Mater. Electron. **28**, 9820 (2017)
CrossRef (https://doi.org/10.1007/s10854-017-6736-6)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=S.%20Jeyaram&author=T.%20Geethakrishnan&journal=J.%20Mater.%20Sci.%20Mater.%20Electron.&volume=28&pages=9820&publication_year=2017)

73. S. Pramodini, P. Poornesh, Laser Phys. **24**, 055402 (2014)
CrossRef (https://doi.org/10.1088/1054-660X/24/5/055402)
Google Scholar (http://scholar.google.com/scholar_lookup?&author=S.%20Pramodini&author=P.%20Poornesh&journal=Laser%20Phys.&volume=24&pages=055402&publication_year=2014)

Copyright information

About this article

Cite this article as:
Badran, H.A., Al-Maliki, A., Alfahed, R.K.F. et al. J Mater Sci: Mater Electron (2018) 29: 10890. https://doi.org/10.1007/s10854-018-9167-0

- Received 04 December 2017
- Accepted 22 April 2018
- First Online 28 April 2018
- DOI https://doi.org/10.1007/s10854-018-9167-0
- Publisher Name Springer US
- Print ISSN 0957-4522
- Online ISSN 1573-482X

- About this journal
- Reprints and Permissions

Personalised recommendations